AGROBIODIVERSITY CONSERVATION AND ECONOMIC DEVELOPMENT

Edited by Andreas Kontoleon,
Unai Pascual and Melinda Smale

Agrobiodiversity Conservation and Economic Development

This book reflects current developments in the economics of agrobiodiversity and focuses its attention on the role agrobiodiversity can have for economic development. As a new and rapidly expanding subfield at the interface of environmental/ecological, agricultural and development economics, the editors and contributors to this volume provide a thorough, structured and authoritative coverage of this field.

Topics covered include the economic modelling of agrobiodiversity, policy and governance solutions for the conservation of biodiversity in agricultural landscapes, contracts, markets and valuation. The authors include well-known and respected academics and researchers who have a real policy perspective into the role of agrobiodiversity and economic development. The book provides coherent and up-to-date coverage of the economics of *in situ* agrobiodiversity conservation which is to a large extent currently absent.

Though the material in *Agrobiodiversity Conservation and Economic Development* is primarily written for economists, its content and style are highly relevant and accessible to ecologists and conservation biologists, and to academics from other broad disciplines that are located within the areas of economics and ecology.

Andreas Kontoleon is a lecturer in Environmental Economics at the Department of Land Economy at the University of Cambridge, UK.

Unai Pascual is a lecturer in Environmental Economics at the Department of Land Economy at the University of Cambridge, UK.

Melinda Smale leads a global research program on economics and genetic resources at the International Food Policy Research Institute in Washington, D.C., USA.

Routledge explorations in environmental economics
Edited by Nick Hanley
University of Stirling, UK

Agrobiodiversity Conservation and Economic Development

Edited by Andreas Kontoleon, Unai Pascual and Melinda Smale

Routledge
Taylor & Francis Group

LONDON AND NEW YORK

This book is dedicated to Erika Ching-Huei Meng, whose subtle intelligence contributed so much to our understanding of plant genetic resources, and whose unmatched courage will endure in our memories. Economist, athlete, linguist, and our friend, Erika persevered with integrity, as did her mother before her.

Royalties from this book will be distributed to the Erika C.H. Meng Scholarship at the University of California, Davis, where Erika completed her PhD. The fund supports graduate students in bridging applied development research and policy, as Erika did so well in her life.

Contents

Figures

Tables

Contributors

Jan Barkmann is a post-doctoral researcher (Valuation of Ecosystem Services) at the Department of Agricultural Economics and Rural Development, Georg-August Universität Göttingen, Germany.

Stefan Baumgärtner is a Professor of Sustainability Economics at the Department of Sustainability Sciences, Leuphana University of Lüneburg, Germany.

Mauricio R. Bellon is a Programme Director at the Diversity for Livelihoods Programme, Bioversity International, Maccarese, Italy.

Ekin Birol is a Research Fellow at the Markets, Trade and Institutions Division of the International Food Policy Research Institute, Washington DC, USA.

Romina Cavatassi is a consultant at the FAO, ESAE, Rome, Italy.

Jean-Paul Chavas is a Professor in the Department of Agricultural and Applied Economics, University of Wisconsin, Madison, USA.

David Cooper is a Senior Programme Officer with the Secretariat of the Convention on Biological Diversity, Montréal, Canada.

Salvatore Di Falco is a Lecturer at the Applied Economics and Business Management, Wye College, Kent Business School, Wye, UK.

Stéphanie Domptail is a PhD candidate at the Justus Liebig Giessen University at the Institut für Agrarpolitik und Marktforschung, Giessen, Germany.

Martin Drechsler works in the Department of Ecological Modelling, Helmholtz Centre for Environmental Research, UFZ, Leipzig, Germany.

Adam G. Drucker is a Senior Research Fellow (Environmental/Ecological Economics) at the School for Environmental Research, Charles Darwin University, Darwin, Australia, and Senior Economist at Bioversity International, Maccarese (Rome), Italy.

Svetlana Edmeades is a former Postdoctoral Research Associate Scientist at the Environment and Production Technology, International Food Policy Research Institute, Washington, DC, USA.

Bezabih Emana is a manager at the Supporting Integrated Development (SID), Addis Ababa, Ethiopia

Pablo Eyzaguirre is a senior scientist (Anthropology and Socio-Economics) at Bioversity International, Maccarese, Italy.

Sébastien Foudi is a scientist at the Lerna, University of Toulouse, France.

Cary Fowler is an Executive Director at the Global Crop Diversity Trust, Rome, Italy.

Franz W. Gatzweiler is a Senior Researcher at the Centre for Development Research, University of Bonn, Bonn, Germany.

Alessandra Giuliani is a former Associate Scientist at the Diversity for Livelihoods Programme, Bioversity International, Rome, Italy.

Klaus Glenk is a scientist at the Macaulay Institute, Craigiebuckler, Aberdeen, UK.

Guillaume Gruère is a Research Fellow, Environment and Production Technology Division, International Food Policy Research Institute, Washington, DC.

Peter Hazell is a Visiting Professor at Imperial College London, Wye campus, UK.

Jaakko Heikkilä is a scientist at the Agrifood Research Finland (MTT), Helsinki, Finland.

Toby Hodgkin is a principal scientist at Bioversity International, Rome, Italy.

Jeffrey Hopkins is an Adviser in Economics and Environmental Policy at Rio Tinto, Washington, DC, USA.

Anni Huhtala is a Professor of Environmental Economics at the Agrifood Research Finland (MTT), Helsinki, Finland.

Fred H. Johnsen is an Associate Professor in the Department for International Environment and Development Studies (NORAGRIC), University of Life Sciences (UMB), Ås, Norway.

Karin Johst works in the Department of Ecological Modelling, Helmholtz Centre for Environmental Research, UFZ, Leipzig, Germany.

Mitri Kitti is a scientist at the Helsinki School of Economics, Helsinki, Finland.

Andreas Kontoleon is a Lecturer in the Department of Land Economy, University of Cambridge, UK.

Vijesh V. Krishna is a Ciriacy-Wantrup Fellow at the Department of Agricultural and Resource Economics, 313 Giannini Hall, University of California, Berkeley, CA, USA.

Karin Larsén is a Postdoctoral Fellow at the Leibniz Institute of Agricultural Development in Central and Eastern Europe (IAMO), Halle, Germany.

Belaineh Legesse is an Assistant Professor at the Alemaya University, Diredawa, Ethiopia.

Leslie Lipper is a Senior Economist at the FAO, ESAE, Rome, Italy.

Rainer Marggraf is Professor (Environmental and Resource Economics) at the Department of Agricultural Economics and Rural Development, Georg-August Universität Göttingen, Germany.

Ruth Meinzen-Dick is a Senior Research Fellow at the Environment and Production Technology Division, International Food Policy Research Institute, Washington, DC, USA.

Ernst-August Nuppenau is a Professor for Environmental and Ecological Economics at the Justus Liebig University of Giessen, Germany.

Cornelia Ohl works in the Department of Economics, Helmholtz Centre for Environmental Research, UFZ, Leipzig, Germany.

Amani Omer is a scientist in Manchester, UK.

Unai Pascual is a Lecturer at the Department of Land Economy, University of Cambridge, UK.

Alexander Popp is a researcher at the Potsdam Institute for Climate Research (PIK), Potsdam, Germany.

Martin F. Quaas is a Professor of Environmental, Resource, and Ecological Economics at the University of Kiel, Germany.

Eric Rayn-Villalba is a PhD student at the Department of Geography, University College London, UK.

Luis Carlos Rodriguez is a scientist at CSIRO Sustainable Ecosystems. GPO Box 284, Canberra ACT 2601, Australia.

Noel Russell is a Lecturer at the School of Economics, University of Manchester, UK.

Johannes Sauer is a Lecturer at Kent Business School, Imperial College Wye Campus, Wye, UK and an Affiliated Associate Professor in the Department of Food and Resource Economics, University of Copenhagen, Denmark.

Aseffa Seyoum is a Junior Researcher at the Centre for Development Research, University of Bonn, Bonn, Germany.

Melinda Smale is a Senior Research Fellow, Environment and Production Technology Division, International Food Policy Research Institute, Washington, DC.

Franz Wätzold works in the Department of Economics, Helmholtz Centre for Environmental Research, UFZ, Leipzig, Germany.

Foreword

The Millennium Ecosystem Assessment concluded that human activities have led to a more rapid loss of biodiversity on Earth over the past 50 years than ever before in human history. The assessment argued that the loss of species and the progressive homogenization of many ecosystems continue to be one of the main threats to the survival of our natural as well as socioeconomic systems. Intensification and the homogenization of agricultural eco-systems have led to significant losses in agrobiodiversity, including the loss of crop and livestock species and genetic diversity, as well as crop-associated biodiversity (such as pest-suppressive biodiversity pollinators, soil biodiversity).

Without proper management of agricultural biodiversity some key functions of the agro-ecosystem may be lost, such as maintenance of nutrient and water cycles, pest and disease regulation, pollination and hand erosion control. Erosion of agricultural biodiversity has negative impacts on the long-term sustainability of agricultural systems and on food security, especially of poor populations living in marginal lands.

Global environmental change and recognizable, irreversible loss of biodiversity have hastened a consensus among citizens, scientists and policymakers that concrete steps must be taken—at national, regional and international scales—to support the conservation of biological diversity. Conservation of biodiversity has become a mainstream issue and not just the concern of those who call themselves conservationists. Yet, despite scientific progress in understanding how to conserve genes and species, little is understood about interactions among components of biological diversity and ecosystem service provision in *agricultural landscapes*.

The mechanisms and tools used for sustainable agricultural biodiversity management are quite distinct from those traditionally used for wild diversity conservation (such as protected areas). This is because agricultural biodiversity management involves necessary trade-offs with human aspirations for improved food security and improved livelihoods. Setting aside lands for agricultural biodiversity conservation is generally not an option in developing societies with growing populations.

The recently released World Bank's *World Development Report* (2008) makes a very strong case for agricultural development as the primary

pathway out of poverty for the developing world, particularly for countries in Sub-Saharan Africa that are still in the early stages of the structural transformation process. For these societies, agricultural biodiversity management has to be seen as an integral part of the overall strategy for agricultural and economic development. We will have to find ways to develop agriculture to improve food security and reduce poverty while at the same time protecting agricultural biodiversity.

This book is the most recent compilation of studies in the emerging field of biodiversity economics. Biodiversity economics is the economic analysis of principles, causes and changes in biological diversity. The particular focus of this book is the interplay between agrobiodiversity and economic development, it brings together work by both academic researchers and researchers from international agricultural research organizations.

The book includes a synopsis of the state of current policy and institutional frameworks that have been designed to support sustainable use, studies on market and non-market mechanisms for agrobiodiversity conservation, and empirical evidence about the relationships between components of agrobiodiversity, economic development and markets.

Finally, I would like to say that I am very pleased to see that this book is dedicated to Erika Meng. Erika focussed her research on understanding the incentive structures that allow farmers to enhance productivity while at the same time sustainably managing crop genetic diversity. Her in-depth field research and analysis have provided important insights in to the economics of agricultural biodiversity and have inspired students and scholars in this field.

<div style="text-align: right">

Prabhu Pingali
Head, Agricultural Policy and Statistics,
Bill and Melinda Gates Foundation, Seattle, USA.
Formerly, Director, Agricultural and Development Economics Division,
FAO, Rome, Italy.

</div>

Acknowledgements

1 Introduction

Agrobiodiversity for economic development: what do we know?

Andreas Kontoleon, Unai Pascual and Melinda Smale

1 'Agrobiodiversity is vital for human survival'

We open this book with a heading that closely matches a recent statement (February 18, 2008) by James G. Butler, Deputy Director of the Food and Agriculture Organization of the United Nations, at the opening session of the thirteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice of the Convention on Biological Diversity. Butler asserted that 'biodiversity is vital for human survival'. His pronouncement epitomizes the policy challenge of agricultural development in the twenty-first century – to secure food for all peoples while protecting the agricultural biodiversity on which both we and future generations largely depend. The challenge is Sisyphean. Paradoxically, some of the world's poorest people are custodians of some of the world's greatest agrobiodiversity assets. Butler's statement also reflects a mounting policy concern for the irreversible loss of biodiversity that occurs with species extinction, long viewed as a pressing problem by conservation biologists and natural resource economists. In the past few decades, much progress has been achieved in understanding the economic causes and implications of mismanaging wildlife and bio-diversity in general. This book explores more closely the linkages between agrobiodiversity and economic development.

Early notions of biological diversity (Norse and McManus 1980) focused almost exclusively on genetic diversity (the amount of genetic variability within species) and ecological diversity (the number of species in a community of organisms). As defined by the UN Convention on Biological Diversity, biological diversity is now understood to encompass 'the variability among living organisms from all sources including . . . terrestrial, marine and aquatic ecosystems and the ecological complexes of which they are a part', including 'diversity within species, between species and of ecosystems'. This notion of biodiversity, combined with the disciplinary perspective of natural resource economics, has generated the field of biodiversity economics. The Earth Summits of Rio de Janeiro and Johannesburg, in particular, marked the emergence of this demanding new field (Kontoleon *et al.* 2007). Biodiversity economics refers to the economic

analysis of the principles, causes and implications of changes in biological diversity.

So far, despite the fact that agriculture is linked fundamentally to biodiversity, the impacts of changes in biodiversity on the world's agricultural landscapes have largely escaped attention. Over millennia, human well-being has been founded on the services that biodiversity provides, the most obvious of which is the production of foods, fuels and fibres in agricultural landscapes. Such services have been and continue to be the basis for economic development for a large proportion of the human population. In a wider context, biodiversity in agricultural landscapes serves critical functions that enhance the environmental base upon which agriculture depends. These functions include regulating and supporting services such as water purification, nutrient cycling, and soil formation (Millennium Ecosystem Assessment 2005).

We consider that agrobiodiversity includes the full diversity of organisms living in agricultural landscapes, including biota for which the precise function, from the human utilitarian point of view, is still unknown (Jackson *et al.* 2005). Agrobiodiversity has two main components. The first, planned agrobiodiversity, is the diversity of crops and livestock managed by farmers. The second, associated biodiversity, refers to the biota (such as soil microbes and fauna, weeds, herbivores, and carnivores) in the agroecosystem that survive according to local management and environmental conditions (Vandermeer and Perfecto 1995). Croplands and fields are also included, as well as habitats and species outside of farming systems that benefit agriculture and support ecosystem functions (Jackson *et al.* 2007).

For an economist, agrobiodiversity is part of natural capital, and the flow of services that it provides is the 'interest' on this capital. Just as investors choose a portfolio of produced capital to maintain the return on capital over a range of market risks, so society needs to choose the mix of genes, species, communities, and ecosystems to maintain the flow of ecosystem services over a range of environmental and social risks (Perrings *et al.* 2006). In order to design agricultural, development and conservation policies that maintain an ecologically acceptable and economically optimal level of biological diversity in agricultural landscapes, an understanding of the risk implications of changes in the mix is required. Economics can offer insights for decision-makers by identifying the 'social opportunity costs' that result from agrobiodiversity loss. Such opportunity costs have to do with complex trade-offs among food production, biodiversity conservation, ecosystem services and human well-being. Thus, inserting agrobiodiversity within the realm of biodiversity economics is imperative – even more so if its role in spurring the development of economies that depend largely upon their agricultural resources is to be illuminated for policy-makers. The capacity to communicate from the sacred forests of Tibet to the *milpa* fields of Oaxaca makes it essential that we better understand our interdependence and how to positively utilize and conserve agrobiodiversity through appropriate policy frameworks.

Today's development policies confront a difficult challenge in the face of the world's population of 6.3 billion people projected to grow to 9 billion by 2050, implying that to meet the increased demand for food and fibre, more land would be converted to agriculture, and agricultural intensification would continue. This process is placing growing pressure on agricultural landscapes, thereby promoting species extinction in managed and constricted wild land habitats. Abandonment of already degraded fragile lands and agricultural encroachment on forest margins would most likely increase, with further loss of agrobiodiversity and its services.

Added to this is the continued integration of international agricultural markets and pressure from the agribusiness sector to shape agricultural landscapes to a more simplified and thus apparently manageable sector, at an ever accelerating pace, especially in developing countries (Barrett *et al.* 2001). Chapters in this volume challenge the view that simpler is better, especially as 'simplifying' agrobiodiversity translates into disinvesting in natural capital and thus increasing the risks of already volatile agricultural commodity markets. Industrial countries with a highly developed financial sector may be able to substitute natural for financial capital to some extent. By contrast, in developing economies, when such financial markets exist, they are often rudimentary and incapable of insuring farmers against 'simplifying' choices. Managing a portfolio of capital without proper insurance mechanisms and well-functioning markets is therefore a risky business.

Furthermore, in the face of global environmental changes, the need for scientific knowledge on the role of agrobiodiversity and human well-being is essential. One type of agrobiodiversity that is reasonably well understood is genetic diversity of cultivars and breeds. In modern production systems, the focus has been on traits that increase yield in relatively homogeneous, controlled production environments, keeping up with the treadmill of rapidly changing virulence of specific pests and diseases, meeting the demand for resistance to an increased range of biotic and abiotic stresses, or increasing the temporal and spatial production of commodities, destined for different uses. In contrast, in traditional production systems, farmers and communities opt to maintain a number of traditional varieties for many reasons.

The link between agrobiodiversity and insuring against global genetic vulnerability is also more evident. Such genetic vulnerability of today's global agricultural systems arises from a common dependence on relatively few crops and varieties. At least since Amartya Sen's pathbreaking study on the Bengal famine, economists have recognized that an adequate supply of food is a necessary but not a sufficient condition for forestalling hunger. However, plant disease epidemics and abiotic stresses, such as the increasing variability of moisture and temperature, underscore the need to 'insure' against crop failures. Each year, crop damage penalizes farmers in many of the world's villages, and for farmers who depend on their crops for their livelihoods, these penalties can be dire (such as liquidation of assets, migration, and undernutrition). In intensive production systems, both the incidence of pests and

plant diseases, and the potential for a large-scale epidemic, are higher. Combating plant disease epidemics incurs costs for nations already strapped for funds, and these can involve unsafe use of chemicals. Coping with persistent crop damage and avoiding disastrous epidemics through maintenance breeding instead of chemical control requires long-term investments and access to a steady supply of diverse genetic resources.

The economic dilemma for small-scale farmers in developing countries is quite clear. Since the social insurance benefits of higher levels of crop genetic diversity are not rewarded in many current markets, farmers have little private incentive to conserve genetic diversity. The most profitable decision is frequently to grow only a few crop varieties, and not to invest in conservation of the varieties that are less 'favoured' by the market. In the case of genetic diversity, farmers who maintain *in situ* crop genetic diversity are essentially conserving a global public good and thus they can be seen as net subsidizers of modern agriculture and food consumers worldwide. However, global institutions are not in place to provide compensation for generating such global benefits. Indeed, one reason for the profitability of modern specialized agriculture is that it is free-riding on those farmers who are investing in such genetic diversity. The net result is that global crop genetic diversity is rapidly being reduced, since the custodians of the global genetic portfolio are not compensated by current international markets, and there are no corrective policies or mechanisms in place (Pascual and Perrings 2007).

After a fuller exposition of some of the issues that have been motivating this compilation of studies that link economic development and agrobiodiversity conservation, the remainder of this chapter previews some of the gaps in the empirical knowledge on such an interface and then describes each of the three parts of the book, folding the authors' approaches and findings into a more general discussion of economics methods and issues.

2 Gaps in empirical knowledge about agrobiodiversity and economic development

Scientific capacity to map the geographical distribution of genes, and endangered genotypes, species and habitats has advanced much in recent years. Applied economists have also made progress in adapting tools to analyze the value and determinants of individual components of agricultural biodiversity, including crop, livestock, forest and aquatic genetic resources (for examples, see the review by Smale and Drucker 2007; Tisdell 2003; Ninan 2007). In fact, little is still known about the nature of the interactions among components, and how these interactions would affect the cost and benefits of conservation programmes. Peer-reviewed, empirical literature on these topics remains sparse in comparison to theoretical studies – particularly with respect to developing economies.[1]

Although there is an emerging consensus among civil society, the research community and policy-makers that concrete steps must be taken to promote

sustainable use of agrobiodiversity, scientific controversy remains over its meaning and how to achieve it. The International Treaty on Plant Genetic Resources for Food and Agriculture requires contracting parties to devise policy mechanisms and measures to support sustainable use. The Convention on Biological Diversity refers to use of the 'components' of biological diversity 'in a way and at a rate' that does not lead to a biodiversity decline. Though intuitively appealing, this concept is far from operational. Biological diversity has many components whose interactions are still poorly understood; policies supporting the sustainable use of one component without full recognition of these interactions could have unintended consequences.

There are at least two reasons why it is essential to integrate research about components of agrobiodiversity from a landscape or habitat perspective. Without doubt, a holistic approach to valuing the components of agrobiodiversity will advance scientific knowledge. In addition, applied research that takes interactions among components into account could lead to estimates of costs and benefits that differ in important ways from those that do not. Ignoring interactions among components could bias policy recommendations. For example, many small-scale farmers address multiple objectives simultaneously, such as producing grains that provide food for humans and forage for animals. By doing so, they integrate the production of two or more agrobiodiversity components – in this case, crops and livestock. In intensive farming systems too, crop products serve as inputs for both livestock and fish production, and manure and animal power also serve as an input to crop production. Planted alongside crops or intermingled within fields, some tree species contribute to favourable growing conditions in addition to supplying primary products. Thus, economic policies and development interventions that affect one component often affect another, with implications for agrobiodiversity conservation. Such connections between agrobiodiversity components become even more complex when the scale of observation and analysis shifts from farm to landscape. Habitats, both agricultural and proximate to agricultural areas, serve as focal points where multiple components of biodiversity converge and interact.

Researchers have recognized that some of the most significant forces driving change in diversity levels within components are also the same across components – such as the processes of agricultural intensification and the spread of market infrastructure. Beyond recognition of this fundamental point, however, the role of markets has not yet been well articulated in the applied economics literature about crop and livestock components of agrobiodiversity. In particular, the direction of causality has been difficult to establish with cross-sectional data: is on farm conservation of agrobiodiversity merely a consequence of having been left out of markets? Can markets develop in such a way that agrobiodiversity is supported?

The applied economics literature about crop biodiversity maintained on farms in developing economies has repeatedly demonstrated that, apart from

agroecological heterogeneity and cultural autonomy, market isolation is a crucial determinant. In more than a dozen case studies conducted recently in primarily low- and middle-income countries (Smale 2006), tests of hypotheses about the effects of seed and product markets on the biodiversity of crops grown by farmers have turned out to be ambiguous. One obvious explanation is that the indicators of market participation, stage of market development, and transactions costs differ substantially across the studies, thus pointing towards the context-dependency of this complex question. Another reason is that rural markets themselves differ in form and organization, and thus the word 'market' cannot be generalized to describe a single institution. Further, markets are most often found to function at different development stages, with different sources and degrees of informational asymmetries and transaction costs between sellers and buyers.

Given the key role of market institutions, emerging empirical research in a set of case studies recently coordinated by Food and Agriculture Organization (FAO) has identified market-related means of supporting local crop biodiversity among poor farmers in low-income countries. Employing the 'marketshed' as the geographical scale of analysis, researchers have analyzed the genetic diversity of seed that passes hands from vendors to farmers in the village markets, linking the supply and demand of traits to transactions costs, local seed policies, and farmer welfare (e.g., Nagarajan *et al.* 2008; Smale *et al.* 2008).

Generalizing across empirical case studies on farm conservation continues to be difficult given existing differences among crop species, agroecologies and institutional contexts. Nevertheless, to implement regional and global conservation strategies, sufficient knowledge about *in situ* and on farm conservation strategies, successes and failures must be accumulated. As a point of contrast, the global information system for plant genetic resources conserved *ex situ* is already well developed. Efforts are underway to georeference accessions in addition to characterizing them with respect to traits frequently demanded by plant breeders and farmers. Similar efforts are necessary for *in situ* and on farm resources.

On-farm conservation of agrobiodiversity depends on understanding the costs and benefits that arise at different scales, i.e. from the farmer to the global economy. Without such calculation it is not possible to demonstrate the need for policies that would create synergies between economic development and *in situ* agrobiodiversity conservation. Thus, economic valuation of agrobiodiversity conservation remains high on the policy agenda. Not just at the demonstration stage but also at the more challenging one, that is, to use estimated values to design market-based incentives and economic mechanisms that can couple both objectives (Pascual and Perrings 2007).

3 The role of valuation, markets and non-market institutions for agrobiodiversity conservation

The idea of using market instruments for the allocation of the private and public good benefits has extended naturally to those derived from agrobiodiversity. This is manifested clearly in both academic and policy circles. Two prominent examples include markets for certified agricultural products that in some way or another are derived from agrobiodiversity-friendly practices and markets for ecosystem services that are provided from the conservation of agrobiodiversity more directly.

The main defining feature of such market solutions (which distinguishes it from other command and control or economic instruments such as subsidies) is that a regulating body only has an indirect secondary role to play in promoting such schemes. This role is confined to delineating and specifying property rights, minimizing transactions costs and facilitating the transfer of information. Conceptually, the establishment of such markets can be viewed as forms of Coaseian bargaining (Pearce 2004). Some economic literature discusses the success of creating markets for agrobiodiversity conservation in terms of both its efficiency (in terms of costs) and effectiveness (in terms of biodiversity conserved). For success to be achieved on both these criteria, the market creation process should follow a three step-process: demonstration, appropriation and benefit sharing (Heal 1999; Pascual and Perrings 2007).

Demonstration refers to the identification and measurement of agrobiodiversity values. It is required for the following reasons: the potential benefits from conserving a specific level of a particular resource may not always be evident. Further, even if potential agrobiodiversity values are easily demonstrated, their magnitude is often not reflected in price data. Finally, the *relative* magnitude of the different values of a particular biodiversity resource is not always readily known. *Capture* (or *appropriation*) refers to the process of capturing some or all of the demonstrated and measured values pertaining to agrobiodiversity so as to provide incentives for its conservation. This is achieved through the design and implementation of mechanisms and markets that allow values to be channelled from those who receive a benefit from the conservation of biological diversity to those who bear the cost. *Benefit sharing* entails that the valuation and appropriation of agrobiodiversity values are not sufficient conditions for providing incentives for agrobiodiversity conservation. The implementation of appropriation mechanisms must be undertaken in such a manner that the captured agrobiodiversity benefits are distributed to those who bear the costs of conservation.

In this tripartite process of agrobiodiversity market creation, valuation plays a vital role in the initial stage of demonstration. Valuation first requires a conceptual framework for defining values. Agrobiodiversity as defined above has been associated with various benefits that have been conceptualized through two main frameworks. One is the well-known Total Economic Value (TEV) paradigm and the other, though similar, is the one coming from

the Millenium Ecosytem Assessment (MEA 2005) framework. The TEV framework is an aggregate concept of value that decomposes agrobiodiversity benefits into direct use (consumptive and non-consumptive), indirect use, option value and non-use values. The MEA framework adopts a services perspective and decomposes agrobiodiversity benefits into provisioning, regulating, supporting, and cultural services. Another useful way of classifying these values (and which bridges the two approaches mentioned above) is one which classifies values in accordance to how they relate to 'planned' agrobiodiversity and 'associated' agrobiodiversity. Both of these aspects of agrobiodiversity entail private and public good dimensions. For example, planned agrobiodiversity is related to provisioning services and direct use values while associated agrobiodiversity is linked to regulating and supporting services. The former provisioning services could be the focus of, say, insurance as well as certified product markets while the latter could be provided via payment (or rewards) for ecosystem services schemes (PES).

These values have been conceptually defined and analyzed using various economic modelling frameworks (for a review, see Goeschl and Swanson 2007). In terms of applied work, economists have used both revealed and stated preference methods to assess the magnitude of these values (Smale 2006). In looking at this emergent body of literature one can conclude that although there have been advances in our understanding of the various values of 'planned' agrobiodiversity, there is considerable less advancement on assessing values for 'associated' agrobiodiversity. A related observation is that although considerable work has been underway on certified products (e.g. premium estimation, assessment of extent of these markets, etc.). we have attained a lesser understanding on how to use valuation work to build market institutions that aim to preserve 'associated' agrobiodiversity, namely PES schemes. This volume also tries to fill in some of the gaps by including recent valuation studies on the role of agrobiodiversity.

4 Overview of the book

In the work compiled here, the authors have sought to address fundamental issues concerning the link between the utilization and conservation of agrobiodiversity and its impacts on and effects arising from economic development. The chapters in Part I provide a synopsis of relevant policy issues and identify gaps that must be addressed in order to design policy frameworks that facilitate positive synergic changes. In Part II, methods and principles of agrobiodiversity economics are applied to case studies that span developed and developing economy contexts, pinpointing some of the trade-offs and synergies involved in meeting the main policy challenges. Among them, the development of markets has often been blamed at least in part for genetic erosion and the loss of biodiversity, though most experts now agree that habitat change is the single most important ingredient, itself a product of multiple forces. Can markets and valuation play a supporting role in

protecting agrobiodiversity? The chapters in Part III examine the role of both market and non-market institutions, as well as the role of valuation.

4.1 Part I: Agrobiodiversity conservation and economic development: emergent policy perspectives

The volume opens with a useful overview of current policy frameworks and perspectives concerning the sustainable use of plant genetic resources for food and agriculture, by Leslie Lipper and David Cooper. These authors focus on plant genetic resources, and in particular, crops. Structuring the public and private benefit streams that plant genetic resources generate by spatial scale (farm → region → globe), time scale (adaptation as compared to adaptability in the longer term), and source of value (traits, portfolio, option, exploration), they discuss the potential for synergies and trade-offs in agriculturally based, developing economies. Already constrained by scarce capital and low income, these nations, like higher-income countries, will face the additional challenges of climate change.

Like other agricultural researchers who have examined the evidence, Lipper and Cooper acknowledge the productivity advances of the 'revolution' in scientific plant breeding that began with the application of Mendelian genetics and hybridization in the early twentieth century, culminating in what became known as the 'Green Revolution' during the 1970s. Spurred by irrigation, application of fertilizers, mechanization, other structural shifts in use of land and water resources, the process of seed-driven technical change was uneven in its impact across regions of Asia and Latin America, bypassing much of Sub-Saharan Africa altogether. In more intensive agricultural systems, such as the Punjabs of India and Pakistan where semi-dwarf wheat varieties were initially introduced, dramatic technical change was later accompanied by environmental externalities such as salinity.

Thus, agricultural research today faces a task with daunting proportions: drawing farm populations who have been left out of the Green Revolution into a form of seed-based technical change that better protects scarce resources, while at the same time reducing the rate of resource degradation in already intensified production systems. With respect to sustaining the stock of plant genetic resources, Lipper and Cooper mention several strategies, including more emphasis on decentralized, participatory approaches that address the need for adaptation to local production and market conditions, combined with a set of supply-side and demand-side policies that enhance not only the productivity but also the resilience of production systems.

Provocatively, Lipper and Cooper argue that there is a demand for diversity on farms and in markets that is not currently met by supply, especially in the formal seed sector. While supply-side policies are fundamental, policies that stimulate demand for diversity will continue to be important as farmers are brought into markets. These policies relate in particular to the structure of the market channel and its performance.

Following the chapter by Lipper and Cooper, the next three chapters examine in greater detail specific issues involved in conserving the plant genetic resources 'component' of agrobiodiversity. In Chapter 2. Melinda Smale, Peter Hazell, and Toby Hodgkin Cary Fowler focus on the global strategy for securing the supply of the major food crops on which the world now largely depends. In this chapter, these authors point out that various global (*ex situ*) agrobiodiversity conservation strategies appear to have, in general, performed rather adequately. However, the authors also warn that the instrumental role of public institutions in providing agrobiodiversity as a key global public good, could be eclipsed in the near future by pressures to privatize agricultural research and thus appropriate benefits through intellectual property rights. Given this emergent scenario the authors call for the attention of policy-makers, to renew the focus upon the structure and management of international gene banks. In addition, the authors also point out the urgent need for robust policy frameworks to manage *in situ* conservation globally, which at the moment is unfortunately largely lacking.

In the next chapter, Mauricio R. Bellon examines the crucial role of crop landraces – the units of crop genetic diversity that are the most accessible to humans – in this strategy. Bellon outlines the state of scientific knowledge about crop landraces and proposes an initial step in constructing such a policy framework. He advocates a global information system that can monitor and assure access to landrace germplasm in a complex of sites placed strategically in multiple locations around the world. Enumerating the arguments in favour of *in situ* conservation, Bellon emphasizes that landraces cannot be separated from the socio-biological systems that generated them. Landrace systems are open and dynamic; landraces cannot be conserved individually and individual farmers cannot conserve them. Instead, landrace systems are sustained by the sharing and exchange of seeds among farmers. The greatest threats to these systems are the social and cultural changes that occur with increased participation or rural people in markets – not only for the crop in question, but for labour, other goods and services. Like the global strategy for *in situ* conservation, the system Bellon envisions would be undermined by restrictions on the international flow of germplasm.

In Chapter 5, Guillaume Gruère, Alessandra Giuliani and Melinda Smale, shift the lens from the major food crops explored in Chapter 3 to the minor crops for which global strategies are less well articulated, investigating the nature of failures and imperfections that must be addressed if production of these endangered crops is to continue. Gruère *et al.* focus on those who have been left out of both the process of technical change and that of market development: growers, gatherers, and locally traders of minor crops that are often called 'underutilized'. The authors begin with a workable definition of underutilized according to three economic characteristics. Underutilized species are locally abundant but globally rare. Though scientific knowledge about them is scant, local users have an in-depth knowledge about them. Current use of these species is limited relative to potential use. Drawing

examples from comprehensive field studies, they propose a conceptual framework to understand the economic factors that cause these species to be underutilized, classifying species with respect to market imperfections or particular market failures. Gruère *et al.* then identify necessary conditions for the successful commercialization of underutilized plant species that also benefits poor actors in the market channel. In addition to the expansion of demand and increased efficiency of supply, a 'supply control' mechanism that differentiates the product from close substitutes, such as geographical denomination of origin based on physical attributes or mode of production, is a necessary ingredient.

Despite the driving role of markets in providing incentives and disincentives for farmers to maintain diverse crops and varieties, in Chapter 6, Ruth Meinzen-Dick and Pablo Eyzaguirre provide us with empirical examples that document the crucial role of non-market institutions as conduits for germplasm and related information. Their portrayal of these institutions reminds us that although economics provides us with tools to measure values and propose solutions to problems, it is society and culture that proscribe behaviour and determine which solutions are acceptable. The genetic resources embodied in seed, and seed as a metaphor for life itself, carry strong social and cultural connotations. Today, many of the seeds planted by the world's farmers are saved by these farmers from their own harvests or acquired from other farmers. Seed transactions follow lines of kin, friendship, affinity and ethnic identity – even in local seed markets (see example documented in Smale *et al.* 2008). This empirical reality contrasts with the image conveyed by neoclassical economic theory of impersonal transactions in competitive markets.

The last chapter in Part I, Chapter 7, by Adam Drucker and Luis Carlos Rodriguez, addresses a second major component of agricultural biodiversity: farm animal genetic resources. The majority of the world's rural poor depend on livestock as a component of their livelihoods. Although much less talked about, genetic erosion in farm animal genetic resources is much more serious than in crops because the gene pool is relatively small and the prospects of irreversible losses through breed and strain extinction are many times greater. Current rates of extinction have been documented, and the threat of loss is estimated to be greatest in developing economies. Extinction is related to the process of development itself, including the introduction of exotic breeds and cross-breeding that is intended to enhance productivity. In response to the neoclassical perspective that loss of local breeds reflects changing price ratios and hence, a socially optimal outcome, they argue that market prices are distorted and do not adequately reflect economic scarcity and the social cost of losing local breeds. Drucker and Rodriguez formulate and apply a conceptual model to empirical data from a recent case study in Mexico. They demonstrate that promoting the continued management of local breeds can actually be achieved cheaply – without an incentive payment to small family backyard producers, and with a negligible premium for large family backyard

producers, supplemented by technical assistance. By comparison, supporting the maintenance of local breeds would be expensive for commercial farmers. Their finding suggests that a 'win–win' policy solution is feasible; the livelihoods of the rural poor could be supported through promoting the use of local breeds.

4.2 Part II: Agrobiodiversity conservation objectives, trade-offs and synergies

The chapters in Part II focus more closely on models and methods that illustrate the existing trade-offs and potential synergies between *in situ* agrobiodiversity conservation and the main provisioning service of agriculture, namely the production of foods and fibres. In a way, it addresses one of the most visible economic sustainability problem, related to the utilization and conservation of agrobiodiversity. While short-run agricultural efficiency may indicate specialization and therefore disinvestment in agrobiodiversity, the longer-term effects may well be lowering the returns from such specialization or/and increased risk (variance) of the flow of provisioning services (interest on the natural capital).

   The first chapter of Part II, Chapter 8, by Amani Omer, Unai Pascual and Noel Russell, provides an illuminating example of the potential dynamic effects of simplifying the agricultural base in already highly intensive agricultural systems, such as those cereal farming regions in industrialized countries. Following a bio-economic model, the authors hypothesize a positive relationship between the stock of agrobiodiversity and optimal levels of crop output and then test such a hypothesis using a stochastic production approach using data from a panel of specialized cereal farms from the east of England. The results support their theoretical hypothesis leading them to conclude that investment in agrobiodiversity in diverse poor systems can lead to a continual outward shift in the output frontier, once controlled for the relevant set of labour and capital inputs. Such a result suggests that there is scope for an agricultural transition towards biodiversity conservation that may still be consistent with an increase in crop output in already biodiversity-poor modern agricultural landscapes.

   Johannes Sauer, in Chapter 9, provides a useful review of the methodological and empirical literature that establishes the link between production efficiency and environmental/biodiversity efficiency. Departing from the more traditional linear programming approach, following the previous chapter, Sauer focuses on how to incorporate agrobiodiversity into stochastic frontier models to achieve more realistic measures of production efficiency. Drawing on an empirical example of tobacco production which affects species diversity in the surrounding forests, he models both the allocative and technical efficiency measures as well as environmental/ biodiversity efficiency. The latter is based on a biologically defined species diversity index which is incorporated either as a desirable output or as a detrimental input, when

this is reduced. In addition, Sauer shows how this method can be used to derive a shadow price of biodiversity.

Next, in Chapter 10, Salvatore di Falco and Jean-Paul Chavas investigate the role of spatial crop diversity in providing resilience in the context of rainfall shocks to cereal production in southern Italy. The chapter documents empirically how greater planned diversity can indeed support resilience and maintain the system productivity under challenging climatic conditions. Di Falco and Chavas tackle a fundamental question about the economics of agrobiodiversity. The debate about the trade-off between agrobiodiversity conservation and productivity has been greatly enriched by the ecological concept of resilience.

Resilience is a useful concept for ecologists and economists alike when dealing with agrobiodivesity. It refers (*sensu* Holling 1988) to the size of perturbation that is required to transform a system from one state to a different one, and is frequently increasing the number of species that are apparently 'redundant' under one set of environmental conditions, but that perform important functions under different environmental conditions. For instance, in biodiversity-poor intensive agricultural systems such as the one described by Omer *et al.* (Chapter 8), the agricultural system can be locked into a narrow range of agricultural technologies. At one level, this can make the system more stable in the sense that there is less variation in the producer's economic activities following minor perturbations, but conversely, it may also reduce the capacity of that system to absorb greater environmental or economic shocks, such as sudden and unexpected commodity price changes. By eliminating options regarding productive diversification, a reduction in agrobiodiversity may also lock farmers into obsolete agricultural technologies (Pascual and Perrings 2007).

In the following chapter, Leslie Lipper, Romina Cavatassi and Jeffrey Hopkins (Chapter 11) analyze the motivations of farmers in eastern Ethiopia for choosing between the adoption of improved sorghum varieties and utilizing landrace varieties in the context of drought risks. Lipper *et al.*'s chapter provides key insights into how farmers choose to manage their crop genetic resources to cope with severe production risks due to severe climatic shocks. Interestingly, using data collected during a drought year, they suggest that in the case study area, improved sorghum variety adoption has not proved to be an effective means of coping with drought. Their results also suggest that while improved crop varieties in their case study tend to be adopted for planting in relatively higher potential areas, they are also associated with a higher rate of crop failure when compared to landraces when facing the risk of crop failure due to drought. Their results seem to support the argument of the importance of landraces in the decision to replant crops, suggesting the importance of the availability of local crop genetic diversity as both a means and outcome of replanting.

Next, in Chapter 12, Stéphanie Domptail, Alexander Popp and Ernst-August Nuppenau depart from the issue of crop genetic diversity and instead

model land users' multiple, although potentially conflicting, strategies and practices when external shocks such as droughts and high rainfall events impact on a specific type of agroecosystem. Taking the example of semi-arid ranching systems in Namibia, where range degradation is a constant concern for scientists, national land use planners and local commercial farmers, they focus on the main trade-off facing the latter community, i.e., the generation of short-term income and the longer-run maintenance of the health of the range. Using a multi-objective (dynamic) bio-economic model, they simulate the impact of varying stocking rates on the range, as dependent on rainfall and natural conditions. Domptail *et al.* show that a positive trade-off indicates that the system becomes degenerative, in turn implying that more income from range production would lead to more range degradation. Their results also suggest that some strategies that may a *priori* be seen as non-conflictive, such as reliance on external fodder, are characteristic of such degenerative outcomes.

After Domptail *et al.*'s study of rangelands, Chapter 13, by Sébastien Foudi, takes another look at the complementarities and trade-offs between planned and associated agrobiodiversity. More specifically, Foudi focuses on the mutual relationship linking soil biota and agricultural practices. He estimates the soil biota and agricultural production interactions on various agroecosystems and tests whether results are in accord with ecological research findings. While he shows that the approach to research may not coincide between economists and ecologists, the results of the econometric procedure that he suggests may be consistent with regard to the latter discipline. The model he proposes is based on biological results on agricultural intensification and soil biodiversity that describes the way farmers influence the biotic resource of the soil and the way such biotic resources influence the productivity of the agro-ecosystem. The application utilizes panel data from a sample of French farmers and considers wheat, maize, oil-producing crops and grassland in the context of both isolated and highly connected agroecosystems.

So far, the role of technological innovation and adoption also affecting agrobiodiversity has been analyzed in Part I. Part II flags this issue again. When it was reported in 2001 that genetically modified maize had contaminated native maize landraces in Oaxaca, Mexico, the familiar controversy and debate over genetically modified organisms (GMOs), or *transgenic*, crops suddenly erupted internationally. The debate over GMOs in Europe and its implications affecting trade agreements is also high on the international political agenda. This worldwide debate echoes the debates about the economic, social and environmental effects of the Green Revolution. On the one hand, there are those who praise the potential role of GMOs as holding the promise to improving agricultural productivity and to some extent increase resistance to pests, thus decreasing the reliance on pesticides. On the other hand, civil society's awareness of the potential risks from cross-pollinated contamination to the wider environment and agrobiodiversity in particular, puts the debate over the development of GMOs and the release into the environment,

in the highly fertile interface between ecology, economics and political science. The economics of the problem becomes ever more complicated when farmers' views need to be accounted for. What are the values and preferences of farmers regarding access to and utilization of transgenic varieties? While some information already exists in developed countries, there is much less evidence about the perceived values of peasants in developing countries, possibly those who would be most affected by the widespread use of GMOs for staple food.

The high profile example of Oaxaca with farmers' concerns of transgenic maize from the USA having the potential to cross-breed with traditional landrace varieties provides a fertile ground for Ekin Birol and Eric Rayn-Villalba (Chapter 14) who address those same Mexican peasants' preferences regarding the choice of continuing with the traditional *milpa* (traditional maize inter-cropping) systems versus the option to cultivate GM maize varieties under the same *milpa* systems. By using a stated preference valuation approach based on a choice experiment, Birol and Rayn-Villalba estimate *milpa* farmers' valuation of the most important components of agrobiodiversity, including intercrop diversity (crop species diversity), infra-crop species diversity (maize variety diversity), and crop genetic diversity (maize landrace). Their results reveal that there is considerable heterogeneity in farmers' preferences for agrobiodiversity management and GM maize cultivation in the *milpas* across three states of Mexico, including Jalisco, Michoacán and the above-mentioned Oaxaca. Their results also tend to confirm that on average farmers do not want GM maize, although they also point out a considerable variability among Oaxacan farmers for demand for this attribute. Further, when the focus is less subsistence-orientated farmers, the results also reveal that farmers derive some positive utility from maize variety diversity, revealing once again the importance of maize diversity in this region. Lastly, given the Oaxaca effect, it is worth pointing out that the authors find that farmers in this state value maize genetic diversity embodied in maize landraces, regardless of the market integration level of *milpa* households.

Parts I and II have echoed the lively debate surrounding the trade-off between the dissemination of high yielding modern varieties and the potential erosion of plant genetic diversity, as the former is often argued to have the potential to induce genetic uniformity rather than crop diversity. Given the rapidly evolving seed markets in emergent countries, the agricultural sectors that impinge on traditional landrace varieties become congenial to the analysis of the impacts of agricultural development policy strategies on *in situ* landrace conservation outcomes. Part II closes with chapter 15 by Vijesh Krishna and Unai Pascual who examine the potential success of economic mechanisms and instruments that could reduce market frictions for conserving landraces *in situ* in the case of eggplant, one of the most important vegetable crops in southern India. Krishna and Pascual argue that the slow progress in the introduction of modern varieties of eggplants into urban markets in India, together with a highly competitive eggplant landrace sector,

may not yet be sufficient to secure the conservation of those landraces. An examination of the supply and demand of eggplant in urban centres in India indicates the existence of an informal market segmentation for landraces, which helps farmers achieve a higher price premium for growing eggplant landraces, thus partially eclipsing the yield advantage of hybrids. The chapter also addresses the value of the landrace attribute from the perspective of the eggplant consumers by applying a contingent valuation model.

The results by Krishna and Pascual suggest that consumers' willingness to pay for the landrace attribute is relatively high, although compared with the farm price incentive, the price farmers obtain currently for the landrace trait is just a small fraction of the value consumers attach to this same characteristic. This further suggests that by developing practical schemes such as voluntary 'eco'-labelling and landrace certification to enhance information by consumers about the landrace attributes of vegetables in such emergent markets and by setting appropriate low cost marketing channels to transfer part of the price premium back to farmers could help farmers to sustain the adoption of landraces against modern varieties. This also echoes the hot topic of developing incentives and mechanisms both in the formal and informal institutional sphere to manage our agrobiodiversity portofolio sustainably. This is the focus of Part III of the book.

4.3 Part III: Market and non-market institutions for agrobiodiversity conservation

Part III of this book focuses more explicitly on understanding the role of both market and non-market institution building for agro-biodiversity conservation. There are certain connecting themes that run through these chapters. These are: (1) understanding the size of price premiums for the development of biodiversity-friendly market crops and the nature and extent of these markets; (2) assessing the intricacies behind designing incentive-compatible contract institutions for promoting agrobiodiversity conservation; (3) the impact on agrobiodiversity from varying degrees of access to food markets and other related markets (such as insurance markets); and (4) understanding farmer participation in voluntary incentive-based agi-environment schemes.

The issue that concerns Chapter 16 by Stefan Baumgärtner and Martin Quaas is that of the unintended or perverse incentives for the conservation of agrobiodiversity that come about with the building of certain market institutions that accompany with economic development. In particular, their work builds on past findings which show that as insurance markets develop (through economic progress) and insurance premiums decrease, the farmers are inclined to care less about preserving agrobiodiversity as an income and yield insurance mechanism. This results from the established finding over the substitutability (for risk-averse farmers) between 'self-insurance' or 'self-protection' on the one hand, and 'market insurance', on the other hand.

Baumgärtner and Quaas build on such conventional wisdom from insurance economics by stressing that agrobiodiversity not only has a private insurance function but also provides public insurance benefits. This brings to light the potential public good problem associated with the private provision of agrobiodiversity, namely that farmers may not take these social benefits into account when making crop choices which in turn may lead to what is a socially sub-optimal level of agrobiodiversity provision. The authors develop a conceptual ecological-economic model in order to analyze the choice of agrobiodiversity by risk-averse farmers who have access to financial insurance. They show that where agrobiodiversity has this public insurance value, the interrelationship between natural and financial insurance becomes more complex. While improved access to financial insurance leads to a lower level of agrobiodiversity, the social welfare effects from the sub-optimal provision of the public good linked to agrobiodiversity are ambiguous and are determined by the properties of the agro-ecosystem under investigation.

The authors analytically derive the specific conditions under which, if financial insurance becomes more accessible, welfare in the absence of regulation increases or decreases. Their results are highly policy relevant in that they indicate that, while at first sight improved access to financial and insurance markets seems to be beneficial to farmers from a welfare point of view, in the longer term and depending on the specific agro-ecosystem properties at hand, this effect may have adverse welfare impacts. Hence, due to the external public good benefits of on farm agrobiodiversity, dealing with its optimal provision through insurance markets is not always efficient. In these cases other (more centralized perhaps) regulatory interventions (such as subsidization schemes) or other forms of markets such as PES schemes could both lead to higher levels of agrobiodiversity and enhance social welfare.

Chapter 17, by Aseffa Seyoum, Bezabih Emana, Franz Gatzweiler and Belaineh Legesse, deals with how optimal contract design can be the solution when managing common property resources such as open access agroforestry systems. In particular, they focus on the degradation of agroforestry land (and the agrobiodiversity within it) in the developing world that emerges from the well-known pressures and drivers of change inherent in these countries. They investigate the option of developing non-market institutions in the form of contracts that could bring about a more efficient utilization of the common resource pool. The aspects of contract design they assess include the costs as well as the determinants associated with participation. Both of these are crucial for the long-term viability of contract schemes. Despite the importance of understanding the cost of designing and implementing such contractual arrangements, as well as the incentives for local participation, there is insufficient empirical understanding of these issues and it is here where the authors make their contribution.

Seyoum and collaborators focus on forest user-groups or collaborative (or communal) management schemes. They use the case study of a forest user-group scheme in Ethiopia that aims to provide incentives to participants to

conserve wild varieties of coffee, namely *Coffea Arabica*. As there are imperfect markets for such varieties and hence inadequate means to capture the (opportunity) costs associated with preserving them, a forest user-group scheme could fill this institutional void by inducing participating farmers to adapt their practices so as to conserve these specific crop varieties. Participation in the collaborative strategy means that the household is a member of the forest user-group. This provide some form of club good benefits to participants in the form of enhanced user and extraction rights but at the same time comes at a cost associated with the responsibilities of conserving and properly utilizing the agroforest land (including preservation of wild coffee varieties).

The authors use household data and first analyze the determinants of participating in this scheme and then explore the determinants of the total costs that each participating farm household incurs due to its involvement in the collaborative conservation of *Coffea Arabica*. Their results show that the number of assets that a family holds as well as the farm plot proximity to the communally managed agroforestry system significantly affect both participation in the collaborative conservation and the level of conservation costs incurred. The level of these conservation costs is found to be significant and this creates conflict between the local community and conservation interventions. A conservation strategy that minimizes these costs can mitigate such conflicts and improve sustainability. This can be undertaken through a contract scheme that would compensate for participation in an *incentive compatible manner*. The authors conclude by exploring one particular type of contract scheme, that of zoning, as a strategy that may enable the local community to share both the responsibilities to conserve biodiversity and the benefits from these conservation efforts.

Next in Chapter 18, Mitri Kitti, Jaakko Heikkilä and Anni Huhtala make the case that the development of 'fair trade' type of markets through improved international trade institutions should not be decoupled from the development of markets for biodiversity conservation. Thus, they investigate the role that price premiums can play in developing countries in both preserving biodiversity and at the same time contributing towards the eradication or at least the alleviation of poverty. The do so by incorporating ecological findings on the role of pollination services into an economic analysis of agroforestry in agricultural production. They use coffee as a case study as it is one of the world's most valuable export commodities while its production remains largely labour-intensive and thus affecting significant proportions of rural populations in developing countries. At the same time, local and international events lead to producing coffee in such a way that degrades natural pollination services (in an important 'associated' type of agro-biodiversity) which has both private and public negative externalities.

Kitti *et al.* investigate whether a market for certified biodiversity-friendly coffee could be developed that would be compatible with a certification scheme that attempts to extract a price premium for poverty alleviation

(fair trade), or whether the coupling of these two objectives would lead to conflicting outcomes when the input use intensity or production cost structure of alternative technologies differs. They develop a bio-economic model that explicitly captures the interaction between coffee yield and pollination to investigate the decline in biodiversity related to two alternative production methods, sun and shade-grown coffee. They then examine the pattern of technology choice at a representative local community level by calibrating an empirical model using data from Costa Rica to find that maintaining environmentally sustainable farming practices requires over-allocation of land to shade-coffee production compared to what would be economically optimal. This results from the inability to coordinate management decisions when several economic agents are involved. By assuming that small-scale farmers choose between shade and sun coffee based on the profitability of each technology, their model yields a dominant equilibrium where a smaller area of shade coffee would produce higher profits per hectare due to better pollination effect. Further, by assuming that the yield of a plant decreases as a function of distance to the forest surrounding the shade-coffee region, they show that for a larger area of shade coffee, more plants are distant from the forest which serves as the source of pollinating bees. This explains why allocating less land to shade coffee would increase the total profits. It also explains why the opportunity costs of shade coffee production are high. With respect to price premiums, they modelling allows an investigation of whether it is possible to prevent loss of biodiversity simultaneously with alleviation of poverty.

Since maintaining environmentally sustainable farming practices requires a considerable allocation to this technology, this entails a high opportunity costs. Furthermore, trade-offs between conservation of biodiversity and the abolition of poverty should be taken into account when designing conservation policies. A policy instrument explicitly designed to promote economic (social) sustainability may turn out to conflict with goals of conserving biodiversity, and vice versa. The results by Kitti *et al.* suggest that capturing price premiums high enough to promote the cultivation of shade coffee may pose a challenge. One important policy recommendation from this work is that aid policies that aim to address poverty could be an important vehicle for simultaneously supporting biodiversity conservation.

A further contribution to our understanding of the link between market institutions and incentives for agrobiodiversity conservation is provided in Chapter 19 by Svetlana Edmeades and Melinda Smale who focus on the relationship between participation in local food or crop markets and conservation of *in situ* crop biodiversity. The particular contribution of this work rests on attempting to shed light on the direction of a possible causal link between market participation and crop diversity. They use cross-sectional data collected in Uganda to explore the case of the link between local access to banana markets and the diversity of banana cultivars. The reciprocity of this relationship is estimated using a two-stage econometric approach

whereby market participation is analyzed both in terms of the decision to participate in banana markets (as either a net seller or a net buyer of banana bunches), and the composition of participation, measured by the number of banana cultivars sold at farm-gate (an indicator of intra-species richness).

Their results confirm that on farm diversity is a necessary, but not a sufficient condition for both aspects of market participation. Thus, greater banana diversity on farms increases the chances that farmers will sell bananas and positively affects the richness of bananas sold at the farm gate. However, greater diversity on farms does not guarantee diversity at the point of sale. There are two important policy implications from these findings. First, greater banana diversity on farms increases cash flows to households (i.e. private benefits) through diversified production and sales without compromising efforts to conserve bananas *in situ*, on farms. Second, diversity on farms is not yet driven by markets. To ensure that, as markets develop, the demand for diversity is market-driven, other conditions will have to emerge, such as well-articulated price premia for quality differentials among different types of bananas.

Chapter 20 contains the second valuation study of this volume by Klaus Glenk, Jan Barkmann and Rainer Marggraf. These authors use a stated preference choice modelling approach to explore the magnitude of the values associated with the preservation of agroforestry systems that have few substitutes. The contribution of this 'value demonstration' exercise is that it focuses on understanding the benefits held by local inhabitants living in proximity to a dynamic agricultural landscape, which to date have not been well examined by the valuation literature. Their case study focuses on the Lore Lindu National Park (LLNP) in Central Sulawesi, a biodiversity 'hotspot' region in Indonesia comprised by mostly smallholder farmer inhabitants. The authors' aim is to obtain welfare measures as well as an understanding of trade-offs between conservation and economic development so as to inform decisions on the design and structure of conservation measures and incentives mechanisms. Further, documenting the existence and nature of local benefits for maintaining or improving the provision of ecosystem services would help to further convince regional or national governments to reallocate their budget to enhanced financial support for agrobiodiversity conservation. Such knowledge is particularly important if conservation schemes based on economic (or market) instruments are lacking. Finally, their work facilitates an assessment of the local acceptance of *alternative* conservation measures which is vital information for implementing policy measures in the long run.

In contrast to Birol and Villalba (Chapter 14), who approach agrobiodiversity in terms of genetic diversity within crops, the study by Glenk *et al.* define biological diversity at the species or ecosystem level of the agricultural 'frontier' lands around the LLNP. Further, instead of investigating preferences for different levels of biodiversity 'holistically', they assess stated preferences for concurrent changes in the provision of *several* different biodiversity-related

ecosystem goods and services relevant to local farmers. From their *choice experiment* data they derive implicit prices of biodiversity-related non-market benefits provided by a dynamically changing landscape comprised of arable land, agroforestry systems and forest lands. Furthermore, they analyse the influence of socio-economic, socio-demographic and attitudinal variables on choice behaviour.

On a methodological level, Glenk and collaborators show how the choice experiment method can be employed in such a rural developing country context, a particular challenge as stated preference techniques have been constructed with a different institutional context in mind. Their 'design adjustments' included the use of visual aids, a strategy to adjust the status quo to the perceptions of the individual respondents, and an ecosystem services approach focusing explicitly on real-world benefits of functional changes in biological diversity at the species and ecosystem level. Their study shows that the choice experiment method (when appropriately adapted) could provide highly useful and policy-relevant information. On a policy level, their results on welfare measures (implicit prices) as well as the determinants of choice can be used to facilitate the design of economically informed and socio-economically sensitive conservation strategies in the Lore Lindu area. In particular, the estimated non-market benefits may be incorporated into a cost-benefit analysis framework of conservation strategies that stop deforestation and encourage the further intensification of cocoa agroforestry systems. At the same time their work allows policy implications to be outlined for the design of certification schemes for 'biodiversity-friendly' products.

Chapter 21 by Karin Larsén offers a further contribution to the literature on understanding farmer participation in biodiversity-enhancing or agri-environmental policies. This chapter complements that of Seyoum *et al.* (Chapter 17), but here Larsén focuses on a developed world context, namely that of Sweden which supports three main types of agri-environmental policies: (1) compensatory payments for measures related to conservation of grazing lands; (2) management of open landscapes; and (3) organic production methods. The aim of the study is to assess farmers' minimum required compensation for programme participation to analyze the determinants of participation, its extent (in terms of land area) and impact on farm performance from participation. The study uses farm-level secondary data first to assess the determinants of the farmers' participation in the agri-environmental subsidy programme as well as the determinants of the extent (acreage) of participation (using a double hurdle model). Second, the study also examines the effect of participation on farm performance (profitability). By examining the effects of the subsidy program, Larsén evaluates its efficiency as well as drawing implications for designing cost-effective subsidization schemes. More importantly, in undertaking this programme evaluation study, the author shows that choosing the methods to analyze the impact of programme participation is not always obvious and some complications

associated with these types of analyses in the context of agri-environmental programme participation are discussed.

The final chapter of Part III and the one that also concludes this book is written by Cornelia Ohl, Martin Drechsler, Karin Johst, and Frank Wätzold, who build up a conceptual analysis that contributes to the literature on the optimal design of the level and distribution of farmers' payments from agri-environmental schemes. Although Ohl *et al.*'s research is motivated by the challenges in agri-environmental payment design and allocation in Europe, their analysis has implications for all countries adopting such schemes. Their contribution to the literature consists of including in their modelling work the importance of creating habitat heterogeneity. The latter is shown to be necessary for biodiversity conservation in agricultural landscapes due to the aim of multi-species conservation, the existence of uncertainties in species habitat requirements and the possible transience of habitat quality. They then try to assess two related questions. First, how to design agri-environmental schemes that generate habitat heterogeneity in a cost-effective manner and, second, whether payment schemes that can be conducive to a heterogeneous agricultural landscape avoid the problem of generating excessive producer surpluses. The latter is inefficient from a social point of view as this implies over- compensation of farmers which in turn entails less public funds available to be allocated elsewhere (including conservation efforts). Their theoretical modelling work addresses these questions by assessing the minimum required compensation payment allocated to land users in order to generate the socially desired habitat heterogeneity at the local level.

This chapter demonstrates that over-compensation to farmers with the lowest opportunity costs may still be required to stimulate the conservation of the target level of habitat heterogeneity in agricultural landscapes. Further, their model reveals that the extent of over-compensation may be asymmetrically distributed among land users with some requiring to be compensated for their individual opportunity costs only, while others would need to be offered an additional payment on top of the opportunity cost. This may lead to problems of fairness in the distribution of payments for conservation across different types of land users. Such problems may be important in poorer parts of the world. If some land users are able to improve their individual income situation by receiving pure transfers (over-compensation) for conservation-friendly land use measures while other land users can hardly make a living, then conflicts between the local land users and resistance to programmes of biodiversity conservation may rise. This calls for future research on taking into account not only efficiency issues but also fairness considerations.

Note

1 A continually updated compilation of the empirical economics literature on conservation of crop and livestock genetic resources can be found at the literature repository of IFPRI (www.ifpri.org/pubs/sgrp/index.asp).

References

Barrett, C.B., Barbier, E.B. and Reardon T. (2001) 'Agroindustrialization, globalization, and international development: the environmental implications'. *Environment and Development Economics* 6: 419–433.

Goeschl, T. and Swanson, T. (2007) 'Designing the legacy library of genetic resources: approaches, methods, and results', in A., Kontoleon, U. Pascual and T. Swanson (eds) *Biodiversity Economics: Principles, Methods and Applications*. Cambridge: Cambridge University Press

Heal, G. (1999) 'Valuing ecosystem services', Columbia Business School, New York, mimeo.

Holling, C.S. (1988) 'Temperate forest insect outbreaks, tropical deforestation and migratory birds', *Memoirs of the Entomological Society of Canada* 146: 21–32.

Jackson, L., Bawa, K., Pascual, U. and Perrings, C. (2005) 'AgroBIODIVERSITY: a new science agenda for biodiversity in support of sustainable agroecosystems', DIVERSITAS report No. 4. Paris.

Jackson, L.E., Pascual, U. and Hodgkin, T. (2007) 'Utilizing and conserving agrobiodiversity in agricultural landscapes', *Agriculture, Ecosystems and the Environment* 121: 196–210.

Kontoleon, A., Pascual, U. and Swanson, T. (2007) *Biodiversity Economics*. Cambridge: Cambridge University Press.

Millennium Ecosystem Report (2005) *Ecosystems and Human Well-being: Biodiversity Synthesis*. Washington, DC: World Resources Institute.

Nagarajan, L., Audi, P. and Jones, R. (2008) 'Supply of pigeonpea genetic resources in local markets of Kenya', draft IFPRI Discussion Paper, Washington, DC.

Ninan, K.N. (2007) *The Economics of Biodiversity Conservation: Valuation in Tropical Forest Ecosystems*. London: Earthscan.

Norse, E.A. and McManus R.E. (1980) 'Ecology and living resources biological diversity', in *Environmental Quality 1980: The Eleventh Annual Report of the Council on Environmental Quality*. Washington DC: Council on Environmental Quality, pp. 31–80.

Pascual, U. and Perrings, C. (2007) 'Developing incentives and economic mechanisms for in situ biodiversity conservation in agricultural landscapes', *Agriculture, Ecosystems and the Environment* 121: 256–268.

Pearce, D.W. (2004) 'Environmental market creation: saviour or oversell?' *Portuguese Economic Journal* 3(2): 115–144.

Perrings, C., Jackson, L., Bawa, K., Brussaard, L., Brush, S., Gavin, T., Papa, R., Pascual, U. and de Ruiter, P., (2006) 'Biodiversity in agricultural landscapes: saving natural capital without losing interest', *Conservation Biology* 20(2): 263–264.

Qualset, C.O., McGuire, P.E. and Warburton, M.L. (1995) ' "Agrobiodiversity" key to agricultural productivity', *California Agriculture* 49: 45–49.

Smale, M., (ed.) (2006) *Valuing Crop Biodiversity: On Farm Genetic Resources and Economic Change*. Wallingford: CAB International.

Smale, M., Diakité, L., Dembélé, B., Seni Traoré, I., Guindo, O. and Konta, B. (2008) 'Trading millet and sorghum genetic resources: women vendors in the open-air markets of San and Douentza, Mali', IFPRI Discussion Paper 746, International Food Policy Research Institute, Washington, DC.

Smale, M. and Drucker, A.G. (2007) 'Agricultural development and the diversity of crop and livestock genetic resources: a review of the economics literature', in A.

Kontoleon, U. Pascual, and T. Swanson (eds) *Biodiversity Economics: Principles, Methods and Applications*. Cambridge: Cambridge University Press.

Tisdell, C. (2003) 'Socioeconomic causes of loss of animal genetic diversity: analysis and assessment', *Ecological Economics* 45(3): 365–376.

Vandermeer, J., and Perfecto, I. (1995) *Breakfast of Biodiversity: The Truth about Rainforest Destruction*. Oakland, CA: Food First Books.

Part I

Policy perspectives

2 Managing plant genetic resources for sustainable use in food and agriculture

Balancing the benefits in the field

Leslie Lipper and David Cooper

1 Introduction

Managing plant genetic resources for sustainable use in food and agriculture is a current and pressing policy objective from the standpoints of supporting productivity, reducing poverty and protecting the environment. Agriculture faces several challenges: the sector is under pressure not only to produce agricultural goods for rapidly growing populations, but also to meet food and livelihood security for large numbers of rural poor, while reducing negative impacts on the environment. Climate change exacerbates these challenges, requiring that agricultural systems adapt in order to sustain, let alone increase, production. Some of the necessary responses to climate change will place additional burdens on agriculture, whether through the demand for biofuels or the need to maintain carbon sinks by reducing the amount of land made available for agriculture.

A number of recent reports highlight these pressures and expectations. For example, the 2008 World Bank Development Report (World Bank 2007) highlights the role of agriculture in contributing to social and economic development, identifying its key role in poverty reduction in agricultural-based economies. The International Assessment of Agricultural Science and Technology (IAASTD) 2008 notes the importance of agricultural science and technology (IAASTD 2007). The Millennium Ecosystem Assessment and the Global Biodiversity Outlook noted that agriculture is the largest driver of biodiversity loss, through land use change, water and nutrient use (MEA 2005; GBO2 2006). At the same time the decline in most ecosystem services risks undermining agricultural productivity. These reports provide varying perspectives and depart from different underlying paradigms. These differences are both worrying and refreshing – and they are manifested in much of the discussion around sustainable use of plant genetic resources for food and agriculture (PGRFA).

The sustainable use of genetic resources can be broadly defined as the use of genetic resources in support of sustainable agriculture, which requires a system of agriculture that produces and facilitates access to sufficient food for all people and contributes to livelihoods and socio-economic development,

while protecting the environment. Sustainable agriculture must be productive – indeed, in many cases, more productive than it currently is – to deliver the food, feed, fibre that are required, and also to generate the economic surpluses needed to support livelihoods, create employment and power economic development. Sustainable agriculture must also be resilient – and here again an increase over current levels is needed – in order to cope with the changes confronting the sector. Finally, sustainable agriculture must be conserving of natural resources in order to maintain productivity and resilience in the future.

The deployment of genetic resources at genetic and species levels, and at the level of the agro-ecosystem and landscape, plays a crucial role in contributing to increases in productivity and resilience and conservation (Figure 2.1). In turn, these are influenced by policies, research and plant breeding, and capacity building.

In this chapter we consider: (1) what is desired in terms of sustainable use of crop genetic resources (essentially in the sense of how genetic resources contribute to sustainable agriculture); (2) what this means in terms of use, or deployment, of genetic resources in the field, which in turn depends on the genetic resources that are made available to farmers and breeders; and (3) what mix of policies, capacity building and research can support these ends.
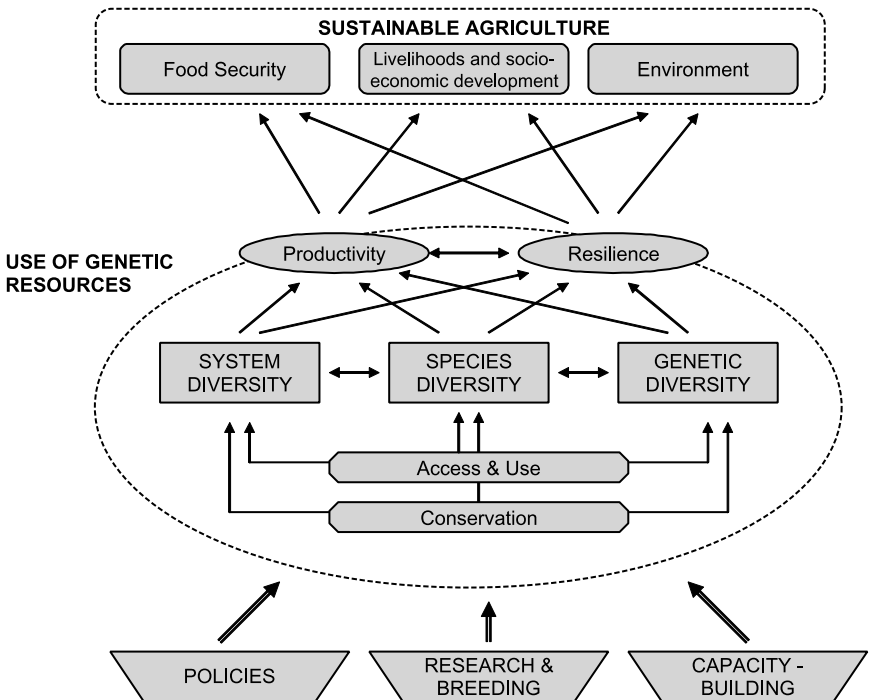
Figure 2.1 Sustainable agriculture.

2 What is the sustainable use of crop genetic resources?

Article 2 of the Convention on Biological Diversity defines sustainable use of biodiversity in general as

> [the] use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations.　　　(Convention on Biological Diversity 1993)

Sustainable use of plant genetic resources, a major component of agricultural biodiversity, is a primary objective of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) which came into force in 2005. Plant genetic resources for food and agriculture are defined as any genetic material of plant origin of actual or potential value for food and agriculture. Article 6 of the ITPGRFA requires contracting parties to develop and maintain appropriate policy and legal measures that promote the sustainable use of plant genetic resources for food and agriculture. No concise definition of sustainable use is provided, although several examples of measures to achieve sustainable use are given, including: broadening the genetic base of crops, increasing the range of genetic diversity available to farmers, promoting plant breeding efforts to develop varieties that are well adapted to the situation of farmers, particularly in marginal areas, and supporting the use of more diverse crop varieties. Cultivation of more diverse local varieties reduces the vulnerability of the crop to epidemics of plant disease and pests, and protects against genetic erosion. These approaches aim to increase world food production in ways that are compatible with sustainable development (ITPGRFA 2004, Article 6.2).

What would a world where crop genetic resources are used sustainably look like? There are multiple actors that can be identified as users of crop genetic resources or the products they provide: farmers and plant breeders and, in a broad sense, even consumers. In this chapter, we focus on farmers as the point of departure. Farmers 'use' crop genetic resources through their selection of the crops and varieties they plant. Their decisions are driven by both supply and demand factors: e.g. the crops and varieties that meet their specific production, marketing and consumption requirements and those that are accessible to them. Both the supply of, and demand for, genetic resources are affected by policies and regulations. For example, the demand for crop varieties is linked to the development of output markets, while the supply of genetic resources is affected by policies governing plant breeding and seed sector regulations.

Farmers' choices of crops and varieties can then be thought of as a constrained optimization; farmers choose the best combination to meet their needs given agro-ecological and social constraints, including those imposed by policies. Their choices can also potentially affect others in the form of

externalities. From the literature, the benefits created by farmers' use of crop genetic resources (Table 2.1) can be grouped into three main categories (Brush 1995; FAO 1998; Wood and Lenné 1999; Lipper and Zilberman 2005; Gepts 2006; Smale 2006; Smale and Drucker 2007):

1   *Private benefits* to farmers via the consumption and production values they derive from producing crops, which are shaped by policies affecting the demand and supply of crop genetic resources.
2   *Local or regional benefits* to farmers, and ultimately, consumers, when the choices make farming more resilient to biotic and abiotic stresses.
3   *Global benefits* to future farmers, plant breeders and consumers, when the choices they make protect against genetic erosion.

Who benefits, the scale of benefits, and the pattern of use that is needed to generate the benefits vary, but all three are necessary for the sustainable use of PGRFA (Table 2.1). Benefits in the first category of benefits are private goods. The second category of benefits is a local public good, benefiting all

Table 2.1 Categorization and description of values associated with crop genetic diversity

	Type of good	Source of value	Time scale	Spatial scale	Space-related
1	Private	Quality traits – can be considered as adaptation to markets	Adaptation (for short-term change)	Local – farmers and consumers	Not necessarily
		Production traits (Resistance and adaptation) – allow adaptation to specific local environment		Local – farmers	Yes
2	Public	Portfolio – range of species/varieties grown in a locality reduces risk to uncertainty (beta-diversity)		Local and regional	Yes
3		Option – option to use known species/varieties and the genes that make them up in different combinations in the future (alpha-diversity)	Adaptability (for long-term change)	Global and local and regional	Not necessarily, but access important
		Exploration – option to discover and use unknown genes in the future for food production or for other purposes		Global	Yes

farmers in a given area, whether or not they actually contribute to generating the good itself. The third benefit is also a quasi public good at the global scale; the benefit of maintaining a savings bank of genetic resources and the evolutionary processes that generate them, both known and unknown, which can benefit future generations of farmers.

The question is, to what extent does a use that generates one form of benefit also generate others? Are there trade-offs or synergies among uses? Will the choices farmers make for their own private benefit also provide the local and global public goods of resilience and conservation? Experience over the course of this century indicates that conflicts may indeed exist: specialization of crops and varieties on farm can generate high private benefits to farmers but reduce local resilience; on farm conservation of globally important genetic resources may reduce farm profits.

3 Characterizing PGRFA

Genetic resources provide two essential attributes: adaptation and adaptability (Simmonds 1962; Cooper *et al.* 2001). Adaptation is the ability of a variety, crop or cropping system to produce what is needed (by a particular market – 'consumption traits') in a particular environment – 'production traits', at a particular time. Adaptation results from the processes of evolution (natural selection), in conjunction with selection by farmers, or professional breeders.

There are several aspects of adaptation that contribute to resilience as well as productivity:

- genetic adaptations to particular fixed conditions (e.g., drought resistance);
- genetic adaptations to variability through phenotypic plasticity (e.g., photoperiodism);
- value of a 'portfolio' of different components – also provides adaptation to variability – if one fails, another may thrive.

Adaptability is the capacity of a variety, crop or cropping system to change over time, through selection. Adaptability is essential for continued crop improvement through selection by farmers or in plant breeding programmes, but tends to be reduced by such selection. Thus there is an inherent conflict between adaptation and adaptability and a continuing need to balance the loss of adaptability through selection by encouraging the influx of new genetic material.

Varieties can be grouped or categorized as: (1) farmers' varieties or landraces which are the product of breeding and selection by farmers, either deliberately or unintentionally; (2) modern or improved varieties from plant breeding programmes, which are the product of an intentional and scientific process of selecting for specific desirable characteristics. Plant

breeding programmes cross-breed or interbreed closely or distantly related species, and/or hybridize plants. A special case of the second category includes genetically modified varieties which are also the product of intentional and scientific selection process but techniques of genetic engineering are used to add or remove genes or gene combinations among species. These categories blur, depending to some extent on the reproductive system of the crop. For example, 'creoles' which are deliberate crosses between landrace and improved varieties made by Mexican farmers (Bellon 1996). Other farmers' varieties result from the spontaneous cross-pollination of landraces and modern varieties in the field, especially when farmers replant the seed they save from the harvests of modern varieties in successive seasons.

A landrace by its very nature is not genetically uniform. Landraces tend to be geographically or ecologically distinctive populations that are highly diverse in genetic composition (FAO 1998; also see chapters by Bellon and Smale *et al.* in this book). Thus, the genetic diversity of such locally adapted varieties includes variation within and between varieties (as well as variation that is temporarily concealed as recessives in heterozygotes). This diversity can be supplemented by the introduction of material from other populations. In many agricultural systems such variability allows continued on farm crop evolution (see Berthaud *et al.* 2001). In modern agricultural systems, locally available variability is considerably reduced by comparison, as diverse landraces have been largely replaced by F1 hybrids and single lines.[1] An improved variety is more genetically uniform and stable. The new crops are often highly adapted to their production environments, which have been altered by irrigation and use of fertilizers. However, their adaptability is reduced.

4 Past, present and future approaches to the use of genetic resources

Over the past 50 years agriculture has been remarkably effective in increasing production to meet the demands of ever-increasing populations. Much of the increase has come from intensification of production systems through increased input use. Adoption of improved crop varieties developed and disseminated by plant breeding programmes has also had a very important role to play. Evenson and Gollin (2007) show the strong impact of improved variety adoption on agricultural productivity growth as a result of international and national plant breeding efforts, particularly in Latin America, and more recently in the Middle East–North African region. While impressive, these accomplishments have come at a cost in terms of their environmental impacts which affect both agricultural and non-agricultural sectors.

The focus of efforts in the recent past to enhance the contribution of the use of plant genetic resources to agriculture has been on:

- productivity rather than resilience (even though there has been substantial investment in breeding for resistance to biotic and abiotic stresses);
- broad-scale adaptation rather than specific adaptation (both to markets and production environments);
- centralization of decision-making by plant breeders rather than farmers.

This approach has been successful in some areas, but not others. Looking across 11 food crops in four regions from the period of 1964–2000, Evenson and Gollin (2007) conclude that the contribution of modern varieties to productivity increases was a 'global success, but for a number of countries a local failure'. Key shortcomings cited have been the focus on varieties adapted for high potential production areas with the use of complementary inputs, which are not suitable for the variable, heterogenous and marginal production areas found in many developing countries. Some approaches have worked against resilience, and thus long-run average productivity. For example, plant breeding approaches that aimed at eliminating photoperiodism from millet and sorghum varieties in the Sahelien band of Africa made the agricultural systems less adapted to year-on-year climate variability (Lambert 1983; Vaksmann *et al.* 1996; Niangado 2001). Another criticism of centralized plant breeding programs has been the lack of farmer involvement and emphasis on widely adapted varieties, which limited attention to traits that are important to local farmers. On the environmental side, increases in pesticide and fertilizer use accompanying the high-yielding varieties have generated serious damage to land and water, generating high economic costs which are only now becoming apparent (Ali and Byerlee 2000; Tilman *et al.* 2002).

Increasing consensus is being reached in the science, technical and policy fields that new and more sustainable forms of agricultural production are needed to meet the agricultural, social and environmental demands of society, however, how to reach this objective is the subject of much controversy and debate. One difference concerns the extent to which expert-driven technology development vs. local participatory approaches should be the key point of departure. Another reason is the variability in the agro-ecosystems and socio-economic contexts under consideration as well as the type of change needed. Improving the access of poor farmers in marginal production environments to the crop genetic resources and reducing the environmental damage associated with capital-intensive production systems are two very different objectives that require two different strategies.

Typologies of countries have been developed in order to discuss strategies for sustainable agricultural development. For example, the World Development Report (2008) (World Bank 2007) groups countries into agricultural-based, transforming and urbanized economies, according to the importance of agriculture in the overall economy. The authors argue that in agricultural-based economies, which include most of Sub-Saharan Africa, increasing the productivity of smallholder farming is a necessary prerequisite to generating

economic growth, and reducing poverty and food insecurity. The IASSTD report, (2007) also looks at issues for agricultural-based economies and argues that more emphasis should be given to client-driven participatory research that incorporates a wide range of stakeholders across multiple scales.

Sub-Saharan Africa typifies examples of agricultural-based economies. In much of the region, farmers are producing on marginal lands, with limited market access and exposed to high levels of risk from climatic variability, invasions of plant pests and epidemics of plant disease. Crop production is focused on food crops for consumption by farm households. Agricultural productivity is low and agricultural input and output markets are not well developed. Most farmers currently rely upon landraces for their crop production, although in some areas, improved varieties from conventional breeding programmes have been widely adopted for a few crops. At present, the use of genetically modified varieties is very limited. Diversified farming systems and the use of low productivity, low risk crops and varieties are key strategies these farmers employ to manage the risks they face.

What is needed to increase the farm level returns to crop genetic resource use under these conditions? Improving productivity and profitability in smallholder agricultural systems, while maintaining or increasing the resilience of such systems, is essential to attain sustainable use for this region. Specifically, increasing agricultural productivity and stability, as well as net returns to marketed surpluses from farming is needed (NEPAD CAADP[2] 2002; World Bank 2007). A wide range of crop genetic resources are needed to meet these goals across the heterogeneity of production systems and agro-ecological conditions that are found in agricultural-based economies.

In thinking about which strategies will be most effective, we must consider not only the characteristics of the genetic resources needed to meet these challenges, but also the access farmers have to them. This includes the availability of the resource as well as the ability of the farmer to acquire it by having information and resources to purchase it or obtain it by other means. Here again, the situation is characterized by a great deal of heterogeneity, with a few general principles. On farm saved seed is generally the form of seed and crop genetic resources that is most easily accessed by farmers. Seeds of these varieties are also procured through informal exchange mechanisms which vary in their rules of exchange, based on social norms (Meizen-Dick and Ezaguirre Chapter 6 in this volume). They are increasingly found in local markets where they are obtained by farmers via purchases, which also vary in terms of rules of exchange and are affected by social norms as well as market forces (Fafchamps *et al.* 2004; Lipper *et al.* 2006). Aside from these informal seed sector sources, farmers may also purchase seed of improved and certified varieties produced by publicly or by privately funded breeding programmes and distributed through government-sponsored organizations or private companies and traders. Across most of Sub-Saharan Africa, however, the development of commercial seed systems has been generally slow and in most countries significant for only a small number of mostly high value crops.

One prominent strategy for the development and dissemination of improved germplasm is the use of participatory plant breeding (PPB) methods which incorporates a broad range of approaches to improving crop varieties, through increased interactions between scientists and farmers. PPB strategies are considered particularly effective in exploiting genotype by environment (G × E) interactions, and in considering traits of importance to farmers. PPB has the potential to generate a diverse range of locally adapted varieties (Bellon 2006; Hardon *et al.* 2006). The strengths of this strategy are its specificity to local conditions and accessibility to farmers, and it is thought to be an important complement to formal breeding methods, if not a replacement (Hardon *et al.* 2006). Strengthening the formal plant breeding and seed system is another key strategy, particularly in increasing marketed returns to agriculture. The strategy essentially involves the development and dissemination of improved varieties and the strengthening of formal seed systems by improving input markets (AGRA PASS[3] 2007; World Bank 2007). The costs associated with obtaining the seeds of these varieties as well as complementary inputs necessary for their success must be lower than the value of the marketed surplus. This is most likely to hold true where a country or region has a comparative advantage in producing a particular crop and where some market development has already occurred. Under these conditions, farmers may increase returns to farm production by specializing in the crops and varieties, which could lead to some homogenization of farm-level use of crop genetic resources.

Improving productivity and livelihoods in agricultural-based economies and achieving economic growth through agricultural development will require more than one approach. The agro-ecological, social and economic conditions present in these areas require substantially greater amounts of diversity in the germplasm on farms than has been the case in many of the areas that have already benefited from the introduction of high-yielding varieties, or requires that farmers have access a greater range of useful genetic diversity. At the same time, increasing economic returns on farms through marketed surpluses may trigger growing specialization in crops where farmers have a comparative advantage, and the adoption of improved varieties that are more genetically uniform and stable. However, specialization on individual farms is likely to be mitigated by the spatial variation in agricultural-based economies, which contributes to diversity among farms. In addition, a key factor element of farm returns to cropping – insuring against production shocks – may actually require a higher degree of on farm diversity.

5 Policies to support the sustainable use of crop genetic resources on farm

The analysis of choices and benefits associated with the sustainable use of crop genetic resources on farms indicates there are both conflicts and synergies. The heterogeneity of agricultural production and marketing systems,

much of which is in marginal production zones, means that enhancing genetic diversity is likely to be essential in improving farmers' livelihoods. This is compatible with maintaining resilience and possibly, conserving genetic resources. On the other hand, specialization could give rise to a loss of resilience and genetic erosion on farms. We have seen fairly significant levels of farm demand for diversity manifested in a high rate of varietal turnover – partly due to supply side policies that encourage it (see Smale *et al.*, Chapter 3 in this volume). Clearly, supply side policies that support the broadening of the genetic base of improved crop varieties and crop and variety diversification are also fundamental in limiting genetic vulnerability (Cooper *et al.* 2001).

While we find that there are good possibilities of achieving synergies in the generation of multiple benefits from on farm use of PGRFA, a range of public policy measures are needed to realize that potential. We divide these policies affecting the demand for and supply of plant genetic diversity. The analysis presented in this chapter and others in this volume suggests that there is considerable farm-level demand for diversity that is not being met by the supply side, particularly in the case of the formal sector, but also in the informal sector. Meeting farmer demand for diversity is a critical way of enhancing the synergies in generating multiple benefits from on farm use of PGRFA, although not a guarantee of achieving it.

Plant breeding and seed system management are key areas for supply side policies affecting farmer access to plant genetic diversity. Broadly, a comprehensive set of actions extending from the international to the local scales is needed to enable farm-level access to a wide range of genetic resources. Genetic enhancement programmes to increase the genetic diversity used in breeders' programmes is a way to achieve resilience and improvements in the stability and productivity of agricultural output (Cooper *et al.* 2001; Smale *et al.*, Chapter 3 in this volume). Increasing the capacity of researchers and plant breeders working in low productivity environments in agricultural-based economies is another policy priority. Linking capacity building in the formal sector to the expansion of decentralized participatory breeding and variety selection programmes is needed to generate a wide range of varieties specifically adapted to particular production environments. Removing barriers to the flow of diversity is another priority among supply side policies. Strict seed regulations can be a serious barrier to supplying and exchanging diverse germplasm on farms and among regions. Seed system regulations that incorporate greater flexibility and heterogeneity in the exchange of crop varieties, including landraces, are critical. Regulations aimed at achieving uniform and standardized crop varieties and seeds, such as those developed for industrialized agriculture, are not appropriate for extremely heterogenous production systems characterized by a large proportion of farmers who are oriented toward subsistence production.

Policies to increase the demand for diversity are important as well. Stimulating farmer demand for diversity through attention to the organiza-

tional form, structure and performance of developing markets is fundamental. Increasing demand for local products by supporting strategies that enhance the growth of local incomes and food sovereignty may also encourage the value of diversity on farms. The development of differentiated output markets that support diversity through *appellations de origin* and niche marketing is a means of increasing non-local demand for diversity through output markets (see Gruère *et al.*, Chapter 5 in this volume).

Overall, a policy environment that minimizes trade-offs and enhances synergies between the benefits obtained from on farm use of PGRFA is needed to obtain the sustainable use of PGRFA. These include both supply and demand side measures at the local, national and international levels of policy-making. The International Treaty on Plant Genetic Resources for Food and Agriculture provides a broad framework for such a policy environment in its Article 6. Farmers, plant breeders, other scientists and development workers need to engage with decision-makers to ensure that this framework is further developed, and that the necessary resources are made available for its implementation.

Note

1 Modern varieties of outbred crops like rice and wheat are mostly single lines, whereas modern varieties of inbred crops like maize are F1 hybrids. However, large areas of maize are still planted to open-pollinating varieties, both landraces and improved varieties.
2 New Partnership for Africa's Development, Comprehensive Africa Agriculture Development Programme.
3 Alliance for a Green Revolution in Africa. Program for Africa's Seed Systems.

References

Ali, M. and Byerlee, D. (2000) 'Productivity growth and resource degradation in Pakistan's Punjab: a decomposition analysis', World Bank Policy Research Working Paper No. 2480. World Bank, Washington, DC.

Alliance for a Green Revolution in Africa (AGRA) Program for Africa's Seeds Systems (PASS) Mission and Vision. Available at: http://www.agra-alliance.org/work/seeds.html (accessed 12 March 2007).

Bellon, M. (2006) 'Crop research to benefit poor farmers in marginal areas of the developing world: a review of technical challenges and tools', *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 1, No. 070.

Bellon, M. (1996) 'The dynamics of crop infraspecific diversity: a conceptual framework at the farmer level', *Economic Botany* 50: 26–39.

Berthaud, J., Clement, J.C., Emperaire, L., Louette, D., Pinton, F., Sanou, J. and Second, G. (2001) 'The role of local-level geneflow in enhancing and maintaining genetic diversity', in H.D Cooper, C. Spillane and T. Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. Wallingford: CABI Publishing.

Brush, S.B. (1995) 'In situ conservation of landraces in centers of crop diversity', *Crop Science* 35(2): 346–354.

Convention on Biological Diversity (1993) Available at: http://www.cbd.int/doc/legal/cbd-un-en.pdf

Cooper, H.D., Spillane, C. and Hodgkin, T. (eds) (2001) *Broadening the Genetic Base of Crop Production*. Wallingford: CABI Publishing.

Drucker, A., Smale, M. and Zambrano, P. (2005) 'Valuation and sustainable management of crop and livestock biodiversity: a review of applied economics literature published for the CGIAR System-wide Genetic Resources Programme (SGRP) by the International Food Policy Institute, the International Plant Genetic Resource Institute and the International Livestock Research Institute', available at: http://www.ilri.org/html/SGRP%20GR%20Valuation%20_DruckerSmaleZambrano.pdf

Evenson, R. and Gollin, D. (2007) 'contributions of national agricultural research systems to crop productivity', in R. Evenson and P. Pingali (eds) *Handbook of Agricultural Economics*, Vol. 3. Oxford: Elsevier B.V.

Fafchamps, M. (2004) *Market Institutions in Sub-Saharan Africa: Theory and Evidence*. Cambridge, MA: MIT Press.

FAO (1998) *The State of the World's Plant Genetic Resources for Food and Agriculture* Rome: FAO.

Gepts, P. (2006) 'Plant genetic resources conservation and utilization: the accomplishments and future of a societal insurance policy', *Crop Science* 46: 2278–2292.

Global Biodiversity Outlook 2 (2006) Available from: http://www.biodiv.org/GBO2/default.shtml

Hardon, J., Almekinders, C., Christinck, A., Humphries, S., Pelegrina, D., Sthapit, B., Vernooy, R., Visser, B. and Weltzien, E. (2006) 'From concept to pilot project and beyond', in *Bringing Farmers Back into Breeding: Experiences with Participatory Plant Breeding and Challenges for Institutionalisation*. Agromisa Special 5, Wageningen: Agromisa.

International Assessment of Agricultural Science and Technology for Development (2007) Interim Report. IAASTD.

International Treaty on Plant Genetic Resources for Food and Agriculture (2004) Available at http://www.fao.org/Legal/treaties/033t-e.htm

Lambert, C. (1983) 'Influence de la précocité sur le développement du mil (*Penisetum typhoides*) en conditions naturelles,' *Agronomie Tropicale* 38(1): 7–15.

Lipper, L., Cavatassi, R. and Winters, P. (2006) 'Seed supply and the on-farm demand for diversity: a case study from Eastern Ethiopia', in M. Smale (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change*. Wallingford: CABI.

Lipper, L. and Zilberman, D. (2005) 'Policies for promoting biodiversity conservation', in J. Cooper, D. Zilberman and L. Lipper (eds) *Agricultural Biodiversity, Biotechnology and Development: Economic Issues in Crop Genetic Resource Management*. Natural Resource Management and Policy Series, New York: Springer Science.

Millennium Ecosystem Report (2005) *Ecosystem and Human Well-Being: Biodiversity Synthesis*. Washington, DC: World Resources Institute.

New Partnership for Africa's Development (NEPAD) Comprehensive Africa Agriculture Development Programme (CAADP) (2002). Available at: http://www.fao.org/docrep/006/y6831e00.htm

Niangado, O. (2001) 'The state of millet diversity and its use in West Africa', in H.D Cooper, C. Spillane and T. Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. Wallingford: CABI Publishing.

Simmonds, N.W. (1962) 'Variability in crop plants: its use and conservation', *Biological Reviews* 37, 422–465.

Smale, M. (ed.) (2006) *Valuing CNP Biodiversity: On-farm Genetic Resources and Economic Change*. Wallingford: CAB International.

Smale, M. and Drucker, A.G. (2007) 'Agricultural development and the diversity of crop and livestock genetic resources: a review of the economics literature', in A. Kontoleon, U. Pascual and T. Swanson (eds) *Biodiversity Economics: Principles, Methods and Applications*. Cambridge: Cambridge University Press.

Tilman, D., Cassman, K., Matson, P., Naylor, R. and Polasky, S. (2002) 'Agricultural sustainability and intensive production practices', *Nature* 418: 671–677.

Vaksmann, M., Traoré, S.B. and Niangado, O. (1996) Le photopériodisme des sorghos africains. *Agriculture et Développement* 9: 13–18.

Wood, D. and Lenné, J.M. (1999) *Agrobiodiversity Characterization, Utilization and Management*. New York: CABI Publishing.

World Bank (2007) *World Development Report 2008: Agriculture for Development*. Washington, DC: World Bank.

3 Do we have an adequate global strategy for securing the biodiversity of major food crops?

Melinda Smale, Peter Hazell, Toby Hodgkin and Cary Fowler

1 Introduction

Over the course of the past century, the commercialization of agriculture and technical change encouraged individual farmers and regions to specialize in the production of fewer crops and varieties according to relative physical endowments and trade advantages. One consequence of these changes is that much of the world's population of over six billion now depends for food on a several hundred modern varieties of a handful of cereal crops. A shared vulnerability to changing pests, diseases and climatic factors might be expected to have led to major food shortages on a global scale.

Why have disasters not occurred? Can we assume that major problems will not arise in the future? As Sherlock Holmes once astutely observed, the significant fact is that the dog has not barked. In this chapter, we outline the strategy that has evolved within the scientific community to manage genetic risks in crop production. Though this strategy has proved highly effective to date, some of its fundamental elements are now challenged by the way that agricultural research is funded and conducted. Changes are needed if the system is to continue to function well in the future. These changes will require a greater degree of international cooperation than in the past.

2 Genetic vulnerability in crop production systems

The modernization of farming in much of the world has induced farmers to shift to more mechanized methods, chemical inputs and scientifically-bred crop varieties. Farms have become more specialized. Diversification of crops and varieties is still apparent across farms or regions more than within them, driven largely by the heterogeneity of agro-ecologies, cultures and economies (see literature reviewed in Brush 2000; Smale 2006). Even so, much of the world's population relies on a few major food crops. Today, "only 150 plant species are under extensive cultivation," and "the majority of humans live on only 15 plant species, which account for over 90 percent of human energy needs" (Gepts 2006: 2281).

Large areas are planted each year to relatively few modern varieties of

these major plant species. Often, these varieties carry similar sources of genetic resistance to environmental stresses. Genetic uniformity makes crops vulnerable to major yield losses from changes in pests, diseases, and climate. The famine that was triggered by the potato blight in Ireland in the nineteenth century is often cited as an historical example of society's vulnerability to a narrow genetic base in food crops. Colonial officers in the Asian subcontinent recorded the devastation and hunger caused by epidemics of rust disease in wheat, as early as 1786. According to such records, wheat landraces in India, which were planted to millions of hectares, were highly susceptible to rust disease (Howard and Howard 1909). The hunger and starvation associated with these events were aggravated by the absence of any serious relief efforts at the time, and hence would be less likely to occur today. Still, epidemics of plant disease can incur significant costs to society, particularly in countries where the physical infrastructure to contain the outbreak, import and supply food to dispersed rural areas is limited.

Fortunately, apart from a few isolated incidents like southern corn leaf blight (*Helminthosporium Maydis*) in the US in 1970[1] and the vulnerability of IR8 rice to brown plant hopper in Asia, there has not been a recorded catastrophe in production of major food crops in modern times. Most crises appear to be localized, although there are recurring threats. A dramatic recent event has been the emergence of Ug99, a new race of stem rust (*Puccinia graminis tritici*) in wheat that emerged in Uganda in 1999 and has spread in wheat-growing areas of Kenya and Sudan (Wanyera *et al.* 2006). Stem rust is a potentially catastrophic disease because of its ability to cause very large losses over wide areas. Though these countries are not major wheat producers, experience suggests that the disease will spread to other regions through trade.

Far from succumbing to greater vulnerability, average grain yields continue to demonstrate positive trends around much of the world. Some initial evidence from the 1970s and 1980s indicated that greater genetic specialization might be raising the coefficient of variation of aggregate grain yields around trend through increasing correlations among regional yields (Hazell 1984; 1989—Table 2.4). Observed to the greatest extent in maize and barley, higher coefficients of variation were also evident for rice and wheat in some rainfed farming systems (Hazell 1985). Since then, there is little evidence that this problem has worsened for either maize or wheat (Gollin 2006).

Why have we not experienced more catastrophic crop failures? Have we just been lucky? In fact, scientists have contributed a great deal of effort behind the scenes in order to prevent disasters. Crop genetic uniformity has been counteracted by spending more on conserving genetic resources for future use, and investing in breeding approaches that broaden the genetic base of varieties supplied to farmers in order to stay ahead of evolving pests and diseases. Scientists have encouraged agricultural policies that support more rapid turnover of modern varieties or greater spatial diversification of crops and varieties on farms. These strategies are discussed next.

3 Strategies for securing the biodiversity of food crops

3.1 Conservation of genetic resources

In a study published in 1972, the National Research Council of the US alerted the scientific community to the dangers of restricting crop improvement to a narrow collection of crop genetic resources. In that same year, Jack Harlan applied the term "genetic erosion" to describe what he viewed as a diminishing global stock of crop genetic resources. Like other eminent scientists at that time, Harlan attributed the "loss" of crop landraces[2] to the popularity of the semi-dwarf varieties of rice and wheat that were released during the Green Revolution. The root causes of genetic erosion are now understood to be much broader, affecting not only rice and wheat, but also other crops.

In comparison to other natural resources, crop genetic resources are not only lost but are largely renewed through human intervention. Definitions of crop genetic resources vary. Fowler and Hodgkin (2004) emphasize that in both scientific and legal contexts the terminology can be problematic. The Convention on Biological Diversity describes them simply as the genetic materials (genes, gene combinations, genotypes) of actual or potential value. Indisputably, they are the basis for all crop production and crop improvement, and the natural insurance against unforeseen threats from new plant diseases or climatic change.

During the 1970s and in the decades that followed, a scientific movement dedicated to documenting the value of crop genetic resources in agriculture, and the importance of conserving them, emerged. Gepts (2006) has recently chronicled some of its major accomplishments. Scientists achieved progress in developing methods to conserve and enhance utilization of genetic resources by breeders and farmers, including techniques to characterize their genetic diversity. The Food and Agriculture Organization (FAO) led a major drive to collect and conserve plant genetic resources for agriculture, establishing the International Board for Plant Genetic Resources (IBPGR) (subsequently known as the International Plant Genetic Resources Institute, and now known as Bioversity International). IBPGR assumed the mandate for catalyzing and coordinating a global initiative to collect and conserve plant genetic resources for agriculture.

Ex situ (off-site) and *in situ* (on-site) approaches comprise the two main strategies used to conserve crop genetic resources and their wild relatives. These two approaches are now recognized as complementary, with relative strengths that depend on factors such as the reproductive biology of the crop, financial and institutional capabilities (Bretting and Duvick 1997).

Ex situ conservation consists of several techniques. Crop species with seeds that can be stored at low relative humidity and and hence, temperature, called "orthodox" seeds, are placed in cold storage. These comprise by far the majority of widely grown crops species, such as the major cereals (maize, rice, and wheat), many legumes (bean, chickpea, lentil, soybean), and numerous

vegetables, onions, cabbages and cucurbits (Gepts 2006: 2282). Species that cannot withstand desiccation (called "recalcitrant" seeds), including many tropical trees species, must be conserved as living plants in field gene banks and vegetatively propagated species such as cassava and banana/plantain are commonly conserved in this way. Cassava and banana/plantain, as well as potato (as well as a number of recalcitrant seeded species can also be conserved in vitro (in test tubes on plant nutrient medium). Other techniques, such as cryopreservation (in liquid nitrogen), are in use or under investigation. Sampling methodologies, such as "core collection" strategies, have been developed to reduce the daunting task of searching large collections of germplasm for useful traits (Hodgkin *et al.* 1995). Molecular markers are now used to characterize genetic diversity in a collection and assist in gene bank management by identifying either underrepresented or overrepresented populations.

Options for *in situ* conservation include natural or wilderness areas (no human intervention), national parks (some human intervention), or specially-managed areas with agricultural zones (farmer intervention). For some species, such as tropical trees, *in situ* conservation is the only feasible approach. In the case of other species, including major cereal crops such as maize, this approach is directed toward maintaining intra-specific diversity in the ecosystems in which it has evolved (Jarvis *et al.* 2007). However,

> deliberately planned in situ conservation of plant genetic resources is uncommon, although it does occur for some wild crop relatives such as teosinte in Mexico and citrus in North India . . . and deliberate conservation of crop landraces on more than a local or experimental scale is even more uncommon.
>
> (Fowler and Hodgkin 2004: 150)

Historically, farmers themselves have borne the cost of this source of insurance, from which global society as a whole has benefited. Particularly in areas not served by modern plant breeding, where communities are isolated, cultures are autonomous, and local agro-ecologies are heterogeneous, farmers have continued to select from their own crop populations, adapting them more gradually to changing needs and circumstances, renewing crop genetic resources *in situ* (on-site). The volumes compiled by Brush (2000), Smale (2006), and Jarvis *et al.* (2007) provide examples of empirically-based research that has been conducted about on farm conservation. The social, economic, and political dimensions of advancing programs to conserve genetic resources on farms pose major challenges.

3.2 Plant breeding for yield stability

Over the past decades, plant breeders have refined strategies for ensuring that the crop varieties grown by farmers can withstand climatic and biotic change. Before releasing new varieties, they test them for stability in different

environments and for resistance to stresses. Strategies such as "pyramiding" genes within a single cultivar are used in order to confer multiple sources of genetic resistance. A recent compilation of research by scientists at the International Center for Maize and Wheat Improvement (Centro Internacional de Mejoramiento de Maíz y Trigo, CIMMYT) documented that since the first modern varieties of spring bread wheat were released in 1965, improvements have continued with respect to heat and drought tolerance, resistance to disease, nitrogen-use efficiency, yield stability and potential, while there is no evidence that genetic narrowing has occurred (Smale *et al.* 2002). More recently, Dreisigacker *et al.* (2004) analyzed the genetic diversity of CIMMYT germplasm using simple sequence repeats (SSRs) and coefficients of parentage (COPs). Their analysis demonstrated a high level of genetic diversity within the germplasm targeted to major global production environments, and a substantial degree of diversity among phenotypes, in spite of a single core of germplasm.

3.3 *Maintenance research*

A final component of the strategy is called maintenance research. Modern crop varieties, like all new research products, depreciate with time. With new varieties, depreciation is largely a consequence of changing physical and biological conditions, such as continually evolving pests and diseases. Productivity enhancement is measured in terms of yield gains; maintenance is estimated in terms of the yield losses that would have occurred in the absence of research. A certain proportion of crop improvement research is allocated to maintenance research, and this proportion depends on the crop. Economists have long argued that this component of research investment has been undervalued in studies of the rates of return to crop and livestock improvement (for example, Townsend and Thirtle 2001). Yet there are very few economic analyses of maintenance research relative to productivity enhancement, and most have been conducted only in industrialized agriculture.

Research at CIMMYT indicated that resistance breeding in wheat generated a substantial portion of returns to international wheat research over the past decades (Byerlee and Traxler 1995; Heisey *et al.* 2002; Marasas *et al.* 2003), and analysis of trial results confirmed that progress in protecting yield potential through leaf rust resistance has been greater than advances in yield potential itself (Sayre *et al.* 1998). Costs streams for maintenance research were not calculated in these studies. Apportioning of costs and benefits is largely arbitrary given the joint activities conducted in a plant breeding program. Adusei and Norton (1990) estimated that the productivity maintenance effort for wheat was 41 percent for the U.S., based on data from a sample survey. Most estimates for the percentage of research expenditures allocated to maintenance research in the international agricultural research centers (Consultative Group on International Agricultural Research, or CGIAR) range from 33 percent to 50 percent.

4 Challenges

The genetic "insurance" system that is the product of scientific research has served us well, but have we become too complacent? The world is changing. To a growing degree, agricultural research is financed and undertaken by the private companies, which have less incentive for generating international public goods such as genetic conservation than publicly-funded organizations. The emergence of intellectual property rights over genetic resources also makes it more difficult for breeders to obtain certain categories of genetic material.

4.1 Privatization of agricultural research

Currently, over 50 percent of agricultural research in the OECD countries is undertaken by the private sector, and the share of agricultural research funded by private companies also appears to be rising in industrializing countries like China, Brazil and South Africa (Pardey *et al.* 2006). Unlike publicly-funded organizations, private firms have much less incentive to contribute to the conservation of agricultural genetic resources outside the working collections of breeders and scientists on their staff. They also have little incentive to share access except on a *quid pro quo* basis. As the public sector becomes a less important actor in agricultural research systems, the financial basis for maintaining and characterizing materials in public, open-access gene banks will also diminish.

The Global Crop Diversity Trust has been created to counterbalance these trends. The Trust has now raised more than $100 million, some $70 million of which is earmarked for an endowment that will provide secure and permanent funding for long-term conservation of crop diversity. So far, funds have been contributed by sources as diverse as the governments of U.S. and Ethiopia, private foundations and corporations, as well as individuals and farmers' organizations. The first long-term grant has been made, interestingly enough, to the International Rice Research Institute (IRRI). In this case, IRRI also committed a significant amount from its reserves, under contract with the Trust, to generate income that will fund their gene bank. In theory, the combination of these two conditions secures the IRRI collection "forever."

4.2 Intellectual property rights

Though a few scientists argue otherwise, most agree that the release of successful crop varieties and the utility of *ex situ* collections have relied on the continual exchange of large numbers of diverse genetic materials among scientists. Both Gepts (2006) and Fowler and Hodgkin (2004) report a drop in the number of accessions acquired by gene banks since the early 1980s. Though it is too soon to establish a causal relationship, these authors, as well as others, have expressed concern over increasingly proprietary regimes for

obtaining genetic materials. Until recently, breeders had free access to the tools of their trade. Reflecting our interdependence and the social value of these resources, many were held in the public domain. Assertion of intellectual property rights makes it more difficult for scientists to obtain genetic material for maintenance research, a problem which is particularly acute for plant breeders in the national research systems of developing economies who seek to enhance locally adapted materials. All nations are interdependent in terms of crop genetic resources, and in no single country can agricultural development occur without these resources.

In this new and changing context, there is no assurance that the current strategy for conserving and using genetic resources will suffice. Greater international cooperation is needed to formulate strategies for maintaining and sharing genetic resources in gene banks and on farms. Locking in the public funding needed to maintain the genetic conservation system and ensuring that breeders have access to materials are two fundamental elements of this strategy. Both private and public breeders need rights of access, and not necessarily on a no-cost basis.

5 A future conservation strategy

Fowler and Hodgkin (2004) recently re-assessed the status of *ex situ* conservation. Between 1974 and 1996, the number of long-term storage facilities grew from five or six to 76, with an estimated 6.2 million accession housed by gene banks located in 137 countries (Ibid.: 152). Estimates generated by experts indicate that by the mid-1990s, only 5 percent of the rice, maize, and wheat gene pools remained unrepresented among these accessions. Yet these authors caution against taking comfort from numbers—for several reasons. First, the estimated percentage of the gene pool that is represented in banks is considerably lower for some other major crops, such as cassava. In general, it is not possible to catalog a crop's gene pool with any precision, so estimates are only indicative. Furthermore, while some duplication is necessary to safeguard accessions, there appears to be considerable redundancy of materials, intended and unintended. Regenerating such large collections incurs significant expense, which raises questions about the longer-term viability of such collections when cost constraints are considered. Many gene banks are under-funded and lack the necessary technical capabilities to maintain their collections on a viable long-term basis. Finally, historic data are not extensive, precise, or reliable (Fowler and Hodgkin, 2004).

Economists have raised similar concerns about the redundancy and sustainability of accessions, claiming that many banks are rarely used directly by plant breeders. A few historical examples are sufficient to demonstrate, however, that even if tapped by crop breeding programs only under rare circumstances, a genetic resource housed in a gene bank can have enormous economic value (Gollin *et al.* 2000). In a detailed case study of one of the world's largest national gene bank networks in the world, the U.S. National

Germplasm System, Day *et al.* (2006) found that demand for resources housed in the collections was substantial and came from a broad range of users. Utilization rates were higher than suggested in previous studies, and countries with developing economies made greater use, relatively speaking, than did high-income countries. Koo *et al.* (2004) have demonstrated the relatively low costs of maintaining large collections of some major crops at the international agricultural research centers.

Gene banks pose management challenges, and gene bank management has been under-funded. The current policy focus is on existing *ex situ* collections of major crops covered under Annex 1 of the International Treaty on Plant Genetic Resources for Food and Agriculture. Recognition of the importance of keeping materials in the public domain motivated the Treaty. The Global Crop Diversity Trust has been established by Bioversity International (formerly IPGRI) and the FAO to develop and promote a global genetic conservation system for important Annex 1 crops. The Trust has a target of about $250 million in endowment. There are also various national and international efforts underway to characterize and map the genetic material already available in seed banks, and to create an accessible information system. Information enhances prospects for utilization, but information for most accessions is typically limited. The analysis by Day *et al.* (2006) confirmed that accompanying data improved the chances that a sample received from the gene bank network was used immediately by a breeding program, evaluated, or used in other ways.

Gene banks are not an entirely adequate solution, even if these challenges are overcome. First, for many crops, a considerable amount of diversity still exists *in situ*. For example, minor crops are poorly represented in gene banks (Padulosi *et al.* 2002). Second, gene banks do not allow for continuing evolution and adaptation to changing environmental or production conditions, such as climatic change. Third, while they are fairly decentralized on a global scale (there are numerous regional and national gene banks), farmers rarely access them. While community gene banks have been promoted by some development organizations as a means of assuring farmers access to local materials, there has been no rigorous analysis of use rates and the cost-effectiveness of these interventions.

Given the risks of habitat destruction through human intervention or natural disasters, *in situ* conservation is not an entirely adequate solution either. There are two obvious challenges for *in situ* conservation. First, while the farmers who manage local materials have access to them, there is no means of ensuring that these materials are available to other farmers or to plant breeders. Most of the genetic diversity remaining *in situ* has not yet been characterized and is virtually "invisible." Second, as with most local development efforts, there are difficulties associated with scale of effort and location-specificity of program design. Programs cannot be easily replicated or standardized.

In situ conservation, in particular, lacks a solid policy footing, even at

important origin sites with known diversity in landraces and wild relatives of major food crops. Economists have sought to shed light on the determinants of crop biodiversity on farms, profiling the characteristics of farmers and localities most likely to continue managing it, in order to identify cost-effective sites for conservation.[3] Current *in situ* efforts are based largely on the goodwill and livelihood interests of local communities and non-governmental organizations rather than on the recognition by governments of the immense public goods value of the genetic diversity that they manage. The lack of a framework to support the availability of *in situ* germplasm to different user groups reflects the limited work in this area, although the genetic diversity found *in situ* is likely to take on increasing importance (Fowler and Hodgkin 2004). The emergence of new types of schemes and markets for providing payments for environmental services (PES) may offer more rewarding opportunities to farmers and communities for *in situ* conservation. So far, such schemes have targeted mostly reforestation and watershed protection. Some recent examples demonstrate the application of PES to generate biodiversity and carbon sequestration services (e.g. World Bank pilot projects in Colombia, Costa Rica, and Nicaragua (World Bank, 2007)). There is need for a more holistic, strategic, and internationally-supported effort to conserve crop genetic resources *in situ*.

Notes

1 This epidemic resulted from genetic uniformity in T male-sterile cytoplasm, in which a mutant form of *Bipolaris maydis* (Nisikado & Miyake) Shoemaker found a welcome home, resulting in a 15 percent decline in national production.
2 There are numerous definitions of crop landraces. Most generally, crop landraces are heterogeneous, locally-adapted cultivars that are maintained by farmers under human and natural processes of selection. Seed is saved and exchanged among farmers. By contrast, modern varieties are bred by professional scientists under controlled conditions on experimental farms. Modern varieties typically must satisfy certain conditions of distinctness, uniformity and stability before release to farmers.
3 See literature assembled in ECOGENLit, *Economics Literature on Plant and Livestock Genetic Resources*. Compiled for the System-wide Genetic Resources Programme (SGRP) by Patricia Zambrano, Melinda Smale, Adam Drucker, Luz Marina Alvaré, and Indira Yerramareddy. http://www.ifpri.org/pubs/sgrp/index.asp.

References

Adusei, E.O. and Norton, G.W. (1990) "The magnitude of agricultural maintenance research in the USA," *Journal of Production Agriculture* 3: 1–6.
Bretting, P. and Duvick, D. (1997) "Dynamic conservation of plant genetic resources," *Advances in Agronomy* 61:1–51.
Brush, S.B. (ed.) (2000) *Genes in the Field: On-farm Conservation of Crop Diversity*. Boca Raton, FL: IDRC/IPGRI/Lewis Publishers.

Byerlee, D. and Traxler, G. (1995) "National and international wheat improvement research in the post-Green Revolution period: evolution and impacts," *American Journal of Agricultural Economics* 77: 268–278.

Day-Rubenstein, K., Smale, M. and Widrlechner, M. (2006) "Demand for genetic resources and the U.S. National Plant Germplasm System," *Crop Science* 46: 1021–1031.

Dreisigacker, S., Zhang, P. Warburton, M. L., Van Ginkel, M., Hoisington, D., Bohn, M. and Melchinger, A.E. (2004) "SSR and pedigree analyses of genetic diversity among CIMMYT wheat lines targeted to different megaenvironments," *Crop Science* 44: 381–388.

Dubin, H.J. and Torres, E. (1981) "Causes and consequences of the 1976–77 wheat leaf rust epidemic in northwest Mexico," *Annual Review of Phytopathology* 19: 41–49.

Fowler, C. and Hodgkin, T. (2004) "Plant genetic resources for food and agriculture: assessing global availability," *Annual Review of Environmental Resources* 29: 143–179.

Gepts, P. (2006) "Plant genetic resources conservation and utilization: the accomplishments and future of a societal insurance policy," *Crop Science* 46: 2278–2292.

Gollin, D. (2006) *Impacts of International Research on Intertemporal Yield Stability in Wheat and Maize: An Economic Assessment*. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

Gollin, D., Smale, M. and Skovmand, B. (2000) "Searching an ex situ collection of wheat genetic resources," *American Journal of Agricultural Economics* 82(4): 812–827.

Harlan, J.R. (1972) "Genetics of disaster," *Journal of Environmental Quality* 1: 212–215.

Hazell, P.B.R. (1984) "Sources of increased instability in India and U.S. cereal production," *American Journal of Agricultural Economics* 66(August): 302–311.

Hazell, P.B.R. (1985) "Sources of increased variability in world cereal production since the 1960s," *Journal of Agricultural Economics* 36(May): 145–160.

Hazell, P.B.R. (1989) "Changing patterns of variability in world cereal production," in J.R. Anderson, and P.B.R. Hazell (eds.) *Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries*. Baltimore, MD: Johns Hopkins University Press.

Heisey, P.W., Lantican, M.A. and Dubin, H.J. (2002) "Assessing the benefits of international wheat breeding research in the developing world: the global wheat impacts study, 1966–1997," Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

Hodgkin, T., Brown, A.H.D., van Hintum, T.J.L. and Morales, E.A.V. (1995) *Core Collections of Plant Genetic Resources*. Rome: International Plant Genetic Resources Institute (IPGRI).

Howard, A. and Howard, G.L.C. (1909) *Wheat in India: Its Production, Varieties, and Improvement*. Calcutta: Thacker, Spink, and Co., for the Imperial Dept. of Agriculture in India.

Jarvis, D.I., Padoch, C. and Cooper, D. (eds) (2007) *Managing Biodiversity in Agroecosystems*. New York: Columbia University Press.

Koo, B., Pardey, P.G. and Wright, B.D. (2004) *Saving Seeds: The Economics of Conserving Crop Genetic Resource Collections in the Future Harvest Centres of the CGIAR*. Wallingford, UK: CAB International.

Marasas, C.N., Smale, M. and Singh, R.P. (2003) "The economic impact of productivity maintenance research: breeding for leaf rust resistance breeding in modern wheat," *Agricultural Economics* 29: 253–263.

National Research Council, Committee on Genetic Vulnerability of Major Crops (1972) *Genetic Vulnerability of Major Crops*. Washington, DC: National Academy of Sciences.

Padulosi, S., Hodgkin, T., Williams, J.T. and Haq., N. (2002) "Underutilized crops: trends, challenges and opportunities in the 21st century", in J. Engels, V.R. Rao, A.H.D. Brown and M.T. Jackson (eds) *Managing Plant Genetic Diversity*. Wallingford: CAB International.

Pardey, P.G., Beintema, N., Dehmer, S. and Wood, S. (2006) *Agricultural Research; A Growing Global Divide*. Washington, DC: Agricultural Science and Technology Indicators Initiative (ASTI), IFPRI.

Sayre, K.D., Singh, R.P., Huerta-Espino, J. and Rajaram, S. (1998) "Genetic progress in reducing losses to leaf rust in CIMMYT-derived Mexican spring wheat cultivars," *Crop Science* 38: 654–659.

Smale, M. (ed.) (2006) *Valuing Crop Biodiversity: On-farm Genetic Resources and Economic Change*. Wallingford: CAB International.

Smale, M., Reynolds, M.P., Warburton, M., Skovmand, B., Trethowan, R., Singh, R.P., Ortiz-Monasterio, I. and Crossa, J. (2002) "Dimensions of diversity in modern spring bread wheat in developing countries from 1965," *Crop Science* 42: 1766–1779.

Townsend, R. and Thirtle, C. (2001) "Is livestock research unproductive? Separating health maintenance from improvement research," *Agricultural Economics* 25(2–3): 177–189.

Wanyera, R., Kinyua, M.G., Jin, Y. and Singh, R.P. (2006) "The spread of stem rust caused by Puccinia graminis f. sp. tritici, with Virulence on Sr31 in wheat in Eastern Africa," *Plant Disease* 90(1): 113.

World Bank (2007) *World Development Report 2008: Agriculture for Development*. Washington, DC: World Bank.

4 Do we need crop landraces for the future?

Realizing the global option value of *in situ* conservation

Mauricio R. Bellon

1 Introduction

The obvious answer to the question posed in the title of this chapter is yes. Landraces contain the genetic diversity used for the generation of new and improved crop varieties, and are the basis for scientific plant breeding. Many farmers, particularly poor farmers in the developing world, continue to rely on them for their sustenance and livelihoods. Because of their importance they have been actively collected and many are maintained in gene banks around the world (known as *ex situ* conservation). The aim of this chapter, however, is not to address the rationale and benefits of *ex situ* conservation of landraces or their contribution to the livelihoods of the poor in developing countries, but to argue for the need of maintaining the social-biological systems that generate crop landraces in the first place. The rationale for this is that these systems provide an important global option value, particularly in the face of climate change. In order for them to be of practical use, it is not enough just to maintain these systems for many different crops around the world. It is also necessary to implement a global information system that monitors and provides access to the germplasm they provide.

The need to maintain crop diversity on farms, and hence the systems that generate this diversity, has been recognized for some time and is referred to as *in situ*/on farm conservation (Brush 1995). Although the rationale for it and advantages it confers have been examined before (e.g. Brown 1999; Brush 2004), the global public goods that *in situ*/on farm conservation can supply have not been adequately examined. Most of the studies of the benefits associated with maintaining crop diversity on farm refer to the provision of local private goods and services to farmers who grow the crops (e.g. studies compiled in Smale 2006) or, more broadly, to local and regional public goods, such as the value of this diversity to manage pests and diseases (e.g. Jarvis *et al.* 2007). Benefits have also been viewed in terms of the provision of desirable varieties to other farmers in a particular community or, at most, in a region (Badstue *et al.* 2006). Many of the benefits of maintaining crop diversity are not captured by prices in markets. As will be argued here, by keeping a decentralized collection of multiple, *in situ* conservation sites for different

crops around the world, and linking them in a global information system, we can better capture the global option value of this form of conservation.

2 The value of crop diversity and the need to conserve it

The diversity of cultivated species has been and continues to be the basis of our food supply and good nutrition. This is equally true of subsistence-based societies and technologically advanced societies. This diversity has two important dimensions: (1) the diversity among cultivated species (inter-specific diversity); and (2) the diversity within species, i.e. the variation of populations belonging to one species (infra-specific diversity). Both types are based on the underlying genetic diversity present within and among culti-vated species. Genetic diversity allows farmers and plant breeders to adapt a crop to heterogeneous and changing environments, a fact attested by the diffusion of a great number of species from their centers of origin to com-pletely new and different environments. It is the basis for increasing crop productivity as well as stability of production by providing, for example, resistance to pests and diseases.

Crop genetic diversity is the result of a co-evolution between the cultivated species and the human populations that grow them over generations, a pro-cess that continues today. Most of the crop genetic diversity used historically and easily available to humans is contained in crop landraces. The concept of a landrace as applied to the diversity of domesticated species is complex but there are some common elements that characterize landraces. These include a high capacity to tolerate biotic and abiotic stress, resulting in high yield stabil-ity and an intermediate yield level under a low-input agricultural system (Zeven 1999). Hence, landraces are usually considered to have very high local adaptation. They are also associated with a set of farmers' practices of seed selection and field management as well as with a knowledge base. Farmers who grow them recognize them as local and are able to identify them as distinct units, even though they may be heterogeneous and farmers may or may not have specific names for them.

Until the advent of scientific plant breeding in the past hundred years, agriculture worldwide relied on landraces. In recent times, crop varieties resulting from scientific plant breeding—originally derived from landraces—have come to dominate agricultural production in developed countries and in many areas of the developing world. The substitution of diverse and variable landraces by scientifically-bred varieties has increased food production dra-matically, but also has raised the concern that the genetic diversity contained in landraces may be lost forever, a process known as crop genetic erosion (Plucknett *et al.* 1987; Hawkes 1983; Harlan 1992; NRC 1993). This concern has led to conservation efforts worldwide, largely focused on the collection and storage of diverse landraces in gene banks, known as *ex situ* conservation (Hawkes 1983; Plucknett *et al.* 1987). *Ex situ* conservation aims to maintain the genetic material in the state in which it was collected, avoiding loss or

degeneration (Brush 2004). There is recognition that the genetic diversity contained in stored landraces is needed for future breeding. The direct use of landraces in many breeding programs is low, however—for reasons that are beyond the scope of this chapter (e.g. Gepts 2006; but also see Smale *et al.*, Chapter 3 in this volume)—and hence there is further recognition of the need to broaden their use in these programs (Cooper *et al.* 2001).

In the past twenty years *in situ* conservation has gained recognition as an important component in a strategy to conserve genetic resources (IPGRI 1993; Maxted *et al.* 1997; Brush 1999; Wood and Lenné 1999). Brush (2004) has summarized the principal advantages of *in situ* conservation: (1) important elements of crop genetic resources cannot be captured and stored off-site—these comprise dynamic factors such as ecological interactions and evolution that characterize a living and continually changing system; (2) gene bank collections do not capture the diversity or resources generated after the collection was made—there is evidence for example, of the divergence between crop populations originated in the same place but maintained ex situ and in situ (Soleri and Smith 1995; Tin *et al.* 2001); (3) all types of conservation are vulnerable, including ex situ conservation, so while in situ conservation is not meant to maintain alleles and/or genotypes unchanged, it can provide potential stores for re-collection of genetic resources; and (4) in situ conservation has been promoted in many policy and scientific circles as an ally of agricultural development in areas bypassed by conventional agricultural research.

Perhaps the most common criticism of in situ/on farm conservation is that it will perpetuate poverty among farmers who maintain diverse landraces by promoting them at the expense of more productive scientifically-bred varieties that would provide farmers with higher incomes and improved welfare. This criticism is in many cases unfair. Often, scientifically-bred varieties are proven to be inadequate for many of the farmers who continue to grow landraces. The seed of scientifically-bred varieties may not be available with certainty because input markets function poorly. Product markets that farmers need in order to profit from increased production and sales may not exist. *De facto* conservation of diverse landraces continues in many parts of the world and for many crops, and is a rational decision of farmers given the circumstances and constraints they face (Brush 2004).

3 Crop landraces as decentralized open genetic systems

Crop species are human artifacts that result from the interaction between species and the humans that grow them, their interests and practices. They are the result of both natural and human selection. Even natural selection is influenced by human actions, such as moving and planting crop species in particular locations and environments and thereby exposing the crops to natural selection pressures including climatic conditions, specific soils, pests and diseases. As indicated by Gepts (2006: 2286): "Through farming practices

(time of planting, thinning, and seed selection), farmers are able to keep landraces adapted to their growing conditions and socio-cultural preferences.''

Recent studies on the use and maintenance of landraces of different crops in many parts of the developing world have shown that farmers rely on their own resources for their main source of seed, either through saving their own seed or obtaining it from others who have saved it (Hodgkin *et al.* 2007). By saving seed, farmers are influencing the genotypes that pass from one generation to the next, whether consciously or not. In some cases this process is well recognized and managed by farmers and in others it is not. Selection is not only linked to agronomic performance but also to the delivery of specific products and properties, such as taste, processing qualities and visual characteristics. The fact that farmers share seed also means that genes and populations move. Both selection and gene flow are important factors shaping the diversity maintained by farmers, although the relative importance of these forces depends on the breeding system of the crop.[1]. While seed selection and seed flows usually happen at the local scale within farming communities, they occur simultaneously in many communities through many regions of a country or among several countries where the specific crops are grown. At a broader scale, these flows can be viewed as shaped by the independent decisions of hundreds or thousands of farmers.[2]

Landraces can be conceptualized as open, dynamic and decentralized genetic systems since they are the crop populations that farmers manage, and which result from farmers' seed selection practices, the flows of seed among them, and farmers' production and utilization strategies. They are open because crop populations are shared among farmers; they are dynamic because these populations, and the genes and traits they contain, are introduced, abandoned and selected over time. This process leads to changes in their genetic structure and performance. The process is decentralized because its structure, performance and dynamics depend on the decisions of a large number of farmers growing crop landraces in different environments and for diverse purposes.

Landraces are the winning combinations of genes and traits that result from the interaction among farmers, their crop and their environments, in a variety of conditions and in a dynamic way. Conditions and environments change and some of those that are rare today can become common tomorrow and vice versa. Hence having a diversity of winning combinations of genes and traits that are constantly responding to change should allow us to cope and adapt better to change. The diversity found in open, decentralized genetic systems should not be viewed as the product of a simple process like a random number generator. Instead, the diversity of these systems can be seen as more akin to a Bayesian process where the winning combinations are constantly updated in response to changing situations and new knowledge.

3.1 Global change: the role of landraces under unpredictability and uncertainty

Global climate change is now widely recognized as a reality and we are already witnessing its dramatic consequences. Climate has been recognized as very important risk factor in agricultural systems and changes in climate can exacerbate those risks substantially. In spite of the fact that important attempts have been made to model and predict climate change and its consequences over agricultural systems, there is a recognition that there are clear limits to our ability to do so (Meinke *et al.* 2004). For example, for Africa, one of the regions where it is expected that climate change will have some of the most dramatic consequences, current models of climate change provide widely different predictions (Challinor *et al.* 2007). This means that dealing with climate change and their consequences for human societies entails coping with a great degree of unpredictability and uncertainty particularly in agricultural systems that are heavily influenced by climatic conditions.

The ability to cope with these changes in agricultural systems depends on the crops and their sensitivity to climate variability, the adaptive capacity of farmers and the role of institutions in adapting to climate change (ibid.). Clearly, the availability of crops and varieties that are adapted or can adapt to these changes is an important component of coping mechanisms, but as stated, many of the changes are uncertain and unpredictable.

So how can diverse agricultural systems in many parts of the world faced with different situations have access to the right germplasm under uncertainty? One component of the availability of such germplasm could be a global network of in situ conservation sites. Such sites would produce and maintain landraces that are continuously evolving and adapting in numerous and different conditions and environments—both biophysical and socio-economic—in decentralized and unpredictable ways. These crop populations may be used either directly by farming communities or indirectly through their inclusion in plant breeding programs.

Establishing multiple in situ conservation sites around the world to provide the germplasm to cope with climate change is not sufficient for meeting the needs of global society, however. These sites must be linked to a global information system that monitors adaptation and evolution processes and enables scientists to identify new combinations that can be used in different places as needed. The status quo, which is *de facto* conservation in situ, is not enough. If global benefits are to be had from it, a global information system will be necessary. Clearly, a global information system will require the development of a new set of tools and methods to monitor evolution and adaptation (and not only genetic erosion). This is one means by which in situ conservation can generate global option values.

4 The threats to open decentralized genetic systems

As argued above, a global system of in situ conservation sites where open genetic systems continue to function and are linked to an information system could be an important mechanism for coping with global climate change. There are threats to maintaining open genetic systems. In particular, the divergence of private and public values of maintaining them as economies develop creates a classic externality problem. Hence, the idea of maintaining these systems is not to keep farmers poor, but to provide them with the right incentives to produce a global public good by maintaining the economic viability of their agricultural systems. The germplasm options needed to cope with climate change are the global public good.

The study of *de facto in situ* conservation systems has provided numerous insights into farmers' reasons for maintaining diversity on farm and in the practices and knowledge used (e.g. Bellon 1996; Zimmerer 1996; Brush 2004; Smale 2006). The diversity of landraces in a crop grown by a farmer or farming community can be seen as the outcome of their attempts to solve multiple problems while meeting their production needs and consumption preferences. While producing a crop, farmers have diverse interests and concerns. These include: (1) farming in a variety of environments; (2) coping with production risks; (3) managing pests and pathogens; (4) avoiding or minimizing labor bottlenecks; (5) fitting different budget constraints; (6) providing variety to monotonous diets; (7) furnishing special consumption items; and (8) fulfilling rituals, generating prestige, and forging social ties. This diversity of interests and concerns translates into the use of diverse varieties of a crop because it is unlikely that one variety has all the traits and/or qualities needed (Bellon 1996).

The factor that probably has the greatest impact on the net loss of diversity of landraces in farmers' production systems is the increased participation of farmers in markets, not only for the crop itself, but also for other goods, services and resources. Although many of market-related factors affecting the survival or loss of landraces in production systems have been studied, three processes are fundamental (Bellon 2004):

1   The availability and affordability of alternative solutions to the problems that diversity of landraces addresses, i.e. the availability of substitutes for crop diversity.
2   The opportunity cost of the resources employed in using and maintaining crop diversity.
3   Cultural change, i.e. changes in the socially shared notions of what is important, acceptable or desirable as they pertain to the solutions that crop diversity provides.

Crop infra-specific diversity has provided farmers throughout history with numerous goods and services, both for production and for consumption.

With increased commercialization, farmers can sell their products in new markets and obtain goods and services produced outside their communities. As producers, farmers gain access to new inputs, such as fertilizers, agro-chemicals, machinery, insurance, expertise and scientifically-bred varieties. In some cases, these inputs lessen the need to adapt to diverse soils or production environment, reducing labor bottlenecks and offering alternative ways to deal with pests and disease or manage risk. As consumers, farmers purchase products, including those that they previously produced themselves, and goods they have never consumed before and cannot produce, such as some vegetables and soft drinks. Participation in markets can provide substitutes for inter- and infra-specific diversity of crops.

For most farmers, agriculture is one among many income-generating activities that often include off-farm labor and temporary migration. Expanded participation in labor markets increases the opportunity cost of time for farmers and their families. In other words, the benefits that farming households would have to forgo by investing their time in other activities rather than participating in labor markets rises. Alternatively, if one crop or a particular variety is better suited for sale and generates higher net income, the income foregone when planting the land to multiple crops or varieties can become too high. The pressures of intensification and commercialization may increase the opportunity cost of maintaining crop diversity to the point where farmers are unwilling to continue.

Of particular relevance may be the growing cost of procuring seed of diverse varieties as access to them declines with a changing farming system. Procuring seed of diverse varieties requires time—time to search for the information about appropriate varieties, search for the seed, and support the social networks that supply them. Higher costs of obtaining access to diversity mean that once a farmer loses a variety, he or she may be less willing to look for it. The smaller the number of farmers who plant certain varieties or save seed from them, the more difficult it is for a farmer to find them in case of loss. A higher opportunity cost of time may also imply less time and willingness to contribute to the social networks that sustain diversity.

Cultural change plays a major role in farmers' choice of varieties. The loss of local culture and increased assimilation into a general or dominant culture may eliminate preferences and practices that make a diversity of crop types valuable. There is increasing evidence of a reduction of cultural diversity around the world (e.g. Sutherland 2003; Maffi 2005). For example, certain varieties that are used as ingredients in dishes prepared for customary festivals and events will disappear if those festivals wane.

Markets, understood as broader social institutions of exchange of goods and services, are related directly to the first two processes cited above and indirectly to the third. Markets foster specialization and provide substitutes, increase opportunity costs and influence culture. In turn, culture affects the first two processes, because culture provides the context for how problems are defined and prioritized, defining what is and is not important. Thus, culture

determines the extent to which goods, services, and behavior are considered to be worthwhile, which are acceptable substitutes, and the magnitude of opportunity costs.

The broad processes identified above actually operate by influencing the demand for and the supply of crop diversity. The demand for crop diversity refers to the fact that farmers value different varieties and are willing to invest resources such as labor, money, and land to grow them. The supply of crop diversity refers to the mechanisms and transactions farmers depend on to gain access to a diverse set of varieties. Therefore, interventions to support on-farm conservation can be conceptualized in terms of the way they influence demand and supply. Demand interventions should increase the value of crop diversity for farmers or decrease the opportunity costs of maintaining it. Supply interventions should decrease the costs of obtaining access to diversity (see Bellon 2004, for a more detailed discussion of these interventions).

In any case, if the goal is to maintain open decentralized genetic systems, then what matters is not to keep specific landraces or crop populations in a particular place, but to sustain the processes that link farmers and crop populations in many different areas and for many different crops. These processes include the practice of saving and sharing seeds. In many cases, these practices involve seed selection as well as farmers' ability to incorporate new crop populations into their production systems. Integral to these processes is the knowledge base that underpins them and the willingness of farmers to continue to expose their crop populations to both natural and artificial selective pressures. Sustaining these processes implies that the farmers' production systems remain economically viable.

Another factor that can hamper the maintenance of open decentralized genetic systems is the increasing restriction on farmer and breeder access to seeds and germplasm, locally and globally. Local constraints on access reflect national seed policies that favor the recognition of only scientifically-bred varieties that are distinct, uniform and stable, discouraging the use of more heterogeneous, variable landraces. Global constraints on access result from asserting the sovereignty of countries over the plant genetic resources found within their national boundaries, coupled with the belief that there are major monetary benefits to be gained by restricting the access of other countries to these resources. Unfortunately, this largely mistaken perception has contributed to restrictions in the global flow of plant genetic resources (Falcon and Fowler 2002). The problem has been identified but is only partially addressed for some crops by the International Treaty for Plant Genetic Resources for Food and Agriculture.

A global program to cope with climate change through in situ conservation, as suggested in this chapter, could be severely hampered by restrictions on access to germplasm. For example, if certain crop populations were identified in one country that could be used in another, restrictions on the international flow of germplasm would hamper their deployment. To be

successful, a global program should not only provide incentives to farmers to manage open, decentralized genetic systems, but also guarantee that germplasm can be exchanged across countries and regions.[3] Without this prerequisite, the global option value of such a system would not be realized.

5 Conclusion

The world is faced with unprecedented environmental change due to human impacts on climate. Climate, always an important risk factor for agricultural production, is becoming ever more uncertain. The dynamic change that characterized crop landrace systems—open, decentralized genetic systems that are constantly evolving to fit farmers' needs and environmental changes—could help in coping with the uncertainty generated by climate change in agriculture. Landraces are the winning combinations of genes and traits that result from multiple and unpredictable interactions among a crop, the farmers that grow it and the variety of conditions and environments in which it is grown.

In order to realize the potential benefits from mitigating the consequences of climate change, it is necessary to look beyond the status quo. *De facto* in situ conservation, as practiced today, is insufficient for the task. This chapter has proposed a decentralized system of multiple *in situ* conservation sites for different crops around the world, linked to a global information system. On the one hand, the system would support the social-biological systems that have generated and will continue to underpin the evolution of crop landraces, particularly in the face of conditions that threaten their viability. On the other hand, the system would entail a global information system that monitors the continual adaptation of landraces, facilitating the identification and sharing of gene combinations that can be utilized in different places as change occurs. Such a system will be challenged by issues related to farmers' rights, economic incentives, and cross-border access to germplasm. If these can be overcome, the system should allow humanity to realize some of the global option value of in situ conservation. Change is global; hence, we need global solutions. Hampering the emergence of such global solutions today only increases our vulnerability in the future.

Acknowledgments

Notes

1 Breeding system refers to the way a crop species reproduces. In general, crops can be: (1) allogamous, which refers to reproduction through the cross-fertilization of one plant by a different one, such as in maize; (2) autogamous, which refers to reproduction through self-fertilization, such as in rice or wheat; or (3) vegetative propagating which is a type of asexual reproduction when new plant individuals are generated without the production of seeds or spores, such as commonly happens in potatoes.

2 Farmers' decisions may not be independent within a particular community since they share a common culture, resource base, may face similar constraints, and rely on each other to obtain seed. However, at a larger scale these decisions can be seen as increasingly independent as the distance among communities increases.

3 Obviously the movement of germplasm should follow the proper phytosanitary procedures to avoid the spread of pests and diseases.

References

Badstue, L.B., Bellon, M.R., Berthaud, J., Juárez, X., Manuel-Rosas, I., Solano, A.M. and Ramírez, A. (2006) "Examining the role of collective action in an informal seed system: a case study from the Central Valleys of Oaxaca, Mexico," *Human Ecology* 34: 249–273.

Bellon, M.R. (1996) "The dynamics of crop infraspecific diversity: a conceptual framework at the farmer level," *Economic Botany* 50: 26–39.

Bellon, M.R. (2004) "Conceptualizing interventions to support on-farm genetic resource conservation," *World Development* 32: 159–172.

Brush, S.B. (1995) "In situ conservation of landraces in centers of crop diversity," *Crop Science* 35: 346–354.

Brush, S.B. (1999) "The issues of in situ conservation of crop genetic resources," in S.B. Brush (ed.) *Genes in the Field*. Rome, Ottawa, and Boca Raton, FL: International Plant Genetic Resources Institute, International Development Research Center, and Lewis Publishers, pp. 3–26.

Brush, S.B. (2004) *Farmers' Bounty: Locating Crop Diversity in the Contemporary World*. New Haven, CT: Yale University Press.

Brown A.H.D. (1999) "The genetic structure of crop landraces and the challenge to conserve them in situ on farms," in S.B. Brush (ed.) *Genes in the Field*. Rome, Ottawa, and Boca Raton, FL: International Plant Genetic Resources Institute, International Development Research Center, and Lewis Publishers, pp. 29–48.

Challinor, A., Wheeler, T., Garforth, C., Craufurd, P. and Kassam, A. (2007) "Assessing the vulnerability of food crop systems in Africa to climate change," *Climatic Change* 83: 381–399.

Cooper, H.D., Spillane, C. and Hodgkin, T. (eds) (2001) *Broadening the Genetic Base of Crop Production*. Wallingford: CABI Publishing.

Falcon, W.P. and Fowler, C. (2002) "Carving up the commons—emergence of a new international regime for germplasm development and transfer." *Food Policy* 27: 197–222.

Gepts, P. (2006) "Plant genetic resources conservation and utilization: the accomplishments and future of a societal insurance policy." *Crop Science* 46: 2278–2292.

Harlan, J.R. (1992) *Crops and Man*, 2nd edn. Madison, WI: American Society of Agronomy.

Hawkes, J.R. (1983) *The Diversity of Crop Plants*. Cambridge, MA: Harvard University Press.

Hodgkin, T., Rana, R., Tuxill, J., Balma, D., Subedi, A., Mar, I., Karamura, D., Valdivia, R., Collado, L., Latournerie, L., Sadiki, M., Sawadogo M., Brown, A.H.D. and Jarvis, D.I. (2007) "Seed systems and crop genetic diversity in agroecosystems," in D.I. Jarvis, C. Padoch and H.D. Cooper (eds) *Managing Biodiversity in Agricultural Systems*. New York: Columbia University Press, pp. 77–116.

IPGRI (International Plant Genetic Resources Institute) (1993) *Diversity for Development: The Strategy of the International Plant Genetic Resources Institute*. Rome: International Plant Genetic Resources Institute.

Jarvis, D.I., Brown, A.H.D., Imbruce, I., Ochoa, J., Sadiki, M., Karamura, E., Trutmann, P. and Finckh, M.R. (2007) "Managing crop disease in traditional agroecosystems: benefits and hazards of genetic diversity," in D.I. Jarvis, C. Padoch and H.D. Cooper (eds) *Managing Biodiversity in Agricultural Systems*. New York: Columbia University Press, pp. 292–319.

Maffi, L. (2005) "Linguistic, cultural, and biological diversity," *Annual Review of Anthropology* 34: 599–617.

Maxted, N., Ford-Lloyd, B.V. and Hawkes, J.G. (eds) (1997) *Plant Conservation: The In Situ Approach*. London: Chapman and Hall.

Meinke, H., Donald, L., DeVoil, P., Power, B., Baethgen, W., Howden, M., Allen, R., and Bates, B. (2004) "How predictable is the climate and how can we use it in managing cropping risks?" in *New Directions for a Diverse Planet*. Proceedings of the 4th International Crop Sciences Congress. 26 Sept.—1 Oct. 2004, Brisbane, Australia. Available at: <http://www.cropscience.org.au/icsc2004/symposia/2/7/1189_meinke.htm> (accessed 11 Oct. 2007).

NRC (National Research Council) (1993) *Managing Global Genetic Resources: Agricultural Crop Issues and Policies*. Washington, DC: National Academy Press,

Plucknett, D.L., Smith, N.H.J, Williams, J.T. and Anishetty, N.M. (1987) *Gene Banks and the World's Food*. Princeton, NJ: Princeton University Press.

Smale, M. (2006) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change*. Wallingford: CABI Publishing.

Soleri D. and Smith, S.E. (1995) "Morphological and phonological comparisons of two Hopi maize varieties conserved in situ and ex situ," *Economic Botany* 49: 56–77.

Sutherland, W.J. (2003) "Parallel extinction risk and global distribution of languages and species," *Nature* 423: 276–279.

Tin, H.Q., Berg, T. and Bjørnstad, Å. (2001) "Diversity and adaptation in rice varieties under static (ex situ) and dynamic (in situ) management," *Euphytica* 122: 491–502.

Wood, D. and Lenné, J.M. (eds) (1999) *Agrobiodiversity: Characterization, Utilization and Management*. Wallingford: CABI Publishing.

Zeven, A.C. (1999) "The traditional inexplicable replacement of seed and seed ware of landraces and cultivars: a review," *Euphytica* 110: 181–191.

Zimmerer, K.S. (1996) *Changing Fortunes: Biodiversity and Peasant Livelihood in the Peruvian Andes*. Berkeley, CA: University of California Press.

5 Marketing underutilized plant species for the poor

A conceptual framework

Guillaume P. Gruère, Alessandra Giuliani and Melinda Smale

1 Introduction

Modern crop production is based on only a few plant species (Prescott-Allen and Prescott-Allen 1990). Ethno-botanic surveys have documented that many less well-known species continue to be grown, managed and collected, particularly by poor people in marginal environments of developing agricultural economies (IPGRI 2002). Numerous terms have been employed to characterize them, including "minor crops," "underutilized" species, "neglected species," "orphan crops," "underexploited" or "underdeveloped" species.

These species persist because they are still useful to local people, occupying special niches in the agro-ecology and an economic role in semi-subsistence production systems. Some demonstrate an agronomic advantage in crop production with low levels of purchased inputs on marginal lands (Padulosi *et al.* 2002). Others provide environmental services or contribute to the restoration of degraded lands (De Groot and Haq 1995). A few publications have underscored their importance in the livelihoods of the poor (e.g., Naylor *et al.* 2004), though their role in rural life has long been recognized by ethno-botanists and anthropologists. Some species are gathered as a source of food or cash, especially during "lean" periods in the agricultural cycle. Others provide diversity, essential nutrients, vitamins or minerals in diets that would otherwise consist primarily of carbohydrates (Johns 2004; Johns and Sthapit 2004). Often, their use reflects cultural values (Johns and Eyzaguirre 2002).

Typically, traditional knowledge is associated with the use of these species, while scientific information is emerging but limited. For example, palm fruits from Brazil are now known to be rich in beta-carotene. The bitter gourd and fenugreek grown in India contain compounds that can improve the body's ability to respond to insulin. The benefits of African leafy vegetables and other plants containing carotenoids such as lycopene and lutein are also well recognized today. Thus, many of these plant species have a current, private use value for some of the world's more vulnerable populations. They also have a potential value, which is both public and private, and is to a large extent unknown.

Increased public awareness about underutilized species was prompted by

the Convention on Biological Diversity (1992) and the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture (FAO 1996). The Consultative Group on International Agricultural Research (CGIAR 2004) recently expanded its agenda to include research about underutilized species.

Despite this recognition, there is no commonly recognized definition of underutilized plant species. In general, the term "minor" refers to the fact that these species contribute little commercial value to world production and trade compared to other agricultural commodities. The term "underutilized" means that they were once grown more extensively, or might be more widely grown in the future, but for economic, agronomic, or genetic reasons, they are now cultivated on a relatively limited geographical scale. These plant species are also described as "neglected" or "orphan" crops since they have received scant attention from either public or private research and development programs (Eyzaguirre *et al.* 1999). Their potential economic value remains "underexploited" (Padulosi and Hoeschle-Zeledon 2004) or "underdeveloped."

In this chapter, we employ the term "underutilized" in order to focus on several economic characteristics of these species. We define underutilized plant species as any agricultural or non-timber forest species, collected, managed, or cultivated, that has the following three characteristics.

First, the species is locally as compared to globally abundant. The plant is collected or produced in a single area or in numerous, but geographically restricted areas. Local abundance often implies a center of diversity for the crop and a significant contribution to agricultural biodiversity, which is a global public good. At least for cultivated species, local abundance also indicates that the crop is of high local use value to rural people as a food staple, source of diet quality, or source of occasional cash.

Second, local users have a practical knowledge of the plant species, but there is a lack of scientific knowledge about the species either among users or outside the circle of users. Not much is known about the physiology of the plant species, its agronomic and ecological attributes, or the properties of plant products (e.g., nutritional, medicinal or aromatic properties of the fruits, leaves, or flowers). For many of these species, the lack of scientific knowledge is linked to an apparent lack of interest on the part of public or private research institutions.

Third, the current use of an underutilized plant species is limited relative to its economic potential. Although the species has a distinctive past, present or potential use value, as well as the potential to generate significant local income, it does not now occupy a significant share of national or international trade. Somehow, local abundance is not associated with major commercial value even at the local level, so that the cash-generating potential of the species is unmet. This characteristic compounds the problem of limited knowledge since there are few perceived benefits from research investment.

As we define underutilized plant species, their uniqueness compared to other plant species derives from the fact that they possess these three

characteristics simultaneously. Minor millets (finger millet, kodo, barnyard, little millet) in India are one example. Relatively less scientific investment has been made in studying minor as compared to major millets, and they are locally abundant in specific geographical areas (Gruère *et al.* 2007). They were more widely grown in the drylands of India before it was feasible to grow pearl millet hybrids and improved wheat under irrigated conditions. In contrast, kiwi fruits no longer fit our definition of underutilized plant species because the global demand for this commodity has expanded.

What explains why these crops have a positive economic value that surpasses their current value? Despite a growing body of scientific literature on underutilized plant species, and an emerging set of case studies about their economic value or market potential (Giuliani 2007), no overarching conceptual framework has been formulated as a basis for systematic economic and policy analysis. In this chapter, we propose a conceptual framework that can be used to guide empirical analyses.

In the next section, we begin by explaining the sources of economic value associated with underutilized species. Then, we identify the causes of underutilization in terms of market failures and imperfections. In the fourth section, we propose an economic classification of underutilized plant species, with examples drawn from empirical case studies. In the fifth section of the chapter, we propose necessary conditions for the commercialization of underutilized plant species in ways that benefit the poor.

2 Sources of economic value in underutilized plant species

We distinguish the *potential* value of the species from the *observed* (or current or expressed) value of the species. By definition, the observed value of any underutilized plant species is inferior to its potential value. The observed and potential values of underutilized plant species can then be characterized according to several criteria. The criteria we consider are the comparison of private and public value, the relationship of the observed value with the knowledge gap, and spatial and temporal dimensions of value.

2.1 Private versus public value

The value of underutilized plant species can be divided into private and public components. The private value is revealed by the propensity of the species to generate income for primary producers or collectors, by its ability to reduce the risk of production shocks, and/or by its value to household members in subsistence consumption. Value in consumption includes the contribution of the plant to better nutrition, a more diverse diet, or medicinal needs of the household. The public value[1] of the species is expressed in terms of three main assets. The first asset is its contribution to agricultural biodiversity including the provision of ecosystem services. The second is the opportunity it provides for future generations to generate income or improve

nutrition. The third asset is its role in maintaining tradition and culture. The public value of the species can be generated by positive externalities of production or consumption, or merely by the existence (or non-disappearance) of the species.

Figure 5.1 differentiates underutilized plant species according to the relative magnitude of their private and public values, both observed and potential.[2] The coordinates of each point are the private and public values from the perspective of the agricultural sector. Each underutilized plant species is represented by an outward vector linking its *observed* value to its *potential* (current or expressed) value. The origin of the vector is the observed value, which is lower (closer to zero) than its potential value. Hence, the vector points outwards.[3] An underutilized plant species cannot be a point (a zero vector) since this would mean that its observed value equals its full potential value. Nor can it be an inward-directed vector, which would represent an "overvalued" species.

The boundaries of the regions are arbitrary but provide a straightforward characterization of different cases. The observed value of the crop can be located in Region 1, 2 or 3. No observed values are found in Region 4, since plant species that already have high private and public values are not strictly underutilized.[4] Similarly, the potential value of the crop can be located in Region 2, 3 or 4. We exclude species whose current status and potential are in Region 1. Since enhancing their value would not significantly improve their status, these may not be relevant underutilized species from an economics perspective.

Five types of directional vectors are shown in Figure 5.1, representing different categories of underutilized species. The horizontal vectors A and B
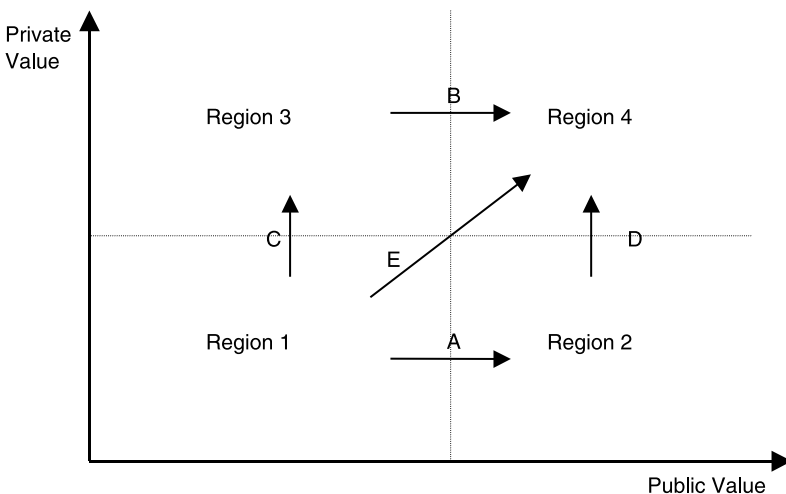
Figure 5.1 Characterization of underutilized plant species according to private and public values.

link Region 1 and 2, and Region 3 and 4, respectively. These vectors represent species that are neglected by policy-makers despite their known contribution as public goods. Vectors C and D both have a vertical direction. These vectors represent plant species for which the observed private value is inferior to their potential.[5] These cases call for public intervention to help markets function better (see the two sections on market characterization for details). Finally, Vector E links Region 1 to Region 4, which means that the associated species has both a private value and public value, neither of which is fully realized. Rice-bean (*Vigna umbellata*) grown in the mountainous areas of Vietnam is an example of a species for which the commercial value of the crop does not reflect its social value. Because of its high nitrogen content, the rice-bean provides an ecological service. The nitrogen content of the rice-bean roots is one of the highest among leguminous plants, so that the plant has potential value in the production of bio-fertilizer (Ha Dinh Tuan *et al.*, 2003).

Since we have treated observed and potential values as perfectly known and static, the examples provided do not account for the long-run interactions between the public and private value of a species that result from changes in value. In fact, increasing the private value of the species may decrease or increase the expression of its public value. For example, a plant species that is overexploited and becomes endangered will likely have a decreasing public value because its contribution to ecosystem services will have greatly diminished. At the same time, the existence value of the same plant species could increase rapidly as it becomes rare. This example suggests that there may be trade-offs between value components.

2.2   The observed value and the knowledge gap

In Figure 5.1, we represented underutilized species as vectors linking the observed value to the potential value. Similarly, the value of each underutilized species can be determined by two points, or by one point, one direction and the norm of the vector. Because it is difficult to assess potential values of species, we propose the use of an evaluation of the knowledge gap. The knowledge gap provides information that is directly related to the observed value and the difference between observed and potential value.

The observed value of underutilized crops can be assessed based on the market or subsistence value, and the presence of competing crop alternatives. Many underutilized crops are collected rather than cultivated, constituting a significant share of income for those who do not have many other alternatives. Other underutilized crops continue to be cultivated, competing with crops that are more extensively grown. A revealed preference for farmers to grow underutilized crops when other alternatives are available, especially when policies favor the other alternatives, is an indicator of the observed, private value of the species.

In addition, the products made from a plant species are only valued if one or more economic agents has at least a basic knowledge about them. Local

collectors and farmers typically have practical knowledge of the crop based on consuming it, though more distant potential consumers know little or nothing. The information gap results from a combination of the fact that the plant is locally abundant and there is a lack of scientific knowledge about it. In turn, this gap is one of the sources of the economic potential of underutilized species. Better transmission of knowledge would likely result in a more complete market valuation of products made from the plant.

2.3 Temporal characterization

The link between knowledge and value also means that the value of the species is a dynamic asset, and that it depends critically on the transmission of knowledge. Many underutilized plant species are locally valued, thanks to traditional knowledge. Others may become valuable because of new scientific evidence related to their intrinsic properties, new cultural trends or fashions. For example, fonio (*Digitaria* spp.) has been used for centuries in West Africa and its use has been transmitted by local tradition. Other species such as quinoa (*Chenopodium quinoa*) have become fashionable in urban areas of developing or developed countries because of a trend towards exotic products, natural products, or traditional products. Soap made with oil extracted from wild laurel (*Laurus nobilis*) has been produced for centuries in Syria, and has now reached the European market through the channel of shops selling natural products (Giuliani 2007).

There are three basic cases, as shown in Figure 5.2. In the first case (Panel I in Figure 5.2), the observed value of a plant species was equal to its potential value in the past, but its observed value has declined. For example, in the past, mallow (*Malva sylvestris*) was used extensively in Syrian rural households to prepare a traditional stew. The stew was lost in urban diets and subsequently in village diets, and is now considered a food of the poor (Giuliani 2007). Similarly, minor millets were widely grown and consumed in the Kolli Hills region of Tamil Nadu, but they have been progressively replaced by other crops and foods (Gruere *et al.* 2007).

A second subcategory of underutilized plant species has very limited past value (observed and potential) but recent knowledge has increased its economic potential (Panel II in Figure 5.2). Cases such as quinoa in the Andes, laurel soap from Northern Syria, and thyme (*Thymus spp.*) from Morocco are examples of underutilized plant species that have long been important only within a restricted area, but are now demanded locally and internationally by consumers interested in health and natural products (Astudillo 2007; Giuliani 2007).

A third subcategory of underutilized plant species has always been undervalued despite the knowledge of its potential (Panel III in Figure 5.2). The multipurpose baobab (Adansona *digitata*) tree is one of the most valuable resources in dry areas of Africa. Despite its wide distribution, the commercial potential for its numerous products has never been realized because of the
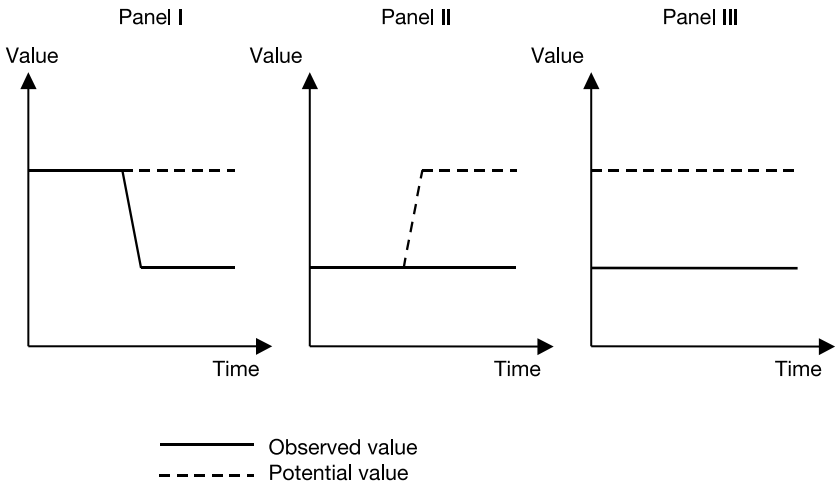
Figure 5.2 Temporal characterization of underutilized plant species.

lack of planting material, management techniques, processing technologies, and organized market chains (ICUC 2004). Similarly, the African eggplant in Ghana remains largely underutilized despite the fact that it is widely used by local consumers (Horna *et al.* 2007).

2.4 Spatial characterization

There are two possibilities with respect to the spatial characterization of the value of underutilized plant species. First, the observed value may be limited to a certain area where the species is produced and consumed. Second, the observed value may be dispersed among multiple areas, and either the plant species is underutilized in each of these areas, or it is only underutilized in certain areas and not others. For example, aloe (*Aloe vera*) is considered to be underutilized in Yemen, whereas there is a large exploitation of the plant in the United States and its products are traded globally. By contrast, minor millets are located in specific regions of Africa and South Asia and are only produced and consumed in those regions. Caper (*Capparis spinosa*) plants are distributed throughout the Mediterranean basin. In Italy, France and Spain, capers are extensively produced, consumed and traded, representing a commercially valuable commodity. In Morocco, Egypt, and Syria, their observed value in trade is limited relative to their potential (Giuliani 2007).

3 Market imperfections and market failures

In a perfectly competitive market, no species would be considered "underutilized" from a private perspective: its use would reflect its low value, and limitation of its collection or cultivation to specific areas would be justified. Plant

species are underutilized as a consequence of market imperfections. In addition, certain species are underutilized from the viewpoint of the social optimum because of market failures. In this section we review the major ways that market conditions of full information and full appropriation are not met for underutilized plant species.

3.1 Missing output market

When primary producers do not or cannot access a market for underutilized plant species, the output market is "missing." We consider two different possibilities depending on the degree of producer access to markets.

First, in the presence of high transaction costs, which constitute an exogenous constraint, producing households may not be able to afford access to markets. This situation is not specific to underutilized plant species. For this situation to characterize an underutilized plant species, the crop must be produced only by households or communities with high transaction costs.

Products derived from underutilized plant species may not only require costly transport, but also costly handling to become marketable. Handling costs may be high because of bulk or freshness constraints, or because making the product usable or suitable for sale is labor-intensive. Consequently, there is no incentive for small-scale, household farms or enterprises to produce or use it, even if the species is highly valued (e.g., nutritionally). For example, extremely short shelf-life, combined with lack of refrigeration, limits the marketability of purslane (*Portulaca oleracea*) in Syria, despite its high potential demand among local consumers who appreciate its taste and suitability in Arab cuisine (Giuliani 2007). The main constraint to the marketing of African eggplant (*Solanum aethiopicum*) lies in the lack of proper post-commercialization system (e.g., storage) (Horna *et al.* 2007).

Second, the marketability of underutilized plant species may be limited by endogenous constraints. The whole community is able to access a local market where the underutilized species could be sold, but there is a lack of economic incentive for each household to sell or buy the underutilized species. At the same time, community members are able to sell or buy other types of crops. For instance, this may occur if the species is used by all producing households, but they allocate only a small area to it because of its low productivity compared to other crops. Alternatively, due to taste preferences, they may decide to keep the underutilized species for their own use, focusing on other crops for marketing purposes. In either case, the species generates less economic rent relative to other opportunities, is only used for consumption by producing households in the community where it is grown, and is not grown elsewhere. For example, jujube (*Zizyphus jujuba*) is cultivated in home gardens along the coast of Syria, where the fruits are known and appreciated. The crop is produced for home consumption and is not traded in local communities because other crops are more competitive, and the fruits are not eaten elsewhere in the country (Giuliani 2007).

3.2 *Suboptimal market equilibrium*

In some situations, there is an established market for underutilized plant species, but the market equilibrium is suboptimal, due to various market imperfections. The market price does not reveal the full value of the product or consumer willingness-to-pay and the quantity produced does not represent the optimal scale of production or production capacity. A suboptimal equilibrium is the direct consequence of one or more market imperfections. At the sector level, there are three possible explanations: (1) weak market demand; (2) inefficient supply; or (3) a combination of the two.

Several factors may have contributed to this outcome. First, the apparent lack of demand may be due to incomplete or asymmetric information among market actors. Consumers may be willing to buy the product, but not in places where it is sold; consumers may have access to the product, but its quality at the point of purchase may be inadequate; or consumers may not know about the product and its quality characteristics. The demand may be restricted to local community users, rural areas, aged consumers (if products of the underutilized plant species have lost their appeal), low income consumers, or members of a community who use underutilized plant species products in a traditional fashion that is not known to the outside world. In some cases, introduced species and products are cheaper or more convenient to buy although the native underutilized plant species have greater nutritional value. For example, in the Altiplano region of Bolivia, rice and maize are consumed locally instead of quinoa because they are sold at lower prices on local markets (Astudillo 2007). In that region, quinoa is mainly produced for the export market as a cash crop.

Second, even if there is a strong demand for products derived from an underutilized plant species, there may be inefficiencies that reduce the supply or quality that is available on the market. In developing economies, the lack of credit and physical infrastructure impedes the ability of actors in the supply chain to improve marketing approaches. Furthermore, the marketing channel may be inefficient or incomplete, due to transaction costs. In particular, an unorganized marketing channel, whether it is simple (collection and distribution) or more complex (wholesale, processing and retailing), can in itself create inefficiencies that are sufficient to limit the market for underutilized plant species. For example, in the case of caper buds in Syria, there is a high mark-up at the end of the supply chain, a lack of transparency, and mistrust among actors, negatively affecting the income share earned by poor collectors in rural areas (Giuliani 2007). Finally, the species may not have been improved through basic selection, resulting in germplasm with both lower productivity potential and lower value, which are critical for commercially-oriented producers. Such inefficiencies reduce the market price that suppliers are able to obtain.

3.3 Market failures

Some underutilized crops are not only underutilized from a market perspective but their limited use also fails to reflect their public value (see Section 2.1). Market development will help increase the incentive for producers to collect or cultivate these crops but public intervention may be needed to reach the socially optimum level. A classic result in the theory of public economics is that profit-maximizing agents will not voluntarily produce or support the use of a public good at the socially optimum level (Laffont 1988).

In cases of missing markets due to endogenous constraints, the value of the crop for primary producers may not reflect its social value. As a result the crop is not widely cultivated and might be used in decreasing areas despite its larger social gains relative to alternative crops.

Lack of product knowledge and economic information about the product can also contribute to market failures, because primary producers and public institutions are not able to assess the social benefits of using the species. For example, local populations may be ignorant of the nutritional benefit of consuming or using products from underutilized species, resulting in a lower demand than would be the case under full information. Another example is when the government supports the production of other primary crops without accounting for differences in nutritional or environmental effects because it lacks scientific information.

The constraints to social optimum can be characterized by the presence and nature of real externalities[6] of production or consumption and by its specific public good nature. All underutilized crops contribute to crop biodiversity, and thus implicitly express a public value, but certain crops may also be able to provide ecosystem services. In addition many of these crops contribute to a local public good, such as insurance against food insecurity and helping to improve diet diversity.

4 Classification of underutilized plant species

Based on the above discussion, we propose that underutilized plant species be classified according to four economic criteria:

1   *Observed and potential value*: relative private and public values; magnitude of the observed value; knowledge gap and distribution; temporal characterization; spatial characterization.
2   *Output market*: missing or not, due to exogenous or endogenous constraints.
3   *Market imperfections*: constraints on the demand and supply side.
4   *Market failures*: specific sources of production or consumption externality (environmental, health, etc.), type of public good provision (local, regional, global)

Examples presented in the text are classified in Table 5.1. This classification

Table 5.1 Classification of selected underutilized plant species according to economic criteria

| | Characterization of the underutilized plant species | | | | | Economic constraints | | | | |
| | Economic value | | Knowledge gap[b] | Vector type[c] | Temporal evolution[d] | Output market | | Market imperfections | | Market failures |
Example	Region	Observed value[a]				Presence	Constraints	Demand	Supply	
Quinoa	Andean region	Cultivated (rice, maize)	Small in & large out	E	I and II	Yes/No	Endogenous Exogenous	Information	Organization, low productivity	Diet quality
	United States	Cultivated (niche market)	Large out	B	II	Yes	None	Information		Diet quality
Capers	Syria	Collected	Small in & out	C	II	No	Exogenous	Information	Organization, processing, no cultivation	Health
	Morocco	Collected, cultivated	Small in & out	C	II	Yes	Exogenous	Information	Oversupply	Health
	Italy	Cultivated (niche market)	Large in & small out	B	II	Yes	None	None	Labor availability	Health
Laurel	Syria	Collected, managed	Large in & small out	C	II	Yes	Endogenous	Information intermediaries	Quality standards	Health
Rice-bean	Vietnam	Cultivated	Small in & out	A, D	III	No	Exogenous	Information	Low productivity	Ecological services
Mallow	Syria	Collected cultivated	Small in & large out		I	Yes/No	Endogenous	Insufficient	Handling, organization	Diet quality

		[a]	[b]	[c]						[d]
Baobab	African dry areas	Collected, managed	Small in & large out	E	II	Yes	Endogenous	Information	Quality standards, processing, Organization	Health
Purslane	Syria	Cultivated, Collected	Small in & out	C	III	Yes	Endogenous	Information	Handling	Diet quality
Jujube	Syria	Collected, managed	Small in & out	C	III	No	Exogenous	Insufficient	Quality standards Organization	Diet quality

Notes: [a] Collected or cultivated and main crop competition if any. [b] Relative amplitude of knowledge gap among local users (in) and out of user circle consumers (out). [c] See Figure 5.1. [d] See Figure 5.2. Source: Based on case studies conducted or reviewed by Giuliani (2007), Astudillo (2007), and Gruere *et al.* (2007).

serves to identify the type of policy intervention that would enhance the value of underutilized plant species for the benefit of the poor. Many policy alternatives exist, but they can be grouped into two approaches, used either separately or simultaneously. The first approach consists of policy solutions that aim to enhance the public good value of the plant through in situ or ex situ conservation strategies. The second approach involves the policies designed to overcome market barriers and market imperfections through lowering transactions costs. Depending on the characterization of the economic value of the plant, one or the other approach may be preferred.

Two types of underutilized plant species will likely require primary intervention in addition to market development: (1) underutilized plant species with limited potential private value but large public value; and (2), underutilized plant species with missing output markets. Set 1 may be better addressed with direct public intervention such as subsidies to support primary producers in order to avoid under-provision of the product. If exogenous market constraints are not particular to the species, Set 2 will call for more fundamental investments in infrastructure before any marketing intervention is feasible. With these two exceptions in mind, we will now suggest necessary conditions for the successful commercialization of underutilized plant species.

5 Necessary conditions for the successful commercialization of underutilized plant species

The aim of market development is to increase the value of the crop to primary producers and other actors in the market chain. With market development, we aim to mitigate the market imperfections that are manifested at a new equilibrium with higher levels of price and quantity. We define "successful" commercialization according to two criteria. First, benefits should be distributed so that actors at the beginning of the chain (farmers, collectors) earn enough to continue producing or collecting the plant. Second, prices and margins should be sustained as demand grows.

We propose three necessary conditions for successful commercialization of underutilized species: (1) expansion of demand; (2) improved efficiency of production and marketing channels; and (3) supply control. Figure 5.3 represents the three conditions in the context of partial equilibrium. The present value of the crop can be defined by a market equilibrium with low quantity and price. Panel A in Figure 5.3 shows the initial market equilibrium E0 (p0, q0) at the intersection of the demand (D0) and supply (S0) curves. Panel B shows the result of two mechanisms (corresponding to necessary conditions 1 and 2). The first mechanism is demand expansion, which relates to increasing the market opportunity of the crops. The second is increased efficiency of production and marketing systems. These two steps lead to an outward rotation of the demand and supply curves, from D0 to D1 and S0 to S1. The market reaches a new equilibrium E1 with a higher price and quantity (p1, q1).
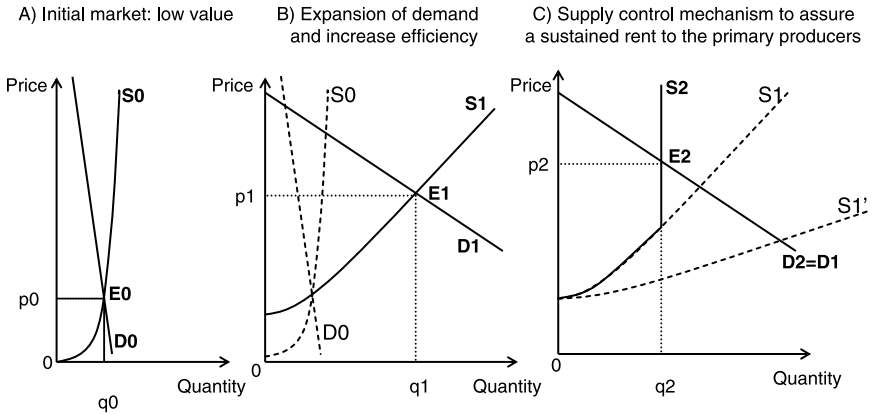
Figure 5.3 Market development for underutilized species: three necessary conditions.

Increasing the value of the crop provides an incentive for the entry of large-scale investments, which may drive a process of commoditization. Efficiency is greater with commoditization and prices are lower, but there are also lower margins and fewer incentives for the poor to produce. To generate a sustainable rent for the poor, some type of supply control is required. Panel C in Figure 5.3 shows the new supply curve S1 with a kink at the level of the supply control (q2). The price rises from p1 to p2.[7] Supply control generates a rent to producers that largely exceeds that obtained through commoditization. In a commoditization process, the equilibrium is represented by the intersection of D2 with supply curve S1' (Panel C). Next, necessary conditions are explained in greater detail.

5.1 Expansion of demand

An underutilized plant species cannot be successfully commercialized without a well-articulated, strong demand for its products. Our definition of underutilized plant species implies the existence of potential demand (implicit in potential value). To expand demand, it is necessary to assess demand opportunities by identifying observed and potential buyers, the potential products that would be demanded, and the scope of the demand.

In general, there is some evidence that there are market opportunities for underutilized plant species that could be exploited as consumer incomes rise. First, there is an increasing global demand for an array of natural (and exotic) products, different qualities of products or product attributes, and a range of related niche markets (some based on eco-labeling schemes) in both developed and developing countries. Related to that, many countries are experiencing a consumption trend towards traditional food products and regional or national cultural assets. At the same time, there is an increased

interest in products that support healthy living, such as natural medicinal or cosmetic products.

Second, grassroots organizations, local non-governmental organizations and several international organizations, supported by such fora such as the Convention on Biological Diversity, have stimulated public awareness of the value of plant diversity for the environment and in the livelihoods and knowledge systems of local (including indigenous) communities.

There are several types of actions that can help these species reach their market potential. One is to provide better information concerning the private and public benefits of the products. For example, product fairs and rural theaters have been used to promote local products and traditional or new recipes among consumers in rural areas. In Syria, poets worked together with extension agents and local project staff to write songs which were used during local festivals to draw attention to products (Sthapit *et al.* 2003). In Southern India, various products using minor millet grains have been promoted and sold by the MS Swaminathan Research Foundation in temple festivals (Gruère *et al.* 2007). Nepalese writers created rural roadside dramas (*Gramin Sadak Natak*) based on village accounts, highlighting the value of in situ conservation with local examples.

Another means of supporting consumer demand is to develop differentiated uses for the product. Product differentiation may open other market opportunities through labeling (e.g., eco-labels or "fair trade" schemes), certification and branding. Grains from underutilized crops, like minor millets and quinoa, require lengthy preparations that cannot compete with grains that are easy to cook, such as rice or maize. The development of processing facilities can remove these obstacles and increase local consumption (Astudillo 2007; Gruère *et al.* 2007).

Public programs can be used to support a stable local or national demand as a complement to other approaches, at least during the initial phase of market development. For example, the M.S. Swaminathan Research Foundation, which leads the market development effort for minor millets in India, has advocated the use of minor millets in public child feeding programs, citing their nutritional qualities compared to other grains. Including underutilized grains in hospital meals or military rations could also support demand.

5.2 Increase efficiency of supply

A successful marketing chain must be able to bring a product of satisfactory quality onto the market at a reasonable price. There may be an endogenous constraint, such as the lack of organizational structure, leading to weak information, risk and vulnerability for primary producers. In addition, production may be restricted exogenously by fixed costs, absence of credit markets, or inadequate infrastructure.

The transmission of information may require basic communication tools.

The organization of producer groups or cooperatives, as well as vertical integration, should be considered in order to allow for a more effective or equitable distribution of margins. Producer groups or cooperatives enable primary actors to share capital investments, gain bargaining power relative to middlemen, and enforce contracts. By organizing themselves vertically, farmers may benefit not only by cooperating but also by absorbing basic processing services in order to sell higher-valued products on the market.

5.3 Supply control mechanism

Strong consumer demand and a relatively efficient marketing chain do not guarantee that we achieve our objective of transmitting a share of the benefits to the poor over time. To avoid pressures toward commoditization and declining prices, supply control (indirect restriction of the quantity supplied) is necessary to preserve minimum rents for the producers. An example of caper production in Northern Morocco illustrates this point. Encouraged by a growing demand from Europe, many farmers in the same area started to produce capers. The price decreased dramatically, leading to the abandonment of caper fields (Giuliani 2007).

Indirect supply control can be achieved by: (1) specifying product characteristics or quality attributes; (2) specifying production process or method used; or (3) linking the product to its area of production (region of origin labeling). Practically, these three mechanisms are enforced through natural supply control if planting is restricted to certain geographical areas, regulations forbidding the cultivation or harvests above a particular scale, or private quality[8] brands and labels (region of origin, traditional process, fair trade, or eco-label). Each of these different strategies depends on the support of well-developed institutions, including cooperative arrangements, joint ventures (NGOs, public or private), legal requirements for distinctness, legal frameworks to ensure access to resources and property rights, grading schemes and quality standards. The institutional organization that achieves supply control may be able to legally guarantee a share of the rent for primary producers.

Supply control mechanisms and quality certification present certain caveats. Although private and public institutional arrangements of this type have been adopted in most if not all high-income countries, they are still rare in low-income countries because of their cost and the difficulty of implementing them where quality standards are largely absent. Public certification systems, such as geographical indications, are not recognized by international agreements and may be difficult to protect in international trade (Boisvert 2006). Quality certification may also be perceived as a pro-export strategy that does not correspond to the reality of subsistence farming and local markets.

6 Conclusion

Our analysis also helps to link underutilized plant species to related economic constraints and to possible policy solutions, as presented in a schematic way in Figure 5.4. Figure 5.4 can be read from left to right, following the outline of the chapter. Read from right to left, interpreting the arrows as "leads to," figure 5.4 indicates which policies will affect which constraints. In this way, the schema can assist in identifying the principal limitations to successful commercialization of underutilized plant species.

Figure 5.4 clearly shows that marketing solutions and policies addressing market imperfections are central issues that likely affect all economic aspects of underutilized plant species. Enhancing the value of this species can have a direct positive effect on the use, income generation for the poor, public conservation efforts and knowledge.

Underutilized plant species pose a challenge for agricultural development, especially in an era of increasingly privatized agricultural research and less-focused agricultural research agendas. These crops are locally abundant or produced in dispersed areas on small scales, scientific information about them is scant, and their use is currently limited relative to their economic potential. Some are potentially high-value crops. To our knowledge, the agricultural economics literature has contributed little to the understanding of how to commercialize these crops of plant products successfully.

In this chapter, we build an economic conceptual framework to define underutilized plant species and analyze the factors that cause them to be underutilized, identifying policy options for market development. Our classification of species is based on four factors: (1) the relationship of the observed to the potential economic value of the species; (2) the presence or absence of an output market; (3) the presence of market imperfections; and (4) the presence of particular market failures. With this economic
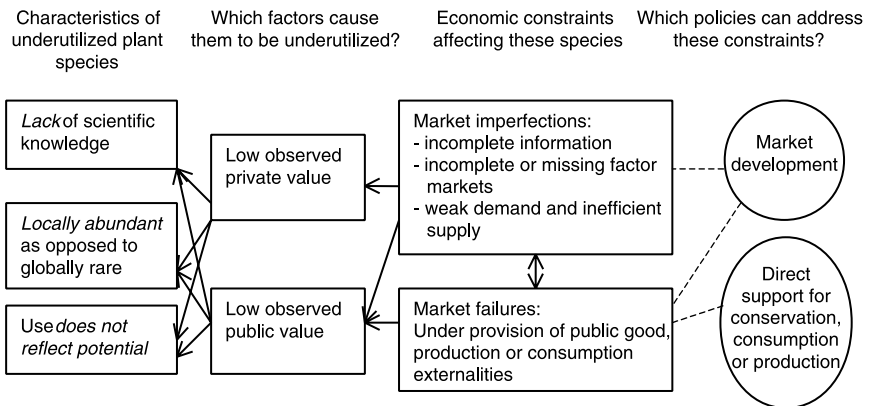
Figure 5.4 Underutilized plant species: characterization to policy solutions.

characterization, we exclude species for which a developing market is in and of itself irrelevant. We then identify three necessary conditions for the successful commercialization of underutilized plant species for the poor: (1) demand expansion; (2) increased efficiency of supply and marketing channel; and (3) supply control mechanism or capacity to differentiate the product from close substitutes.

While these general conditions are necessary, they are not sufficient. Based on a comparison of minor millets and other crops in the Kolli Hills region of Tamil Nadu, India, Gruère *et al.* (2007) show that success required collective action among local users. In the case of quinoa in the Southern Bolivian Altiplano, Astudillo (2007) shows that rapid commercialization based on a strong international demand can lead to a decline of local consumption to the detriment of diet quality in the primary producing area. More studies are needed to expand upon the framework presented here. This framework can help generate testable hypotheses concerning the commercialization of underutilized plant species, appropriate policy interventions, and social welfare implications.

Notes

1 We define public value as the aggregate value of the species and all products derived from it that it is not private. Following this definition, the social value of the species will be equal to the sum of its private and public value.
2 Smale and Bellon (1999) proposed a similar classification at the variety level to relate genetic diversity and conservation strategies.
3 A more restrictive definition of underutilized plant species would be based on a "Pareto" valuation, which would require vectors to be a positive linear combination of unit vector in the direction of A and C. In other words, an underutilized plant species could not lose any of its public or private value by reaching its potential.
4 In fact, some of the species in Region 4 may be underutilized, but their high value makes them less useful cases to study from a public policy perspective unless doing so sheds light on the causes of success. It may be that policies have already had an effective, positive impact on the production and marketing of these crops.
5 If we only include species that have a significant potential public value through their contribution to agricultural biodiversity, vector C is not strictly an underutilized plant species.
6 A real (or nonpecuniary) production (consumption) externality is defined as an indirect effect of production (consumption) created by an economic agent and affecting another without being transmitted through prices (Laffont 1988).
7 This case may not be typical. Our goal is to preserve opportunities for the primary producers, and not necessarily to increase the rent they can obtain from relaxing demand and supply constraints.
8 As compared to standards imposed through public regulations, private quality brands are imposed by chain actors. This often implies greater quality differentials or finer product distinctions.

References

Astudillo, D. (2007) "An evaluation of the role of quinoa in the livelihoods of the households in the Southern Bolivian Altiplano: A case study in the municipalities of Salinas and Colchak," Rome: Bioversity International & Fundación PROINPA.

Boisvert, V. (2006) "From the conservation of genetic diversity to the promotion of quality foodstuff: Can the French model of 'Appelation d'Origine Contrôlée' be exported?" CAPRI Working paper #49, Washington, DC: International Food Policy Research Institute.

Consultative Group on International Agricultural Research (CGIAR) (2004) *Innovation in Agricultural Research*. Annual Report, CGIAR Secretariat, Washington, DC: United Nations.

De Groot, P. and Haq, N. (1995) "Promotion of traditional and underutilized crops". Report of a workshop held in Valetta, Malta, June 1992. ICUC/CSC Commonwealth Science Council Series No. CSC(95) AGE 23. Technical Paper 311. London; International Centre for Underutilized Crops and Commonwealth Science Council.

Eyzaguirre, P., Padulosi, S. and Hodgkin, T. (1999) "IPGRI's strategy for neglected and underutilized species and the human dimension of agrobiodiversity," in S. Padulosi (ed.) *Priority Setting for Underutilized and Neglected Plant Species of the Mediterranean Region*. Report of the IPGRI Conference, ICARDA, Aleppo, Syria, 9–11 February 1998, Rome: International Plant Genetic Resources Institute.

Food and Agricultural Organization of the United Nations (FAO) (1996) *Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture*. Section 12, Rome: FAO.

Giuliani, A. (2007) *Developing Markets for Agrobiodiversity: Securing Livelihoods in Dryland Areas*. London: Earthscan Publications, and Rome: Bioversity International.

Gruère, G., Nagarajan, L. and King, E.D.O. (2007) "Collective action and underutilized plant species: The case of minor millets in Kolli Hills, Tamil Nadu, India." CAPRi Working paper #69, Washington, DC: International Food Policy Research Institute.

Ha Dinh Tuan, Nguyen Ngoc Hue, Sthapit, B.R. and Jarvis, D.I. (eds) (2003) "On-farm management of agricultural biodiversity in Vietnam," in *Proceedings of a Symposium in Hanoi, Vietnam, 6–12 December 2001*. Rome: International Plant Genetic Resources Institute.

Hayes, D., Lence, S.H. and Stoppa, A. (2004) "Farmer owned brands?" *Agribusiness*, 20: 269–285.

Horna, D., Timpo, S. and Gruère, G. (2007) "Marketing underutilized crops: The case of African Garden Egg (*Solanum aethiopicum*) in Ghana," Report of the Global Facilitation Unit for Underutilized Species, Rome: Bioversity International.

International Centre for Underutilised Crops (ICUC) (2004) "Baobab—Africa's multipurpose upside-downtree to improve rural livelihoods," Briefing paper for non-governmental and community-based organizations (NGOs and CBOs).

International Plant Genetic Resources Institute (IPGRI) (2002) *Neglected and Underutilized Plant Species: Strategic Action Plan of the International Plant Genetic Resources Institute*. Rome: IPGRI.

Johns T. (2004) "Underutilized species and new challenges in global health," *LEISA Magazine*, 20(1): 5–6.

Johns, T. and Eyzaguirre, P.B. (2002) "Nutrition and the environment," in *Nutrition: A Foundation for Development*, Geneva: United Nations Standing Committee on Nutrition.

Johns T. and Sthapit, B.R. (2004) "Biocultural diversity in the sustainability of developing country food systems," *Food Nutrition Bulletin* 25: 143–155.

Laffont, J.J. (1988) *Fundamentals of Public Economics*. Cambridge, MA: The MIT Press.

Naylor, R.L., Falcon, W.P., Goodman, R.M., Jahn, M.M., Sengooba, T., Tefera, H. and Nelson, R.J. (2004) "Biotechnology in the developing world: a case for increased investments in orphan crops," *Food Policy* 29: 15–44.

Padulosi, S., Hodgkin, T., Williams J.T. and Haq, N. (2002) "Under-utilized crops: trends, challenges and opportunities in the 21st century," in J.M.M. Engels *et al.* (eds) *Managing Plant Genetic Resources*. Wallingford: CABI-IPGRI, pp. 323–338.

Padulosi, S. and Hoeschle-Zeledon, I. (2004) "Underutilized plant species: what are they?" *LEISA Magazine* 20(1): 5–6.

Prescott-Allen, R. and Prescott-Allen, C. (1990) "How many plants feed the world?" *Conservation Biology*, 4(4): 365–374.

Smale, M. and Bellon, M. (1999) A conceptual framework for valuing on-farm genetic resources. In: D. Wood and G.M. Lenné (Eds.), *Agrobiodiversity: Characterization, Utilization and Management*, pp. 387–408. CABI Publishing, Wallingford, UK.

Sthapit B., Subedi, A. Rijal, D., Rana, R. and Jarvis, D. (2003) "Strengthening community-based, on-farm conservation of agricultural biodiversity: Experiences from Nepal," in *Conservation and sustainable use of agricultural biodiversity*, a sourcebook produced by CIP-UPWARD, in partnership with GTZ GmbH, IDRC of Canada, IPGRI and SEARICE.

6 Non-market institutions for agrobiodiversity conservation

Ruth Meinzen-Dick and Pablo Eyzaguirre

1 Introduction

Despite the recent policy interest in market mechanisms to provide incentives for biodiversity conservation, in many places throughout the world non-market mechanisms predominate. A major reason for this fact is that markets do not capture many of the values people place on diversity. Market failures on both the input and output side compound the problem. In this chapter, we review the sources of market failure (see also Chapters by Gruère *et al.*, in this volume). We then consider the range of non-market institutions that people use, both directly and indirectly, to ensure access to a desired and trusted range of genetic resources for agriculture. Examples of institutions that maintain the access of rural people to plant, animal, and aquatic genetic resources are discussed. The robustness and effectiveness of these institutional options are then assessed.

The array of use and non-use values associated with genetic resources (including option and bequest values) makes it difficult to capture and quantify their full value; even within uses, there are many products and use values that are difficult to translate into prices. For example, the maize landraces grown by farmers in Mexico have many different uses—for eating and drinking in a range of preparations, for animal fodder, and for crafts, to name only a few (Bellon *et al.* 2007). Specific uses are often strongly associated with family or cultural identity. Indeed, it would be antithetical to put a price on some values placed on certain types of genetic diversity, particularly those associated with cultural or religious uses. For example, some crop varieties have ritual and spiritual value in ceremonies or in maintaining family traditions that users themselves are unwilling to sell or price in a market.

Economists have repeatedly demonstrated that the value of crop genetic resources when used in international plant breeding is high (examples include Alston *et al.* 2000; Evenson and Gollin 2003). A more recent body of work explores the value of diversity in crop and livestock genetic resources (see literature reviewed by Smale and Drucker 2007). Pimentel *et al.* (1997) estimate the global value of these resources in plant breeding at US$ 115 billion per annum, which is at best approximate. Furthermore, genetic resources

have a range of uses and values aside from those associated with plant breeding programs. Even if it were possible to quantify and put a price on all the values that people hold with regard to the diversity of genetic resources, two important sources of market failure would still explain the need for non-market institutions to support the access of farmers to these resources. These relate to both the supply of farm inputs and outputs.

With respect to the crop genetic resources embodied in seed, the majority of small farmers in developing countries use seeds from informal sources rather than certified, commercial seeds. The continued importance of non-commercial sources results from both the limited reach and efficacy of markets for commercial seed and the preference of smallholder farmers for seed that is well adapted to local growing conditions and multiple uses. Procuring seed is inherently risky. Typically, it is difficult to know from visual inspection whether the seed will be viable and the germplasm will perform as expected for that variety. Seed quality or performance must be attested or certified by persons or institutions that confer trust. Therefore, farmers need to either know the plant that produced the seed (from growing it) or trust the person who is the source of the seed.

Farmers often lack trust in the quality of seed offered through markets, particularly when the seed quality is not well regulated, as is the case in many in developing countries (see, for example, Cromwell *et al.* 1993; Almekinders *et al.* 1994; Tripp 1997; Sperling and Longley 2002). When marketed seed is guaranteed, this is usually done through standardization and offering a more limited range of varieties. Plasticity and adaptive potential in crop varieties are often sacrificed for uniformity and high average yields. By comparison, the landraces of smallholder farmers are typically more genetically heterogeneous, and they often grow more than one simultaneously. Smallholder farmers often want this diversity in order to deal with the range of ecological niches on their farms, or to reduce their risks, or to provide for a variety of products, cultural values, etc. (Bellon *et al.* 2007).

On the output side, markets may not provide suitable outlets for the variety of produce that comes from farms with high genetic diversity. Many fruit and vegetable species do not have regular markets. Even for crops that are marketed, varieties that have high variability in color, size, or other qualities may be rejected. When purchasing agricultural output, traders usually seek standardized products, and this tendency is increasing with the rise of supermarkets.

In the remainder of this chapter we examine the sources of market failure for genetic resources, and then turn to examples of non-market institutions that people around the world use to protect agrobiodiversity through the exchange of genetic resources. We conclude by considering the prospects for these multiple institutions (formal and informal) as a continued source of agrobiodiversity.

2 Non-market institutions for access to diverse genetic resources

If we wish to understand how genetic resource flows are governed, we need to look beyond market institutions, to recognize the full range of other institutions that are involved. These range from formal public sector providers to social institutions such as kinship or friendship networks, which farmers use to access and transmit trusted seed. Eyzaguirre and Dennis (2007) classify these into institutions that provide direct access to genetic resources, and those that provide indirect pathways for access.

Institutions for direct access to genetic resources often have an explicit focus on seed. This may be through some form of collective action around seed conservation or sharing. One of the clearest examples is seen in community seed banks, often organized for farmers to pool seed and storage facilities to deal with uncertainty about whether their preferred varieties will be available and affordable. For example, seed banks established by NGOs in Ethiopia allow farmers to borrow seed if they return a greater amount at the end of the season, which maintains a stock of locally adapted varieties (Worede *et al.* 2000). In Kenya, dairy goat associations provide their members with access to a buck for cross-breeding with their own goats, and a breeding register to keep track of the improvement in quality of the animals. A federated structure allows the local associations to rotate bucks among the different groups, to prevent in-breeding (Kariuki and Place 2005).

The institutions that provide indirect pathways for access to genetic resources are even more diverse. Their overt purpose is often seemingly unrelated to genetic resources, but they are still important mechanisms for the transmission of agrobiodiversity. Kinship, neighborhood, and friendship relations are often the basis of trust for effective seed exchange. Indeed, exchanging seed, plants, or animals may even be seen as an important symbol to cement a social relationship.

In Uzbekistan, there are strong neighborhood institutions and kinship ties, with clear norms that govern the exchange of seed to relatives and neighbors who request it. This cultural motive contributes to relatives, followed by neighbors, being most utilized source for seeds. Another customary institution at the village or ward level, the *mahalla,* [1] facilitates awareness about local varieties and has a judicial role in dispute resolution that effectively minimizes the risk that someone will knowingly or maliciously provide diseased, underperforming, or improper genetic material or agricultural information. The symbolic as well as material importance of seed exchanges is illustrated in the importance of weddings as a forum for seed exchange, when both the bride and groom's family provide seed to the new couple (Dennis *et al.* 2007).

In Oaxaca, Mexico, maize has many different cultural and economic functions and farmers have a repertoire of varieties. Farmers prefer varieties that they have seen growing in their environment because of the strong genotype-by-environment interactions. Thus less than 20 per cent of maize seed is

directly purchased; most is saved from farmers' harvests or acquired from relatives, friends and neighbors. Notions of the "good farmer" reward farmers who save and share good seed, while the shame of being a "bad farmer" who loses his or her seed is a check against free riders who do not contribute to the gene pool (Badstue *et al.* 2007).

Among the Kurichya tribe in Kerala, India, diversity of rice varieties is maintained by seed exchanges between hamlets that follow kinship lines. Marriage ties between groups allow farmers to find out about the seed, see it growing, and check its reputation. Both the *pittan,* or headman of an extended family, and his wife are involved in the selection, but the exchange itself is negotiated and takes place as a highly formalized exchange between *pittans* in the presence of the hamlet leader, who monitors all seed flows and endorses the exchange. Accessing seed without the knowledge of the *pittan* is sanctioned by loss of reputation and a belief that such seed is cursed with bad omen and will not yield well (Padmanabhan 2006).

The Raika pastoralists in Rajasthan, India have a range of institutions that provide individuals and households with access to both traditional stock (which often fares better during drought) and improved varieties (which may be more productive during good years). Social exchange of animals among relatives or friends provides flow of genetic material along social network lines. Village ownership of male breeding stock for cattle and buffalo provides all members with access to good animals. Loaning of the best breeding stock of sheep promotes genetic exchange between villages to prevent inbreeding. Even private livestock are governed by strong social and religious rules that designate breeding stock as sacred, and thereby restrict their sale or slaughter. These mechanisms ensure that rich and poor alike have access to a range of good breeding stock (Anderson and Centonze 2007).

In Cambodia, religious institutions, Buddhist pagodas, play an important role in protecting and providing access to aquatic biodiversity. Most pagodas have a temple pond that is protected from fishing. These serve as fish nurseries. When the rains come, fish migrate from the ponds to the flooded rice fields. Those that are not caught during the rice season often collect in private ponds in fields or homesteads. Several government and non-government organizations are working with the pagodas to expand the sacred ponds as collective refuges of fish genetic resources and aquatic biodiversity by planting more cover vegetation and encouraging each household with a private pond to release two healthy adult fish into the pagoda pond during the dry season. Linking the resources in private ponds with those held collectively and in trust by the pagoda is proving to be an effective way to ensure healthy breeding stock for farmers who live around the pagoda.

Using multiple types of institutions to gain access to genetic resources gives households the possibility to use greater diversity of plant and animal species, breeds and varieties. In addition to the biological diversity that is used to minimize risk and exploit diverse niches, informal agrobiodiversity networks provide information and build the trust (knowledge and social

capital) that are essential assets for secure rural livelihoods. Unlike most anonymous market transactions, when one acquires genetic material through an informal or "indirect" network, it is usually accompanied by information about the traits of the parent germplasm or stock, and the ways the product can be used. Knowing the person who is providing the seed also builds trust in the quality of the seed. This trust may develop through direct experience of observing the supplier's farm or eating in their home, through the reputation of the supplier as a good farmer or honest person, and through having multi-stranded linkages between the supplier and recipient: one would not want to risk souring good relations between relatives or neighbors by providing bad quality seed.

Yet another reason for the continuing role of social and cultural institutions in the transmission of agrobiodiversity relates back to range of values that are often associated with diverse species and varieties. Heritage and cultural identity values are enhanced when the plant or animal is acquired from someone who is a relative or elder in the community. Badstue *et al.* (2007) refer to the "affection value" of maize seed in Mexico, which is passed on from one generation to another. Sharing of genetic material can be a symbolic means of creating or strengthening bonds, as at an Uzbek wedding. Religious values of the plants or animals may be enhanced when the transfer is accompanied by some form of ceremony or blessing. Rice terraces and rice paddies in Philippines and Indonesia are all imbued with a ritual character that extends to the particular types of seeds that are planted and the harvests that are gathered (Pfeiffer *et al.* 2006).

Conversely, social prestige and religious values can be used to enhance incentives for maintaining and sharing genetic resources. Farmers who provide seed to others gain prestige as "good farmers" in Oaxaca or "generous people" in Kerala. Raika pastoralists with the best breeding stock have high social prestige, as well as religious merit from associating with the animals.

Public institutions provide other ways of developing transparency and trust. National agricultural research and extension systems are sources of new seeds or breeding stock that are backed by scientific expertise. In Uzbekistan, the Vavilov Institute (named after the famed geneticist who identified centers of origin of cultivated plants) is seen as a reliable source of diverse genetic materials (Dennis *et al.* 2007). But public research and extension services are not always trusted as a source of genetic materials, particularly in many developing countries. This may be because the system is perceived to deliver too narrow a range of varieties, which are not suited to the many growing conditions or do not have the desired output traits (Adato and Meinzen-Dick 2007). It may also be because scientific expertise is not trusted, particularly when there is a large gap between scientific knowledge and farmers' experiential knowledge.

Seed fairs organized by public institutions, communities, or non-governmental organizations can also increase transparency in the seed quality, serving as a bridge between scientific and experiential knowledge of

the varieties. County fairs in the United States, for example, encourage farmers to bring their best produce to be judged. Cooking contests at the fair provide additional information on taste qualities. Moreover, the involvement of the whole family (including special competitions for children) would allow participants to judge the family, to see who would be "good farmers," and who would be likely to provide reliable seed. Although the role of such fairs in providing transparency on seed quality has been largely replaced by certified seed available through the market in the USA, winning prizes at fairs continues to play an important role in certifying the quality of animals for breeding.

Biodiversity seed fairs represent a major body of institutional innovations that have been spread through research and development projects on crop genetic diversity and neglected crops in developing countries. They have become a feature of seed exchange among traditional farming communities in areas of unique or rich biodiversity from South and Southeast Asia, Africa and Latin America. We have yet to fully assess their impact on the amount and value of the agricultural biodiversity that they help to maintain and extend. However, as institutions, their frequency and extent represent a significant change in agrobiodiversity management by farmers (Nathaniels and Mwijage 2000; FAO 2006; Rohrbach and Mazvimavi 2006).

Organizations such as Seed Savers' Exchange provide new mechanisms for people to identify sources of diverse plant varieties that go beyond person-to-person exchanges. These organizations publish lists of suppliers and catalogs that list the traits of particular seeds that are offered, but because they are membership-based, non-profit organizations with a code of conduct for suppliers, they still create a sense of community among people who are sharing "heritage" seeds.

3 Non-market institutions for selling diverse agricultural produce

If farmers are producing primarily for direct home (or localized) consumption, the diversity of output is often an advantage. Planting different varieties can increase the period when the produce is available, give variety of taste, or provide for many different uses. But when output is marketed, homogeneous products are generally preferred to reduce the costs of sorting, grading, and bulk processing. Farmers who grow a diverse range of varieties often find it difficult to meet the standardization requirements of many markets, especially if they are smallholders with a limited output of any particular variety. Institutions that provide markets for diverse planting material do not help in marketing output for consumption. Planting material and products are generally linked only when there is strong vertical integration, as is the case for some high-valued export crops. Supermarkets and agro-processors often require particular standards for produce that they will buy; both are increasingly entering into contract farming arrangements in which they specify or

even supply the seed varieties to be grown, which may limit agrobiodiversity even when the array of products supplied to the urban consumer is differentiated.

Collective action institutions can help farmers to create and access output markets for products that are not standardized. Farmers' markets that sell directly to consumers can market small quantities of diverse produce. Because of the personal contact between seller and buyer, these fora can also increase awareness of the traits and advantages of different crops or varieties. However, farmers' markets are generally limited to a localized area.

Reaching wider markets often requires getting smallholders to group their produce together, and may further require some assistance in reaching or expanding particular niche markets. For example, the M.S. Swaminathan Foundation has been working with tribal groups in the Kolli Hills, India, to expand markets for minor millets by developing new recipes and processed products (Gruère, *et al.* 2007). The Papa Andina program helps smallholders in the Andes who grow a wide variety of potatoes to develop market niches among urban consumers and add value to their produce, both by educating consumers about the values of diverse varieties and developing better packaging and marketing channels (Devaux *et al.* 2006). Such collective approaches can even be formalized into "appellation of origin," gaining legal recognition for the particular traits from local production.

These examples point to one other set of non-market institutions that can encourage the profitability of genetically diverse agricultural produce: norms regarding what foods or products are desirable. Changing taste preferences toward polished white rice or starchy potatoes have often created a stigma against traditional crops like minor millets and indigenous vegetables or diverse varieties such as Andean potatoes, which are often regarded as "poor man's food." Advertising campaigns highlighting the nutritional or taste advantages can help to change norms. Engaging with outlets that are perceived as upscale can also valorize diverse crops or varieties. This has been seen with the resurgence of traditional leafy vegetables in Africa when they were marketed through supermarkets, and "heritage" varieties of tomatoes in the United States when they were lauded by top chefs.

Expanding the options to profit from growing diverse varieties often requires engaging with market institutions at some level. But small quantities of varied produce face many disadvantages in the market. Rather than only engaging with the market on its own terms, other non-market institutions, notably collective action and norms regarding the products, can help to expand markets and increase returns to the farmers who conserve and use agrobiodiversity.

4 Conclusion

Even as markets expand, non-market institutions continue to play a critical role in the conservation of agrobiodiversity. A range of kinship, friendship,

and neighborhood institutions not only facilitate access to seed and produce but also help to overcome the lack of transparency about the quality of the seed and the genetic resources it contains by providing trust based on reputation and multi-stranded linkages between supplier and recipient. As markets become more regulated, they may also be able to provide more trust and transparency; but this is often at the cost of standardization of the products. It is doubtful whether seed companies will ever be able to cover the full range of genotype-by-environment interactions of maize varieties in Oaxaca, for example, and while local farmers' markets may provide a range of heritage tomatoes, this is more difficult in supermarkets.

In addition to information about the genetic material, non-market institutions play an important role in conveying information about the use of the products. Recipes or tips for using products are often passed on through social networks. Other institutions such as county fairs have also played an important role in conveying information about the uses. Markets can also promote agrobiodiversity by offering recipes and directions for using unfamiliar products.

But beyond these direct uses, non-market institutions also embody the non-monetary value of particular varieties that are often critical to their conservation. Some species have religious values; many particular varieties have sentimental value because of their association with kin, friends, or location. While these values may be eroded by increasing commoditization, non-market institutions are likely to continue to play a role.

Acknowledgements

Note

1 Historically, *mahallas* were autonomous social institutions built around familial ties and Islamic rituals. Before the establishment of the Soviet rule in Uzbekistan, *Mahallas* fulfilled local self-government functions connecting the private sphere with the public sphere. Religious rituals, life-cycle crisis ceremonies, resource management, conflict resolution, and many other community activities were performed at *mahalla,* or (neighbourhood) level. An informal council of elders (*oksakal*) provided leadership. They continued to function as neighborhood committees under

Soviet rule and have assumed greater importance since the independence from the Soviet Union in 1993.

References

Adato, M. and Meinzen-Dick, R. (eds) (2007) *Agricultural Research, Livelihoods, and Poverty: Studies of Economic and Social Impacts in Six Countries*. Baltimore, MD: Johns Hopkins University Press and International Food Policy Research Institute.

Almekinders, C., Louwaars, N.P., and de Bruijn, G.H. (1994) Local seed systems and their importance for an improved seed supply in developing countries. *Euphytica* 78: 207–216.

Alston, J.M., Marra, M.C., Pardey, P.G. and Wyatt T.J. (2000) *A Meta Analysis of Rates of Return to Agricultural R&D: Ex Pede Herculeum?* IFPRI Research Report No. 113. Washington, DC: International Food Policy Research Institute.

Anderson, S. and Centonze, R. (2007) "Animal genetic resources management and poverty," *World Development* 35(9): 1529–1541.

Badstue, L.B., Bellon, M.R., Berthaud, J., Ramírez, A., Flores, D. and Juárez, X. (2007) "The dynamics of seed flow among maize growing small-scale farmers in the Central Valleys of Oaxaca, Mexico," *World Development* 35(9): 1579–1593.

Bellon, M.R., Adato, M., Becerril, J. and Mindek, D. (2007) "The impact of improved maize germ plasm on poverty alleviation: the case of tuxpeño-derived material in Mexico," in M. Adato and R. Meinzen-Dick (eds) *Agricultural Research, Livelihoods, and Poverty: Studies of Economic and Social Impacts in Six Countries*. Baltimore, MD: Johns Hopkins University Press and International Food Policy Research Institute.

Cromwell, E., Wiggins, S. and Wentzel, S. (1993) *Sowing beyond the State: NGOs and Seed Supply in Developing Countries*. London: Overseas Development Institute.

Dennis, E.,Ilyasov, J., Van Dusen, E., Treshkin, S., Lee, M. and Eyzaguirre, P. (2007) "Local institutions and plant genetic conservation: exchange of plant genetic resources in rural Uzbekistan and some theoretical implications," *World Development* 35(9): 1564–1578.

Devaux, A., Thiele, G., López, G. and Velasco, C. (2006) *Papa Andina: Innovación para el Desarrollo en los Andes—Logros y Experiencias de la Segunda Fase: 2002–2006*. Lima: International Potato Center (CIP)—Papa Andina.

Evenson, R.E. and Gollin, D. (eds) (2003) *Crop Variety Improvement and its Effect on Productivity: The Impact of International Agricultural Research*. Wallingford: CAB International.

Eyzaguirre, P. and Dennis, E.M. (2007) "The impacts of collective action and property rights on plant genetic resources," *World Development* 35(9): 1489–1498.

FAO (2006) *Community Diversity Seed Fairs in Tanzania: Guidelines for Seed Fairs*. FAO-LinKS Project. Report No. 51. Rome: FAO.

Gauchan, D. and Smale, M. (2007) "Comparing the choices of farmers and breeders: the value of rice land races in Nepal," in D. Jarvis, C. Padoch, and H.D. Cooper (eds) *Managing Biodiversity in Agricultural Ecosystems*. New York: Columbia University Press.

Gruère, G.P., Nagarajan, L. and King, E.D.I.O. (2007) "Collective action and marketing of underutilized plant species: the case of minor millets in Kolli Hills, Tamil Nadu, India," CAPRi Working Paper 68. Washington, DC: International Food Policy Research Institute.

Kariuki, G. and Place, F. (2005) "Initiatives for rural development through collective action: the case of household participation in group activities in the highlands of Central Kenya," CAPRi Working Paper 43. Washington, DC: International Food Policy Research Institute.

Nathaniels, N.Q.R. and Mwijage, A. (2000) "Seed fairs and the case of Marambo village, Nachingwea District, Tanzania: implications of local informal seed supply and variety development for research and extension," Network Paper No. 101. Agricultural Research & Extension Network (AgREN), Overseas Development Institute (ODI), UK.

Padmanabhan, M.A. (2006) "Collective action in plant genetic resources management: gendered rules of reputation, trust and reciprocity in Kerala, India," CAPRi Working Paper 56. International Food Policy Research Institute (IFPRI), Washington, DC.

Pfeiffer, J.M., Dun, S., Mulawarman, B. and Rice, K.J. (2006) "Biocultural diversity in traditional rice-based agroecosystems: indigenous research and conservation of *mavo* (*Oryza sativa* L.) upland rice landraces of eastern Indonesia," *Environment, Development and Sustainability* 8(4): 609–625.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T. and Cliff, B. (1997) "Economic and environmental benefits of biodiversity," *BioScience* 47(11): 747–757.

Rohrbach, D. and Mazvimavi, K. (2006) "Do seed fairs improve food security and strengthen rural markets?" Briefing Note 3. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Zimbabwe.

Smale, M. and Drucker, A.G. (2007) "Agricultural development and the diversity of crop and livestock genetic resources: a review of the economics literature," in A. Kontoleon, U. Pascual, and T. Swanson (eds) *Frontiers in Biodiversity Economics*. Cambridge: Cambridge University Press.

Sperling, L. and Longley, C. (2002) "Beyond seeds and tools: effective support to farmers in emergencies," *Disasters* 26(4): 283–287.

Tripp, R. (1997) *New Seed and Old Laws: Regulatory Reform and the Diversification of National Seed Systems*. London: Intermediate Technology Publications.

Worede, M., Teshome, A. and Tesemma, T. (2000) "Participatory approaches linking farmers' access to genebanks: Ethiopia," in E. Friis-Hansen, and B. Sthapit (eds) *Participatory Approaches to the Conservation and Use of Plant Genetic Resources*. Rome: International Plant Genetic Resources Institute.

7 Development, intensification and the conservation and sustainable use of farm animal genetic resources

Adam G. Drucker and Luis Carlos Rodriguez

1 Introduction

Agricultural biodiversity refers to all diversity within and among species found in domesticated crop, tree, aquatic, and livestock systems. Livestock biological diversity encompasses both phenotypic as well as genotypic variation (Smale and Drucker 2007). The term animal genetic resources (AnGR) is used to include all animal species, breeds and strains (and their wild relatives) that are of economic, scientific and cultural interest to humankind in terms of food and agricultural production for the present or in the future (Rege and Gibson 2003).

There are more than 40 species of animals that have been domesticated (or semi-domesticated) during the past 10,000–12,000 years which contribute directly or indirectly to agricultural production (FAO 2000). Approximately 70 per cent of the world's rural poor depend on livestock as a component of their livelihoods (LID 1999). Animals of different species and breeds provide outputs that suit different household and community needs, and frequently also have a role in the maintenance of local cultures and identity. Livestock diversity thus contributes in many ways to human survival and well-being, including its contribution to supporting sustainable agricultural development pathways (Drucker and Anderson 2004).

Despite the importance of this diversity, an estimated 16 per cent of uniquely adapted breeds bred over thousands of years of domestication in a wide range of environments have been lost over the last century (Hall and Ruane 1993). A further 20 per cent (16 per cent of mammals and 30 per cent of avian species) are at risk of becoming extinct[1] and the rate of extinction continues to accelerate (FAO, 2007).

Although much less talked about, genetic erosion in farm AnGR is much more serious than in crops because the gene pool is much smaller (6,000–7,000 breeds/strains of some 40 species) and only very few wild relatives remain. Furthermore, of the livestock breeds existing today, 70 per cent are in developing countries where the risk of loss is highest (Rege and Gibson 2003). Such an irreversible loss of genetic diversity reduces opportunities to improve food security, reduce poverty and shift towards sustainable agricultural practices.

Factors that threaten indigenous AnGR can result from both the economic development process itself (e.g. urbanisation and its impact on traditional animal agriculture), as well as related interventions ostensibly designed to improve social welfare by increasing economic productivity. The latter include: cross-breeding with and/or replacement by imported breeds in programmes designed to improve animal productivity; as well as market interventions that promote shifts in social settings, production systems and demand for certain animal products. At the same time, the process of development may be expected to reduce the effect of other factors threatening AnGR such as civil strife/conflicts, droughts, floods and famines.

It is therefore apparent that while AnGR make an important contribution to livelihoods and development, a number of the principal threats to AnGR arise from the advance of the development process itself. This issue is now examined in more detail. Having developed a conceptual model in Section 2, an applied analysis based on case study data is carried out in Section 3. Section 4 summarises the findings and highlights conclusions and policy implications.

2 Conceptual model

As Swanson (1997) noted, human societies have been expanding and developing over time through a process involving biodiversity depletion. This process can be understood in terms of a trade-off between maintaining the stock of diverse biological resources and the benefits to human society derived from the depletion of this stock.

The rate at which the development process is resulting in such conversion has also been accelerating as a result of the process of globalisation.[2] In particular, the impacts of globalisation on the livestock sector include (Hiemstra *et al.* 2006):

- reduced costs of international breed transfers;
- the replacement of breeds in developing countries with those from developed countries (Swanson dominance effect);
- specialisation by comparative advantage leading to reduced demand for multi-purpose breeds;
- changes in the availability and price of feed imports;
- increasingly large flows of capital investment, information and technology, particularly by national and international food processors and retailers.

AnGR erosion can, thus, be seen in terms of the replacement of the existing slate of domestic animals with a small range of specialised 'improved' breeds. Such replacement occurs not only through substitution but also through cross-breeding and the elimination of livestock because of production system changes, often associated with the overall development process. AnGR

erosion therefore needs to be understood within a production systems evolution context (biophysical, socio-economic, markets, etc.) in order to understand genotype choices and threats to animal genetic diversity. Moreover, systems dynamics also have implications for the mechanisms through which AnGR conservation activities may sustain smallholder competitiveness (particularly in the context of the increased demand for livestock products due to the 'livestock revolution'). Consequently, the conservation of AnGR must also take place within a systems evolution context, where conservation needs to be managed so as to direct changes in a way that has a positive impact on people's livelihoods.

As noted by Drucker *et al.* (2001), from an economic point of view, AnGR erosion can be seen as a result of drivers generating a bias towards investment in specialised genotypes, which in turn results in under-investment in a more diverse set of breeds. Economic rationality suggests that investment decisions will be determined by the relative profitability of the two options (assuming risk neutrality and well-functioning markets). However, from a farmer's private perspective the relevant rates of return are those that accrue to him/her rather than to society or the world as a whole. To the farmer, the loss of the local breed appears to be economically rational because the returns may simply be higher than those from activities compatible with genetic resources conservation, especially since the latter may consist of non-market benefits that accrue to people other than the farmer. This divergence will be further compounded by the existence of distortions in the values of inputs and outputs, such that they do not reflect their economic scarcity.

The above divergence between private and public returns is important. As Pearce and Moran (1994) noted, the recognition of the broader total economic value (i.e. direct use values, indirect use values, option and existence values) of natural assets can be instrumental in altering decisions about their use, particularly in investment decisions which present a clear choice between erosion/destruction or conservation. When the activity of biodiversity (and genetic resource) conservation generates economic values which are not captured in the marketplace, the result of this 'failure' is a distortion where the incentives are against genetic resources conservation and in favour of the economic activities that erode such resources.

In this view, such outcomes are associated with market failure (i.e. distortions due to missing markets regarding the external benefits generated by biodiversity conservation), intervention or policy failure (i.e. distortions due to government actions in intervening in the workings of the market-place, even where those appear to serve some social purpose), and/or global appropriation failures (i.e. the absence of markets/mechanisms to capture globally important external values). Note that global missing markets can co-exist with local market failure and intervention failure. The loss of biodiversity and genetic resources is a case in point (Drucker 2007).

2.1 Description and adaptation of the 'Steinfeld' model

Considering the increasing demand for livestock and livestock products as a result of development and economic growth, the intensification of livestock production, i.e. the manipulation of inputs and outputs in order to increase production and/or the productivity of animals, has been a desired policy objective particularly (1) where the linkages to urban markets are strong and hence larger returns can be expected; and/or (2) where smallholder farmers are being targeted as part of poverty reduction policy interventions.

However, as previously noted, this process of development through intensification can have negative impacts on the conservation of low-input/low-output indigenous breeds through their replacement with high-input/high-output exotic breeds. In order to examine the implications of the breed replacement process and the degree to which it represents an economically optimal conversion process, it is useful to adapt a model originally presented by Steinfeld (2000). The model considers the effect of intensification of livestock production and its relationship with the gross margins of indigenous and exotic breeds (Figure 7.1).

Given the important adaptive traits associated with indigenous breeds, Steinfeld (2000) notes that typically, indigenous AnGR perform better than exotics in local environments, which are not, or only slightly, modified by external inputs. With increasing production intensity the production environment is modified to the extent that exotic[3] breeds (developed for productive traits under modified environments) are more productive because of their higher responsiveness to external inputs. This is typically the case in areas which are favoured in terms of natural potential and market access. By contrast, in marginal environments, returns to external inputs are low, and
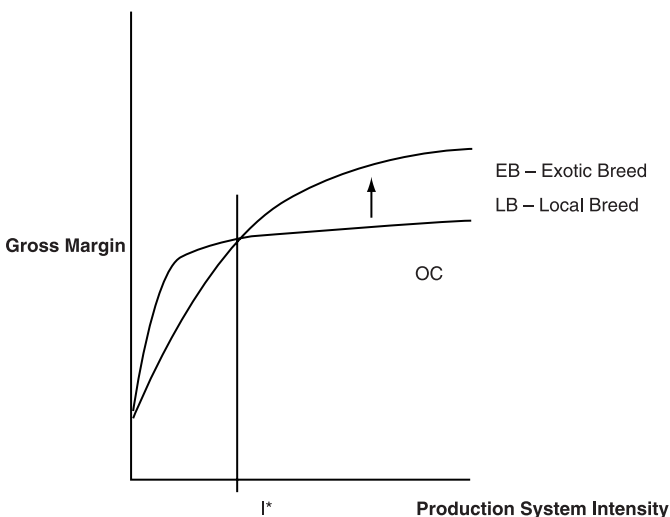
Figure 7.1 Production function of local and exotic breeds.

these tend to be still dominated by breeds adapted to the harsh conditions prevailing.

Consequently, as can be seen in Figure 7.1, indigenous or local breeds (LB curve) would outperform exotic breeds (EB curve) up to a given level of production system intensity (I*).[4] After I* is reached, the farmer will face increasing incentives to replace his/her local breed with an exotic breed. The size of this incentive can be determined by the distance OC, which is a measure of the opportunity cost differential associated with keeping a local breed beyond I*.

The *replacement point* I* will be optimally determined assuming farmers have perfect information about the relative costs and benefits of different breeds, as well as input and output prices reflecting their true economic scarcity. However, where such assumptions do not hold, it may be expected that the replacement point I* would only be reached at a higher level of production system intensity (I*′), as can be seen in Figure 7.2.

Circumstances under which this could happen include, for instance (1) an underestimation of the total economic value of the local breed (LB shifts upward to the left to LB′). This may occur if non-market values are ignored (e.g. traction, manure, disease resistance, financing and insurance functions, socio-cultural values); (2) an overestimation of the performance of the exotic breed (EB shifts downwards to the right to EB′). The latter could result from a market failure associated with the presence of external costs and benefits, such as environmental externalities; and (3) important intervention failures that provide disincentives for efficient resource allocation (EB shifts downwards to the right to EB′). For example, capital subsidies clearly favour an industrial mode of development, leading to investments in commercial units
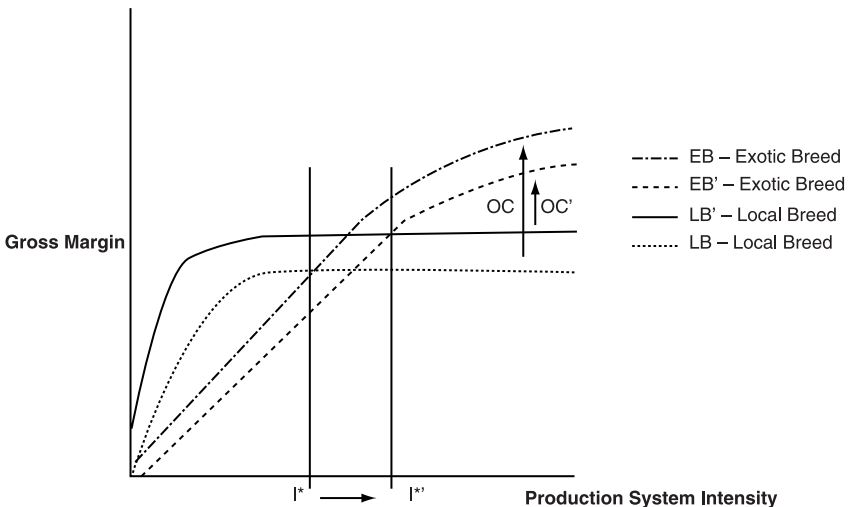
Figure 7.2 Production function of local and exotic breeds in the presence of market distortions.

with large economies of scale, coupled with high input use (modifying the production environment to the requirements of exotic breeds) and uniform products. These policy distortions can take many forms, including subsidised grain imports, free or subsidised support services, e.g. artificial insemination services, and support prices for livestock products. These policies may have specific social benefits, e.g. support the supply of affordable and safe animal protein to urban centres, but they also create a bias against less intensive production systems.

Figure 7.2 shows the effect of accounting for such market and intervention failures. In such cases, the economic (as opposed to financial) value of local breed production for any given level of output will be higher (shifting LB upwards and to the left, to LB′) and decreasing the economic value of exotic breed production (shifting EB downwards and to the right, to EB′). The result of these two shifts is that the economically optimal replacement point I*′ would be to the right of I* and associated with a higher level of production system intensity I*′. Similarly, the opportunity cost of maintaining local breeds beyond the economically optimal replacement point is only OC′ rather than OC.

While the precise distance between I*′ and I* is determined by the relative elasticities of the LB and EB curves, it is possible to draw some general conclusions from this simple analytical model:

- The economically rational/optimal replacement point between breeds is later than that indicated in Figure 7.1. Current levels of replacement may therefore be sub-optimal and thereby unnecessarily placing many indigenous or local breeds at risk.
- Once the replacement point has been reached, i.e. the opportunity cost differential OC is positive, conservation goals can no longer be achieved by promoting sustainable use. Instead conservation programmes *per se* must be supported. Brush and Meng (1996) argue that least cost conservation programmes can be defined and the cost of such programmes can be measured in terms of the distance OC′.

The above conceptual model implies that imperfect information, market failures and intervention failures could play a significant role in promoting non-economically optimal breed replacement/substitution and, hence, in the absence of conservation programmes, the loss of AnGR diversity.

The degree to which such theoretical findings are supported by empirical evidence are now explored in Section 3, applying a Mexican case study based on primary data. In particular, we seek: (1) to provide a real-life example of how the development process can lead to changing production systems, profitability and breed preferences; (2) to address the fact that imperfect information can indeed lead to AnGR loss not being necessarily driven by profitability decline; (3) to show that market/intervention failures and policy distortions lead to highly distorted markets (including the use of large

subsidies) that favour exotics and their crosses; and (4) to show that the resource requirements of least cost conservation programmes for breeds threatened by replacement can be calculated and can be relatively small

3 Mexico creole pig production case study

3.1 Background

Drucker and Anderson (2004) note that *Cuino* and *Pelón* were the only pig breeds reared in Mexico up until the end of the nineteenth century. During the first seven decades of the twentieth century these local pigs were displaced from the majority of different Mexican pig production systems, their importance declining from 95 per cent of pigs reared in 1910 to less than 30 per cent in the 1970s, with a total estimated local pig population of 2 million (Anon 1992). This process has continued over the last few decades and by 1990, the backyard pig population (all breeds and crosses) had declined to 29,300 (INEGI 1991). Currently, the local pig breed is considered as 'critically endangered' according to the FAO (1999) classification system.

   Drucker and Latacz-Lohmann (2003) and Drucker (2001) note that the introduction of a series of fiscal incentives led to large pig farm enterprises being attracted to the region between 1992–1994. These large commercial farms have since dominated the sector. The commercial pig sector has thus grown from 69,000 animal population units of 100kgs in 1970 to approximately 622,000 in 1998 (INEGI 1998). In 1998, the state of Yucatán was the fourth largest producer in terms of Mexican pig production (Secretaria del Gobierno del Estado de Yucatán 1998), producing 76,672 tonnes in 1998 with a total value of approximately US$124 million or 39.5 per cent of total livestock sales (INEGI, various years).

   All of the large commercial farms raise 'improved' breeds, which include Yorkshire, Landrace, Hampshire, Duroc Jersey, Poland China and/or Pietrain pigs. Uncontrolled cross-breeding when these animals have found their way into the village production systems explains to a large degree the genetic erosion of the local creole breed, found mainly in backyard and small-scale commercial systems.

3.2 Survey findings

A series of studies covering both the backyard and commercial pig farming systems was carried out between 1996 and 2000. A summary of the methodologies used, survey approaches and sample sizes can be found in Drucker and Anderson (2004), while full details are reported elsewhere (see Anderson *et al.* 2000 and 1999; Drucker *et al.* 1999; Pattison 2002; and Scarpa *et al.* 2003). The results of these surveys clearly show among other issues: (1) the scale of genetic erosion that has taken place in the local pig population; (2) the changes in backyard pig rearing that have taken place in terms of the

numbers of families involved and the purposes of pig keeping; (3) factors which influence the distribution of pigs in this system; and (4) the animal characteristics and traits that the pig keepers consider important and the livelihood importance of backyard pig rearing.

Drawing on Scarpa *et al.* (2003), Table 7.1 reveals how the costs and benefits of production vary according to the type of breed used in backyard production systems, as well as relative to large commercial farms using imported breeds. The data presented for the backyard production systems was generated through a stated preference choice experiment survey and consequently already accounts for certain non-market values related to disease resistance, foraging capability and heat tolerance.[5]

Within the 'small family'[6] backyard production system, local breed animals generate a gross margin of $19.6 per animal as their adaptive traits (disease resistance, heat tolerance, foraging capability) mean that production costs are virtually zero. By contrast, the exotic breed kept under this type of production system incurs production costs of Mex$627.5 (US$66) and generates a loss of US$3.4 per animal. However, as the production system intensity increases, the exotic breeds become increasingly competitive. In 'large family' backyard production systems, where a higher level of animal management inputs are available, local and exotic breeds generate a similar gross margin of $8.1 and $8.8 per animal, respectively.

Interestingly, in small/medium commercial farming systems, local breed pigs are no longer profitable, generating a loss of $59 per animal, while exotic breeds generate a profit of $29 per animal. In large commercial farms, where feed economies of scale are captured, such profits are in the region of $55–60 per animal, while local breeds would continue to be unprofitable.

Figure 7.3 illustrates these findings graphically. Assuming a continuous function, this means that the replacement intensity I* for local breed pigs is found as one approaches the 'large family' backyard production level of intensity.

3.3 Impact of development on breed choice

It is apparent that the gross margin generated per animal in either of the backyard systems is much smaller ($8.1–$19.6) compared to that which can be generated even within the smallest commercial farms using imported breeds ($29). This provides a good illustration of how, as the development process advances and farmers have increasing access to inputs, they will increasingly face incentives to move away from local breeds in backyard production systems to exotic breeds in commercial production systems.

At the same time, it is interesting to note that breed replacement is taking place even within the backyard systems where either it is not profitable to do so ($19.6 vs. −$3.4) or the opportunity cost is minimal ($8.1 vs. $8.8). This suggests that non-economic factors are playing an important role. Such factors might include biased extension advice (imperfect information) and

Table 7.1 Costs and benefits per animal of fattener pig production by breed under backyard and commercial production systems in Yucatan, Mexico

	Backyard system (small, younger, less well-educated family)§§	Backyard system (small, younger, less well-educated family)§§	Backyard system (larger, older, better educated family)§§	Backyard system (larger, older, better educated family)§§	Intensive commercial system (small/medium)#	Intensive commercial system (small medium)#	Intensive commercial system (large and mega)#
Number of animals (fatteners or equiv.)	3.7	3.7	3.7	3.7	350/800	350/800	2,500/14,000
Breed	Local	Exotic	Local	Exotic	Local	Exotic	Exotic
Sale weight at 6 months (kgs)	35	90	35	90	35%	100	100
Weight gain (kg) at end of 6 month period assuming 10kg weaning weight	25	80	25	80	25	100	100
Value to farmer or sale value/kg (Mex$)	7.44	7.44	3.06	3.06	11.12	11.12	11.12
Gross income	186	595.2	76.5	244.8	278	1,112	1,112
Feed cost (Mex$)[a]	0	284.8	0	74.2	713**	713**	501–461**
Bath cost (Mex$)[b]	0	96.3*	0	24.5*	Not available	Not available	Not available
Veterinary cost (Mex$)[c]	0	246.4	0	62.8	Not available	Not available	Not available
Gross cost (Mex$)	0	627.5	0	161.5	839**	839**	589–542**
Net income (Mex$)	186	–32.3	76.5	83.3	–561**	273	522–569**
Net Income (US$ Equivalent)##	19.6	–3.4	8.1	8.8	–59	29	55–60
Benefit/Cost Ratio&&	Very Large	0.95	Very large	1.52	0.33	1.33	1.89–2.05

Notes: §§Source: Adapted from Scarpa *et al.* (2003) and Drucker and Anderson (2004). Based on sample size of 270 households.   # Source: Drucker (2001).   * Value based on an exotic breed bathing frequency of twice per day, as per frequency identified in survey/monitoring data.   ** Estimated at 85% of total costs.   % Assumes that improved feed and vet care have no impact on weight gain.   This assumption results in an upper-bound estimate of the gross margin losses.   [a] Proxy for disease resistance;   [b] Proxy for heat tolerance;   [c] Proxy for foraging capability;   ##US$ 1 = approximately Mex$9.5 pesos between 1999–2001. NB. Official symbol for the Mexican Peso is '$'. We have used 'Mex$' in order to avoid confusion with the US$.   && Benefit/Cost ratio is in this case calculated as gross benefits/gross costs.
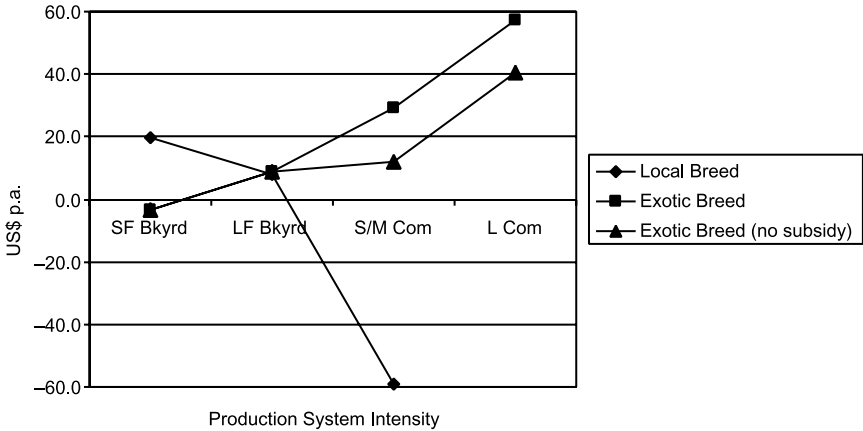
Figure 7.3 Yucatecan pig farm gross margin by breed.

Notes: SF Bkyrd: small family backyard system.
LF Bkyrd: large family backyard system.
S/M Com: small/medium farm commercial system.
L Com: large/mega farm commercial system.

support, as well as difficulties in sourcing local breed breeding stock in practice.

An additional point worth noting is that the benefit-cost ratio reveals that returns to local breed production can be very high given that production costs are near zero. This therefore provides a good example of how productivity within low-input/low-output systems can in fact be large despite the fact that absolute returns (the focus of most conventional livestock economic studies) may be low. The data thus suggest that intensification is likely to be playing a significant role in reducing breed diversity in Mexico. A similar pattern is also reported in Vietnam where on-going development processes and poverty alleviation projects based on the use of exotic pig breeds have led to 10 of the country's 14 local breeds being at risk of extinction (Huyen *et al.* 2005).

3.4 Impact of subsidies on breed substitution

While the private financial implications of the choice of breeds within different production systems was illustrated above, the public implications are somewhat different given the presence of subsidies. The OECD (2002) defines a 'subsidy' (also frequently referred to as transfers, payments, support, assistance and aid) as a benefit provided to individuals or businesses as a result of government policy that raises their revenues or reduces their costs and thus affects production, consumption, trade, income, and/or the environment.

Efficient resource allocation requires prices to equal marginal costs, and minimum average costs in the long run. Subsidies distort relative prices and shift the allocation of resources away from more productive sectors in the

economy. Subsidies can also exacerbate pre-existing efficiency losses (Fischer and Toman 2000). Drucker *et al.* (2006) note that OECD countries spend US$235 billion a year supporting local food production, with, in 2002, approximately three-quarters of this spent by the European Union (US$100.6 billion), Japan (US$43.9 billion) and the United States ($39.6 billion). These subsidies provide a notable portion of farm receipts – 31 per cent for the OECD on average, but up to 60 per cent in some cases (OECD 2002). Most of the money goes to the largest, and usually richest, farms, while small and poor farmers (who are the most likely to be maintaining local crop varieties and livestock breeds) are often bypassed (Reuters 2003).[7]

The FAO (undated) notes that such explicit and implicit subsidies to livestock production increase the advantages of imported breeds which require more external inputs (e.g. veterinary services, artificial insemination,[8] concentrate feed, etc.). Karugia *et al.* (2001) also argue that the net benefits of exotic-based breeding programmes have often been overestimated, leading to the promotion of exotic livestock breeds at the expense of local livestock breeds. Additional costs are also ignored, as the mandatory changes in production systems necessary for increased productivity are often associated with higher levels of risk, while replacement of local breeds has socioeconomic and environmental implications due to the loss of the (usually non-market) values of the local genotypes.

3.5 *Subsidies to commercial Mexican pig farmers*

Drucker and Anderson (2004) report that the total value of government support to Yucatan under the 'Alianza para el Campo' programme in 1998 was US$1.1 million (US$14 per head on participating farms). The non-enforcement of environmental legislation (reducing production costs by 3–5 per cent (Taiganides *et al.* 1996; Drucker *et al.* 1999), leads to a further effective 'natural resource degradation' subsidy of approximately US$37 million (or US$ 3.3 per head).

A 'back of the envelope' calculation of the total value of these subsidies therefore suggests a value of at least US$38.1 million p.a. to the commercial pig farm sector. This works out at approximately US$17 per head, a figure similar to that quoted by Escalente-Semerena (1997) with regard to Canadian pig subsidies and that of Drucker *et al.* (2006), who identified a minimum of 15 types of Vietnamese pig subsidies, totalling 19–70 per cent of gross margin. Further (to date unquantified) subsidies exist in the Mexican context in the form of cheap loans and subsidised transport infrastructure and fuel.

Table 7.2 shows the returns to Mexican pig farming net of subsidies. Given that it is the small/medium and large commercial systems using exotic breeds that benefit almost exclusively from these subsidies, the calculated gross margin would be significantly reduced in both cases in the absence of subsidies. While large commercial farms would continue to have the highest gross margin of all farm types ($38–43), small/medium commercial farms would have a

gross margin of only \$12, which is inferior to that of the local breeds in the 'small family' backyard systems. Thus, in the absence of subsidies, the breed replacement point I*′ would be located somewhere between small/medium and large commercial farm sizes rather than close to the 'large family' backyard farm size.[9]

Hence, it is clear that subsidies to the Mexican pig farming sector may well be playing an important role in promoting breed substitution at inappropriate levels of intensification. While neoclassical economics suggests that the loss of local breeds can be viewed simply as manifestations of changing returns to different types of breed production and socially optimal outcomes associated with higher levels of welfare, this view fails to account not only for a range of non-market values but also for agricultural/livestock subsidies, which may be an important driver in this process. In turn, the existence of such externalities and market distortions calls into question the social optimality of irreversible breed loss.

Given the current precarious state of local breeds as a result of such externalities and distortions in both Mexico and Vietnam, mitigating measures for AnGR conservation urgently need to be implemented rather than, or in addition to, simply advocating the removal of distorting subsidies. The cost of specific mitigation measures in Mexico are discussed in more detail in the following section. However, it should be noted that the success of such measures in improving the survival probability of a given breed depends on the effective population size, with breeds having passed a certain critical threshold being beyond saving, as a result of both technological and economic constraints. Such breeds will be beyond public policy interventions (Fadlaoui *et al* 2006).

3.6 Conservation costs

The Convention on Biological Diversity advocates *in situ* conservation of genetic resources and the potential costs of such a conservation programme will largely depend on its scope; that is: the number of breeds targeted; the size of the area targeted; and the number of households deemed necessary to ensure an adequate level of security for conservation.

Brush and Meng (1996), in the context of crops, propose that a 'least cost' programme can be identified by focusing on those households that are the most likely to continue to maintain such breeds, since these will be the least costly to incorporate into a conservation programme. The cost of an *in situ* conservation programme can thus be expressed as the cost necessary to raise the comparative advantage of such breeds above that of competing breeds, animals or off-farm activities; and a relatively small investment may suffice to maintain their advantage in a particular farming system. Drucker (2006) has shown that such an approach can be applied to AnGR.

In terms of the above Mexican case study, the conservation cost per animal is represented by the distance OC or OC′. As can be seen in Table 7.2,

Table 7.2 Yucatecan pig farm gross margin per animal, ranking and opportunity costs in the presence and absence of subsidies

	Backyard system (small, younger, less well-educated family)	Backyard system (small, younger, less well-educated family)	Backyard system (larger, older, better educated family)	Backyard System (larger, older, better educated family)	Intensive commercial system (medium)	Intensive Commercial System (small medium)	Intensive Commercial System (large and mega)
Breed	Local	Exotic	Local	Exotic	Local	Exotic	Exotic
Gross margin (US$ Equivalent)	19.6	−3.4	8.1	8.8	−59	29	55–60
Overall ranking	3	6	5	4	7	2	1
Estimated subsidy (US$/head)						17	17
Estimated gross margin in the absence of subsidy (US$/head)	19.6	−3.4	8.1	8.8	−59	12	38–43
Overall ranking	2	6	5	4	7	3	1
Implied opportunity cost of maintaining local breed in the presence of subsidy (US$ equivalent)	0		0.7		88		
Implied opportunity cost of maintaining local breed in the absence of subsidy (US$ equivalent)	0		0.7		71		

Source: Adapted from Scarpa *et al.* (2003) and Drucker (2001).

conservation through sustainable use can be achieved without an incentive payment to small family backyard producers (as the gross margin of local breed pigs is larger than that of the exotics), while a payment of $0.70 per animal would be necessary to motivate large family backyard producers to keep local breeds. At the small/medium commercial farm level, this payment would need to increase to $88 and would therefore be expensive compared to interventions at the backyard level. Pattison (2002) and Pattison *et al.* (2007) provide detailed estimates of the technical and infrastructural costs that would accompany such a conservation programme, based either on a community-based conservation scheme or an open nucleus scheme. Pattison (2002) also notes that a large number of backyard producers would not need any financial incentive at all (as per the small family backyard producers identified above), although technical assistance with breeding management planning and boar rotation would be important.

4 Conclusion

AnGR make an important contribution to livelihoods and economic development. However, the paradox is that a number of the principal threats to AnGR arise from the advance of the development process itself, which in turn are compounded by the existence of distorted markets resulting from both market and government intervention failure. An examination of theoretical expectations and empirical data from a Mexican case study reveals that these type of distortions are in fact capable of promoting the replacement of local breeds with exotic breeds in production systems where this would not otherwise occur.

   Neoclassical economics suggests that the loss of local breeds can be viewed simply as a manifestation of the changing returns to different types of breed production and socially optimal outcomes associated with higher levels of welfare as the development process advances. However, this view is predicated on the assumption that, *inter alia*, markets are not distorted and prices reflect their economic scarcity. Given the existence of a range of non-market values and subsidies, society needs to view the loss of local livestock breeds with much more concern than that suggested by neoclassical economics and appropriate enabling policy frameworks created (including unbiased extension service advice and support, increased breeding management capacities, access to appropriate genetic material, etc.).

   In such cases, economic analysis of AnGR may be usefully focussed on understanding the financial incentives that livestock keepers face in making the choice between raising local and/or exotic breeds. It can also be used to help design the interventions necessary in order to ensure that the on-going agricultural development process will be compatible with the conservation and sustainable use of local livestock breed diversity.

   In both cases, such analyses will be dependent on the continuation of methodological advances related to AnGR valuation. Smale and Drucker

(2007) argue that particularly when used in conjunction with rural appraisal methodologies, such methodologies can reveal useful estimates of the values that are placed on market, non-market and potential breed characteristics. Such data are crucial for:

- identifying trait values in breeding programmes;
- demonstrating the benefits, as well as the costs of conservation;
- identifying cost-efficient, diversity-maximising, or optimal conservation strategies;
- orienting policies aimed at the conservation/sustainable use of genetic resources including through support for benefit sharing.

The challenge is to now both develop the required data, as well as to apply further AnGR valuation work in contexts where the results can be taken up so as to actively benefit sustainable livestock production. Taking up this challenge should form part of the activities associated with the Global Plan of Action for Animal Genetic Resources agreed at the 2007 First International Technical Conference on Animal Genetic Resources for Food and Agriculture (Interlaken, Switzerland).

Notes

1 Breeds at risk are defined by the FAO (1999: 43) as

> any breed that may become extinct if the factors causing its decline in numbers are not eliminated or mitigated . . . Risk of extinction may result from, *inter alia*, low population size; direct and indirect impacts of policy at the farm, country or international levels; lack of proper breed organisation; or lack of adaptation to market demands. Breeds are categorised as to their risk status on the basis of, *inter alia*, the actual numbers of male and/or female breeding individuals and the percentage of pure-bred females. FAO has established categories of risk status: critical, endangered, critical-maintained, endangered-maintained, and not at risk.

2 Globalisation is understood to be related to the international integration of food markets arising from the liberalisation of international commercial policy and the bundle of inter-related technological changes underlying the process (Hobbs and Kerr 1998).
3 In the context of this chapter and for the purposes of simplification, this is understood to include local × exotic crosses that are more closely associated with the exotic breed. Similarly, 'local' breeds are considered to include local × exotic crosses that are more closely associated with the local breed. Full details of the classification criteria used can be found in Drucker *et al.* (1999).
4 Note that Steinfeld's original graph compared 'cost' (x-axis) and 'output' (y-axis). We have adapted these measures to relate to 'production system intensity' and 'gross margin', respectively.
5 Full details are given in Scarpa *et al.* (2003). As with other studies which have shown the importance of non-market values (for example, see Tano *et al.*, 2004; Zander and Drucker, in press), the data reveal the significant values that local breeds have in terms of disease tolerance, heat resistance and foraging capability.

These are in addition to the finance and insurance functions that these animals play. Gibson and Pullin (2005) have estimated that approximately 80 per cent of the value of livestock in low-input developing country systems can be attributed to non-market roles, while only 20 per cent is attributable to direct production outputs. By contrast, over 90 per cent of the value of livestock in high-input developed country production systems is attributable to the latter.

6 Small families are defined as comprising a household with 4 members, a single income earner, and a 25-year-old respondent with two years of education. Large families comprise households with at least ten members, two income earners, and a 45-year-old respondent with seven years of education.

7 For example, two-thirds of US crop supports go to 10 per cent of cotton, grain and oilseed growers.

8 Subsidies for artificial insemination (AI) frequently favour imported breeds as that is usually the only type of semen made available through this technology. The FAO recommends that the potential advantages of easily available AI need to be carefully evaluated against biodiversity objectives, as well as general market principles (FAO, undated).

9 We note that this conclusion in part arises from the fact that the Mexican pig gross margin curves are in fact a somewhat different shape from that hypothesised by Steinfeld (2000). In turn, this is a result of data availability and the relabelling of the axes (as previously noted).

References

Anderson, S., Drucker, A. and Clark, S. (2000) 'Livelihoods and animal genetic resources: how can people's conservation contribute to poverty reduction?' Paper presented at the 'The local livestock breeds and sustainable rural livelihoods' Workshop, Sadri, Rajasthan, India, November 2000. Proceedings published in 2003.

Anderson, S., Ferraes-Ehuan, N. and Teresa-Rivera, J. (1999). 'The criollo pig population in Yucatán, Mexico: a genetic impact statement, Animal Genetic Resources Information', is Memorias del Seminario Internacional sobre Agrodi-versidad Campesina del 12 al 14 de mayo de 1999. Centro de Investigaciones en Ciencias Agropecuarias de la Facultad de Geografía de la UAEM.

Anon. (1992) 'Perspectivas del uso de razas autoctonas en la porcicultura rural', *Porcirama* 17(182): 35–41.

Brush, S. and Meng, E. (1996) 'Farmers' valuation and conservation of crop genetic resources', paper prepared for the Symposium on the Economics of Valuation and Conservation of Genetic Resources for Agriculture, Centre for International Studies on Economic Growth, Tor Vergata University, Rome, 13–15 May.

Drucker, A. (2001) 'Getting incentives right: a comparative analysis of policy instruments for pig slurry treatment in Yucatán, Mexico', unpublished PhD thesis. University of London.

Drucker, A. (2006) 'An application of the use of safe minimum standards in the conservation of livestock biodiversity', *Environment and Development Economics* 11(1): 77–94.

Drucker, A. (2007) 'The role of economic analysis in improving farm animal genetic resource Conservation and Sustainable use'. in *FAO State of the World's Animal Genetic Resources*. Rome: FAO.

Drucker, A. and Anderson, S. (2004) 'Economic analysis of animal genetic resources and the use of rural appraisal methods: lessons from Southeast Mexico' *International Journal of Sustainable Agriculture* 2(2): 77–97.

Drucker, A., Bergeron, E., Lemke, U., Thuy, L.T. and Valle Zárate, A. (2006) 'Identification and quantification of subsidies relevant to the production of local and imported pig breeds in Vietnam', *Tropical Animal Health and Production*. 38(4): 305–322

Drucker, A., Gomez, V. and Anderson, S. (2001) 'The economic valuation of farm animal genetic resources: a survey of available methods', *Ecological Economics* 36(1): 1–18.

Drucker, A., Gomez, V., Ferraes-Ehuan, N., Rubio, O. and Anderson, S. (1999) 'Comparative economic analysis of creole, crossbreed and imported pigs in backyard production systems of Yucatán, Mexico', FMVZ-UADY mimeo.

Drucker, A. and Latacz–Lohmann, U. (2003) 'Getting incentives right?: A comparative analysis of policy instruments for livestock waste pollution abatement in Yucatán, México'. *Environment and Development Economics* 8: 261–284.

Escalante–Semerena, R. (1997) *La Porcicultura en México: una visión de conjunto*. Facultad de Economia, UNAM, Mexico.

Fadlaoui, F., Roosen, J. and Baret, P.V. (2006) 'Setting priorities in farm animal conservation choices – expert opinion and revealed policy preferences', *European Review of Agricultural Economics* 33: 173–192.

FAO (1999) *The Global Strategy for the Management of Farm Animal Genetic Resources*. Rome: FAO.

FAO (Food and Agriculture Organization of the United Nations) (2000) *World Watch List for Domestic Animal Diversity* 3rd edn.Rome:. FAO,

FAO (undated) 'Loss of biodiversity in livestock – policy options', available at: http://lead.virtualcentre.org/en/dec/toolbox/homepage.htm

FAO (2007) *State of the World's Animal Genetic Resource*. FAO, Rome

Fischer, C. and Toman, M. (2000) 'Environmentally and economically damaging subsidies: concepts and illustrations', Climate Change Issues Brief No. 14. (Resources for the Future). Washington, DC.

Gibson, J.P. and Pullin, S.V. (2005) *Conservation of Livestock and Fish Genetic Resources*. Rome: Science Council Secretariat, FAO.

Hall, S.J.G. and Ruane, J. (1993) 'Livestock breeds and their Conservation: global review', *Conservation Biology* 7(4): 815–825.

Hiemstra, S.J., Drucker, A.G., Tvedt, M.W, Louwaars, N., Oldenbroek, J.K., Awgichew, K., Abegaz Kebede, S., Bhat, P.N. and da Silva Mariante, A. (2006) Exchange, Use and Conservation of Animal Genetic Resources: Policy and Regulatory Options. Centre for Genetic Resources, University of Wageningen, The Netherlands and Rome: FAO,.

Hobbs, J. and Kerr, W. (1998) 'Structural developments in the Canadian livestock subsector: strategic positioning within the continental market', In R.M.A. Loyns *et al.* (eds) *Proceedings of the Fourth Agricultural and Food Policy Systems Information Workshop, Economic Harmonization in the Canadian/U.S./Mexican Grain-Livestock Subsector*. University of Guelph and Texas A&M University, pp. 125–143.

Huyen, Le Thi Thanh Roessler, R., Lemke, U. and Valle Zárate, A. (2005). Impact of the use of exotic compared to local pig breeds on socio-economic development and biodiversity in Vietnam. Verlag Grauer, Beuren, Stuttgart, 2005.

INEGI (Instituto Nacional de Estadística Geografía e Informática) (Various years) *Anuario Estadístico del Estado de Yucatán*. Mecico: INEGI.

Karugia, J., Mwai, O., Kaitho, R., Drucker, A., Wollny C. and Rege, J.E.O. (2001)

'Economic analysis of crossbreeding programmes in Sub-Saharan Africa: a conceptual framework and Kenyan case study', in *Animal Genetic Resources vol.* 2, Nairobi: ILRI.

Livestock in Development (1999) *Livestock in Poverty-focused Development*. Crewkerne: Livestock in Development.

OECD (2002) 'Work on defining and measuring subsidies in agriculture', OECD, Directorate for Agriculture, Food and Fisheries, Paris, 7–8 November 2002. Background workshop paper.

Pattison, J. (2002) 'Characterising backyard pig keeping households of rural Mexico and their willingness to accept compensation for maintaining the indigenous creole breed: a study of incentive measures and conservation options', unpublished MSc thesis, University of London.

Pattison, J., Drucker, A. and Anderson, S. (2007) 'The cost of conserving livestock diversity? Incentive measures and conservation options for maintaining indigenous Pelón pigs in Yucatán, Mexico', *Tropical Animal Health and Production* 39(5): 339–353.

Pearce, D. and Moran, D. (1994) *The Economic Value of Biodiversity*. London Earthscan.

Rege, J.E.O. and Gibson, J.P. (2003) 'Animal genetic resources and economic development: issues in relation to economic valuation', *Ecological Economics* 45(3): 319–330.

Reuters (2003) 'Farm subsidies common globally, bypass small farms', 8 June 2003.

Scarpa, R., Drucker, A., Anderson, S., Ferraes-Ehuan, N., Gomez, V., Risopatron, C. and Rubio-Leonel, O. (2003) 'Valuing animal genetic resources in peasant economies: the case of the Box Keken creole pig in Yucatan', *Ecological Economics* 45(3): 427–443.

Secretaria del Gobierno del Estado de Yucatán. (1998) *III Informe del Gobierno*. Junio 1998. Merida, Yucatán.

Smale, M. and Drucker, A.G. (2007) 'Agricultural development and the diversity of crop and livestock genetic resources: a review of the economics literature', in A. Kontoleon, U. Pascual and T. Swanson (eds) *Biodiversity Economics: Principles, Methods and Applications*. Cambridge: Cambridge University Press.

Steinfeld, H. (2000) 'Valuing animal genetic resources: some basic issues', in: A. Drucker (ed.) *Report of the Research Planning Workshop on 'Economic Valuation of Animal Genetic Resources'*. February 2–4, 2000. Nairobi: ILRI Headquarters.

Swanson, T. (1997) *Global Action for Biodiversity*. London: Earthscan.

Taiganides, E., Perez-Espejo, R and Giron-Sanchez, E. (1996) *Manual para el manejo y control de aguas residuales y excretas porcinas en Mexico*. Mexico: CMP.

Tano, K., Faminow, M., Kamuanga, M and Swallow, B. (2003) 'Using conjoint analysis to estimate farmers' preferences for cattle traits in West Africa', *Ecological Economics* 45(3): 393–407.

Zander, K. and Drucker, A. (in press) 'Conserving what's important: using choice model scenarios to value local cattle breeds in East Africa', *Ecological Economics*.

Part II

Multiple objectives, trade-offs and synergies between productivity and agrobiodiversity

8 Biodiversity conservation and productivity in intensive agricultural systems

Amani Omer, Unai Pascual and Noel Russell

1 Introduction

Agricultural practice in industrialised countries is focused on creating the optimum environment for a single target species (the 'crop'), by adjusting the environment so that growing conditions for the target species are optimised while those for competing species (e.g. 'weeds' and 'pests') are deliberately reduced. This approach to the agro-ecosystem has dominated modern agricultural practice, and implies the simplification of ecosystems (Jackson *et al.* 2005; forthcoming; Pascual and Perrings forthcoming; Perrings *et al.* 2006). The result is that modern intensive agriculture has largely ignored symbiotic interactions and resource use complementarities between species.

More recently, approaches to agricultural intensification are being discussed as a way to reduce *ex situ* impacts on non-agricultural habitats to conserve wild biodiversity at the landscape level (Green *et al.* 2005). At the same time, it is being proposed that ecosystem sustainability is related to the maintenance of specific ecosystem functions, through functional diversity, rather than conserving species *per se* (Altieri 1999). Agricultural sustainability would then be about preserving species that support the necessary ecosystem functions rather than about the diversity of species (Tilman *et al.* 1996; 2001). The economic implications can be important, as is now being recognised in agricultural and natural resource economics (Pascual and Perrings forthcoming).

As a result, the role of biodiversity in agro-ecosystems is disputed and further research is being called for (Jackson *et al.* 2005). For instance, additional species might reduce agricultural productivity of the main crop through competition (for nutrients, light, etc.), or alternatively might increase output by supporting landscape-level ecosystem functions that help to enhance productivity, e.g. through pollination, soil nutrient enhancement, integrated pest control, rotational effects, etc. (Tscharntke *et al.* 2005). Although the time scales of these effects may differ, thus creating a complex picture of the effect of biodiversity on crop output, there is a potential balance between direct competition among different species and the functional support provided by non-crop species for the growing crop.

While agro-ecologists analyse the potential balance/trade-off often in farm-based field experiments (e.g., Tscharntke *et al.* 2005), economists often focus on the actual use-value provided by agriculture through agricultural markets, i.e., the 'realised' supply of biodiversity and crop output. For instance, some authors have analysed the contribution of crop diversity to the actual (realised) productivity and variability of a main crop output and farm income (Smale *et al.* 1998; Di Falco and Perrings 2003, 2005). However, these studies are mostly based on non-intensive agricultural systems, where biodiversity is relatively high. But biodiversity-related loss of ecosystem services may matter more in biodiversity-poor managed or heavily impacted systems than in biodiversity-rich 'wild' or lightly impacted systems (Perrings *et al.* 2006).

In this chapter, we investigate the economic effects of biodiversity conservation on productivity in an intensive agricultural landscape. Intensive practices have effectively simplified the relevant ecosystem by replacing the natural system's internal regulatory processes with high levels of chemical and mechanical inputs (Jackson *et al.* 2005; forthcoming). We address the dynamics of this relationship using a bio-economic model that describes the effect of 'associated' on-farm biodiversity' (Altieri 1999) on the supply of marketable crop output. The theoretical results on the optimal dynamic relationship between crop output, productivity and biodiversity are tested empirically using economic and ecological data from a panel of specialised cereal producers in the UK, where there is evidence that on-farm biodiversity is declining over recent decades (Winter 2000; Stoate *et al.* 2001).

There have been recent assessments of productivity in the UK agricultural sector (Thirtle and Bottomley 1992; Wilson *et al.* 2001). However, there have been few attempts to assess productivity while also accounting for environmental externalities. Notable exceptions are Barnes (2002) and Thirtle and Holding (2003), which focus on pesticide pollution. The empirical model used here focuses on productivity and changes in biodiversity.

The rest of the chapter is organised as follows. The next section presents the theoretical model of the effects of biodiversity on crop output. Section 3 describes the data used in the empirical analysis and Section 4 presents the econometric results, based on a stochastic production frontier approach. The final section recapitulates the main findings and draws out the main implications for the sustainable conservation of biodiversity in intensive agricultural systems.

2 A model of biodiversity change in intensive agriculture

The model assumes that economic decisions such as the optimal allocation of agricultural inputs, for a given area of farm land, are motivated both by levels of crop output and by the agro-ecosystem's environmental quality, reflected by the state of on-site biodiversity. It is assumed that decision-makers maximise the discounted present value of utility flows derived from both outputs.[1]

The stylised direct utility function is specified as $U = U(y_t, b_t)$ where y_t represents the flow of 'marketable' agricultural output at time t, and b_t is biodiversity loss, also a flow variable. This loss is attributable to intensive use of artificial inputs, x_t, which therefore negatively impacts on utility, i.e. $U_y > 0, U_{yy} < 0$, and $U_b < 0, U_{bb} < 0$, for a strictly concave and linearly separable utility function. This specification reflects a subset of economic decisions that would affect land use activities, and the welfare that these activities generate. The problem is to find the inter-temporal optimal levels of utility yielding services (flows) based on (1) marketable agricultural supply and (2) physical depreciation of biodiversity.[2]

Following recent studies (e.g., Tscharntke *et al.* 2005), the crop production function is assumed to be affected by the stock of biodiversity, z_t, alongside the conventional agricultural input set x_t. In addition, the 'state of the art' of agricultural technology is captured by a_t, as an exogenous shifter of the production possibility frontier, representing neutral technical progress Normalising the unit price of crop output, the value production function is represented by $f(x_t, z_t, a_t)$, which is assumed to exhibit well-behaved properties, i.e. $f_i > 0, f_{ii} < 0$ for $i = x_t$, z_t and a_t, and to be linearly separable in all its elements. We further assume that the stock z_t can be increased by conservation investment, c_t. Thus, we assume that the farmer accounts for the evolution of the stock of biodiversity in the agro-ecosystem by allocating the total proceeds from agricultural production, $f(x_t, z_t, a_t)$, to: (1) some 'marketable (value) output' y_t, and also (2) expenditure (investment) for biodiversity conservation.[3] So,

$$c_t = f(x_t, z_t, a_t) - y_t \tag{8.1}$$

If the focus is on the functional diversity of species, the effect of a change in z_t, on the marginal product of x_t is likely to be different at each level or sublevel of z_t. For example, an increase in insect or micro-organism diversity would increase the marginal product of fertiliser if it enhances soil productivity ($f_{xz} \geq 0$). On the other hand, an increase in natural vegetation diversity might decrease the marginal product of fertiliser if it increases the competition with cultivated crops ($f_{xz} \leq 0$).

The biodiversity impact (or loss) function, which results in disutility, is expressed by $b_t = b(x_t, z_t)$. Following Altieri (1999), the ability of the agro-ecosystem to tolerate and overcome the potential adverse effects of agricultural land use activities depends on the current biodiversity stock, z_t such that. $b_z < 0, b_{zz} > 0$. At the margin, biodiversity loss increases (decreases) at an increasing (decreasing) rate due to increases in input intensification, i.e. $b_x > 0, b_{xx} > 0$, for simplicity, $b_t = b(x_t, z_t)$ is also assumed to be linearly separable in x_t and z_t.

To maximise utility, the farmer needs to choose the optimal levels of the control variables y_t and x_t, at each point in time, subject to the evolution of z_t. This evolution reflects biodiversity stock, conservation investments, c_t, and artificial input use, x_t, that reflects the level of intensification.

$$\dot{z} = g(z_t, c_t, x_t) \tag{8.2a}$$

The evolution of biodiversity is captured by equation (7.2a), which can be interpreted as an extended logistic function to allow a closed form solution of:

$$\dot{z} = a_1 z_t (1 - z_t / k) + a_2 c_t - a_3 x_t \tag{8.2b}$$

The natural rate of growth of the biodiversity stock is given by $a_1 > 0$. The parameter k reflects the maximum potential diversity that could be sustained in the ecological system.[4] According to equation (8.2b), z_t is density dependent and it also increases with investment in conservation, a_2 being the rate of induced growth. The parameter a_2 can also be interpreted as the marginal degradation in z_t caused by increase in y_t (from 8.1 above), negatively affected by input use (intensification), reflected by the parameter a_3. It is worth noting that while biodiversity is considered to be natural capital, it is assumed here that no depletion in biodiversity occurs as a result of its supporting role in the production process. In intensive agricultural systems, which are biodiverse poor relative to their potential maximum (e.g., their 'wild' state), the term z_t/k can be considered as negligible, and thus (8.2b) can be simplified through further approximation as:

$$\dot{z} = a_1 z_t + a_2 c_t - a_3 x_t \tag{8.2c}$$

The optimisation problem is expressed, for a positive utility discount rate ($\rho > 0$) as:

$$\max_{y, x, c} W(y_t, b_t) = \int_{t=0}^{\infty} e^{-\rho t} U(y_t, b_t) dt \tag{8.3}$$

subject to: (1) the environmental conservation investment function (equation 8.1); (2) the evolution of z_t, (equation 8.2a); (3) the impact function $b(.)$; (4) the initial condition $z(0) = z_0$ and (5) the non-negativity constraints $x \geq 0$ and $b \geq 0$. This yields the current-value Hamiltonian:

$$\tilde{H} = U(y_t, b_t) + \varphi(a_1 z + a_2 f(.) - a_2 y_t - a_3 x_t) \tag{8.4}$$

where φ is the current shadow value of biodiversity. The properties of the optimal trajectories for the state and control variables can be deduced after applying the Maximum Principle, and a subset of these properties are illustrated by a phase diagram in the (z_t, y_t) space (Figure 8.1). Figure 8.1 depicts the joint evolution of $\dot{z} = g(z_t, y_t)$ and $\dot{y} = h(z_t, y_t)$ as a saddle-path towards the steady state (long-run) equilibrium with two convergent isosectors (labelled I
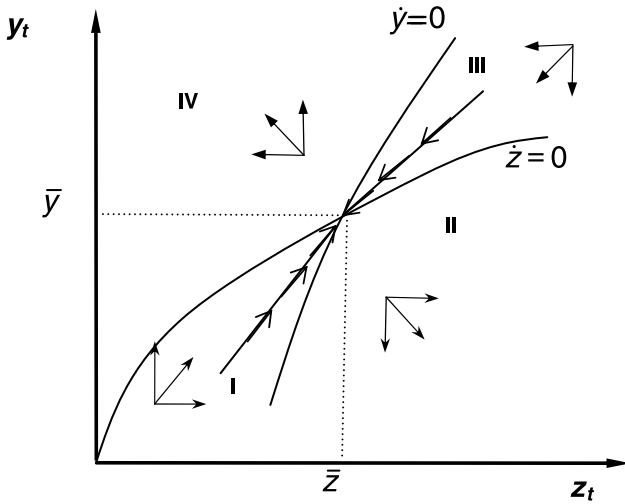
Figure 8.1 Saddle point equilibrium in the biodiversity–marketable output (z_t, y_t) phase space.

and III). For the current analysis, attention is focused on low-biodiversity intensive agro-ecosystems represented by points within isosector I.

The effect on optimal crop output supply of a change in the stock of biodiversity z_t, can be investigated from both a comparative static and a dynamic perspective. It can be shown that the optimal supply of marketable output can increase (albeit at a declining rate) along the transition path to the long-run equilibrium of output and biodiversity stock when the latter increases in the transition towards the steady state.[5]

The issue being addressed here is whether increasing productivity is consistent with biodiversity conservation in agricultural landscapes, and hence whether policies to promote sustainable agriculture should focus on promoting low-yield extensive production practices, or seek to develop high-yielding sustainable technologies with their attendant advantages for food security and land use. The positive relationship suggested by the theoretical analysis supports the latter approach. In the remainder of this chapter we set out an empirical test of this relationship, using a frontier production function to represent the production surface in the theoretical model and constructing a data set that allows estimates of the relevant parameters.

3 The data

The production data used in this study come from a panel of approximately 230 cereal producers from the East of England, for the period 1989–2000, yielding a total sample size of 2,778 observations in an unbalanced panel. The data are from the UK's annual Farm Business Survey (FBS) undertaken

by the Department of Environment, Food and Rural Affairs of the UK
(DEFRA 2002). Further, the UK Countryside Surveys (CS2000) undertaken
in 1978, 1990 and 1998 have been used to construct a farm-level biodiversity
index (Haines-Young *et al.* 2000).

The data set includes information on cereal output, level of input applica-
tion, participation in and payments from agri-environmental schemes, and
socio-economic characteristics of the farm households. In addition, a vari-
able measuring on-farm functional biodiversity is constructed. The per-
hectare variables used in the econometric model are: crop enterprise output
(marketed), hired and imputed family labour, use of machinery, fertilisers
and pesticides, and the biodiversity index (BI). All the variables, except for
BI, are derived from value measures deflated by the relevant Agricultural
Price Index (base year 1989), and are thus measures of volume. Summary
descriptive statistics for these variables appear in Table 8.1.

The data allow the estimation of stochastic production frontier (SPF)
models that provide an explicit representation of the production surface
underlying the theoretical analysis, where it is assumed that farmers
optimally adjust their production processes so that they operate along the
production frontier.

Frontier models can be traced back to Farrell's (1957) and Shephard's
seminal theoretical work. Aigner *et al.* (1977) and Meeusen and van den
Broeck (1977) introduced contemporary empirical approaches to dealing
with stochastic production frontier models. Since then, a large and increasing
body of literature that focuses on estimating agricultural production frontiers
has appeared. Here, we estimate separate stochastic frontier production func-
tions, of the type proposed by Battese and Coelli (1995). One weakness of the
SPF approach, relative to nonparametric approaches such as data envelop-

Table 8.1 Summary statistics for variables in the stochastic frontier models for cereal
farmers in the East of England

Variable	Mean	St. Dev	Minimum	Maximum
Crop output (£/ha/API)	874.85	194.49	261.55	5141.61
Biodiversity index (BI)	13.63	1.04	9.99	16.22
Fertiliser application (£/ha/API)	87.55	32.78	0.68	571.90
Labour application (£/ha/API)	163.87	92.56	3.34	1093.45
Machinery application (£/ha/API)	208.98	93.51	12.55	1382.01
Pesticide application (£/ha/API)	91.41	27.57	1.99	345.62
Farm area (ha)	178.58	137.21	7.89	1008.18
Farmer's age (years)	50.91	10.52	27	79
Environmental Payments (£/ha/API)	2.77	11.00	0	93.63
Share of hired labour from total labour (0–1)	0.44	0.25	0	1

Note: A total of 2,788 observations were obtained in an unbalanced panel of approximately 230
different specialist cereal farms over the period 1989–2000. API: Agricultural Price Index for the
relevant inputs (or output) and year.

ment analysis (DEA) (e.g., Lansink and Reinhard 2004), is the potential for mis-specification of the functional form of the production technology. However, the strength of the SPF is that it allows for white noise or random fluctuations representing influences outside the control of farmers. Since in agriculture, even in intensive systems, random fluctuations are important, we use the SPF approach rather than DEA.

The key dynamic relationship between agricultural activity and biodiversity is based on measures of species diversity from the UK Countryside Survey (Haines-Young *et al.* 2000, 2003) and indices of input use and conservation activity on panel farms from the UK Farm Business Survey (DEFRA 2002). Because data from the Countryside Survey is not fully integrated with data from the Farm Business Survey (due to issues related to confidentiality of farm business records), this relationship cannot be directly estimated in conjunction with the production frontier. Instead, the adopted approach is to initially estimate parameters of this relationship for the panel as a whole, and then apply these parameter values to the farm-level data set to generate a farm-level biodiversity index (BI) for all farms over the period 1989–2000. The BI is constructed following a three-step process.

The first step is to construct an aggregate biodiversity index for the whole area studied, based on measures of plant species richness from individual survey plots. This information corresponds to the so-called Environmental Zone 1 (EZ1) in the UK Countryside Survey that covers major parts of the eastern lowland counties of England and overlaps closely with the area spanned by the panel of farms in this study. The environmental zone thus reflects an aggregation of land classes chosen to reflect major environmental variation. Hence, the biodiversity index exploits information disaggregated by eight 'aggregate vegetation classes' (AVC)[6] and ten so-called 'broad habitat' (BH) types within EZ1.

The idea is to take into account biodiversity of agricultural landscapes that include non-cropped areas such as field margins, hedgerows and other semi-natural habitats embedded in the cropping area. This is consistent with a number of ecological studies (e.g. Altieri 1999; Tscharntke *et al.* 2005) that emphasise the role of landscape level biodiversity (associated andfunctional) affecting the ecological functioning of arable agro-ecosystems. The aggregation approach used to construct the biodiversity index is described by Wenum *et al.* (1999). The index (representing the variable *z* in the theoretical model) is given by:

$$z = \sum_j \sum_i a_j n_{ij} s_{ij} \tag{8.5}$$

where, s_{ij} is the mean plant species richness on a given plot located in aggregate vegetation class (AVC) i within broad habitat (BH) type j; n_{ij} stands for the measure of *AVC-i* dominance in BH type-*j*, i.e. the number of AVC-*i* plots in BH type-*j* relative to the total number of plots of all AVCs in BH-*j*; lastly a_j

is a scalar associated with *BH-j* dominance, i.e. the relative area of BH_j within Environmental Zone 1. Using this approach, an aggregated index is derived for five periods. Besides the 1978, 1990 and 1998 periods for which the data from the major ecological surveys are available, two additional observations, for 1997 and 1999, have been constructed from the national estimates on each AVC published as part of CS2000 results adjusted for EZ1. The data for 1978 are not presented by broad habitat (BH), so the BH breakdown from 1990 is used as a proxy for 1978 by merging the two data sets at plot level and then using only those plots for 1978 which are repeated in 1990 to construct the 1978 value of the index.

In the second step, the evolution of the biodiversity index at the aggregate level is calibrated as a non-linear discrete-time aggregate version of equation (8.2b). This requires calibration of biodiversity conservation, ct, and biodiversity-degrading input intensification, x_t on biodiversity. The indices of input use intensity and biodiversity conservation are derived from the Farm Business Survey sample.

$$z_{t+1} - z_t = a_1 \ln z_t + a_2 c_t - a_3 \ln x_t, \tag{8.2b'}$$

where c_t is proxied by categorical-dummy variable (1/0) showing whether the farmer is a beneficiary of the introduction of agri-environmental schemes following the EU's Common Agricultural Policy reform in 1992, and x_t is average per hectare pesticide use on the sample farms.[7]

The calibrated parameter values (standard deviations in brackets) are: $a_1 = 0.32$ *(0.18)*, $a_2 = 0.31$ *(0.41)*, $a_3 = 2.24$ *(0.88)*. The last step involves using the parameterisation of the state equation at EZ1 level, in an iterative process, to estimate the value of z_t for each farm in the panel, given the existing farm-level observations for c_t, x_t, and a farm-level starting value for z_0.

4 The empirical model

In order to test the key proposition from the theoretical model, a reduced form dynamic parametric frontier model is used and fitted to the data from the panel of cereal farmers from the East of England during 1989–2000. The stochastic production frontier (SPF) approach allows estimation of both the output production frontier that represents best practice among farmers (as assumed in the theoretical model) and the possibility of real deviations from the frontier attributed to the effects of variation in the sampled farmers' level of technical efficiency (TE). Controlling for technical inefficiency, it is possible to qualify the key relationships derived from the theoretical model along the production frontier as it evolves over time. It should be noted that the frontier provides a closer approximation to the 'optimal path' than a more traditional econometric specification, which does not allow for technical inefficiency. Hence, the data on marketed crop output is used to estimate the output optimal path, reduced to an estimable function $y(x_t, z_t, a_t)$.

The model fitted to the 12 years, $t = 1, 2, \ldots, T$, and farm-specific data, i, takes the following form:[8]

$$y_{it} = \beta_0 + \sum_k \beta_k \, p_{kit} + v_{it} - u_{it} \qquad (8.6)$$

where:

y_{it} = natural log of crop marketed output of farm i at time t ($\times$ £100 per hectare/Agricultural Price Index)

p_1 = natural log of BI (biodiversity index)

p_2 = natural log of fertiliser input value ($\times$ £100 per ha/API)

p_3 = natural log of labour input value ($\times$ £100 per ha/API)

p_4 = natural log of machinery input value ($\times$ £100 per ha/API)

p_5 = natural log of pesticide input value ($\times$ £100 per ha/API)

p_6 = year of observation where $p_6 = 1, 2, \ldots, 12$.

Assuming that v_{it}s are independently and identically distributed random errors $N(0, \sigma_v^2)$, independent of the non-negative random error term, u_{it}, associated with technical inefficiency in production, β_k is the parameter vector to be estimated.

The assumption that farms cluster around the efficiency frontier and that their frequency decreases with rising inefficiency levels, implies that the distribution of the residuals is negatively skewed. In other words, it should have the 'longer tail' on the low efficiency side. Hence, the first step in the estimation procedure is to check the sign of the third moment and the skewness of the OLS residuals associated with the sample data (Waldman 1982). The third moment of the OLS residuals for the models is −0.003. The negative sign suggests that the residuals of the sample data possess the correct pattern for the implementation of the MLE procedure, hence the justification of the model specification.[9] Results for three general Cobb-Douglas SFP models, based on different specifications for the error term u_{it}, are presented, (equations 8.7a–8.7c).

Several versions of each of these three models are estimated using FRONTIER4 (Coelli 1996), such as the trans-log model, although this is not presented here because the statistical significance of the estimated parameters are masked by significant multicolinearity between the interaction terms. We thus present the results of a standard generalised Cobb-Douglas functional form as the approximate representation (to the true yet unknown) agricultural technology.

Model 1 is a time-varying inefficiency model, in which the inefficiency effect is defined as (Battese and Coelli 1992):

$$u_{it} = \{\exp[-\eta(t - T)]\}u_i \qquad (8.7a)$$

where η is an unknown parameter to be estimated, and $u_i = 1, 2, \ldots, N$, are independent and identically distributed non-negative random variables obtained by the truncation, at zero, of a $N(\mu, \sigma_u^2)$ distribution. The relative technical efficiency between farms is obtained by scaling it by a factor that increases (if η is positive) or decreases (if η is negative) deterministically over time. This specification assumes that the ranking of farms is unchanged over time and the inefficiency evolves identically for all farms.

Model 2 corresponds to a neutral inefficiency effects model, the inefficiency effects being defined as (Battese and Coelli 1995):

$$u_{it} = \delta_0 + \sum_j \delta_j q_{jit} + w_{it} \tag{8.7b}$$

where w_{it} is an unobservable non-negative random variable assumed independent and identically distributed, obtained by the truncation at zero of a $N(0, \sigma_u^2)$ distribution. The δ_j coefficients are associated with the effects of the following inefficiency effects covariates:

q_1 = natural log of farmer's age (years)
q_2 = natural log of the amount of environmental payment (subsidies) obtained by the household
q_3 = dummy variable, 1 if the farm participates in any agri-environmental scheme introduced in 1992, 0 otherwise
q_4 = proportion of hired to total labour applied in the farm
q_5 = dummy variable, 1 if use of hired labour hours, 0 otherwise
q_6 = year of observation, $t = 1, 2 \ldots, 12$.

Model 3 is a non-neutral inefficiency model (Battese and Broca 1997):

$$u_{it} = \delta_0 + \sum_j \delta_j q_{jit} + \sum_j \sum_k \delta_{jk} p_{kit} q_{jit} + w_{it} \tag{8.7c}$$

This model is an extended version of Model 2, with interactions between farm-specific variables and the input variables in the stochastic frontier. This approach is similar to the approach by Pascual (2005) to test the bidirectional effect of soil fertility (also an environmental input) with potential simultaneous effects on frontier output and TE.

Table 8.2 shows the results of various hypothesis tests regarding the specification of the three models. Given the specification of model 1, the null hypothesis that deviations from the frontier are insignificant (technical inefficiency is absent), i.e. $H_0: \gamma = 0$, is strongly rejected by the data, parameter γ being defined as $\gamma \equiv \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$. The hypotheses of a time stationary frontier (no technical change), $H_0: \beta_6 = 0$, and deviations (technical inefficiency effects) as being time invariant, $H_0: \eta = 0$, are also rejected by the data at any meaningful significance level. In addition, the half-normal distribution

Table 8.2 Generalized likelihood-ratio tests for SPF models for cereal farmers in the East of England 1989–2000

Null hypothesis	Log likelihood	LR statistic	CV* (5%)
Model 1	1604.34		
$H_0: \gamma = 0$	1007.31	1194.07	7.05
$H_0: \beta_6 = 0$	1311.12	586.44	3.84
$H_0 = \eta = 0$	1586.76	35.17	3.84
$H_0 = \mu = 0$	1602.66	3.36	3.84
Model 2	1261.79		
$H_0: \gamma = \delta_0 = \delta_j = 0$	1007.31	508.97	16.27
$H_0 = \beta_1 = 0$	1257.26	9.07	3.84
$H_0 = \beta_6 = 0$	1084.93	353.72	3.84
$H_0: \delta_1 = \ldots = \delta_6 = 0$	1159.36	204.87	12.59
Model 3	1361.13		
$H_0: \gamma = \delta_0 = \delta_j = \delta_{jk} = 0$	1007.31	707.65	55.19
$H_0 = \beta_1 = 0, \delta_{1j} = 0, j = 1, \ldots, 6$	1352.69	16.87	14.07
$H_0: \beta_6 = 0, \delta_{6j} = 0, j = 1, \ldots, 6$	1177.02	368.23	14.07
$H_0: \delta_{jk} = 0, k, j = 1, \ldots, 6$	1261.79	198.67	43.77
$H_0: \delta_{6k} = \delta_{k6} = 0, k = 1, \ldots, 6$	1318.76	84.73	11.07
$H_0: \delta_{6j} = \delta_{6j} = 0, j = 1, \ldots, 6$	1313.58	95.09	11.07
$H_0: \delta_{3k} = \delta_{4k} = 0, k = 1, \ldots, 6$	1341.35	39.56	19.92

Note: *Critical Values are also obtained from Kodde and Palm (1986). LR: Likelihood Ratio.

is an adequate representation of the distribution of the technical inefficiency effects, i.e. $H_0: \mu = 0$ cannot be rejected at the 5 per cent significance level. Under Model 2, the null hypotheses that inefficiency is absent, $H_0: \gamma = \delta_0 = \delta_j = \delta_{jk} = 0$, and that there is no technical change, $H_0: \beta_6 = 0$, are also both rejected. Additionally, the hypothesis that the neutral specification of the model outperforms Model 3 ($H_0: \delta_{jk} = 0$) is also rejected. Similarly, the null for no year interaction with the explanatory variables in the inefficiency sub-model, $H_0: \delta_{6k} = 0$ can be rejected. Therefore, the results presented in Table 8.3 correspond to Models 1 and 3.

Battese and Broca (1997) derive the elasticity of crop output with respect to kth input variable (cf. Appendix B). The elasticity of mean output with respect to the kth input variable has two components: (1) the elasticity of frontier output with respect to the kth input, given by the estimated β_k parameters and (2) the elasticity of TE with respect to the kth input.[10] The mean output, frontier and efficiency elasticities for each of the variable inputs, averaged throughout the 1989–2000 period, are presented in Table 8.4.

Before any meaningful policy implication can be discussed based on the coefficient estimates of the frontier model, the data need to be tested for theoretical consistency (Sauer *et al.*, 2006). The two main theoretical assumptions to be checked are the ones of monotonicity and concavity. In other words, the check is about whether our data support the *a priori* assumption of the law of diminishing marginal rate of technical substitution. The necessary

Table 8.3 MLE parameter estimates of the generalized Cobb-Douglas SPF models 1 and 3

		Model 1		Model 3	
		Coefficient	*t-ratio*	*Coefficient*	*t-ratio*
Constant	β_0	1.81	23.49	1.69	12.33
p1: biodiversity	β_1	0.07	2.58	0.13	2.58
p2: fertiliser	β_2	0.04	5.17	0.05	4.03
p3: labour	β_3	0.02	2.91	0.01	2.91
p4: machinery	β_4	0.08	8.56	0.05	4.16
p5: pesticides	β_5	0.14	14.47	0.14	11.63
p6: time	β_6	0.05	35.91	0.04	31.67
Inefficiency model					
constant	δ_0			−0.60	−3.62
q1: age	δ_1			−0.05	−2.47
q2: environmental pay	δ_2			0.10	3.50
q3: d1	δ_3			−0.68	−0.73
q4: hired labour	δ_4			0.38	0.42
q5: d2	δ_5			0.71	0.77
q6: time	δ_6			0.29	2.16
p1.q1	δ_{11}			0.02	2.78
p1.q2	δ_{12}			−0.04	−3.50
p1.q3	δ_{13}			0.42	1.18
p1.q4	δ_{14}			−0.04	−0.11
p1.q5	δ_{15}			−0.24	−0.70
p1.q6	δ_{16}			−0.08	−1.66
p2.q1	δ_{21}			0.01	4.74
p2.q2	δ_{22}			−0.01	−2.83
p2.q3	δ_{23}			0.75	5.16
p2.q4	δ_{24}			0.22	2.41
p2.q5	δ_{25}			−0.20	−2.62
p2.q6	δ_{26}			−0.04	−6.27
p3.q1	δ_{31}			0.00	3.09
p3.q2	δ_{32}			0.00	1.81
p3.q3	δ_{33}			−0.19	−2.43
p3.q4	δ_{34}			−0.19	−3.33
p3.q5	δ_{35}			−0.05	−1.29
p3.q6	δ_{36}			0.02	4.02
p4.q1	δ_{41}			0.00	1.29
p4.q2	δ_{42}			−0.01	−2.93
p4.q3	δ_{43}			0.11	0.92
p4.q4	δ_{44}			−0.46	−5.14
p4.q5	δ_{45}			0.24	3.76
p4.q6	δ_{46}			0.00	−0.50
p5.q1	δ_{51}			0.01	5.45
p5.q2	δ_{52}			0.00	0.79
p5.q3	δ_{53}			0.10	0.92
p5.q4	δ_{54}			−0.05	−0.58
p5.q5	δ_{55}			−0.38	−5.81
p5.q6	δ_{56}			−0.05	−6.74
p6.q1	δ_{61}			0.00	1.63

Table 8.3 Continued

		Model 1		Model 3	
		Coefficient	t-ratio	Coefficient	t-ratio
p6.q2	δ_{62}			0.00	2.10
p6.q3	δ_{63}			−0.02	−1.59
p6.q4	δ_{64}			−0.05	−5.30
p6.q5	δ_{65}			−0.06	−4.86
p6.q6	δ_{66}			−0.01	−13.34
Variance Parameters					
σ^2		0.05	11.10	0.08	17.05
γ		0.73	28.35	0.86	63.98
η		0.04	6.00		
Log-likelihood		1586.76		1361.13	

Notes: d1: Dummy variable for participation in agri-environmental schemes (1 if participating, 0 otherwise); *d2* dummy variable for hired labour (1, if positive expenditures on hired labour, 0 otherwise)

Table 8.4 Average crop output elasticities with respect to all the inputs in Model 3, 1989–2000

Variable	Frontier output elasticity	Technical efficiency elasticity	Mean output elasticity
Biodiversity	0.13	−0.10	0.04
Fertiliser	0.05	−0.02	0.03
Labour	0.01	−0.05	−0.03
Machinery	0.05	0.00	0.05
Pesticides	0.14	0.14	0.28
Time	0.04	0.09	0.13

and sufficient condition of local concavity can be checked by using the average values of the output and the input vector as the points of approximation. It can be shown that the conditions for the desired curvature criterion of the estimated production frontier function are met, as the negative definiteness of the Hessian matrix indicates (Appendix C). In addition, it can also be shown that the monotonicity check is passed, given the positive frontier elasticities and the non-negative values of the inputs/output for every observation. Lastly, besides the positive marginal products, these are decreasing in input levels, at the point of approximation (Table 8.5).

Change in crop supply can be investigated by obtaining estimates of the time derivative of the realised mean crop output. From Table 8.3 it can be seen that the estimated time coefficient is significantly different from zero, and points towards technical progress of the crop output frontier of about 5 per cent per annum. The decomposition of productivity growth into (1) technical change in the frontier and (2) TE change is depicted in Figure 8.2 for the

Table 8.5 Test of theoretical consistency (*monotonicity and concavity*): first and second derivatives at the point of approximation (sample means)

Derivative	Value	Derivative	Value	Hessian minor	Value
$f_1 > 0$	8.3441	$f_{11} < 0$	−0.5326	$|H_1| = f_{11} < 0$	−0.53260
$f_2 > 0$	0.4996	$f_{22} < 0$	−0.0054	$|H_2| > 0$	2.8648×10^{-3}
$f_3 > 0$	0.0534	$f_{33} < 0$	−0.0003	$|H_3| < 0$	-9.2193×10^{-7}
$f_4 > 0$	0.2093	$f_{44} < 0$	−0.0010	$|H_4| > 0$	8.664×10^{-10}
$f_5 > 0$	1.3399	$f_{55} < 0$	−0.0126	$|H_5| < 0$	-1.0499×10^{-11}
$f_6 > 0$	34.9940	$f_{66} < 0$	−4.4326	$|H_6| > 0$	4.4452×10^{-11}
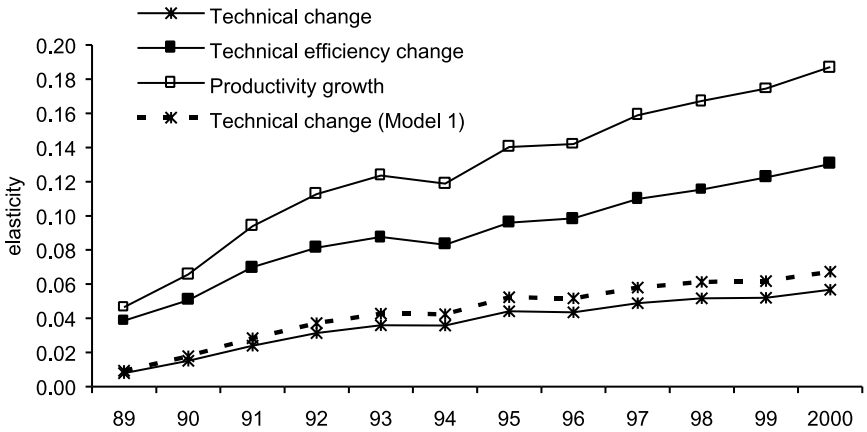
Figure 8.2 Technical change and productivity growth, 1989–2000.

whole period. According to the data, there has been technical progress in frontier output reaching 5.7 per cent in 2000. This result is consistent with the results by Thirtle and Holding (2003) for cereal farms in the UK who find frontier efficient performance improving at over 5 per cent per year in the UK. Our results indicate that the rate of technical change along the frontier is positive (about 3.7 per cent per year) and that it has not declined. In fact, the change in technical efficiency has been positive throughout the period, and may reflect the turnover of farms during the 1990s where smaller, less-efficient farms have been leaving the sector and larger, more efficient ones are increasing in scale (data for 1997–2002 show average cereals area per farm increasing by around 14 per cent from 48 to 55 hectares, DEFRA 2003).

Biodiversity positively affects mean output levels over the whole period, even though greater levels of biodiversity appear to have negatively affected TE in the sector (Table 8.4). This has also occurred with the application of fertilisers and more dramatically with the use of farm labour. The negative effect of farm labour on efficiency seems to outweigh the positive effect on the frontier, implying over-use of labour in cereal farming. By contrast, the relatively large mean output elasticity for pesticide use is due to its positive

effect both on the frontier and on TE. This impact on mean output is consistent with a range of other studies that suggest underutilization of pesticides in crop production (e.g. see Lansink and Reinhard, 2004), while the increase in technical efficiency may point towards the role of pesticides in reducing output variability by controlling damaging pest outbreaks.

What is of more interest here is the effect of the evolution of the stock of biodiversity, proxied by BI (z_t), on the levels of 'frontier output', since this is directly associated with optimal marketable crop output as described in the theoretical model (variable y_t). The results as depicted in Figure 8.3 are consistent with the hypothesis from the theoretical model: that there is a positive, although declining, effect. The frontier elasticities with respect to BI are positive and have tended to decrease at a rate of 0.06 per cent per annum. It also appears that the effect of the stock of biodiversity on TE has been different before and after 1996. While there is initially a negative elasticity of TE, after 1996 the elasticity becomes positive reaching 0.15 in 2000. The net effect of biodiversity through the impacts on both frontier output and TE indicates that higher levels of biodiversity were associated with declining mean yields (average elasticity of −0.1) until 1993 (the year after broad environmental payments were introduced in the farming sector). After the incorporation of the environmental payments for biodiversity conservation, the impact on mean output has reversed with an elasticity in 2000 of 0.26. These results suggest that biodiversity conservation schemes have not undermined the productive performance of the cereal sector.
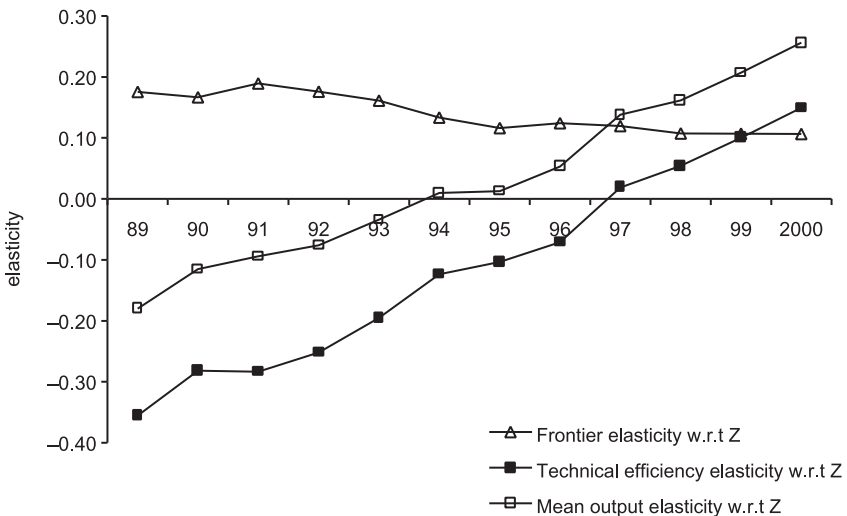
Figure 8.3 Change in elasticity of output with respect to biodiversity, 1989–2000.

5 Conclusions

A distinguishing characteristic of modern agricultural landscapes is the increasing size and homogeneity of crop monocultures. The concerns for the potentially negative environmental effects of monocultures are well established, although relatively less attention is being paid to the economic effects of biodiversity loss. While ecologists mostly agree that increased intensification is the driver of biodiversity loss, the feedback effects on productivity are less well understood. On the one hand, increasing the number of species on a farm may reduce productivity levels of the main crop in the short run through greater competition for abiotic and biotic resources. On the other hand, biodiversity, by providing ecological services (e.g. through pollination, soil nutrient enhancement, and integrated pest control) may increase agricultural output in the longer run (Jackson *et al.* forthcoming).

This chapter has explored one key link between conservation of biodiversity and crop output in the context of a specialised intensive farming system. A behavioural model is used to establish the hypothesis that biodiversity can support increased marketable output in the longer run, by outward shifts in the production frontier. The key factors behind this theoretical result are: (1) an agricultural technology in which there is a positive relationship between biodiversity and agricultural productivity; and (2) decision-maker preferences that reflect this positive relationship and generate resource allocation decisions that support it.

The empirical analysis to test this hypothesis is based on an output distance function approach using data from cereal farms in England for the period 1989–2000. The econometric analysis does not reject the hypothesis. This has important implications for the design of agri-environmental policy, since it suggests that the introduction of biodiversity conservation policies can represent a win–win scenario. This study supports the claim that biodiversity in agricultural landscapes can be enhanced without negatively affecting agricultural productivity in intensified agricultural systems so long as the correct incentives are put in place. These empirical results complement the findings of McInerney *et al.* (2000) that additional conservation investment induced by the agri-environmental policy system can generate additional efficiency benefits for farmers and society at large through supporting and enhancing agricultural multifunctionality.

These results support the view that increasing productivity is consistent with biodiversity conservation and that policies to promote sustainable agriculture can focus on developing high-yielding sustainable technologies with their attendant advantages for food security and land use. This is not inconsistent with the current structure of the reformed schemes of the EU CAP, in that biodiversity conservation is encouraged, at least in principle, at all levels.[11] What remains, however, is a range of uncertainties about how the implementation of these schemes might be fine-tuned to deliver a truly

multifunctional agro-ecosystem that follows a trajectory of sustainable intensification.

This area of promising research clearly needs greater interdisciplinary scope, in particular, to refine the integration between ecologically meaningful biodiversity information and economically consistent data at both the farm and the landscape scale. Landscape analysis is also important, since the interactions between farmers and off-farm species should be taken into account in both theoretical and empirical research.

Appendix A The theoretical model

The maximum principle

From the Hamiltonian (cf. equation 8.4), eliminating the time subscript for convenience, the first order conditions for an optimal interior solution are:

$$U_y - a_2\varphi = 0 \tag{A1a}$$

$$U_b b_x + \varphi(a_2 f_x - a_3) = 0 \tag{A1b}$$

$$\dot{\varphi} = -U_b b_z - \varphi(a_2 + a_2 f_z - \rho) \tag{A1c}$$

$$\dot{z} = a_1 z + a_2 [f(.) - y] - a_3 x \tag{A1d}$$

Condition (A1a) establishes that the current shadow value of biodiversity (φ) is positive, while (A1b) states that x should be allocated such that the marginal utility and disutility of artificial input use are balanced. For an interior solution, the bracketed term ($a_2 f_x - a_3$) is positive as φ is positive and the first term is unambiguously negative. Equation (A1c) is the standard non-arbitrage condition which dictates that for an optimal solution, no gain in utility can be achieved by reallocating natural capital in the form of biodiversity from one period to another. This occurs when the current marginal return to z equals its marginal cost.

It can be shown that the current value Hamiltonian is maximised and that the solution of the first order conditions leads to a steady state solution marked as ($\bar{z}, \bar{y}, \bar{x}, \bar{\varphi}$) and that this is reachable from the initial state condition $z(0) = z_0$. Thus, there is an implicit terminal state $\lim_{t \to \infty} z_t = \bar{z}(\varphi)$ where φ is a vector of exogenous parameters (see Pascual *et al.* 2003, for further details).

Steady state and optimal paths for y_t and z_t:

The following differential equation for y_t is derived from the basic solution:

$$\dot{y} = -\frac{U_y}{U_{yy}}\left[a_1 - \rho + a_2 f_z - (a_2 f_x - a_3)\frac{b_z}{b_x}\right] \tag{A2}$$

which together with the evolution of biodiversity (A1d) describes the dynamic system of equations in (z_t, y_t) space: $\dot{y} = h(z_t, y_t)$ and $\dot{z} = g(z_t, y_t)$. Since at equilibrium, the steady state occurs when $\dot{z} = \dot{y} = 0$. The isoclines for z_t and y_t are respectively given by:

$$g(z, y) \equiv a_1 z + a_2 f(.) - a_2 y - a_3 x = 0 \qquad (A3a)$$

$$h(z, y) \equiv a_1 - \rho + a_2 f_z - (a_2 f_x - a_3)\frac{b_z}{b_x} = 0 \qquad (A3b)$$

Qualitatively, the two demarcation curves ($\dot{z} = 0$ and $\dot{y} = 0$) divide the phase space into four regions, with a different mix of time derivatives for y_t and z_t (cf. Figure 8.1).

The steady state values of y_t and z_t are derived from the linearised system of equations (A3a–A3b). The Jacobian matrix, J_S, evaluated at the steady state $(\bar{z}, \bar{y})$ is:

$$J_s = \begin{bmatrix} g_z & g_y \\ (+) & (-) \\ h_z & h_y \\ (-) & (+) \end{bmatrix} \equiv \qquad (A4)$$

$$\begin{bmatrix} a_1 + a_2 f_z + (a_2 f_x - a_3)x & -a_2 + (a_2 f_x - a_3)x \\ a_2 f_{zz} - \left[\dfrac{(a_2 f_x - a_3)b_x b_{zz} + a_2 b_x b_z f_{xx} x_z - (a_2 f_x - a_3)b_z b_{xx}}{b_x^2}\right] & -\dfrac{[a_2 b_x b_z f_{xx} - (a_2 f_x - a_3)b_z b_{xx}]x_y}{b_x^2} < 0 \end{bmatrix}$$

the sign of the J_s is negative provided that the slope of the $\dot{y} = h(z_t, y_t) = 0$ isocline is steeper than that of the $\dot{z} = g(z_t, y_t) = 0$ isocline. The steady state equilibrium for biodiversity and output is given, respectively, by:

$$\bar{z} = -\frac{1}{|J_s|}\left[h_y(a_1 z + a_2 f(\cdot) - a_2 y - a_3 x) + g_Y \frac{U_y}{U_{yy}}\right.$$
$$\left.\left(a_1 - \rho + a_2 f_z - (a_2 f_z - a_3)\frac{b_z}{b_x}\right)\right] \quad (A5a)$$

$$\bar{y} = -\frac{1}{|J_s|}\left[-h_z(a_1 z + a_2 f(\cdot) - a_2 y - a_3 x) - g_Z \frac{U_y}{U_{yy}}\right.$$
$$\left.\left(a_1 - \rho + a_2 f_x - (a_2 f_x - a_3)\frac{b_z}{b_x}\right)\right] \quad (A5b)$$

The comparative dynamic analysis

The time paths of z_t and y_t are identified as:

$$\begin{bmatrix} \dot{z} \\ \dot{y} \end{bmatrix} = \begin{bmatrix} \dot{z}_z & \dot{z}_y \\ \dot{y}_z & \dot{y}_y \end{bmatrix}\begin{bmatrix} z - \bar{z} \\ y - \bar{y} \end{bmatrix} = J_d \begin{bmatrix} z - \bar{z} \\ y - \bar{y} \end{bmatrix} \qquad (A6a)$$

where:

$$\dot{z}_z = \frac{\partial \dot{z}}{\partial z} > 0, \quad \dot{z}_y = \frac{\partial \dot{z}}{\partial y} < 0, \quad \dot{y}_z = \frac{\partial \dot{y}}{\partial z} < 0, \ \dot{y}_y = \frac{\partial \dot{y}}{\partial y} > 0$$

The general solution is in turn given as:

$$\begin{bmatrix} z_t \\ y_t \end{bmatrix} = \begin{bmatrix} \bar{z} \\ \bar{y} \end{bmatrix} + \begin{bmatrix} z_v \\ y_v \end{bmatrix} \tag{A6b}$$

where $\begin{bmatrix} \bar{z} \\ \bar{y} \end{bmatrix}$ represents the steady state equilibrium, and $\begin{bmatrix} z_v \\ y_v \end{bmatrix}$ represents the complementary functions based on the reduced equations of the system

$$\begin{bmatrix} \dot{z} \\ \dot{y} \end{bmatrix} - \begin{bmatrix} \dot{z}_z & \dot{z}_y \\ \dot{y}_z & \dot{y}_y \end{bmatrix} \begin{bmatrix} \bar{z} \\ \bar{y} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{A6c}$$

For a dynamically stable equilibrium, $\begin{bmatrix} z_v \\ y_v \end{bmatrix} \to 0$ as $t \to \infty$. The optimal transitional paths to the steady state is given by:

$$\begin{bmatrix} z(t; z_0, \varphi) \\ y(t; z_0, \varphi) \end{bmatrix} = \begin{bmatrix} \bar{z} \\ \bar{y} \end{bmatrix} + v_1 \begin{bmatrix} 1 \\ k \end{bmatrix} e^{r_1 t} + v_2 \begin{bmatrix} 1 \\ k \end{bmatrix} e^{r_2 t} \tag{A6d}$$

for $v_1 = z(0) - \bar{z}$ when $v_2 = 0$, $k_1 = \dfrac{-\dot{y}_z - (r_1 - \dot{z}_z)}{r_1 - \dot{y}_y + \dot{z}_y} < 0$, and r_1 and r_2 being characteristic roots that for a saddle equilibrium need to be of opposite signs, e.g. $r_1 < 0$ and $r_2 > 0$. The definite solution of the dynamic system of the model, is given as:

$$\begin{bmatrix} z(t; z_0, \varphi) \\ y(t; z_0, \varphi) \end{bmatrix} = \begin{bmatrix} \bar{z} \\ \bar{y} \end{bmatrix} + [z_0 - \bar{z}] \begin{bmatrix} 1 \\ k_1 \end{bmatrix} e^{r_1 t} \tag{A7}$$

This information allows the analysis of the comparative dynamics, i.e. the effect of z_t on levels of y_t. along its optimal transitional time path. It provides the main hypothesis that *the effect of biodiversity conservation is to increase marketable output along the optimal transitional path towards the new steady state equilibrium (at a declining rate).*

$$\frac{dy(t; z_0, \varphi)}{d\bar{z}} \bigg|_{z_0 = \bar{z}} = -k_1 e^{r_1 t} > 0 \tag{A8}$$

Note that in the long run, for $r_1 < 0$, the term $k_1 e^{r_1 t}$ approaches zero as time goes to infinity.

Appendix B The empirical model

Under Model 3, the elasticity of crop output with respect to kth input variable can be calculated as

$$\frac{\partial \ln E(y_{it})}{\partial p_k} = \frac{\partial \beta p}{\partial p_k} - C_{it}\left(\frac{\partial \mu_{it}}{\partial p_k}\right) \tag{B1a}$$

where

$$\mu_{it} = \delta_0 + \sum_j \delta_j q_{jit} + \sum_j \sum_k \delta_{jk} p_{kit} q_{jit} \tag{B1b}$$

$$C_{it} = 1 - \frac{1}{\sigma}\left\{\frac{\varphi\left(\frac{\mu_{it}}{\sigma} - \sigma\right)}{\varphi\left(\frac{\mu_{it}}{\sigma} - \sigma\right)} - \frac{\varphi\left(\frac{\mu_{it}}{\sigma}\right)}{\varphi\left(\frac{\mu_{it}}{\sigma}\right)}\right\}_{it} \tag{B1c}$$

and φ and ϕ represent the density and distribution functions of the standard normal random variable, respectively.

It follows from Battese and Broca (1997) that the elasticity of *frontier output* with respect to the kth input, $\dfrac{\partial \beta p}{\partial p_k}$, is different from the elasticity of *TE* with respect to the kth input:

$$- C_{it}\left(\frac{\partial \mu_{it}}{\partial p_k}\right).$$

Lastly, the decomposition of the rate of change of mean crop output with respect to time is given by equation (B2):

$$\frac{\partial \ln E(y)}{\partial t} = \frac{\partial \beta p}{\partial t} - C\left(\frac{\partial \mu}{\partial t}\right) \tag{B2}$$

where the first and second terms in the right-hand side of the equation represents the impact of exogenous technical change and the change in TE levels, respectively.

Appendix C

The necessary and sufficient conditions for monotonicity and concavity of the production function are checked by the bordered Hessian matrix (H_B).

$$H_B = \begin{bmatrix} 0 & f_1 & f_2 & f_3 & f_4 & f_5 & f_6 \\ f_1 & f_{11} & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} \\ f_2 & f_{21} & f_{22} & f_{23} & f_{24} & f_{25} & f_{26} \\ f_3 & f_{31} & f_{32} & f_{33} & f_{34} & f_{35} & f_{36} \\ f_4 & f_{41} & f_{42} & f_{43} & f_{44} & f_{45} & f_{46} \\ f_5 & f_{51} & f_{52} & f_{53} & f_{54} & f_{55} & f_{56} \\ f_6 & f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & f_{66} \end{bmatrix} \tag{C1}$$

The alternating sign of the principal minors of the Hessian matrix (H) conform to $(-1)^n|H_n| > 0$ for the n-th principal minor, thus proving the negative-definiteness of the Hessian matrix.

Acknowledgements

Notes

1 The model is set up in a general fashion to accommodate a 'decision-maker' at different levels, including an individual farmer, a social group or a national or regional authority. The choice on the level of the decision-maker is, however, tied to the notion of a 'given area of land'. In the case of individual farmers, the scale of land-use is the plot or farm, whereas for a social decision-maker the agricultural landscape scale is the farm or appropriate focus. Due to data availability, subsequent empirical analysis to test the results of the model is based on the individual farm level. In this case, following the standard tradition in agricultural household models, it is assumed that our hypothetical rational and forward looking farmer follows an optimal (utility maximizing) pathway.

2 While z_t refers to the 'level' (*stock*) of biodiversity in time t, b_t refers to bio-diversity 'loss' or physical depreciation (a *flow* variable). Furthermore, while b_t is an argument in the direct utility function, it depends on the level of application of artificial inputs and the 'current' level of biodiversity through a 'biodiversity impact function'.

3 This general formulation allows conservation investment to be interpreted as 'forgone output', either as direct current investment in conservation activities or as reduced output arising from adopting environmentally enhancing production practices.

4 The parameter k is linked to the idea of 'carrying capacity' in standard species population growth models. In a biodiversity context, it portrays a rather more abstract concept and thus we do not attempt to measure it. It only states what would be the maximum potential level of diversity which could be sustained naturally.

5 It can also be shown that crop output can be increased by investing in improvement of biodiversity-neutral agricultural technology. These two theoretical propositions, and the details of the optimal solution, can be obtained from the authors on request. The properties of the optimal adjustment pathway and an analysis of the impact on agricultural output of biodiversity are provided in Appendix A.

6 The eight Aggregate Vegetation Classes in the Countryside Survey are, Crops/

Weeds, Tall Grass/Herbs, Fertile Grassland, Infertile Grassland, Lowland Woodland, Upland Woodland, Moorland Grass, and Heath/Bog. Not all of these are represented in EZ1.

7 See Winter (2000) and Kleijn and Sutherland (2003) for a review of effectiveness of the different the types of agri-environmental schemes applied in arable farming in the UK and EU, respectively, since 1992.

8 An alternative way to model the dynamics of the system econometrically could have been based on the use of a lagged dependent variable. But in our current application, previous levels of crop output would have very little bearing on current output levels on a given area of land under intensive agriculture. Instead, the essential dynamics of the problem analysed in the theoretical model have been subsumed into the calculations of the biodiversity index that appears as an independent variable in the frontier production function. This is because an explicit *in situ* measure of farm-level biodiversity is not available (see Section 3).

9 Since, in the stochastic regression frontier, the $v_{it}s$ are symmetrically distributed, the third moment is also the third sample moment of the ui. Consequently, if it is negative, it implies that the OLS residuals are negatively skewed, and suggests the presence of technical inefficiency. The computed value of Coelli's (1995) standard normal skewness statistic (M3T) based on the third moment of the OLS residuals is -14.06 ($p = 0.000$, for H_0: M3T = 0).

10 Here we assume that a farm's input decisions are not influenced by its productivity. Otherwise, estimating the stochastic production frontier regression without considering this kind of endogeneity would yield inconsistent coefficient estimates. The size of this inconsistency may depend on the slope parameters (δ_i and y) as well as the variances of the error terms. Hence, the model assumes that the choice of inputs used to maximise marketable output is only subject to 'human error', which in turn is uncorrelated with the error specification in the stochastic frontier model.

11 The cross-compliance provisions under the EU Single Farm Payment ensure adherence to principles of good agricultural practice that support conservation while basic and more advanced conservation practices are specifically encouraged under the Entry Level and Higher Level Stewardship schemes, respectively.

References

Aigner, D., Lovell, C.A.K. and Schmidt, P. (1977) 'Formulation and estimation of stochastic frontier production function models', *Journal of Econometrics* 6: 21–37.

Altieri, P. (1999) 'The ecological role of biodiversity in agroecosystems', *Agriculture, Ecosystems and Environment* 74: 19–31.

Barnes, A. (2002) 'Publicly-funded UK agricultural R&D and "social" total factor productivity', *Agricultural Economics* 27: 65–74.

Battese, G.E. and Broca S. (1997) 'Functional forms of stochastic frontier production functions and models for technical inefficiency effects: a comparative study for wheat farmers in Pakistan', *Journal of Productivity Analysis* 8: 395–414.

Battese, G.E. and Coelli, T.J. (1992) 'Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India', *Journal of Productivity Analysis* 3: 153–169.

Battese, G.E. and Coelli, T.J. (1995) 'A model for technical inefficiency effects in a stochastic frontier production function for panel data', *Empirical Economics* 20: 325–332.

Battese, G.E., Heshmati, A. and Hjalmarsson, L. (2000) 'Efficiency of labour use in

the Swedish banking industry: a stochastic frontier approach' *Empirical Economics* 25: 623–640.

Coelli, T.J. (1995) 'Estimators and hypothesis tests for a stochastic frontier function: a Monte Carlo analysis', *Journal of Productivity Analysis* 6(3): 247–268.

Coelli, T.J. (1996) 'A guide to FRONTIER v.4.1: A computer program for stochastic frontier production and cost function estimation', Working Paper, vol. 7/96. Centre for Efficiency and Productivity Analysis, Department of Econometrics, University of New England, Australia.

DEFRA (2002) *Farm Incomes in the United Kingdom 2000/01*. London: Department for Environment, Food and Rural Affairs.

DEFRA (2003) *Agriculture in the United Kingdom 2002*. London: Department for Environment, Food and Rural Affairs.

Di Falco, S. and Perrings, C. (2003) 'Crop genetic diversity, productivity and stability of agroecosystems: a theoretical and empirical investigation', *Scottish Journal of Political Economy* 50(2): 207–216.

Di Falco, S. and Perrings, C. (2005) 'Crop biodiversity, risk management and the implications of agricultural assistance', *Ecological Economics* 55(4): 459–466.

Farrell, M. (1957) 'The measurement of productivity efficiency', *Journal of the Royal Statistical Society* CXX(3): 253–290.

Green, R.E., Cornell, S.J., Scharlemann, P.W. and Balmford, A. (2005) 'Farming and the fate of wild nature', *Science* 307: 550–555.

Haines-Young, R.H., Barr, C.J., Firbank, L.G., Furse, M., Howard, D.C., McGowan, G., Petit, S. *et al.* (2003) 'Changing landscapes, habitats and vegetation diversity across Great Britain', *Journal of Environmental Management* 67(3): 267–281.

Haines-Young, R.H., Barr, C.J., Black, H.I.J., Briggs, D.J., Bunce, R.G.H., Clarke, R.T., Cooper, A., Dawson, F.H., *et al.* (2000) *Accounting for Nature: Assessing Habitats in the UK Countryside*. London: Department of the Environment Transport and the Regions.

Jackson, L., Bawa, K., Pascual, U. and Perrings, C. (2005) 'Agrobiodiversity: a new science agenda for biodiversity in support of sustainable agroecosystems', DIVERSITAS report. N. 4. Paris.

Jackson, L., Pascual, U. and Hodgkin, T. (forthcoming) 'Utilizing and conserving agrobiodiversity in agricultural landscapes', *Agriculture, Ecosystems and the Environment*.

Kleijn, D. and Sutherland, W.J. (2003) 'How effective are European agri-environment schemes in conserving and promoting biodiversity?' *Journal of Applied Ecology* 40: 947–969.

Kodde, D. and Palm, A. (1986) 'Wald criteria for jointly testing equality and inequality restriction', *Econometrica* 54(5): 1243–1248.

Lansink, A.O. and Reinhard, S. (2004) 'Investigating technical efficiency and potential technological change in Dutch pig farming', *Agricultural Systems* 79(3): 353–367.

McInerney, J., Barr, D., MacQueen, G. and Turner, M. (2000) 'What's the damage? A study of farm level costs of managing and maintaining the countryside', Special Studies in Agricultural Economics No. 51, Agricultural Economics Unit, University of Exeter.

Meeusen, W. and van den Broeck, J. (1977) 'Efficiency estimation from Cobb-Douglas production functions and composed error', *International Economic Review* 81: 435–444.

Omer, A.A.L. (2004) 'An economic analysis of interactions between agriculture and

biodiversity', thesis submitted for the degree of Doctor of Philosophy in the Faculty of Social Sciences and Law, University of Manchester.

Pascual, U. (2005) 'Land use intensification potential in slash-and-burn farming through improvements in technical efficiency', *Ecological Economics* 52(4): 497–511.

Pascual, U. and Perrings, C. (forthcoming) 'Developing incentives and economic mechanisms for *in-situ* biodiversity conservation in agricultural landscapes', *Agriculture, Ecosystems and the Environment*.

Pascual, U., Russell, N.P. and Omer, A.A. (2003) 'Does loss of biodiversity compromise productivity in intensive agriculture?' Discussion Paper No. 0322, School of Economic Studies, University of Manchester.

Perrings, C., Jackson, L., Bawa, K., Brussaard, L., Brush, S., Gavin, T., Papa, R. *et al.* (2006) 'Biodiversity in agricultural landscapes: saving natural capital without losing interest', *Conservation Biology* 20(2): 263–264.

Sauer, J., Frohberg, K. and Hockmann, H. (2006) 'Stochastic efficiency measurement: the curse of theoretical consistency', *Journal of Applied Economics* 9(1): 139–165.

Shephard, R. (1970) *Theory of costs and production functions*. Princeton, NJ: Princeton University Press.

Smale, M., Hartell, J., Heisey, P.W. and Senauer, B. (1998) 'The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan', *American Journal of Agricultural Economics* 80: 482–493.

Stoate, C., Boatman, N.D., Borralho, R.J., Rio Carvalho, C., de Snoo, G.R. and Eden, P. (2001) 'Ecological impacts of arable intensification in Europe', *Journal of Environmental Management* 63: 337–365.

Thirtle, C. and Bottomley, P. (1992) 'Total factor productivity in UK agriculture, 1967–90', *Journal of Agricultural Economics* 43(3): 381–400.

Thirtle, C. and Holding, J. (2003) *Productivity of UK Agriculture: Causes and Constraints*. Final report on DEFRA Project ER0001/3. London: Department for Environment, Food and Rural Affairs.

Tilman, D., Reich, P., Knops, J., Wedin, D., Mielke, T. and Lehman, C. (2001) 'Diversity and productivity in a long-term grassland experiment', *Science* 294: 843–845.

Tilman, D., Wedin, D. and Knops, J. (1996) 'Productivity and sustainability influenced by biodiversity in grasslands ecosystems', *Nature*, 379: 718–720.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., and Thies, C. (2005) 'Landscape perspectives on agricultural intensification and biodiversity ecosystem service management', *Ecology Letters* 8(8): 857–874.

Waldman, D. (1982) 'A stationary point for the stochastic frontier likelihood', *Journal of Econometrics* 18: 275–279.

Wenum, J., Buys J. and Wossink, A. (1999) 'Nature quality indicators in agriculture', in F. Brouwer and B. Crabtree (eds) *Environmental Indicators and Agricultural Policy*. Wallingford: CABI Publishers.

Wilson, P., Hadley, D. and Asby, C. (2001) 'The influence of management characteristics on the technical efficiency of wheat farmers in eastern England', *Agricultural Economics* 24: 329–338.

Winter, M. (2000) 'Strong policy or weak policy? The environmental impact of the 1992 reforms to the CAP arable regime in Great Britain', *Journal of Rural Studies* 16: 47–59.

9 Pricing agrobiodiversity
A stochastic approach to model environmental efficiency

Johannes Sauer

1 Introduction

It is well known that agricultural intensification has been one of the main causes of biodiversity loss around the world. The economic concept of efficiency is closely related to this detrimental causation as it focuses the evaluation of the relative waste of resources. Moreover, a trade-off between agricultural production efficiency and environmental efficiency can be assumed. In recent decades a significant amount of literature has been produced concerned with establishing a link between production efficiency and environmental efficiency with respect to quantitative modelling. This has been mainly addressed by focusing on the incorporation of undesirable outputs (e.g. polluting emissions) or the incorporation of environmentally detrimental inputs (as e.g. nitrogen surplus). However, while the debate with respect to linear programming-based DEA modelling is already at an advanced stage (see Färe *et al.* 1989; Ball *et al.* 1994; Scheel 2001; Hailu and Veeman 2001; Kuosmanen 2005), the corresponding one with respect to stochastic frontier modelling has been initially started by Reinhard *et al.* 1999 and 2002 but still needs considerable efforts. Neglecting stochastic influences, the former approach seems to be less appropriate with respect to the stochastic nature of agricultural production. Existing stochastic modelling approaches nevertheless show methodical shortcomings with respect to the choice of the functional form (estimates of environmental efficiency are restricted to a certain parameter range as well as functional flexibility) as well as exclusively considering environmentally detrimental inputs.

This chapter focuses on the case of agrobiodiversity and the appropriate incorporation in stochastic frontier models to achieve more realistic measures of agricultural production efficiency and reveal relative measures of agri-environmental efficiency. We use the empirical example of tobacco production in Tanzania drawing from as well as affecting species diversity in an agricultural landscape which is integrated with forests. Tobacco production in Tanzania is largely characterized by traditional technology with respect to plant growing and curing. Consequently the crop has remained one of the most input-intensive agricultural activity which seems to contrast the

fundamental goal of sustainable development. We apply a shadow profit function approach as well as a fixed-effects non-radial technique to reveal input and output allocative as well as output-oriented technical efficiency measures. We also consider functional consistency by imposing convexity on the translog profit function model. Based on a biologically defined species diversity index we incorporate: (1) agrobiodiversity as a production influencing factor; (2) as a desirable output, or (3) agrobiodiversity loss as a detrimental input. In contrast to earlier stochastic approaches on the producer level, our approach can be applied by using any first or second order flexible functional form.

Section 2 offers a brief summary of the current state of the discussion on quantitative efficiency measurement and the consideration of environmental efficiency. Based on this, Section 3 makes some general analytical considerations on the concept of environmental efficiency in a profit frontier framework. Subsequently, Section 4 introduces the shadow price approach as well as the fixed effects based non-radial model of stochastic efficiency analysis whereas Section 5 discusses different perspectives on agrobiodiversity (i.e. species diversity) in a farming production context and the evaluation of relative scarcity. Section 6 develops the different estimation models and outlines the estimation procedure applied. Finally, Section 7 discusses the empirical results and possible modelling and policy implications. Section 8 concludes.

2 Measuring environmental efficiency

During the past 15 years the notion that realistic efficiency measures require the incorporation of environmentally relevant variables into analytical models of efficiency measurement has prevailed. The literature on the measurement of environmental efficiency can basically be distinguished by the analytic approach chosen: non-parametric mathematical programming versus parametric econometric techniques.

2.1 Non-parametric approach

The former approach is usually modelled by using data envelopment analysis which builds on linear programming. One strand of DEA modelling defines negative environmental effects as undesirable outputs (Färe *et al.* 1989; Chung *et al.* 1997). Such measures commonly assume a weak disposable technology with respect to the detrimental outputs i.e. that the disposition of such outputs involves costs for the producer. Weak-disposable best-practice production frontiers are then calculated and the relative performance of the individual production unit is measured with respect to this environmental efficiency frontier (see also Yaisawarng and Klein 1994; Zofio and Prieto 1996). Another deterministic modelling strand calculates relative efficiency scores as well as corresponding shadow prices with respect to the undesirable output (Färe *et al.* 1993; Ball *et al.* 1994). However, the issue of modelling

undesirable outputs within a deterministic framework has not been satisfactorily solved at an applied level yet (see Scheel 2001; Agrell and Bogetoft 2004; Kuosmanen 2005). The hypothesis of weak disposability implies that if a production unit is on the revealed efficiency frontier, a second unit showing more desirable and less undesirable output cannot be part of the same production set (Shepherd 1970; Chambers *et al.* 1996). The linear programming procedure further removes the slacks of the undesirable outputs implying that inefficient units are part of the frontier (Scheel 2001).

Following earlier studies on polluting emissions (see e.g. Pittman 1981), Hailu and Veeman (2001) suggested treating the undesirable output as an input which is, however, physically problematic as this implies that an infinite amount of desirable output could be produced by an infinite amount of detrimental input (i.e. undesirable output, see Färe and Grosskopf 2004). Scheel (2001) suggests using a monotonic decreasing transformation function to transform the undesirable ouput into an ordinary output which is then maximized by programming techniques. This approach has the shortcoming of considering inefficient production units as efficient and following this idea Färe and Grosskopf (2004) introduce the use of a directional distance function consisting of the directional vector $(1, -1)$ with respect to the desirable and the undesirable outputs respectively. Other recent studies finally point to the fact that such a directional vector qualifies some inefficient units as being efficient depending on the slope of the frontier, and alternatively apply a vector consisting of the relative observation values.

2.2 Parametric approach

The measurement of environmental efficiency by parametric econometric techniques still needs considerable analytical effort. Pittman (1983) estimated the shadow price of a single undesirable output for a sample of US mills to develop an adjusted Törnqvist productivity index assuming the weak disposability of the undesirable output biochemical oxygen demand. The same strategy was basically followed by Hetemäki (1996) who estimated a translog output distance function by revealing technical efficiency scores as well as shadow prices for the environmental 'bad'. The general strategy of such studies has been to include environmental effects in the output vector of a stochastic distance function to obtain inclusive measures of technical efficiency and occasionally measures of productivity change over time. Reinhard *et al.* (1999, 2002) formulate a single output translog production frontier model to relate the environmental performance of individual farms to the best practice of environment-friendly farming. Here the environmental effect is modelled as a conventional input rather than an undesirable output as in earlier studies and consequently output-oriented technical as well as input-oriented environmental efficiency measures are obtained.

Based on this mixed approach, Reinhard *et al.* (2002) further stochastically investigate the variation of environmental efficiency with respect to different

factors. The modelling approach chosen is quite appealing as it approaches the connection between an output- and an input-oriented efficiency measure in one stochastic framework. However, this approach shows severe shortcomings from a modelling perspective: The validity of the introduced measure of environmental efficiency is restricted to the choice of the underlying functional form implying finally the restriction of some parameter values to a certain functional range.[1] As a consequence, the Cobb-Douglas representation of technology cannot be applied as here the measure for environmental efficiency would collapse to the one measuring technical efficiency. In the case of the translog representation, the two measures can differ. However, as the required negative or zero value of the second own derivative with respect to the environmentally detrimental input is not guaranteed, and hence has to be imposed over the whole range of the functional form, the latter is no longer globally flexible. Hence, from the perspective of a theoretically consistent econometric modelling approach, also the translog specification is ruled out and consequently a globally flexible and consistent functional form other than the translog has to be chosen. Unfortunately the translog specification can be expected to show the best empirical performance of all second order flexible functional forms currently available as different applications have previously shown (Sauer 2006). Hence, this means a severe restriction for empirical work. In addition, the approach chosen by Reinhard *et al.* do not consider allocative considerations by solely focusing on technical and environmental performance. Nevertheless, producer decisions are also driven by allocative considerations with respect to the relative price ratios of the inputs used. The two-stage frontier model used in Reinhard *et al.* (2002) to subsequently regress the estimates for environmental efficiency gained by the first-stage frontier on different explanatory factors by using a second frontier technique is inconsistent with respect to the econometric specification (see Kumbhakar and Lovell 2000: Chapter 7). However, this approach further lacks consistency with respect to the underlying production theory of the frontier specification as the latter is not based on a proper definition of an 'environmental' production function (i.e. relating output to inputs by an assumed technology) as required to consider the resulting functional estimates as defining a best-practice frontier. The chosen approach simply regresses scores of environmental efficiency on arbitrarily chosen explanatory variables and subsequently corrects for best practice.

The most current empirical application in the literature by Omer *et al.* (2007) uses a Cobb-Douglas frontier framework and defines biodiversity as a productive—i.e. desirable—input to cereal production on the farm level. While the definition of diversity as a conducive input to farm production is convincing, no price ratios and, related to that, no allocative considerations are done. Further, the whole approach focuses on technical and not on environmental efficiency and it can be questioned whether the applied econometric procedure is consistent with respect to the inefficiency variation

regression as here the inputs for the frontier are again used as explanatory factors and so the error term appears not to adhere to the iid assumption. Finally, the application of a rather limited first order Cobb-Douglas approximation has to be mentioned.

This chapter follows the econometric strand of efficiency measurement and builds on a second-order flexible translog functional form. By combining the shadow price approach with a fixed-effects non-radial model, we are able to measure technical and environmental efficiency as well as allocative efficiency. This is achieved by applying a profit function approach either in a single output specification or a multi-output specification. In the first case, the environmentally relevant variable is incorporated as a simple invariant control variable or a group-wise profit shifter or as a detrimental input. In the second case it is incorporated as a desirable output. With respect to the control variable approach, the non-environmental production output is maximized. Consequently, estimates of systematic output-oriented technical efficiency and systematic input and output allocative efficiency (Model I) or systematic output-oriented technical efficiency and systematic input and output allocative efficiency as well as environmentally conditional group-wise profit efficiency and environmentally conditional group-wise input allocative efficiency (Model II) are obtained. The input approach (Model III) enables the measurement of systematic output-oriented technical efficiency as well as that of systematic input and output allocative efficiency and systematic input environmental efficiency by minimizing the use of the detrimental input. Finally, the output approach (Model IV) delivers estimates of systematic output-oriented technical efficiency, of systematic input and output allocative efficiency and finally of systematic output environmental efficiency. We estimate all models in an unconstrained (specification A) as well as a curvature constraint (i.e. convexity) specification (specification B) and compare the results. Through this modelling approach we try to overcome some of the shortcomings of earlier empirical attempts with respect to functional consistency and flexibility, allocative considerations as well as the accurate treatment of the environmental variable.

3 Allocative, technical and environmental efficiency using a profit frontier approach

Before we describe the modelling approaches in more detail, it seems appropriate to briefly review the different economic concepts of efficiency used. As we basically apply a profit frontier framework to capture allocative issues, we assume that producers face output prices $p \in R_{++}^{M}$ and input prices $w \in R_{++}^{N}$. They maximize the profit ($p^T y - w^T x$) gained by employing $x \in R_{+}^{N}$ to produce $y \in R_{+}^{M}$. A measure of profit efficiency πE can be denoted by a function

$$\pi E_i (y, x, p, w) = (p^T y - w^T x) / \pi_i (p, w) \tag{9.1}$$

where *i* denotes the production unit and $\pi(p, w) > 0$ holds. πE must satisfy the following four properties:

(i) $\pi E(y, x, p, w) \leq 1$, with $\pi E(y, x, p, w) = 1 \Leftrightarrow y = y(p, w)$, $x = x(p, w)$ so that $(p^T y - w^T x) = \pi(p, w)$

(ii) $\pi E(\lambda y, x, p, w) \geq \pi E(y, x, p, w)$, $\lambda \geq 1$

(iii) $\pi E(y, \lambda x, p, w) \leq \pi E(y, x, p, w)$, $\lambda \geq 1$

(iv) $\pi E(y, x, \lambda p, \lambda w) = \pi E(y, x, p, w)$, $\lambda > 0$.

Unlike measures of cost or revenue efficiency, profit efficiency is not bounded below by zero, since negative actual profit is possible. πE is further non-decreasing in *y*, non-increasing in x, and homogeneous of degree 0 in output prices and input prices collectively. By assuming an output orientation for technical efficiency, πE can be decomposed as follows

$$\pi E_i(y, x, p, w) =$$
$$\left\{ \begin{array}{l} TE_{i^o}(x, y) * AE_{i^o}(x, y, p) * [r(x, p) / p^T y(p, w)] * p^T y(p, w) \\ - [AE_{i^i}(x, y, w)]^{-1} * [c(y / TE_{i^o}(x, y), w) / w^T x(p, w)] * w^T x(p, w) \end{array} \right\} / \pi(p, w)$$
(9.2)

where the Debreu-Farrell measure of output-oriented technical efficiency is formulated as the function TE satisfying $TE_{i^o}(x, y) = [\max \{\varphi : \varphi y_i \in F(x)\}]^{-1}$ with $F(x)$ as the production frontier, $AE_{i^o}(x, y, p)$ denotes output allocative efficiency satisfying $AE_{i^o}(x, y, p)/TE_{i^o}(x, y)$ with RE as revenue efficiency, r(x, p)/$p^T y(p, w)$ is the ratio of maximum revenue *r* (which is possible given fixed input levels *x* and output prices *p*) to observed revenue, $[AE_{i^i}(x, y, w)]^{-1}$ is input allocative efficiency and *r* denotes the total revenue and *c* the total costs of production unit I (see Kumbhakar and Lovell 2000).

$\pi E_i(y, x, p, w) = [p^T y(p, w) - w^T x(p, w)] / \pi_i(p, w) = 1$ if, and only if, all seven terms in equation (9.2) are unity. In other words, to achieve full efficiency with respect to the profit frontier the production unit is required to reach either input-oriented or output-oriented technical efficiency and both input and output allocative efficiency as well as scale efficiency.

As shown by the previous section, environmental efficiency (EE) can be economically defined in various ways. The following single output and multi-output function modelling approaches make use either of an input or an output-related measure of EE. Following the stochastic modelling strang which considers the environmentally relevant effect as a detrimental input *z* to the production of a single output *y*, a profit function based measure of input environmental efficiency is provided by

$$EE_{i^i}(z, y, w_z) = CE_i(y, x, z, w_x, w_z) / [TE_{i^i}(y, x, z) * AE_{i^i}(x, y, w_x)] \quad (9.3)$$

where CE denotes the cost efficiency or economic efficiency of production unit i as the product of technical and allocative efficiency of production unit i. EE_{i^o} has to satisfy the following properties (v–viii):

(v) $0 < EE_{i^i} (z, y, w_z) \leq 1$

(vi) $EE_{i^i} (z, y, w_z) = 1 \Leftrightarrow \lambda \leq 1$ so that $\lambda z = z(y, w_z)$

(vii) $EE_{i^i} (\lambda z, y, w_z) = EE_{i^i}(z, y, w_z)$ for $\lambda > 0$

(viii) $EE_{i^i} (z, y, \lambda w_z) = EE_{i^i}(z, y, w_z$ for $\lambda > 0$.

Consequently EE_{i^i} is bounded between zero and unity, and homogeneous of degree 0 in input prices and quantities. Decomposing profit efficiency given by equation (9.2) to get input environmental efficiency would deliver

$$EE_{i^i} (x, z, y, w_x, w_z) =$$
$$\left\{ \begin{array}{l} [c(y \,/\, TE_{i^o} (x, z, y), w_x, w_z) \,/\, ((w_x^T x(p, w_x)) * (w_z^T z(p, w_z)))] \\ \left/ \left[\begin{array}{l} TE_{i^o} (x, z, y) * AE_{i^o} (x, z, y, p) * (r(x, z, p) \,/\, p^T y(p, w_x, w_z)) \\ * p^T y(p, w_x, w_z) - \pi E_i (y, x, z, p, w_x, w_z) * \pi(p, w_x, w_z) \end{array} \right] \right. \\ \left/ AE_{i^i} (x, z, y, w_x, w_z) \right. \end{array} \right\} \quad (9.4)$$

By considering on the other side the environmentally relevant effect as an undesirable output y_u in a multi-output production context based on an output distance function $D_i (x, y)$, a measure of output environmental efficiency is provided after transforming it into a desirable output y_d by using an arbitrary directional vector (Färe *et al.* 1989)

$$P_i (x) = \{y' : D_i(x, y') \leq 1\} \text{ where } y' = y \, v = [y_{d_1}, y_u][1, -\varphi] = [y_{d_1} y_{d_2}] \quad (9.5)$$

with y as the output, v as the directional vector, $-\varsigma$ as the arbitrary chosen negative direction on yu and d_1 and d_2 as the vector elements resulting in the new output vector

$[y_{d_1}, y_{d_2}]$, by
$$EE_{i^o} (x, y_{d_2}, p_{d_2}) = RE_i (x, y_{d_1}, p_{d_1}, y_{d_2}, p_{d_2}) \,/\, [TE_{i^o}(x, y) * AE_{i^o} (x, y_{d_1}, p_{d_1})] \quad (9.6)$$

EE_{i^o} has to satisfy the following properties (ix–xii):

(ix) $0 < EE_{i^o} (x, y_{d_2}, p_{d_2}) \leq 1$

(x) $EE_{i^o} (x, y_{d_2}, p_{d_2}) = 1 \Leftrightarrow \lambda \geq 1$ so that $\lambda y_{d_2} = y_{d_2}(x, p_{d_2})$

(xi) $EE_{i^o} (x, \lambda y_{d_2}, p_{d_2}) \leq EE_{i^o} (x, y_{d_2}, p_{d_2})$ for $\lambda > 0$

(xii) $EE_{i^o} (x, y_{d_2}, \lambda p_{d_2}) = EE_{i^o} (x, y_{d_2}, p_{d_2})$ for $\lambda > 0$.

Consequently $EE_{i'}$ is bounded between zero and unity, and homogeneous of degree 0 in output prices and quantities. Decomposing finally profit efficiency given by equation (9.2) to obtain output environmental efficiency would deliver

$$EE_{i'}(x, y_{d_2}, p_{d_2}) =$$

$$\left[\begin{array}{l} \pi E_i(y_{d_1}, y_{d_2}, x, p_{d_1}, p_{d_2}, w)^* \; \pi(p_{d_1}, p_{d_2}, w) + (1 \, / \, AE_{i'}(x, y_{d_1}, w))^* \\ (c(y \, / \, TE_{i'}(x, y_{d_1}), w) \, / \, w^T x(p_{d_1}, p_{d_2}, w)) * w^T x(p_{d_1}, p_{d_2}, w) \end{array} \right] \quad (9.7)$$

$$/[(TE_{i'}(x, y) * AE_{i'}(x, y, p) * (r(x, p_{d_1}, p_{d_2}) \, / \, p^T y(p_{d_1}, p_{d_2}, w)) * p^T y(p_{d_1}, p_{d_2}, w))]$$

4 Shadow prices and non-radial fixed effects: the basic model

Due to the vast literature on shadow prices (see for an overview, e.g. Khumbhakar and Lovell 2000), non-observable shadow price ratios have to be considered as the relevant ones for producer decisions in distorted as well as developing agricultural markets. The divergence between the analysed (i.e. estimated) shadow prices and the observed market prices can be interpreted as the sum of allocative inefficiency due to the prevalence of various market constraints as well as optimization failure by the management of the respective production unit.[2] Different approaches to model this divergence can be found in the literature: the usual method consists of additively translating observed prices to create shadow prices. Alternatively shadow prices can be modelled by multiplicatively scaling observed prices into shadow ones (Lau and Yotopoulos 1971). We follow the latter approach here and define the relationship between the normalized shadow input and output prices w^*, p^* and the normalized market prices w, p as

$$w^*_j = \theta_j w_j \qquad p^*_k = \kappa_k p_k \tag{9.8}$$

where θ_j, κ_k are (non-negative) price efficiency parameters and j, k indicate input j and output k respectively. If no bending market restrictions are the case, then θ_i, κ_k equal unity, if market distortions restrict optimizing behaviour, then $\theta \geq 0 \wedge \theta \neq 1$, $\kappa \geq 0 \wedge \kappa \neq 1$. Consequently, a production unit can be regarded as allocatively efficient with respect to observed market prices only if observed market prices reflect the management's opportunity cost with respect to inputs and outputs. It has to be considered that the price efficiency parameters θ_j, κ_k may reflect both effects of market distortions as well as optimization errors.

4.1 A shadow profit model

Following an output-oriented approach with respect to the measurement of technical efficiency, observed normalized profit is

$$\frac{\pi}{p_1} = y_1 + \sum_{m>1}\left(\frac{p_m}{p_1}\right) y_m - \sum_{n}\left(\frac{w_n}{p_1}\right) x_n = \varphi\pi\,[(p,\,w)^*;\beta]$$

$$\left\{1 + \sum_{m}\left(\frac{1-\kappa_m}{\kappa_m}\right)R^*_m + \sum_{n}\left(\frac{1-\theta_n}{\theta_n}\right)S^*_n\right\} \quad (9.9a)$$

where $\pi[(p,\,w)^*;\beta]$ is the normalized shadow profit function, $(p,\,w)^* = \left[\kappa_m\left(\frac{p_m}{p_1}\right),\,\left(\frac{\theta_n}{\varphi}\right)\left(\frac{w_n}{p_1}\right)\right]$ is a normalized shadow price vector incorporating output-oriented technical inefficiency $0 < \varphi \leq 1$ and systematic allocative inefficiency (κ_m, m = 2, ..., M and θ_n, n = 1, ..., N). The corresponding output and input shadow profit shares are respectively[3]

$$R_m^* = \frac{\partial\ln \pi[(p,\,w)^*;\beta]}{\partial\ln p^*_m},\ m = 2, ..., M \qquad (9.9b)$$

$$S_n^* = \frac{\partial\ln \pi[(p,\,w)^*;\beta]}{\partial\ln w^*_m},\ n = 1, ..., M \qquad (9.9c)$$

Observed normalized profit is related to shadow normalized profit by

$$\ln\frac{\pi}{p_1} = \ln \pi[(p,\,w)^*;\beta] + \ln H + \ln \varphi \qquad (9.10a)$$

where

$$H = \left\{1 + \sum_{m}\left(\frac{1-\kappa_m}{\kappa_m}\right) R^*_m + \sum_{n}\left(\frac{1-\theta_n}{\theta_n}\right) S^*_n\right\} \qquad (9.10b)$$

and the observed profit shares can be related to the shadow profit shares simply by

$$R_m = \frac{p_m y_m}{\pi} = \frac{1}{H} * \frac{1}{\kappa_m} R_m^*,\ m = 2, ..., M \qquad (9.10c)$$

$$S = \frac{w_n x_n}{\pi} = -\frac{1}{H} * \frac{1}{\theta_n} S_n^*,\ n = 1, ..., N \qquad (9.10d)$$

In the case of a single output equation (9.9a) collapses to

$$\frac{\pi}{p} = y - \sum_{n}\left(\frac{w}{p}\right) x_n = \kappa\pi\left[\left(\frac{w}{p}\right)^*;\beta\right] + \kappa\sum_{n}\frac{1-\theta_n}{\theta_n}\left(\frac{w}{p}\right)_n \frac{\partial\pi\left[\left(\frac{w}{p}\right)^*;\beta\right]}{\partial\left(\frac{w}{p}\right)_n} \qquad (9.11)$$

(see Lau and Yotopoulos 1971). Well known for its empirical accuracy as well as functional flexibility, the translog functional form is used here. A translog normalized shadow profit function is given by

$$\ln \pi \left[(p, w)^*; \beta\right] = \beta_0 + \sum_m \beta_m \ln p_m^* + \sum_n \gamma_n \ln w_n^* + \frac{1}{2} \sum_j \sum_m \beta_{jm} \ln p_j^*$$

$$\ln p_m^* + \frac{1}{2} \sum_k \sum_n \gamma_{kn} \ln w_k^* \ln w_n^* + \sum_m \sum_n \delta_{mn} \ln p_m^* \ln w_n^* \tag{9.12a}$$

and the associated shadow profit shares can be written as

$$R_m^* = \beta_m + \sum_j \beta_{jm} \ln p_j^* + \sum_n \delta_{mn} \ln w_n^*, \, m = 2, \ldots, M \tag{9.12b}$$

$$S_n^* = \gamma_n + \sum_k \gamma_{kn} \ln w_k^* + \sum_m \delta_{mn} \ln p_m^*, \, n = 1, \ldots, N \tag{9.12c}$$

This system of equations to be estimated consists then of

$$\ln \frac{\pi}{p_1} = \ln \pi \left[(p, w)^*; \beta\right] + \ln H + \ln \varphi \tag{9.13a}$$

$$R_m = \frac{R_m^*}{H^* \kappa_m}, \, m = 2, \ldots, M \tag{9.13b}$$

$$S_n = \frac{-S_n^*}{H^* \theta_n}, \, n = 1, \ldots, N \tag{9.13c}$$

by simply using equations (9.10b) and (9.12a–12c).

4.2 *Fixed effects non-radial model*

By linking this shadow price approach to a fixed effects non-radial model (see e.g. Kumbhakar 1989; Greene 2005; Sauer and Frohberg 2007), we are able to measure also group-wise environmentally conditional profit efficiency and group-wise environmentally conditional allocative efficiency. Hereby we are able to model the change in relative profit and allocative efficiency as the environment of a production unit would change. The outlined translog normalized shadow profit system in equations (9.12a) to (9.12c) is reformulated by incorporating b_q as a binary dummy variable for q different groups of producers in the sample classified along different criteria depending on the underlying research question

$$\ln \pi [(p, w)^*; \beta] = \sum_m \beta_m \ln p_m^* + \sum_n \gamma_n \ln w_n^* + \frac{1}{2} \sum_j \sum_m \beta_{jm} \ln p_j^* \ln p_m^* +$$

$$\frac{1}{2} \sum_k \sum_n \gamma_{kn} \ln w_k^* \ln w_n^* + \sum_m \sum_n \delta_{mn} \ln p_m^* \ln w_n^* + \sum_q \zeta_q \ln b_q \quad (9.14a)$$

$$R_m^* = \beta_m + \sum_j \beta_{jm} \ln p_j^* + \sum_n \delta_{mn} \ln w_n^* + \sum_{q_m} \zeta_{q_m} \ln b_{q_m},$$
$$m = 2, \ldots, M \quad (9.14b)$$

$$S_n^* = \gamma_n + \sum_k \gamma_{kn} \ln w_k^* + \sum_m \delta_{mn} \ln p_m^* + \sum_{q_n} \zeta_{q_n} \ln b_{q_n},$$
$$n = 1, \ldots, N \quad (9.14c)$$

where symmetry ($\beta_{jm} = \beta_{mj}$, $\gamma_{kn} = \gamma_{nk}$) holds as usual. The dummy variable B is used here for determining efficiency and ζ denotes the parameters with respect to the efficiency variable. With respect to the cross-sectional context the subscript q, with q = 1, . . ., Q indicates a group of producers due to a specific classification. This classification is necessary with respect to degrees of freedom problems. The common intercept term is dropped to avoid omitted variable problems. If panel data were available this procedure could be avoided and efficiency estimates are obtained for every producer. The profit function system in (9.14a) to (9.14c) is 'corrected' with respect to the 'best' group of households by calculating the inefficiency τ_{ik}

$$\tau_q = \zeta_q - \min_q (\zeta_q) \quad (9.15a)$$
$$\tau_{q_m} = \zeta_{q_m} - \min_{q_m} (\zeta_{q_m}) \quad (9.15b)$$
$$\tau_{q_n} = \zeta_{q_n} - \min_{q_n} (\zeta_{q_n}) \quad (9.15c)$$

τ_q represents overall profit inefficiency of the *qth* group and can be interpreted as the amount by which the profit could be increased by radially reducing the use of all inputs and/or by radially increasing the production of all outputs *ceteris paribus*. τ_{q_m} represents output-specific allocative inefficiency of the *qth* group with respect to output m and can be interpreted as the amount by which the profit could be increased by increasing the production of output m *ceteris paribus*. Finally, τ_{q_n} represents input-specific profit inefficiency of the *qth* group with respect to input n and can be interpreted as the amount by which the profit could be increased by reducing the use of input n *ceteris paribus*. If $\tau_q = 0$ or $\tau_{q_m} = 0$ and $\tau_{q_n} = 0$ the specific group of producers is on the stochastic frontier and can be considered as fully profit efficient or allocative efficient respectively, e.g. profit efficiency for group *q* is therefore obtained by

$$\pi E_q = \pi_q^* / \pi_q = 1 + (\tau_q / \pi_q) \quad (9.16)$$

with subscripts as explained above and π_q as the maximum profit attainable by producing a given mix and level of outputs by a given mix and level of inputs. However, as is the case with every approach attempting to measure efficiency, some drawbacks with respect to the described approach have to be mentioned. If 'only' cross-sectional data are available, with respect to the number of observations as well as the number of regressors, a classification of groups of observations is necessary to maintain sufficient degrees of freedom. Such a classification is always subject to arbitrariness by the researcher due to the decision on the classifying criteria. As a consequence, inefficiency does not vary over producers in a particular group of producers. Efficiency measures are always relative to the 'best' group of producers in the sample producing on the stochastic frontier. By correcting an average function, this approach implies that the structure of 'best practice' production technology is the same as the structure of the 'central tendency' production technology. On the other hand, the approach applied here requires no special distributional assumptions for the efficiency containing parameters. It is also not necessary to assume their independence from other regressors of the profit function as is the case for the 'mainstream' error components approach (see also Kumbhakar 1989). Furthermore, the underlying technology can be specified by a particular functional form adhering to theoretical consistency, global curvature correctness as well as flexibility.

4.3 Curvature correct modelling

Different recent contributions point to the crucial importance of considering the consistency of the estimated frontier with basic microeconomic requirements, i.e. monotonicity with respect to input prices as well as convexity of the function in a profit-maximizing context (see e.g. Ryan and Wales 1998; Sauer 2006). Monotonicity of the estimated profit function—i.e. positive first derivatives with respect to all input prices—holds as all variable inputs are positive for all observations in the sample. The necessary and sufficient condition for a specific curvature consists in the definiteness of the bordered Hessian matrix as the Jacobian of the derivatives $\partial\Pi/\partial w_n$ with respect to w_n and $\partial\Pi/\partial p_m$ with respect to p_m: if $\nabla\Pi^2(p,w)$ is positive semidefinite, Π is convex, where ∇^2 denotes the matrix of second order partial derivatives with respect to the shadow translog profit model defined by equations (9.12a) and (9.12c) respectively. The Hessian matrix is positive semidefinite at every unconstrained local maximum. Hence, the underlying function is convex and an interior extreme point will be a global maximum. The condition of convexity is related to the fact that this property implies a concave cost function, a quasi-concave production function, and consequently a convex input requirement set (see in detail e.g. Chambers 1988). Hence, a point on the isoquant is tested, i.e. the properties of the corresponding production function are evaluated subject to the condition that the amount of production remains constant. With respect to the translog shadow profit function model,

curvature depends on the specific variable input price and output price bundle, as the corresponding Hessian H for a two input, two output case shows

$$H = \begin{pmatrix} \beta_{11} + \beta_1^2 - \beta_1 & \beta_{12} + \beta_1\beta_2 & \delta_{11} + \beta_1\gamma_1 & \delta_{12} + \beta_1\gamma_2 \\ \beta_{12} + \beta_1\beta_2 & \beta_{22} + \beta_2^2 - \beta_2 & \delta_{21} + \beta_2\gamma_1 & \delta_{22} + \beta_2\gamma_2 \\ \delta_{11} + \beta_1\gamma_1 & \delta_{21} + \beta_2\gamma_1 & \gamma_{11} + \gamma_1^2 - \gamma_1 & \gamma_{12} + \gamma_1\gamma_2 \\ \delta_{12} + \beta_1\gamma_2 & \delta_{22} + \beta_2\gamma_2 & \gamma_{12} + \gamma_1\gamma_2 & \gamma_{22} + \gamma_2^2 - \gamma_2 \end{pmatrix} \quad (9.17)$$

Given a point x^0, necessary and sufficient for curvature correctness is that at this point v'Hv ≤ 0 and v's = 0 where v denotes the direction of change. For some input and output price bundles convexity may be satisfied but for others not and hence what can be expected is that the condition of positive semidefiniteness of the Hessian is met only locally or with respect to a range of input bundles. The respective Hessian is positive semidefinite if the determinants of all of its principal submatrices are positive in sign (i.e. $D_j > 0$ where D is the determinant of the leading principal minors and j = 1, 2, . . ., n). Hence, with respect to our translog shadow profit model, it has to be checked *a posteriori* for every input and output bundle that monotonicity and convexity hold. If these theoretical criteria are jointly fulfilled, the obtained estimates are consistent with microeconomic theory and consequently can serve as empirical evidence for possible policy measures. Convexity can be imposed on our translog shadow profit model at a reference point (usually at the sample mean) following Jorgenson and Fraumeni (1981) and Ryan and Wales (1998). By this procedure the bordered Hessian in (18D) is replaced by the product of a lower triangular matrix Δ times its transpose Δ′. Imposing curvature at the sample mean is then attained by simply setting

$$\beta(\gamma)_{rs} = (\Delta\Delta')_{rs} + \beta(\gamma, \delta)_{rs}\lambda_{rs} + \beta(\gamma)_r \beta(\gamma)_s \quad (9.18)$$

where r = j, k and s = n, m and λ_{rs} = 1 if r = s and 0 otherwise and $(\Delta\Delta')_{rs}$ as the rs-th element of ΔΔ′ with Δ as a lower triangular matrix. As our point of approximation is the sample mean, all data points are divided by their mean transferring the approximation point to an (n + 1)-dimensional vector of ones. At this point the elements of H do not depend on the specific input and output price bundle. The estimation model of the normalized translog shadow profit frontier given in (9.14a) to (9.14c) is then simply reformulated as follows

$$\ln \pi[(p, w)^*;\beta] = \sum_m \beta_m \ln p_m^* + \sum_n \gamma_n \ln w_n^* + \frac{1}{2} \sum_j \sum_m (h_{jm} + \beta_{jm}\lambda_{jm} +$$

$$\beta_j\beta_m) \ln p_j^* \ln p_m^* + \frac{1}{2} \sum_k \sum_n (h_{kn} + \beta_{kn}\lambda_{kn} + \gamma_k\gamma_n) \ln w_k^* \ln w_n^* +$$

$$\sum_m \sum_n (h_{mn} + \delta_{mn}\lambda_{mn} + \beta_m\lambda_n) \ln p_m^* \ln w_n^* + \sum_q \zeta_q \ln \quad (9.19a)$$

$$R_m^* = \beta_m + \sum_j (h_{jm} + \beta_{jm}\lambda_{jm} + \beta_j\beta_m) \ln p_j^* + \sum_n (h_{mn} + \delta_{mn}\lambda_{mn} + \beta_m\gamma_n)$$

$$\ln w_n^* + \sum_{q_m} \zeta_{q_m} \ln b_{q_m}, \, m = 2, \ldots, M \qquad (9.19b)$$

$$S_n^* = \gamma_n + \sum_k (h_{kn} + \beta_{kn}\lambda_{kn} + \gamma_k\gamma_n) \ln w_k^* + \sum_m (h_{mn} + \delta_{mn}\lambda_{mn} +$$

$$\beta_m\gamma_n) \ln p_m^* + \sum_{q_m} \zeta_{q_n} \ln b_{q_n}, \, n = 1, \ldots, N \qquad (9.19c)$$

However, the elements of Δ are nonlinear functions of the decomposed Hessian, and consequently the resulting normalized translog model becomes nonlinear in parameters. Hence, linear estimation algorithms are ruled out even if the original function is linear in parameters. By this 'local' procedure a satisfaction of consistency at most or even all data points in the sample can be reached. The transformation in (9.18) moves the observations towards the approximation point and thus increases the likelihood of getting theoretically consistent results at least for a range of observations (see Ryan and Wales 2000). However, by imposing global consistency on the translog functional form, Diewert and Wales (1987) note that the parameter matrix is restricted, leading to seriously biased elasticity estimates. Hence, the translog function would lose its flexibility. By a second analytical step we finally (*a posteriori*) check the theoretical consistency of our estimated model by verifying that the Hessian is positive semidefinite (i.e. functional convexity). The detailed estimation models are shown in Section 6.

5 The price of species diversity: the case of forest and tobacco in Tanzania

For the empirical application we refer to the case of highly resource-intensive small-scale tobacco production in the Iringa region of Tanzania. As the use of advanced inputs (e.g. power-driven equipments, fertilizers and sustainable crop processing technologies) is beyond the reach for the majority of those farmers, an expansion in production is only possible by clearing more forest land. In combination with uncoordinated sectoral policies, high agricultural input prices and ineffective market reforms, this has been resulted in environmental degradation and a loss of biodiversity in the form of a decreasing number of tree species. Tobacco curing is the process that causes the destruction of the tobacco plants' chlorophyll, giving the tobacco leaves a yellow appearance by converting starch into sugar and removing the moisture in the plants. By this procedure the aroma and flavour of each tobacco variety is brought out. The efficiency of this curing process is mainly due to the barn

technology as well as the variety of different kinds of firewood used i.e. the mixture of tree species (Eucalyptus and Miombo woodlands). The firewood is collected in the surrounding forest areas (see Monela and Abdallah 2005; Sauer and Abdallah 2007). Figure 9.1 gives an illustration of the basic interrelations between tobacco production and forest species diversity.

5.1 Species diversity

In general, biodiversity can be considered at different levels: genetic diversity, species diversity as well as ecosystem diversity. Whereas genetic diversity refers to the diversity between and within populations (Norse *et al.* 1986), species diversity focuses the variety of species found, i.e. the number of different species existing in a biome, taxonomic grouping or a geographically defined area (Magurran 1988). Ecosystem diversity finally refers to the diversity between and within ecosystems. The following considerations solely focus on species diversity with respect to trees. The question of how many different species exist in a particular environment is central to the understanding of why it is important to promote and preserve species diversity. A uniform population of a single species of plants adapted to a particular environment is more at risk if environmental changes occur. A more diverse population consisting of many species of plants has a better chance of including individuals that might be able to adapt to changes in the environment. Hence, species diversity identifies and characterizes the biological community and the functional conditions of a habitat as well as the overall ecosystem (Kenchington *et al.* 2003). However, estimates of precise loss rates with respect to biological diversity are hampered by the absence of any baseline measurement (Pearce and Moran 1994). Different biodiversity indices— Simpson's Diversity Index, Species Richness Index, Shannon Weaver Index, Patil and Taillie Index, Modified Hill's Ratio—have been applied to mathematically combine the effects of species' richness and eveness. Each has its merits, putting more or less emphasis upon richness or eveness. The Shannon Weaver Diversity Index (H′, also called the Shannon Index or the
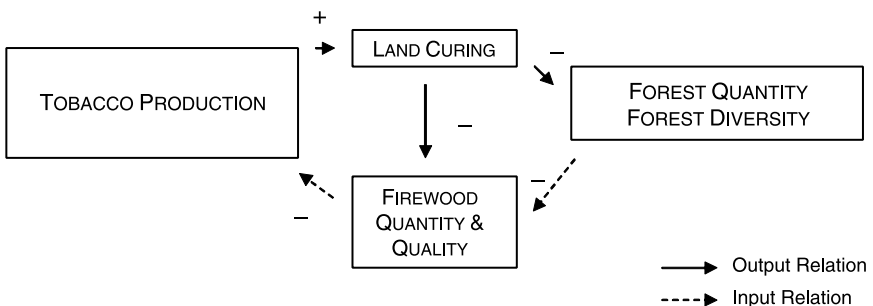
Figure 9.1 Tobacco production and forest diversity.

Shannon-Wiener Index) as the most widely used shows the relative advantage of correcting for the 'abundance' of species and can be mathematically described by

$$H' = -\sum_{i=1}^{s} p_i \log_e p_i \tag{9.20}$$

where p_i as the proportion of each species in the sample (relative abundance), $\log_e$ as the natural log of p_i, and s denotes the number of species in the community (species richness). The minimum value of 0 for H′ denotes a community consisting of only one species and is increasing as the number of species increases and the relative abundance becomes more even (see also Kindt *et al.* 2002). In a survey in 2003/2004, 131 species have been found for the Miombo woodlands' forest in Tanzania: *Brachystegia boehmii Taub.* contributed about 10 per cent to the total number of stems *Brachystegia spiciformis Benth.* about 7 per cent and *Vitex payos (lour.) Merr.* about 5 per cent. With respect to the family-managed forests, the most dominant species were found to be *Combretum zeyheri Sond* (about 20 per cent), *Vitex paro (lour.) Merr.* (19 per cent) *Markhamia obtusifolia (Bak.) Sprague* (18 per cent) and *Lannea humilis (Oliv.) Engl.* (8 per cent). With respect to the forest reserves, the main dominant species are *Brachystegia boehmii Taub.* (12 per cent), *Diplorhynchus condylocarpon (Muell. Arg.) Pichon* (8 per cent), *Acacia tortilis (Forsk.) Hayne* (7 per cent). Some 90 per cent of the tobacco farmers interviewed named these species as being normally used for tobacco curing. The Shannon-Weaver Index calculated consequently ranges from 1.41 to 3.46 over the sample.

5.2 Data

Table 9.1 contains a descriptive statistic for the variables used, the number of cross-sectional observations are 110. The total quantity of tobacco produced varies quite a bit over the sample and accordingly also the total profit made in the reference period (2003). Some farms even showed a net loss in the period. As inputs (family/hired) labour, firewood, land and fertilizer are used in the analysis. The quantity of labour used was calculated by summing up the mandays for family and hired labour with respect to the following operations: nursery, land clearing and tilling, transplanting, weeding, fertilizer application, pesticides spraying, topping and desuckering, harvesting, curing, grading and bailing.

The price of labour was obtained by applying the opportunity costs of labour equalling the price for labour by the 'second-best' usage (a weighted average labour price for the private rural sector). As firewood is freely collected in the forests, the costs for firewood are obtained by considering the acquisition costs with respect to firewood cutting, loading, unloading as well

Table 9.1 Descriptive statistics

Variable (unit)	Mean	SD	Min	Max
Total profit/loss (usd)	649.977	161.484	−1101.352	3957.45
Tobacco output (kg)	935.329	913.937	165	6780
Price of tobacco (usd/kg)	0.808	0.152	0.470	1.190
Labor (man-days)	353.494	242.219	23	1250
Firewood (m³)	4.073	2.086	1	12
Land (ha)	0.971	0.754	0.202	4.856
Fertilizer (50 kg bags)	10.298	8.528	2	60
Price of labour (usd/md)	1.599	0.717	0.67	2.74
Price of firewood (usd/m³)	16.017	6.244	2	28.32
Price of land (usd/ha)	3.049	0.562	1.89	3.49
Price of fertilizer (usd/bag)	16.415	0.750	15.77	17.28
Total costs (usd)	782.084	562.960	144.75	4106.36
Diversity index	1.928	0.696	1.46	3.41
Costs of sisal twine (usd/year)	1.070	0.879	0	5.030
Jute twine (kg/year)	2.766	2.552	0	16
Loan (usd/year)	86.141	80.262	0	556.02
Land cleared (ha)	0.418	0.495	0	1
Experience (years)	21.418	14.109	4	44
Barn design	0.327	0.471	0	1
Distance (km)	6.300	3.779	0.5	20
Education (years)	5.691	3.55	0	11
Village	2.909	1.351	1	5
Sex	1.818	0.387	1	2
Age (years)	43.3	12.688	20	78
Source of firewood	0.345	0.478	0	1

as transport. The price of firewood is simply total costs for firewood divided by the sum of the firewood used in the curing cycles. The price of fertilizer was obtained from the dealers' records. As finally there are no prices for agricultural land in the majority of regions in Tanzania, the opportunity cost approach was again used by considering the rental rate for land with respect to the different villages in the sample. Total costs of tobacco production are obtained as the sum of all input cost items. The *diversity index* denotes the species diversity index on the base of the Shannon-Weaver formula. As additional control variables influencing the profitability of tobacco production on the farm level, the following variables are considered in the analysis according to data availability: the *costs of sisal twine* used in production, the quantity of *jute twine* used, and the total *loan* amount received in the production year. Further, the decision of the farmers to use already cultivated or newly *cleared land* is reflected by a binary variable denoting the land type used—newly cured forest land or already cultivated tobacco land. *Experience* denotes the farming experience of the respective household head whereas *barn design* is a binary proxy for the different tobacco-curing technologies applied in the form of an improved furnace or a more traditional one. The

level of education of the household head is reflected by the proxy variable *education* as the number of years of formal schooling received. The distance (in km) from the location of the farm to the edge of the next forest is considered by *distance, source of firewood* as a binary dummy variable reflects if the firewood used for tobacco curing was obtained from woodlands managed under community-based arrangements or from woodlands managed by other forms of arrangements (i.e. open access or family-based management). *Sex* finally refers to the gender of the farm head and *age* gives the age of the same. The variable *village* is incorporated to control for possible effects by the institutional setting of the village.

5.3 The price of diversity

As a profit maximization framework is used in this study, prices are the relevant categories with respect to the empirical analysis. However, from a production analysis point of view, there are basically three different perspectives on biodiversity (i.e. species diversity, see also Section 3):

> *Proposition 1*: The diversity of species found in the surrounding forests influences the level of profit made on the individual farm level.

Hence, *DI* (for diversity index, with $DI \in R_+^U$) controls for negative and/or positive effects on the profit frontier Π', and consequently the measure for environmentally conditional profit efficiency is

$$\pi E_E(y, x, DI, p, w) = [(P^T y - w^T x) / \pi(p, w)] : (y, x, DI) \in \Pi' \quad (9.21)$$

where πE_E has to satisfy the properties

(i) $\pi E_E(y, x, DI, p, w) \leq 1$, with $\pi E_E(y, x, DI, p, w) = 1 \Leftrightarrow y = y(p, w)$, $x, DI = x(p, w)$ so that $(p^T y - w^T x) = \pi(p, w)$

(ii) $\pi E_E(\lambda y, x, DI, p, w) \geq \pi E_E(y, x, DI, p, w), \lambda \geq 1$

(iii) $\pi E_E(y, \lambda x, DI, p, w) \leq \pi E_E(y, x, DI, p, w), \lambda \geq 1$

(iv) $\pi E_E(y, x, DI, \lambda p, \lambda w) = \pi E_E(y, x, DI, p, w), \lambda > 0$.

Following proposition 1, a construction of a diversity price vector is not necessary as species diversity enters the empirical model additively as a control variable by simply using the relative index numbers constructed by the Shannon-Weaver Diversity Index H'.

> *Proposition 2*: The loss of diverse tree species in the surrounding forests as a consequence of increased land clearing and use of firewood can be considered as a detrimental input to production beside the ordinary inputs labor, land, firewood, and fertilizer.

It is assumed that the lower the diversity index in the surrounding forest area (i.e. the higher the scarcity of variety), the higher the price for using it as an input to production. Hence, w_{DI} (as the price of diversity, with $w_{DI} \in R_{++}^U$) is incorporated in the profit function as follows

$$\Pi (y, x, x_{DI}, p, w, w_{DI}) = [(p^T y - w^T x - w_{DI} x_{DI}) / \pi (p, w, w_{DI})] \qquad (9.22)$$

and consequently the measure for input environmental efficiency is

$$EE_{IDI} (x_{DI}, y, w_{DI}) = CE (y, x, x_{DI}, w_x, w_{DI}) /$$
$$[TE_I (y, x, x_{DI})^* AE_I (x, y, w_x)] \qquad (9.23)$$

where EE_{IDI} has to satisfy the properties:

(v) $0 < EE_{IDI} (x_{DI}, y, w_{DI}) \le 1$

(vi) $EE_{IDI} (x_{DI}, y, w_z) = 1 \Leftrightarrow \lambda \le 1$ so that $\lambda x_{IDI} = x_{DI} (y, w_{DI})$

(vii) $EE_{IDI} (\lambda x_{DI}, y, w_{DI}) = EE_{IDI} (x_{DI}, y, w_{DI})$ for $\lambda > 0$

(viii) $EE_{IDI} (x_{DI}, y, \lambda w_{DI}) = EE_{IDI} (x_{DI}, y, w_{DI})$ for $\lambda > 0$.

and the efficiency notations are based on the definitions as given before.

Proposition 3: The diversity of species found in the surrounding forests can be regarded as a desirable output of production beside the ordinary output tobacco produced.

It is assumed that the lower the diversity index in the surrounding area, the higher the value of the output species diversity (i.e. the value of creating less diversity loss) for the adjacent livelihoods, and consequently the higher its price. Hence, p_{DI} (as the price of diversity, with $p_{DI} \in R_{++}^S$) can be incorporated in the profit function as follows

$$\Pi(y, y_{DI}, x, p, p_{DI}, w) = [(p^T y + p_{DI} y_{DI} - w^T x) / \pi(p, p_{DI}, w, w_{DI})] \qquad (9.24)$$

and consequently the measure for output environmental efficiency is

$$EE_{o_{DI}}(x, y_{DI}, p_{DI}) = RE(x, y, p, y_{DI}, p_{DI}) / [TE_o (x, y)^* AE_{o_{DI}}(x, y_{DI}, p_{DI})]$$
$$\qquad (9.25)$$

and $EE_{o_{DI}}$ has to satisfy the following properties

(ix) $0 < EE_{o_{DI}} (x, y_{DI}, p_{DI}) \le 1$

(x) $EE_{o_{DI}} (x, y_{DI}, p_{DI}) = 1 \Leftrightarrow \lambda \ge 1$ so that $\lambda y_{DI} = y_{DI} (x, p_{DI})$

(xi) $EE_{o_{DI}}(x, \lambda y_{DI}, p_{DI}) = EE_{o_{DI}}(x, y_{DI}, p_{DI})$ for $\lambda > 0$

(xii) $EE_{o_{DI}}(x, y_{DI}, \lambda p_{DI}) = EE_{o_{DI}}(x, y_{DI}, p_{DI})$ for $\lambda > 0$.

Following proposition 2 or proposition 3, a price vector for the detri-
mental input species diversity or the desirable output species diversity
respectively can be constructed by using the diversity scale found in the
sample following

$$w_{DI_f} = w_{DI_{f-1}} - (H'_f - H'_{f-1}) \qquad (9.26)$$

where $f = 1, \ldots, 6$ and $w_{DI_f} = \max(H')$ (for $f = 1$. Such a simple price vector
would be consistent with the individual index relations: the higher H' (i.e. the
higher the quantity of different species) the lower the relative scarcity in this
forest area f and the lower consequently the price w_{DI_f} for using it or for
producing it. Table 9.2 summarizes the generated price vector and it can also
be illustrated as shown by Figure 9.2.

Table 9.2 The price of species diversity

Forest area f	1	2	3	4	5	6
SW-Index (H')	1.46	1.5	1.73	1.92	2.43	3.41
w_{DI_f}	3.41	3.37	3.14	2.95	2.44	1.46
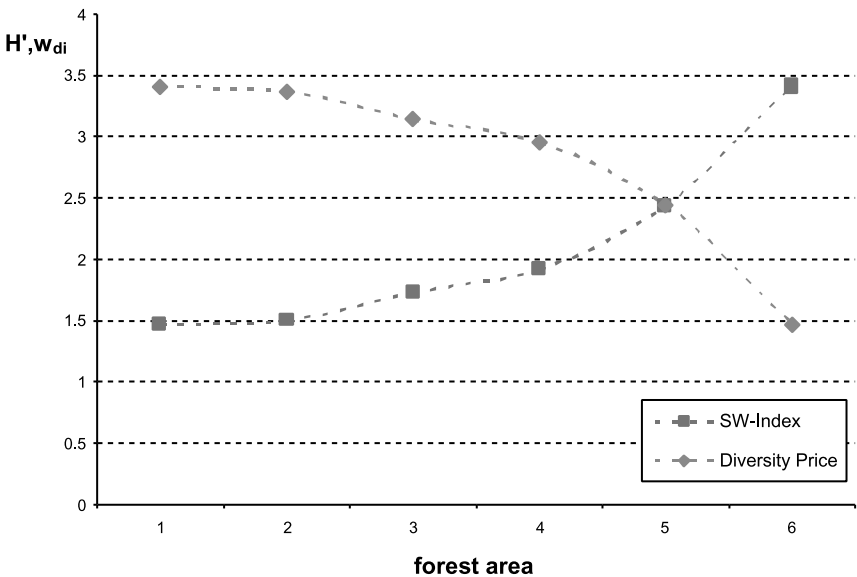
Figure 9.2 Species diversity: index-based price and quantity.

6 Different stochastic estimation models

As briefly outlined in Section 2, this chapter tries to combine the shadow price approach with a fixed effects non-radial model by using a translog functional form. Whereas Models I–III use a single ouput profit frontier approach, Model IV is built on a multi-output function specification.

6.1 Model I: invariant controlling for diversity

Species diversity is incorporated as a simple control variable DI_i invariant over the sample of producers. Using the output tobacco produced and the inputs fertilizer, firewood, labour and land where the output price serves as a numeraire, the translog shadow profit system in equations (9.14a)–(9.14c) is then reformulated and estimated following (9.13a)–(9.13c) as

$$\ln \pi = \sum_n \gamma_n \ln\left(\frac{\theta_n w_n}{kp}\right) + \frac{1}{2}\sum_n \gamma_{nn}\left[\ln\left(\frac{\theta_n w_n}{kp}\right)\right]^2 + \sum_k \sum_n \gamma_{kn}\ln\left(\frac{\theta_k w_k}{kp}\right)$$

$$\ln\left(\frac{\theta_n w_n}{kp}\right) + \sum_o \varsigma_o \ln C_o + \zeta_{DI}\ln DI + \ln\left\{1 + \left(\frac{1-k_m}{k_m}\right)R_m * + \right. \tag{9.27a}$$

$$\left.\left(\frac{1-\theta_n}{\theta_n}\right)S_n *\right\} + \ln \varphi$$

$$S_n = \frac{-\left(\gamma_n + \sum_k \gamma_{kn}\ln\left(\frac{\theta_k w_k}{kp}\right)\right)}{\left[1 + \left(\frac{1-k_m}{k_m}\right)\left(\sum_n \delta_{mn}\ln\left(\frac{\theta_n w_n}{kp}\right)\right) + \left(\frac{1-\theta_n}{\theta_n}\right)\left(\gamma_n + \sum_k \gamma_{kn}\ln\left(\frac{\theta_k w_k}{kp}\right)\right)\right]\theta_n} \tag{9.27b}$$

where k, n = fertilizer, firewood, labour, land and m = tobacco. Classical error terms are additively appended and one share equation is deleted, the remaining system of 5 equations is estimated by using iterated seemingly unrelated regression (ITSUR). By following the procedure shown in (9.17)–(9.19c) convexity is imposed on Model I (Model IB).

6.2 Model II: group-wise controlling for diversity

As in Model I species diversity is incorporated as a simple control variable DI_q, but different from Model I it varies over groups of tobacco producers defined along the diversity index H′ found in the surrounding forest areas. Using the output tobacco produced and the inputs fertilizer, firewood, labour and land where the output price serves as a numeraire the translog shadow profit system becomes now

$$\ln \pi = \sum_n \gamma_n \ln\left(\frac{\theta_n w_n}{kp}\right) + \frac{1}{2} \sum_n \gamma_{nn}\left[\ln\left(\frac{\theta_n w_n}{kp}\right)\right]^2 + \sum_k \sum_n \gamma_{kn} \ln\left(\frac{\theta_k w_k}{kp}\right)$$

$$\ln\left(\frac{\theta_n w_n}{kp}\right) + \sum_o \varsigma_o \ln C_o + \zeta_q \ln DI_q + \ln\left\{1 + \left(\frac{1 - k_m}{k_m}\right) R_m^* + \right. \tag{9.28a}$$

$$\left. \left(\frac{1 - \theta_n}{\theta_n}\right) S_n^*\right\} + \ln \varphi$$

$$S_n = \cfrac{-\left(\gamma_n + \sum_k \gamma_{kn} \ln\left(\frac{\theta_k w_k}{kp}\right) + \zeta_q \ln DI_q\right)}{\left[\begin{array}{l}\left[1 + \left(\frac{1-k_m}{k_m}\right)\left(\sum_n \delta_{mn} \ln\left(\frac{\theta_n w_n}{kp}\right) + \zeta_q \ln DI_q\right) + \left(\frac{1-\theta_n}{\theta_n}\right)\right] \\ \left(\gamma_n + \sum_k \gamma_{kn} \ln\left(\frac{\theta_k w_k}{kp}\right) + \zeta_q \ln DI_q\right)\end{array}\right]^{\theta_n}} \tag{9.28b}$$

where k, n = fertilizer, firewood, labour, land and m = tobacco. Classical error terms are additively appended and one share equation is deleted, the remaining system of 5 equations is again estimated by using ITSUR. By following the procedure shown in (9.17)–(9.18) convexity is imposed on Model II (Model IIB).

6.3 Model III: diversity as an input

Species diversity is now incorporated as an input for production x_{di} varying over the sample of producers. The system of equations to estimate is then

$$\ln \pi = \sum_n \gamma_n \ln\left(\frac{\theta_n w_n}{kp}\right) + \frac{1}{2} \sum_n \gamma_{nn}\left[\ln\left(\frac{\theta_n w_n}{kp}\right)\right]^2 + \sum_k \sum_n \gamma_{kn} \ln\left(\frac{\theta_k w_k}{kp}\right) \ln\left(\frac{\theta_n w_n}{kp}\right)$$

$$+ \sum_o \varsigma_o \ln C_o + \ln\left\{1 + \left(\frac{1 - \kappa_m}{\kappa_m}\right) R_m^* + \left(\frac{1 - \theta_n}{\theta_n}\right) S_n^*\right\} + \ln\varphi \tag{9.29a}$$

$$S_n = \cfrac{-\left(\gamma_n + \sum_k \gamma_{kn} \ln\left(\frac{\theta_k w_k}{kp}\right)\right)}{\left[1 + \left(\frac{1-k_{km}}{k_m}\right)\left(\sum_n \delta_{mn}\ln\left(\frac{\theta_n w_n}{kp}\right)\right) + \left(\frac{1-\theta_n}{\theta_n}\right)\left(\gamma_n + \sum_k \gamma_{kn}\ln\left(\frac{\theta_k w_k}{kp}\right)\right)\right]\theta_n} \tag{9.29b}$$

where now k, n = fertilizer, firewood, labour, land as well as species diversity and m = tobacco. The estimation procedure follows the one applied before.

Again following the matrix procedure shown in (9.17)–(9.18) convexity is further imposed on Model 3 (Model IIIB).

6.4 Model IV: diversity as an output

Species diversity is now incorporated as an output of production y_{di} varying over the sample of producers. The system of equations to estimate is then

$$
\ln \pi = \beta_{di} \ln \left(\frac{k_{di} p_{di}}{k_{tob} p_{tob}} \right) + \sum_n \gamma_n \ln \left(\frac{\theta_n w_n}{k_{tob} p_{ob}} \right) + \frac{1}{2} \sum_n \gamma_{nn} \left[\ln \left(\frac{\theta_n w_n}{k_{tob} p_{tob}} \right) \right]^2
$$

$$
+ \frac{1}{2} \beta_{didi} \left[\ln \left(\frac{k_{di} p_{di}}{k_{tob} p_{tob}} \right) \right]^2 + \sum_k \sum_n \gamma_{kn} \ln \left(\frac{\theta_k w_k}{k_{tob} p_{ob}} \right) \ln \left(\frac{\theta_n w_n}{k_{tob} p_{tob}} \right)
$$

$$
+ \sum_n \delta_{din} \ln \left(\frac{k_{di} p_{di}}{k_{tob} p_{ob}} \right) \ln \left(\frac{\theta_n w_n}{k_{tob} p_{tob}} \right) + \sum_o \varsigma_o \ln C_o + \ln \left\{ 1 + \left(\frac{1 - k_{di}}{k_{di}} \right) R_{di}^* \right.
$$

$$
\left. + \left(\frac{1 - k_{tob}}{k_{tob}} \right) R_{tob}^* + \left(\frac{1 - \theta_n}{\theta_n} \right) S_n^* \right\} + \ln \varphi
$$

(9.30a)

$$
R_{di} = \frac{\left(\beta_{di} + \sum_n \delta_{din} \ln \left(\frac{\theta_n w_n}{k_{tob} p_{tob}} \right) \right)}{\left[\begin{array}{c} \left[1 + \left(\frac{1 - k_{di}}{k_{di}} \right) \left(\sum_n \delta_{din} \ln \left(\frac{\theta_n w_n}{k_{tob} p_{tob}} \right) \right) \right] + \left[1 + \left(\frac{1 - k_{tob}}{k_{tob}} \right) \right. \\ \left. \left(\sum_n \delta_{tobn} \ln \left(\frac{\theta_n w_n}{k_{tob} p_{tob}} \right) \right) \right] + \left(\frac{1 - \theta_n}{\theta_n} \right) \left(\gamma_n + \sum_k \gamma_{kn} \ln \left(\frac{\theta_k w_k}{k_{tob} p_{tob}} \right) \right) \end{array} \right]^{k_{di}}}
$$

(9.30b)

$$
S_n = \frac{-\left(\gamma_n + \sum_k \gamma_{kn} \ln \left(\frac{\theta_k w_k}{k_{tob} p_{tob}} \right) \right) + \sum_n^{top} \delta_{din} \ln \left(\frac{k_{di} p_{di}}{k_{tob} p_{ob}} \right)}{\left[\begin{array}{c} \left[1 + \left(\frac{1 - k_{di}}{k_{di}} \right) \left(\sum_n \delta_{din} \ln \left(\frac{\theta_n w_n}{k_{tob} p_{tob}} \right) \right) \right] + \left[1 + \left(\frac{1 - k_{tob}}{k_{tob}} \right) \right. \\ \left. \left(\sum_n \delta_{to\,bn} \ln \left(\frac{\theta_n w_n}{k_{tob} p_{tob}} \right) \right) \right] + \left(\frac{1 - \theta_n}{\theta_n} \right) \left(\gamma_n + \sum_h \gamma_{kn} \ln \left(\frac{\theta_k w_k}{k_{tob} p_{tob}} \right) \right) \\ + \sum_{base} \delta_{din} \ln \left(\frac{k_{di} p_{di}}{k_{tob} p_{ob}} \right) \end{array} \right]^{\theta_n}}
$$

(9.30c)

where k, n = fertilizer, firewood, labour, land and m = tobacco as well as species diversity. The estimation procedure follows again the one applied before and convexity is also imposed on Model IV (Model IVB) following

(9.17)–(9.19c). Hence, in total 8 different model specifications as well as the corresponding efficiency measures are estimated.

7 Results and implications

The estimations reveal a relatively good overall model fit of Model IA, Model IIIA, and Model IVB (see Table 9.3). This implies that for the cross-sectional data set used the modelling options of controling for diversity (I), incorporating diversity as an input (III), and incorporating diversity as an output (IV) in a constrained specification are superior to the modelling option of controling for group-wise diversity by fixed effects (II). More than 90 per cent of all individual parameter estimates over all estimation models are statistically significant (the more than 450 parameter estimates can be obtained from the author). Imposing curvature correctness on the translog profit system (i.e. convexity of the profit function) led to an improvement in theoretical consistency of up to 412 per cent (Model III). However, from a theoretical point of view this seems not very convincing as the different models still violate curvature at least for 50 per cent of the observations in the sample.

Table 9.4 summarizes the different efficiency scores with respect to the various model specifications estimated.

Systematic allocative efficiency varies quite a bit over the different models estimated. Controlling for species diversity (Model I) delivered relatively high values for allocative efficiency with respect to the input land and the input firewood. Mixed evidence was found for the inputs ferilizer and labour as well as the output tobacco. The fixed effects based model (Model II) showed high values for output allocative efficiency as well as for input allocative efficiency with respect to firewood. The opposite was found for the input fertilizer. Mixed evidence can be reported for labour and land. Modelling species diversity as an input to tobacco production (Model III) delivered for both specifications a high allocative efficiency with respect to the use of the input firewood and a relatively modest allocative efficiency for the use of the inputs labour and land. As for Model I mixed evidence was found for the input fertilizer and the output tobacco. Finally modelling species diversity as an output of a joint production structure (Model IV) resulted in mixed evidence

Table 9.3 Model statistics

Model	I		II		III		IV	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Adj R^2 (profit system)	0.954	0.651	0.590	0.239	0.829	0.599	0.389	0.326
F-Value	5500	1223	7131	9701	2822	3603	4884	3.602
P>|F|	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Convexity (%)	20.91	50.91	34.54	40.1	7.27	30.1	16.4	30.91

Notes: A: unconstrained specification, B: constrained specification.

Table 9.4 Systematic efficiency scores

Model	I		II		III		IV	
	A	B	A	B	A	B	A	B
Allocative Efficiency								
Syst. output AE	0.292***	0.555***	0.803***	0.826***	0.342***	0.873***	0.171***	0.458***
Syst. input AE fertilizer	0.131***	0.667***	0.027***	0.003***	0.760***	0.319***	0.074***	0.328***
Syst. input AE firewood	0.735***	0.619***	0.899***	0.782***	0.950***	0.908***	0.245***	0.769***
Syst. input AE labour	0.025***	0.787***	0.470***	0.835***	0.405***	0.360***	0.105***	0.730***
Syst. input AE land	0.813***	0.842***	0.980***	0.565***	0.462***	0.375***	0.066***	0.557***
Technical Efficiency								
Syst. output-oriented TE	0.476	0.100	0.823	0.706	0.603***	0.564	0.165***	0.507***
Environmental Efficiency								
Syst. input EE	–	–	–	–	0.182***	0.214***	–	–
Syst. output EE	–	–	–	–	–	–	0.174***	0.135***

Notes: A: unconstrained specification, B: constrained specification.
AE: allocative efficiency, TE: technical efficiency, EE: environmental efficiency.
*, **, ***: significance at 10, 5, and 1% -level respectively.

with respect to all forms of systematic allocative efficiency investigated. Whereas the unconstrained model specification showed low values for almost all inputs and the output tobacco, the constrained one resulted in a relatively high efficiency with respect to land, labour as well as fertilizer and a relatively modest efficiency for fertilizer and tobacco. Comparing the allocative efficiency values over all unconstrained specifications (Models IA–IVA) gives (more or less) consistent levels of efficiency for the inputs fertilizer, firewood and labour for at least three out of four models. Focusing on the other side the allocative efficiency values over all constrained specifications (models IB–IVB) gives (more or less) consistent levels of efficiency with respect to the output tobacco and the inputs firewood, labor and land for at least three out of four models.

Systematic output-oriented technical efficiency was found to be relatively high following Model II and Model III whereas mixed evidence has to be reported for Model I and Model IV. However, comparing again technical efficiency over all unconstrained specifications (Models IA–IVA) gives consistent levels of efficiency for at least three out of four models. The same holds for the comparison with respect to the constrained specifications (Models IB–IVB). It has to be noted that not all technical efficiency estimates were found to be statistically significant.

Environmental efficiency was estimated in a systematic input related (Model III) as well as a systematic output-related specification (Model IV). Nevertheless, both model assumptions led to a relatively low level of environmental efficiency (0.135–0.214) with respect to species diversity. As Figure 9.3 illustrates, these findings are confirmed by the unconstrained and the constrained model case (Models IIIB and IVB).

Environmentally conditional efficiency was estimated by applying a fixed
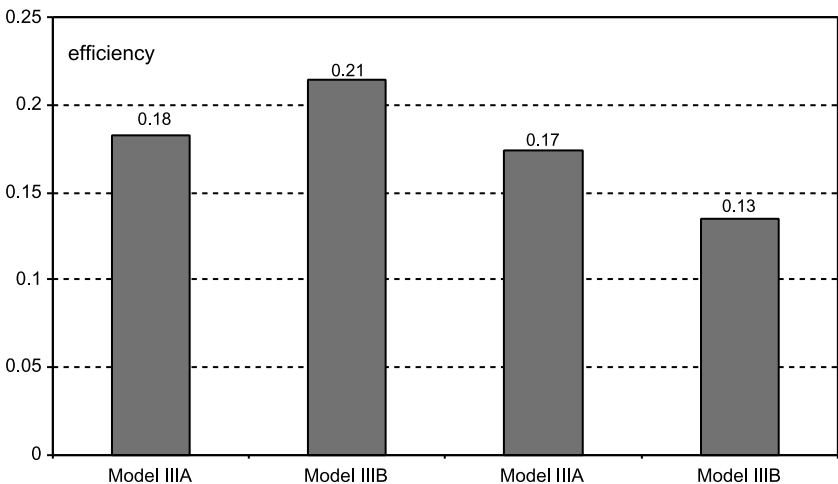
Figure 9.3 Environmental efficiency (EE).

effects model approach and controlling for different levels of species diversity (H′) in the surrounding forest areas (Model II). Table 9.5 summarizes the empirical findings for each of the five groups of tobacco producers by input and model specification.

Overall environmentally conditional profit efficiency was found to be the highest for producers of group 1 followed by those in group 4. This was obtained by both model specifications. The same was revealed for environmentally conditional allocative efficiency with respect to land. However, for the inputs fertilizer, firewood and labour the group-wise efficiency estimates differ to some extent between the unconstrained and constrained model. A significant correlation between the ranking of the producer groups (i.e. species diversity index) and the ranking of the environmentally conditional efficiency estimates could only be confirmed for the allocative efficiency with respect to the use of fertilizer (see table 9.6): the higher the diversity index H′, the higher the allocative efficiency with respect to fertilizer.

From a policy point of view, the following implications have to be noted. The relatively modest level of allocative efficiency with respect to the use of labour and land as well as the relatively low level of allocative efficiency with respect to the use of fertilizer point to market distortions in the rural agricultural input markets. Structural measures targeting the allocation of these inputs due to their relative price ratios could lead to an improvement in the efficiency of small-scale tobacco production. The modest allocative efficiency of the output-related production decisions further highlight existing scope for policy actions aiming to influence the farmers' production decisions with respect to scarcity considerations. Improvements in technical efficiency are possible by targeting the education of the farmers and/or facilitating the choice of more modern technology, e.g. by fostering the modernization of the barn design and/or strengthening agricultural consulting services. The rather low level of environmental efficiency on farm level with respect to species diversity in the surrounding forest areas impressively point to the need for policy measures aimed at reducing the negative impacts of tobacco production on biodiversity in rural areas of Tanzania. One option could be to establish a system of compensation payments for using firewood of predefined species which are not endangered by species loss. In addition, a diversification of small-scale agricultural production towards less environmentally detrimental (as well as more allocatively efficient) crops could lead to an increase in environmental efficiency of tobacco-producing farms. The significant positive correlation of the group-wise species diversity index and allocative efficiency with respect to the use of fertilizer for tobacco cultivation finally delivers empirical evidence for the crucial role of chemical fertilizers for the biological and geophysical processes with respect to forest trees (see e.g. Geist 1999). This implies that the environmental efficiency of tobacco-producing farms can be increased by enhancing the allocative efficiency of fertilizer use.

From a modelling point of view, the empirical results deliver evidence with respect to the following points: the clear deviation of the constrained

Table 9.5 Environmentally conditional efficiency (Model II)

Group of producers / Model specification	Profit efficiency		Input AE fertilizer		Input AE firewood		Input AE labour		Input AE land	
	A	B	A	B	A	B	A	B	A	B
1 (H' = 3.41)	1	1***	1***	0.609***	0.686	1***	0.345***	1**	1***	1***
2 (H' = 2.43)	0.558	0.584	0.885	0.850	1	0.966	1***	0.518	0.231	0.237
3 (H' = 1.73)	0.276	0.599	0.899	0.879	0.689	0.665	0.816	0.606	0.214	0.238
4 (H' = 1.5)	0.777	0.728	0.254	0.517**	0.300*	0.979	0.884	0.271***	0.503	0.685*
5 (H' = 1.46)	0.362	0.652***	0.725***	1***	0.896***	0.963***	0.293***	0.792*	0.291***	0.174***

Notes: A: unconstrained specification, B: constrained specification.
AE: allocative efficiency. By definition one group of producers is on the frontier; i. e. shows a relative efficiency score of 1.
*, **, ***: significance at 10, 5, and 1% level respectively.

Table 9.6 Spearman's rank correlation (Model II)

Species diversity	Profit efficiency		Input AE fertilizer		Input AE firewood		Input AE labour		Input AE land	
	A	B	A	B	A	B	A	B	A	B
Model specification										
H'	0.5	0.1	0.8*	−0.4	0.0	0.5	0.3	0.3	0.2	0.6

Notes: A: unconstrained specification, B: constrained specification; *: significance at 10% level respectively.

efficiency estimates from the unconstrained efficiency estimates shows that stochastic performance scores are very sensitive with respect to the underlying functional form and its correct curvature (see also Sauer 2006). However, the effect of the underlying modelling assumption—i.e. controlling for diversity, group-wise environmentally fixed effects, diversity as an input or output—was found to be not that crucial as initially assumed: controlling for diversity (I), incorporating diversity as an input (III), and incorporating diversity as an output (IV) in a constrained specification showed to be superior specifications compared to the group-wise fixed effects model approach (II). Hence, the underlying modelling proposition 1, proposition 2 as well as proposition 3 formulated in Section 5 are proved to be empirically valid with respect to the different efficiency measures analysed. Focusing the stochastic measurement of environmental efficiency, it became clear that from an empirical point of view a flexible shadow profit function approach incorporating diversity as a productive input to production as well as a flexible shadow profit function approach incorporating diversity as a desirable output of production should be chosen.

8   Conclusion

The preceding analysis attempts the stochastic modelling of efficiency frontiers considering also environmental efficiency. As an empirical example, this chapter has addressed the case of small-scale tobacco production and its links to species diversity in surrounding forest areas. Four different modelling approaches were chosen based on three underlying propositions with respect to the incorporation of species diversity. The current discussion on the effects of theoretical consistency and functional flexibility on stochastic efficiency measures is considered by estimating all efficiency models in an unconstrained as well as a constrained specification.

The empirical result reveal that the underlying modelling assumption is not essential with respect to the statistical validity and empirical consistency of the efficiency estimates. From an empirical point of view, a flexible shadow profit function approach incorporating biodiversity as a productive input to production as well as a flexible shadow profit function approach incorporating biodiversity as a desirable output of production are shown to be superior. As previous investigations have revealed, stochastic performance measures are very sensitive with respect to the theoretical consistency of the underlying functional form. With respect to the accuracy of the econometric results the latter point seems to be more crucial than the underlying proposition with respect to the appropriate incorporation of the environment related variable. Hence, this chapter aims to contribute to the ongoing discussion on the stochastic modelling of environmental efficiency by empirically verifying the concern for theoretical consistency of the econometric model as well as the need for statistical significance.

The empirical results finally point to the need for policy actions to increase

the allocative efficiency of agricultural input markets as well as the technical and environmental efficiency of small-scale tobacco farms. Future research should focus on the analysis of the dynamics of environmental efficiency.

Notes

1 As it is built on a mathematical formula only valid as the discriminant included takes a nonnegative value
2 However, the divergence between shadow and market prices can be also due to modelling error or errors in variables.
3 Estimation could be also based on the system of observed output supply and input demand equations.

References

Agrell, P. J. and Bogetoft, P. (2004) 'Economic and environmental efficiency of district heating plants', *Energy Policy* 33(10): 1351–1362.

Ball, V. E., Lovell, C.A.K. Nehring, R. F. and Somwaru, A. (1994) 'Incorporating undesirable outputs into models of production', *Cahiers d'Économie et Sociologie Rurales* 31:60–74.

Chambers, R. (1988) *Applied Production Analysis: A Dual Approach*. Cambridge: Cambridge University Press.

Chambers, R. G., Chung, Y. and Färe, R. (1996). 'Benefit and distance functions', *Journal of Economic Theory* 70: 407–419.

Chung, Y. H., Färe, R. and Grosskopf, S. (1997) 'Productivity and undesirable outputs: a directional distance function approach', *Journal of Environmental Management* 51: 229–240.

Diewert W. E. (1973) 'Functional forms for profit and transformation functions', *Journal of Economic Theory* 6: 284–316.

Diewert W. E., and Wales, T. J. (1987) 'Flexible functional forms and global curvature conditions', *Econometrica* 55: 43–68.

Färe, R., Grosskopf, S, Lovell, C.A.K. and Pasurka, C. (1989) 'Multilateral productivity comparisons when some outputs are undesirable: a nonparametric approach'. *The Review of Economics and Statistics* 71 (1): 90–98.

Färe, R. and Lovell, C.A.K. (1978). 'Measuring the technical efficiency of production', *Journal of Economic Theory* 19: 150–162.

Geist, H. J. (1999) 'Global assessment of deforestation related to tobacco farming', *Tobacco Control* 8: 18–28.

Greene, W. H. (2005). 'Fixed and random effects in stochastic frontier models, *Journal of Productivity Analysis* 23(1): 7–32.

Hailu, A. and Veeman, T. S. (2001) 'Non-parametric productivity analysis with undesirable outputs: an application to the Canadian pulp and paper industry', *American Journal of Agricultural Economics* 83(3): 605–616.

Hetemäki, L. (1996) 'Essays on the impact of pollution control on a firm: a distance function approach', Finnish Forest Research Institute. Research Papers 609. Helsinki. Finland.

Jorgenson D. W. and Fraumeni, B. M. (1981) 'Relative prices and technical change', in E. R. Berndt, (ed.) *Modelling and Measuring Natural Resource Substitution*. Cambridge, MA: MIT Press, pp. 17–47.

Kenchington, R., Ward, T. and Hegerl, E. (2003) *The Benefits of Marine Protected Areas*. RAC Marine PTY Ltd, Box 588, Jamison, ACT 2614.

Kindt, R., Degrande, A., Turyomurugyendo, I., Mbosso, C., Van Damme, P. and Simons, A. J. (2002) 'Comparing species richness and evenness contributions to on-farm tree diversity for data sets with varying sample sizes from Kenya, Uganda, Cameroon, and Nigeria with randomized diversity profiles', unpublished Manuscript.

Kopp, R. J. (1981) 'The measurement of productive efficiency: a reconsideration', *Quarterly Journal of Economics* 96: 477–503.

Kopp, R. J. and Diewert, W. E. (1982) 'The decomposition of frontier cost function deviations into measures of technical and allocative efficiency', *Journal of Econometrics* 19: 319–331.

Kumbhakar, S. C. (1989) 'Estimation of technical efficiency using flexible functional form and panel data', *Journal of Business and Economic Statistics* 7/2: 253–258.

Kumbhakar, S. C. and Lovell, C. A. (2000) *Stochastic Frontier Analysis*, Cambridge: Cambridge University Press.

Kuosmanen, T. (2005). 'Weak disposability in nonparametric production analysis with undesirable outputs', *American Journal of Agricultural Economics* 87(4): 1077–1082.

Lau, L. J. (1976) 'Characterization of the normalized restricted profit function', *Journal of Economic Theory* 12: 131–163.

Lau, L. J. and Yotopoulos P. A. (1971). 'A test for relative efficiency and application to Indian agriculture', *American Economic Review* 61: 94–109.

Magurran, A. E. (1988) *Ecological Diversity and Its Measurement*. London: Croom-Helm.

Monela, G. C. and Abdallah, J. M. (2005). 'Challenges of Tanzanian forestry management', unpublished manuscript.

Norse, E. A., Rosenbaum, L. K., Wilcove, D. S., Wilcox, B. A., Romme, W. H., Johnston, D. W. and Stout, M. L. (1986) *Conserving Biological Diversity in Our National Forests*. Washington, DC: The Wilderness Society.

Omer, A. A., Pascual, U. and Russell, N. P. (2007). 'Biodiversity conservation and productivity in intensive agricultural systems', *Journal of Agricultural Economics* 58: 308–329.

Pearce, D. and Moran, D. (1994) *The Economic Value of Biodiversity*. London: Earthscan.

Pittman, R. W. (1981) 'Issues in pollution control: interplant cost differences and economies of scale', *Land Economics* 57: 1–17.

Pittman, R. W. (1983) 'Multilateral productivity comparisons with undesirable outputs', *Economic Journal* 93: 883–891.

Reinhard, S., Lovell, C.A.K. and Thijssen, G. (1999) 'Econometric estimation of technical and environmental efficiency: an application to Dutch dairy farms', *American Journal of Agricultural Economics* 81: 44–60.

Reinhard, S., Lovell, C.A.K. and G. Thijssen, (2002) 'Analysis of environmental efficiency variation', *American Journal of Agricultural Economics* 84: 1054–1065.

Ryan D. L. and T. J. Wales (1998) 'A simple method for imposing local curvature in some flexible consumer demand systems', *Journal of Business and Economic Statistics* 16: 331–338.

Ryan D. L. and Wales, T. J. (2000) 'Imposing local concavity in the translog and generalized Leontief cost functions', *Economics Letters* 67: 253–260.

Sauer, J. (2006) 'Economic theory and econometric practice: parametric efficiency analysis' *Empirical Economics* 31: 1061–1087.

Sauer, J. and Abdallah, J. M. (2007) 'Efficiency, biodiversity and resource management—tobacco and forest in Tanzania' *Forest Policy and Economics* 9: 421–439.

Sauer, J. and Frohberg, K. (2007) 'Allocative efficiency of rural water supply—a globally flexible SGM cost frontier', *Journal of Productivity Analysis* 27: 31–40.

Scheel, H. (2001) 'Undesirable outputs in efficiency valuation', *European Journal of Operational Research* 132: 400–410.

Shephard, R. W. (1970) *Theory of Cost and Production Functions*. Princeton, NJ: Princeton University Press.

Yaisawarng, S., and Klein, J. D. (1994) 'The effects of sulfur dioxide controls on productivity change in the U.S. electric power industry', *Review of Economics and Statistics* 76: 447–460.

Zofio, J. L. and Prieto, A. M. (1996) DEA Environmental Standards Modelling. Working Paper. Department of Applied Economics, Universidad Autónoma de Madrid, Spain.

10 Diversity, productivity and resilience in agro-ecosystems

An example from cereal production in Southern Italy

Salvatore Di Falco and Jean-Paul Chavas

1 Introduction

The relationship of crop species diversity to productivity and resilience has been extensively investigated in the scientific literature on agro-ecology. Most of the evidence indicates that there are some beneficial effects of crop species diversity on the functioning of agro-ecosystems[1]. A prime example is the work of Tilman and colleagues. In a series of plot experiments, they find that plant biomass is an increasing function of the diversity of species (Tilman and Downing 1994; Tilman *et al.* 1996; Tilman *et al.* 2005). Thus, higher levels of diversity are associated with greater productivity in the agro-ecosystem (Giller *et al.* 1997).

Ecologists have provided two different explanations for the beneficial role of crop biodiversity in the function of agro-ecosystems. The first explanation is based on the observation that growing more diverse crop species increases the probability of growing the best-adapted species. This is known as the "sampling effect" hypothesis (Tilman *et al.* 2005). The second explanation, known as the complementarity effect, stresses the role of niche partitioning and facilitation (Loreau and Hector 2001). Different crop species have different traits and characteristics. A more diverse agro-ecosystem will have a broader range of traits and be more likely to perform under different environmental conditions (Sala 2001). Genetic variability within and among species confers the potential to resist biotic and abiotic stresses (Giller *et al.* 1997). Therefore, the coexistence of multiple species can occur "if there is an inter-specific trade off such that each species is a superior competitor for a limited range of values of the physical factor and if the physical factor is heterogeneous" (Tilman *et al.* 2005).

Moreover, it has been argued that more diversity or complexity of the ecosystem improves the capacity of the system to withstand external shocks and maintain productivity (Perrings and Stern 2000), known as Holling resilience. When analyzed at the regional scale, the positive relationship between biodiversity, resilience and productivity seems to be due to "partitioning" (Cardinale *et al.* 2004). Indeed, at a regional level, agro-ecosystems are typically composed of many different patch types that generate spatial

heterogeneity. Given that partitioning may occur both within and across patches, aggregate production can increase when biodiversity increases. In essence, this is "niche partitioning at regional scale" (Bond and Chase 2002). Therefore, growing diverse crop species can, for instance, enhance productivity in years or "field locations" where rainfall regimes or environmental conditions are more challenging.

Crop biodiversity, a component of agricultural biodiversity, refers to all diversity within and among domesticated crop species (Qualset *et al.* 1995; Lenne and Wood 1999). Based on this literature, we hypothesize that maintaining crop biodiversity *in situ* will tend to provide an agro-ecosystem with a wider range of productive responses to weather shocks. This is particularly important in agro-ecosystems where complexity has been simplified and the number of crop species reduced for the purpose of agriculture (Conway 1993). In such systems, crop biodiversity is the most important component of the overall agrobiodiversity.

Screening the empirical economics literature, we found that economists have devoted little attention to examining the role of crop biodiversity in the productivity and resilience of agro-ecosystems. For instance, Smale *et al.* (1998) studied the relationship between the intra-specific diversity of wheat and the partial productivity of wheat in the Punjab of Pakistan. They found that greater genealogical distance among varieties and a higher number of varieties grown per district were associated with higher mean yield. In a study of rice productivity in China, Widawsky and Rozelle (1998) found that a higher level of diversity reduced both the mean and variance of rice yields. Di Falco and Perrings (2005) found a positive relationship between crop species diversity and cereal production in a case study conducted in southern regions of Italy. Based on farm data from Sicily, Di Falco and Chavas (2006) found a positive correlation between crop genetic diversity and productivity of wheat. They also found that wheat biodiversity reduces yields variability and the risk of crop failure.

Each of these studies models crop biodiversity as an input in a static production process. Static approaches neglect the dynamic contributions of crop biodiversity to productivity in the agro-ecosystem, which grow strong through time (Cardinale *et al.* 2004). In addition, several of these studies use area-weighted or spatial diversity indices (e.g., Herfindahl, Simpson or Shannon indices). Such indices could be endogenous in an economic model based on farmer decision-making, leading to biased results.

To illustrate these points, this chapter presents an analysis in three steps. First, we present a case study of the contribution of crop biodiversity to cereal production by using a standard static panel data approach. Then, a dynamic specification of the production model is presented and the results compared. The dynamic panel data analysis relies on a GMM estimator, which provides efficient parameter estimates while correcting for potential endogeneity bias associated with the biodiversity index.

Finally, the role of crop biodiversity in reducing the possible negative

impact of climate change is explored. Thus, in the dynamic analysis of productivity, examining the effects of crop biodiversity in interaction with rainfall provides a basis for testing whether crop biodiversity can help mitigate the adverse effects of declining moisture. The analysis is applied to regional data for the period 1970–1993 from one of the most important areas for cereals production in Europe: southern Italy.

Southern Italy is a Vavilovian center of mega-diversity for cereals. The area has a Mediterranean dry climate, and is entirely rainfed, which restricts production possibilities for agriculture. In the absence of irrigation, the impact of rainfall reduction on the system productivity cannot easily be mitigated. Both environmental and market conditions restrict potential economic substitution among different crops or activities (e.g. more than 70 percent of wheat for pasta and bakery products produced in Italy are from southern Italy).

Southern Italy is now considered to be under threat of desertification. (IPCC WGII Report 2003). Annual precipitation trends in southern Europe showed a reduction in annual rainfall of up to 20 percent during the past 40 years, and recent projections forecast a further decrease between 5 percent and 15 percent over the next decade (UK; Hulme *et al.* 1999; Parry 2000; Brunetti *et al.* 2001; IPCC WGII Report 2003; EEA Report No 2/2004).

Reduced rainfall has paramount importance for managed ecosystems such as agro-ecosystems. Agro-ecosystems are ecological systems transformed and simplified for the purpose of agriculture. Lower rainfall increases the level of environmental stress affecting the capability of the system to maintain productivity (Tisdell 1996). However, given the complexity of agro-ecosystems dynamics, the nature and magnitude of productivity decline remain poorly understood. For example, productivity decline may involve a regular decline in soil fertility because of nutrient mining or loss of stability and resilience in the agroecosystem (Holling 1973). In many situations, crop biodiversity provides the link between stress and loss of resilience (Perrings *et al.* 1995). In this context, we investigate the productivity of the agro-ecosystem in response to changing weather conditions, considering the diversity of cereal crop species in interaction with rainfall.

2 Framework

In agricultural productivity analysis, a range of mathematical representations of the production technology has been invoked (Mundlak 2001). Let $y_{it} = f_{it}(x_{it}, \cdot)$ denote the production function, where y_{it} is quantity of cereals produced in the i-th region at time t, x_{it} is the vector of inputs used in the it-h region at time t, and "$\cdot$" denotes other factors. The vector x_t includes conventional inputs (i.e., land, labor, capital, and fertilizer) along with rainfall and crop biodiversity. To introduce dynamics into the analysis, consider that $f_{it}(x_{it}, \cdot)$ takes the form $f_{it}(x_{it}; y_{i,t-1}, \ldots, y_{i,t-p}, x_{i,t-1}, \ldots, x_{i,t-q})$ for some $p \geq 0$ and $q \geq 0$. This means that the kth lagged production $y_{i,t-k}$ enters the production

function up to lag k = p. It also allows the kth lagged inputs x_{t-k} to affect production y_{it} up to lag k = q. As a result, the production process is represented by $y_{it} = f_{it}(x_{it}; y_{i,t-1}, \ldots, y_{i,t-p}, x_{i,t-1}, \ldots, x_{i,t-q})$. We consider the following production function specification

$$\ln(y_{it}) = A + \alpha \ln(x_{it}) + \sum_{k=1}^{p} \beta_k \ln(y_{i,t-k}) + \sum_{k=1}^{q} \gamma_k \ln(x_{i,t-k})$$

$$+ \delta_0 \ln(\text{diversity}_t) \ln(\text{rainfall}_t) + \delta_1 \ln(\text{diversity}_t) \ln(\text{rainfall}_{t-1})$$
$$+ \mu_i + v_{it}, \tag{10.1}$$

where α and γ_k are respectively vectors of parameters associated with the current and kth lagged input vector x, and β_k is the parameter of the kth lagged dependent variable. The error terms, μ_i and v_{it}, are independently distributed with mean zero and finite variance. The term μ_i measures region-specific effects, while the error term v_{it} denotes the remaining disturbance that can vary over time as well as across regions.

Note that the specification (10.1) reduces to a Cobb-Douglas specification when $\delta_0 = \delta_1 = 0$, and in the absence of dynamics (where $\beta_k = 0$ and $\gamma_k = 0$ for all k). It is well known that the Cobb-Douglas specification is not a flexible functional form, imposing unitary elasticity of substitution among inputs. To allow for a more general representation of the underlying technology requires introducing second-order terms between inputs in (10.1). In our analysis, we are particularly interested in the effects of rainfall and of cereal diversity on productivity. Considering that both rainfall and biodiversity are among the inputs *x*, we introduce the additional terms [ln(rainfall) ln(diversity)] in (10.1). These terms are expressed in both current interaction effects of rainfall with diversity (as captured by the parameter δ_0) and lagged interaction effects (as captured by the parameter δ_1). This gives a flexible specification of the production function, capturing dynamic as well interaction effects between rainfall and diversity.[2]

Equation (10.1) is a panel data model, combining data across regions as well as over time. The panel nature of the analysis has several advantages. First, it can control for cross-section heterogeneity and unobservable or missing values (Baltagi 2001). Second, it can improve the efficiency of the parameter estimates. Finally, panel data analysis provides a basis for studying dynamics and the estimating of short-run, intermediate-run as well as long-run effects of the explanatory variables. Equation (10.1) can be alternatively written as

$$\Delta\ln(y_{it}) = \alpha \Delta\ln(x_{it}) + \sum_{k=1}^{p} \beta_k \Delta\ln(y_{i,t-k}) + \sum_{k=1}^{q} \gamma_k \Delta\ln(x_{i,t-k})$$

$$+ \delta_0 \Delta[\ln(\text{diversity}_t) \ln(\text{rainfall}_t)] + \delta_1 \Delta[\ln(\text{diversity}_t) \ln(\text{rainfall}_{t-1})]$$
$$+ \Delta v_{it}, \tag{10.2}$$

where $\Delta z_t = z_t - z_{t-1}$ is the first-difference operator. The first-difference transformation eliminates the individual effects (Baltagi 2001) and reduces serial correlation. Equation (10.2) provides a basis for estimating the parameters. When some of the explanatory variables are endogenous, a generalized method of moments (GMM) estimator can generate consistent parameter estimates. When the error terms v_{it} are serially uncorrelated, valid instruments in the estimation of the first-difference model include lagged values of the dependent variable (see Arellano and Bond 1991). Given an appropriate choice of the instruments and weights, GMM can provide asymptotically efficient parameter estimates.

3 Description of the cropping system

The area considered in this study includes eight regions in southern Italy. These regions fall under the same climatic area (Buffoni *et al.* 1999). Cultural and climatic characteristics of this area make agriculture an important sector. Agriculture in Southern Italy accounts for 8 percent of overall European Union agricultural land and the average ratio of value added in agriculture to value added in industry has been persistently 0.4 from 1960 to 1993. Cereals are among the most important crops in this agro-ecosystem. Cereals are generally grown, and farmers practice rotation with legumes and nitrogen-fixing crops.

Between 1990 and 2000, on average, cereals produced in southern Italy accounted for 4 percent of the overall European cereal production. On a regional basis, they accounted for 43 percent of total agricultural land use, with the percentage reaching 70 percent in the Basilicata region. In the past 20 years, 68 percent of national durum wheat production, a staple product in Italy, has come from regions in southern Italy. Durum and bread wheat production is spread uniformly, with some areas producing large quantities of output. For instance, the regions of Abruzzo and Campania have produced respectively 72,144 and 75,838 tons of bread wheat (using around 25 different cultivars). The Sicily and Puglia regions produced the largest part of the durum wheat, with the latter accounting for 482,689 tons and the former for 434,730 tons. Thus, wheat (bread and hard) is dominant. Barley, oat and corn are less common. For instance, barley and oat account for respectively 5 percent and 4 percent of the land share sown to cereals. Corn is even less widely cultivated, with four regions out of eight allocating less than 1 percent of their land to the crop.

The production of cereals is particularly favored since the dry and warm weather in this area suits this family of crops. Cold, frosty winters and sudden changes in the temperature affect yields negatively. These weather conditions may, to some extent, reduce the spread and proliferation of pests. Pests are, indeed, more likely to spread when humidity is high. In some areas the soil is sandy. This reduces the ability of plant roots to absorb fertilizers, and hence the benefit of fertilizer use. In the time span considered in this chapter,

institutional conditions were quite homogeneous. The entire region was classified as "objective one" by the European Common Agricultural Policy. Considered broadly, agricultural assistance involved the same set of policy instruments throughout the period of study.

4 Data sources and variables description

Data were obtained from ISTAT, the Italian National Institute of Statistics, and the INEA, the National Institute for Agricultural Economics. The series are drawn from the Statistiche Agrarie and Annuario for eight regions in Southern Italy (Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria, Sicily and Sardegna), including the years from 1970 to 1993. During this time span all the regions benefited from the same set of financial instruments aimed at supporting farm income. Thus, farmers faced the same price and income incentives for growing different cereals.

Tables 10.1 and 10.2 and present the descriptive statistics and the definitions of the variables used in this empirical analysis. The quantity of cereal produced is expressed in tons. Fertilizer applications per hectare and labor force participation are conventional inputs. Capital is measured as investment in structure and machineries (at constant prices). The quantity of rainfall per year captures the weather impact on productivity.

The ecological literature has developed many metrics to calculate ecological diversity (Magurran 1988). In agricultural systems, one of the most commonly adopted measures of diversity is crop species richness or evenness found in a given geographical area. Both richness and evenness are intuitive

Table 10.1 Variable descriptions

Variable	Definition
Labor	Labor force in thousands of units
Fertilizer	Quantity of fertilizers and chemicals in 100kg per hectare
Capital	Expenditure in machinery and buildings in thousands million Italian lira
Land	Land size to cereal production in hectare
Diversity	Shannon Index for cereal crop diversity
Rain	Annual rainfall in mm

Table 10.2 Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
Labor	68.88	53.88	9.02	330.299
Fertilizer	2.68	1.26	0.85	13.05
Capital	557.4	287.67	89	1260.9
Land	684456	440784	176484	1643634
Diversity	1.02	0.32	0.22	1.45
Rain	615.49	234.18	181	1531

concepts and data are easily available at some geographical level for agroeco-systems. In this study, the Shannon[3] index is adapted to measure the spatial biodiversity (e.g., Smale *et al.* 1998; Smale *et al.* 2003). As shown by Weitz-man (2000), this index represents the unique functional form allowing consistent aggregation over classification levels. The Shannon index is

$$H = - \Sigma_i \, p_i \cdot \log(p_i)$$

where p_i is the planted area share of the ith species in a reference region.

The use of a Shannon index of spatial diversity in this context bears pro-vides two important benefits. The first benefit is that the index is sensitive to both to the evenness (measuring proportional abundance) and richness of species (the count per unit of area). This property implies that either a greater number of crop species, or greater evenness in their spatial distribution can increase the value of the index. A contested issue in biodiversity analysis is the existence of the so-called "sampling" effect (Tilman *et al.* 2005). The sampling effect implies that the effect of one particular crop species domin-ates the effect of heterogeneity. The Shannon index serves to control for this effect. A second benefit of using the Shannon index is that, when used to model cereals production in the aggregate, it accounts for the restricted eco-nomic substitution among cereals. This feature reduces the potential bias that can arise in production function approaches that are based on a model of a single crop (Mendelsohn *et al.* 1994). The index implicitly incorporates information about possible economic substitutions among cereals.

Note that alternative indices of spatial diversity have appeared in previous literature. Spatial indices belong to the Hill family of indices, which implies that they "can be linked to a more general information theory" and to a generalized formulation of entropy (Keylock 2005). These include the com-monly used Simpson index. However, the Simpson index is "heavily weighted toward the most abundant species in the sample while being less sensitive to species richness" (Magurran 1988: 40). In this empirical contest, the Simpson index appears ill-suited to represent spatial diversity in cereal crop diversity because of the dominance of one crop (durum wheat). By construction, spa-tial indices are a source of endogeneity bias. Indeed, the share of land to be allocated to the ith species is a choice variable.

Genetic distance indices have also been used to measure biodiversity. Weitzman (1992) proposed a distance measure that maximizes diversity among the surviving members of the set. Solow *et al.* (1993) proposed that the distance measures should take into account the size of the set (to capture richness) as well as the distance among members. Given the complexity of biodiversity valuation, at this point, no single measure has been identified as superior to others (e.g., Mainwaring 2001). However, Brock and Xepapadeas (2003) argue that "ecologically oriented measures" seem to be appropriate when the benefit of biodiversity stems from its contribution to agroeco-systems services, such as food production. The authors showed that even if

genetic distance is very small, the value of biodiversity can be large. Genetic distance indices are neither feasible nor applicable in this study, which examines crop species diversity in an agro-ecosystem by cereal crops.

5 Empirical evidence from Southern Italy

To compare the static and dynamic estimation, we provide the econometric results of both estimation procedures in Table 10.3. The dynamic production function given in (10.2) is estimated using the generalized method of moments (GMM) approach proposed by Arellano and Bond (1991).[4] Two lags are included for the dependent variable (p = 2), and one lag for the explanatory variables (q = 1). This provides a reasonable flexible representation of the dynamics of productivity. Rainfall is considered to be strictly exogenous, conventional inputs are considered as predetermined variables and the lagged values of the dependent variable and the biodiversity index are considered to be endogenous. To test for endogeneity for the diversity index, we adopted a residual-based test (Davidson and MacKinnon 1993; Wooldridge 2002). Lagged values of the index were used as instruments. We

Table 10.3 Dynamic panel data (GMM) estimation result

Variables	Static Panel data model Fixed effects (A)	Dynamic Model Arellano-Bond GMM estimation of (10.2) (B) 1[a]
y_{t-1}	–	0.12 (0.2)
y_{t-2}	–	0.12* (0.07)
$Diversity_t$	15.02*** ((4.04)	10.4*** (3.82)
$Diversity_{t-1}$	–	4.24* (2.5)
Interaction $Diversity_t$ & $Rain_t$	−1.98*** (0.61)	−1.5*** (0.56)
Interaction $Diversity_t$ & $Rain_{t-1}$	–	−0.41** (0.2)
$Land_t$	2.81*** (0.9)	2.82*** (1.1)
$Land_{t-1}$	–	−1.36* (0.8)
$Labor_t$	0.56* (0.3)	1.18* (0.7)
$Labor_{t-1}$	–	−0.38 (0.5)
$Fertilizer_t$	1.61 (0.46)	1.18***(0.29)
$Fertilizer_{t-1}$	–	0.14 (0.2)
$Capital_t$	0.66** (0.32)	1.41**(0.67)
$Capital_{t-1}$	–	−0.184 (0.7)
$Rain_t$	0.08 (0.37)	0.06 (0.15)
Constant	−16.16 (13.13)	0.43 (0.99)

Notes: [a]Source: Di Falco and Chavas, 2008.
Significance levels: *** = 1 percent, ** = 5 percent, * = 10 percent; 'a' = 10 percent one tailed test.
Robust standard errors are in parentheses.
Arellano-Bond test, H_0 of no first-order serial correlation in the residuals: z = −5.85.
Arellano-Bond test, H_0 of no second-order serial correlation in the residuals: z = −0.65, p-value = 0.513.

rejected the null hypotheses of exogeneity at the 10 percent significance level. This result suggests that the model should be estimated using an instrumental variable method in order to correct for endogeneity bias.

The Sargan/Hansen test of over-identifying restrictions was performed. The null hypothesis of the Sargan/Hansen test is that the instrumental variables are uncorrelated with the residuals. If this is not the case, the GMM estimator cannot be assumed to be consistent. The null hypothesis is not rejected. Thus, based on the Sargan/Hansen test, the instruments satisfy the orthogonality conditions required of the GMM estimator.

It is interesting to note that the static and dynamic estimation procedures provide coefficient estimates that are broadly similar both in terms of algebraic signs and magnitudes. This finding underscores the robustness of the estimates. However, some of the lagged explanatory variables are found to be statistically significant, which highlights the role of dynamics in the relationship of cereal crop diversity and productivity. Both $y_{i,t-1}$ and $y_{i,t-2}$ are positive, although only the latter is statistically significant. Thus, current production is related to past production values. This indicates that dynamic productivity effects generate a positive correlation between past and current production (Di Falco and Chavas 2008).

Cereal crop diversity is positively related with production both in terms of current and lagged effects. This result indicates that maintaining more spatially diverse cereal crops enhances agricultural productivity both in the short run and in the intermediate run, and is consistent with experimental evidence showing that the effect of crop biodiversity on productivity is increasingly positive through time (Cardinale *et al.* 2004). Changes in biomass can result from local processes and species interactions, but also from pest and pathogens evolutions. Indeed, "the crop mix dynamics are controlled to maintain a desirable gene pool equilibrium" (Brock and Xepapadeas 2003). In our case, this suggests that the cropping system exhibits significant dynamics, generating services (i.e. food production) both in the short and in the longer run (Gunderson and Holling 2001; Brock and Xepapadeas 2003).

The interaction terms between crop biodiversity and rainfall are negative and significant in both current and lagged effects. This result illustrates the relevance of a higher biodiversity regime as a means of coping with scarce rainfall, providing evidence that crop biodiversity ensures productivity under conditions of lower rainfall. The effects of land on production are found to be statistically significant both in current and in lagged effects. As expected, the estimated impact of land is relatively large. The significance of lagged land captures the effect on productivity of bringing "marginal land" into production over time.

The coefficients for the current levels of other conventional inputs (fertilizer, capital and labor) are all positive and statistically significant. However, in column (B) of Table 10.3, the lagged effects of these conventional inputs are not statistically significant. This result could be explained by the fact that

they are conventional, variable inputs whose effects are less important when placed in a dynamic as compared to a static context.

The dynamic panel data framework allows the assessment of dynamic responses, including the evaluation of short-run and long-run elasticities. The estimated coefficients from the dynamic model are used to calculate dynamic elasticities of production. Evaluated at sample means, the elasticity of production with respect to crop biodiversity is 0.87 in the short run, and 3.29 in the long run. This procedure leads to two important results. First, crop biodiversity has a positive and fairly large impact on productivity, both in the short run and in the long run. This finding supports the argument that crop biodiversity plays a key role in supporting agroecosystem productivity. Second, the long-run impact is much larger than its short-run impact. This result highlights the importance of dynamics in the function of the agro-ecosystem.

The interaction effects in the model imply that the role of biodiversity varies with rainfall. To illustrate, consider the production elasticity with respect to crop biodiversity when rainfall is 20 percent below the sample mean. Compared to the evaluation at sample means, this elasticity increases from 0.87 to 1.14 in the short run, and from 3.29 to 3.75 in the long run. This finding demonstrates that the productivity benefits of biodiversity are larger when rainfall declines and the ecosystem face environmental stress. The estimated elasticity from the static model, instead, identifies an elasticity of 2.4. Therefore, neglecting the dynamics of crop biodiversity causes an underestimation of the elasticity in the long run and its overestimation in the short run.

6 Conclusion

Previous studies focusing on the determinants of crop biodiversity *in situ* have found that farm and farmer characteristics, risk hedging, the development of market infrastructure, and agro-ecological conditions in the region are factors explaining the diversity levels in a given area. Yet, one of the major issues in the debate about biodiversity, which has not been adequately explored with empirical data, is the relationship of crop biodiversity to productivity and resilience.

This chapter contributes to the understanding of this issue through an empirical application to data on cereal crop production in southern Italy, a Vavilovian mega-center that is current under threat of desertification due to declining rainfall. Crop biodiversity is measured by a Shannon index of spatial diversity. Using regional data over a 20-year period, we tested how levels of rainfall, cereal crop diversity and their interactions affect productivity in a dynamic as well as a static context.

We found that while the coefficients estimated were broadly consistent in the static and dynamic models, the lagged effects were statistically significant. The econometric results show that levels of crop biodiversity are positively and significantly related to productivity. Positive effects are found to be

stronger in the long term than in the short term, reflecting the dynamics of agro-ecosytem productivity. Thus, maintaining diverse cropping systems enhances overall agricultural productivity. More importantly, the positive contribution of crop biodiversity is found to be stronger when the level of rainfall is lower. This result suggests that maintaining high crop biodiversity helps the productivity of the agro-ecosystem when a limiting physical factor becomes important. Taken together, findings are consistent with the notion that agro biodiversity can buffer and insure against negative environmental effects, supporting the resilience of the system under adverse weather conditions associated with anticipated climate changes.

Acknowledgements

Notes

1 Agro-ecosystems are defined as ecological and socioeconomic system comprising domesticated plants and/or animals and the people who husband them, intended for the purpose of producing food, fiber, or other agricultural products (Conway 1985, 1986, 1987; Conway and Barbier 1990).
2 A more general functional specification that allowed for interaction between other inputs was also estimated (i.e. translog). However, multicollinarity adversely affected the econometric estimates and made the results more difficult to evaluate.
3 Assumptions underlying the use of the Shannon index include random sampling from an infinitely large population and the representation of all species from the defined area in the sample (Magurran 1988).
4 As mentioned above, we also estimated the model using a system GMM estimator by exploiting the initial conditions. The econometric results were similar.

References

Arellano, M. and Bond, S. (1991) "Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations," *The Review of Economic Studies* 58: 277–297.

Baltagi, B.H. (2001) *Econometric of Panel Data Analysis*. Chichester: John Wiley & Sons, Ltd.

Bond, E.M. and Chase, J.M. (2002) "Biodiversity and ecosystem functioning at local and regional spatial scales," *Ecology Letters* 5: 467–470.

Brock, W.A. and Xepapadeas, A. (2003) "Valuing biodiversity from an economic perspective: a unified economic, ecological and genetic approach," *American Economic Review* 93(5): 1597–1614.

Brunetti, M., Colacino, M. Maugeri, M. and Nanni, T. (2001) "Trends in the daily intensity of precipitation in Italy from 1951 to 1996," *International Journal of Climatology* 21: 299–316.

Buffoni, L., Maugeri, M. and Nanni, T. (1999) "Precipitations in Italy from 1833 to 1996," *Theoretical and Applied Climatology* 63: 33–40.

Cardinale, B.J., Ives, A.R. and Inchausti, P. (2004) "Effects of species diversity on the primary productivity of ecosystems: extending our spatial and temporal scale of inference," *Oikos* 104: 437–50.

Conway, G.R. (1993) "Sustainable agriculture: the trade-offs with productivity, stability and equitability," in E. D. Barbier (ed.) *Economics and Ecology: New Frontiers and Sustainable Development*. London: Chapman.

Davidson, R. and MacKinnon, J. G. (1993) *Estimation and Inference in Econometrics*. New York: Oxford University Press.

Di Falco, S. and Chavas, J.-P. (2006) "Crop genetic diversity, farm productivity and the management of environmental risk in rainfed agriculture," *European Review of Agricultural Economics* 33: 289–314.

Di Falco, S. and Chavas, J.-P. (in press) "Rainfall shocks, resilience, and the effects of crop biodiversity on the productivity of the agroecosystems," *Land Economics*.

Di Falco, S. and Perrings, C. (2005) "Crop biodiversity, risk management and the implications of agricultural assistance," *Ecological Economics* 55(4): 459–466.

EEA Report No 2 (2004) *Impacts of Europe's Changing Climate*. Copenhagen: European Environment Agency, European Topic Center for Air and Climate Change.

Evenson, R. E. and Gollin, D. (1997) "Genetic resources, international organizations, and improvement in rice varieties," *Economic Development and Cultural Change* 45(3): 471–500.

Giller, K.E., Beare, M.H., Lavelle, P., Izac, A.M.N. and Swift, M.J. (1997) "Agricultural intensification, soil biodiversity and agro-ecosystem function," *Applied Soil Ecology* 6: 3–16.

Gunderson, L. and Holling, C.S. (2001) *Panarchy: Understanding Transformations in Systems of Humans and Nature*. Washington, DC: Island Press.

Heal, G. (2000) *Nature and the Marketplace: Capturing the Value of Ecosystem Services*. New York: Island Press.

Holling, C.S. (1973) "Resilience and stability of ecological systems," *Annual Review of Ecology and Systematics* 4: 1–23.

Hulme, M., Barrow, E.M., Arnell, N. W., Harrison, P.A., Johns, T.C. and Downing, T.E. (1999) "Relative impacts of human-induced climate change and natural climate variability," *Nature* 397: 688–691.

IPCC WGII Report (2003) *Climate Change Impacts, Adaptation and Vulnerability*. Geneva: Intergovernmental Panel on Climate Change, World Meteorological Organization.

ISTAT, *Annuario di Statistica Agraria*, *1970–1993*. Rome.

Keylock, C.J. (2005) "Simpson diversity and the Shannon–Wiener index as special cases of a generalized entropy," *Oikos* 109(1): 203–207.

Lenne J. and Wood, D. (1999), "Optimizing biodiversity for productive agriculture," in D. Wood and J. Lenne (eds) *Agrobiodiversity: Characterization, Utilization and Management*. Wallingford: CABI Publishing.

Loreau, M. and Hector, A. (2001) "Partitioning selection and complementarity in biodiversity experiments," *Nature* 412: 72–76.

Magurran, A.E. (1988) *Ecological Diversity and Its Measurement*. London; Croom Helm.

Mainwaring, L. (2001) "Biodiversity, biocomplexity, and the economics of genetic dissimilarity," *Land Economics* 77: 79–93.

Mendelsohn, R., Nordhaus, W.D. and Shaw, D. (1994) "The impact of global warming on agriculture: a Ricardian analysis," *American Economic Review* 84(4): 753–771.

Mundlak, Y. (2001) "Production and supply," in B.L. Gardner, and G.C. Rausser (eds) *Handbook of Agricultural Economics*. Amsterdam: North Holland.

National Academy of Science (2001) *Climate Change Science: An Analysis of Some Key Questions*. Washington, DC: Committee on the Science of Climate Change, National Academy Press.

Parry, M.L. (2000) *Assessment of the Potential Effects and Adaptations for Climate Change in Europe: The Europe ACACIA Project*. Norwich: Jackson Environmental Institute, University of East Anglia.

Perrings, C., Mäler, K.G., Folke, C., Holling, C.S. and Jansson, B.O. (eds) (1995) *Biodiversity Loss: Economic and Ecological Issues*. Cambridge: Cambridge University Press.

Perrings, C. and Stern, D. I. (2000) "Modelling loss of resilience in agroecosystems: Rangelands in Botswana," *Environmental and Resource Economics* 16: 185–210.

Qualset, C.O., McGuire, P.E. and Warburton, M.L. (1995) "Agrobiodiversity: key to agricultural productivity," *California Agriculture* 49(6): 45–49.

Sala, O.E. (2001) "Price put on biodiversity," *Nature* 412: 34–36.

Smale, M., Bellon, M.R. and Aguirre Gomez, J.A. (2001) "Maize diversity variety attributes and farmers' choices in Southeastern Guanajuato, Mexico," *Economic Development and Cultural Change* 50(1): 201–225.

Smale, M., Hartell, J. Heisey, P.W. and Senauer, B. (1998) "The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan," *American Journal of Agricultural Economics* 80: 482–493.

Smale, Meng, M. E., Brennan, J.P. and Hu, R. (2003) "Determinants of spatial diversity in modern wheat: examples from Australia and China," *Agricultural Economics* 28(1): 13–26.

Solow, A., Polasky, S. and Broadus, J. (1993) "On the measurement of biological diversity," *Journal of Environmental Economics and Management* 24(1): 60–68.

Tilman, D. and Downing, J. A. (1994) "Biodiversity and stability in grasslands," *Nature* 367: 363–365.

Tilman, D., Polasky, S. and Lehman, C. (2005) "Diversity, productivity and temporal stability in the economies of humans and nature," *Journal of Environmental Economics and Management* 49(3): 405–426.

Tilman, D., Wedin, D. and Knops, J. (1996) "Productivity and sustainability influenced by biodiversity in grassland ecosystems," *Nature* 379: 718–720.

Tisdell, C. (1996) "Economic indicators to assess the sustainability of conservation farming projects: an evaluation," *Agriculture, Ecosystems and Environment* 57(2): 117–131.

Weitzman, M.L. (1992) "On diversity," *Quarterly Journal of Economics* 107: 363–405.

Weitzman, M.L. (2000) "Economic profitability versus ecological entropy," *Quarterly Journal of Economics* 1: 237–263.

Widawsky, D. and Rozelle, S. (1998) "Varietal diversity and yield variability in Chinese rice production," in M. Smale (ed.) *Farmers, Gene Banks, and Crop Breeding*. Boston: Kluwer.

Wooldridge, J. (2002) *Econometric Analysis of Cross-Section and Panel Data*. Cambridge, MA: MIT Press.

11 The role of crop genetic diversity in coping with drought

Insights from eastern Ethiopia

Leslie Lipper, Romina Cavatassi and Jeffrey Hopkins

1 Introduction

Improving agricultural productivity and farm level resilience to agricultural production shocks is essential to reducing poverty and improving household food security throughout the developing world, and most particularly in Ethiopia. One of the primary causes of household food insecurity in Ethiopia is the risk of agricultural production failure due to drought, resulting in reduced farm incomes and farm household food security (Devereaux 2000; Dercon 2001). Dercon estimates that the incidence of drought, together with illness and population growth resulted in a 13 percent decline in per capita consumption among adults, and a 23 percent increase in poverty in Ethiopia from 1989 to 1995 (Dercon 2001).

The Ethiopian government is pursuing a strategy of improving agricultural productivity primarily through agricultural intensification, involving the increased use of modern inputs, including seeds of improved crop varieties (Byerlee *et al.* 2007). Considerable resources have been devoted to the development and dissemination of improved varieties,[1] however, adoption rates have been low, and farmers maintain the use of landrace seeds for many crops and in many areas of the country (ibid.). Understanding the motivations of farmers in selecting the varieties they plant is essential for designing better strategies to improve agricultural productivity. In the Ethiopian context, the impact of drought risk on the choice of variety to plant is a key aspect to consider.

Sorghum is a crop essential for food security throughout semi-arid Sub-Saharan Africa. The crop generally requires a long growing season, but improved varieties that are early maturing and require a shorter growing season have been developed as a way of coping with drought. Early maturity for drought avoidance is one of the key characteristics focused upon in breeding programs, including that of Ethiopia (Matlon 1990; Ahmed *et al.* 2000; McGuire 2005). Adoption of improved sorghum varieties has generally been very low in Sub-Saharan Africa, including Ethiopia, even though they have been shown to be effective in reducing downside production risk in some situations (Matlon 1990; Sanders *et al.* 1996; Ahmed *et al.* 2000). Understanding

why farmers adopt or reject improved sorghum varieties designed to reduce a major source of production risk facing farmers is thus essential in designing an effective strategy for intensifying agricultural production.

Another reason for analyzing farmer motivations for adopting improved varieties is the potential implications of adoption for crop genetic erosion. Concern has been expressed since the 1970s about the impact on important genetic resources of widespread replacement of landraces by improved varieties (Frankel 1970; Harlan *et al.* 1973; Hawkes 1983; Brush 1995; Perales *et al.* 1998). The cultivation of landraces provides in situ conservation of crop genetic diversity, preserving an evolutionary process affected by both human and natural selection. Eastern Ethiopia is the center of origin for sorghum and thus the area is very rich in local crop genetic diversity (Vavilov 1956). Widespread replacement of local diversity with improved varieties could be a cause for concern regarding genetic erosion, thus providing another reason for understanding the motivations farmers have to grow improved varieties of sorghum as compared to landraces.

In this chapter, we explore how agricultural households in the Hararghe region of eastern Ethiopia manage their sorghum crop genetic resources to cope with drought, focusing on the implications of cultivating improved varieties versus landraces. Sorghum is the most extensively grown crop in the area and critical for food security. We use a unique dataset from eastern Ethiopia, an area rich in crop genetic diversity, but with low and variable agricultural productivity and high rates of poverty. The study area is a center of origin and domestication for sorghum, and about three-quarters of the farms grow sorghum landraces rather than improved varieties. Early maturing improved varieties of sorghum, developed as a means of coping with drought, have been developed and disseminated in the area.

The chapter presents an analysis of farmers' motivation to adopt improved varieties of sorghum in the context of managing risk in a highly variable production environment. The dataset combines detailed crop and physical data on plant varieties (independent field work was used to validate that plant varieties had mutually exclusive forms and structures) with in-depth information on household well-being (including income, assets and debts from both farm and off-farm sources). In the year that the data were collected (2002–2003 production season), eastern Ethiopia experienced a major drought and crop failure ensued. Inclusion of a shock year in the dataset provides important insights. Households employ a range of strategies to cope with the shock, with varying implications for resource damage and extraction.

2 Crop genetic resources and agricultural productivity in Ethiopia

Ethiopia is the second most populous nation in Africa and one of the poorest of the world. Of an estimated population of over 67 million, 40 to 50 percent are estimated to be food-insecure. Ethiopia's economy is mainly based on

small-scale agriculture, accounting for half of GDP and employing 85 percent of the labor force (Shiferaw and Holden 1997; MEDAC 1999; Zegeye *et al.* 2001). Agricultural productivity is low, with the sector characterized by high agricultural population land densities, field sizes that are frequently less than one hectare, limited technical change and lack of any conservation practices. Land degradation and declining agricultural productivity have resulted (Shiferaw and Holden 1997). In addition, drought is a major problem hobbling agricultural productivity. In the 2000 and 2003 production seasons, major drought affected the food security of over 10 million people (Bramel *et al.* 2004).

Improving productivity in the intensive margin is the main means by which Ethiopia can increase agricultural production, due to a lack of new lands to bring into agricultural production. Enhancing the productivity of crop genetic resources and farmer access to these resources is thus the primary objective of government strategy of increasing agricultural production. Food production in Ethiopia is expected to grow at 4.2 percent per year over the next ten years, while population is expected to grow at only 2.5 percent. Estimates are that in 2014 the food deficit will be less than half what it is today (USDA 2005). Growth in productivity of staple food crops is a specific target, since only about 10 percent of the total sown area to cereals is irrigated and variability of yields is one of the highest in the world (Rashid *et al.* 2006; World Bank 2006).

At present, only an estimated 3–5 percent of Ethiopian farmers use improved varieties for any crop; the vast majority plant landraces instead (Byerlee *et al.* 2007). Landraces are the product of centuries of selection by farmers and the natural environment. Landraces are typically more genetically heterogenous than improved varieties and adapted to specific agro-ecological niches and usually grown with very little capital inputs such as fertilizer, pesticides or irrigation. In contrast, improved varieties have primarily been bred for high-potential environments in which the yield response to complementary inputs is greater than it is for landraces. Yield "cross-overs" where landraces are found to perform better than improved varieties have often been observed in farming systems with low capital inputs and marginal production conditions (Matlon and Spencer 1984; Matlon 1990; Perales *et al.* 1998; Ceccarelli and Grando 2002; Smale personal communication, 2007). Landraces are often well adapted to extreme or marginal environments, and thus their cultivation may contribute to resilience in the face of production shocks (Harlan 1992; FAO 1998; Di Falco *et al.* 2007).

As with other crops, sorghum landraces are generally considerably lower in grain productivity as compared with improved varieties when grown under optimal moisture conditions with recommended practices. For example, reported sorghum yields on farms are 1.21 metric tonnes/hectare, while yields of improved varieties on the experiment station show an average of 2.79 tonnes/hectare (Byerlee *et al.* 2007). However, sorghum landraces have been found to outperform improved varieties under the conditions found on farms

in Eastern Ethiopia (Mulatu 2000; McGuire 2005). Without the use of accompanying inputs to improve soil fertility and water retention, modern sorghum varieties are not likely to result in productivity increases. Thus farmers operating under marginal conditions are unlikely to benefit from the adoption of these varieties.

Yet the role of improved sorghum varieties in reducing the risk of crop failure due to drought is potentially more important for improving productivity of Ethiopian farmers, given the high risk of drought. Evidence from other parts of Sub-Saharan Africa have indicated that early maturing, improved varieties of sorghum have been effective in decreasing downside risk (Matlon 1990; Ahmed *et al.* 2000). The question is the extent to which improved sorghum varieties are effective in reducing drought risk in the Ethiopian context, and whether Ethiopian farmers base their adoption decisions on reducing drought risk.

The remainder of the chapter presents an analysis of the adoption of improved sorghum landrace varieties in eastern Ethiopia, the potential impacts it has on coping with drought risk and the motivations of farmers in choosing between improved varieties or a sorghum landrace. The following sections examine the supply and demand for improved sorghum varieties in Ethiopia. The planting decisions of farmers are the outcome of both demand and supply side forces: the types of varieties needed to fit the specific production and consumption characteristics of the farm household and the availability and accessibility of varieties (Bellon 2004). Section 3 presents a conceptual model for analyzing the adoption of improved sorghum varieties in the context of drought risk. Section 4 presents the data and methods used in the empirical analysis, followed by descriptive statistics and econometric results. The chapter concludes with a discussion of the implications of the findings for sorghum breeding and seed distribution in Ethiopia.

2.1 *The Ethiopian formal seed sector for sorghum*

Ethiopia, with one of the largest national agricultural research systems in Africa in terms of staff and budget, has been following an agricultural-led growth strategy for years (Weijenberg *et al.* 1995), with crop breeding for improved varieties a major focus of efforts. Due to the importance of sorghum in food security, the government has allocated considerable resources to the breeding program (McGuire 2005). Approximately one million hectares are sown to sorghum, making it the third most important crop grown in the country, and moreover it is a major staple in the diet of the population—particularly the poor. A breeding program for sorghum has been in place since the 1950s with somewhere between 27 to 30 improved varieties of the crop released since then (ibid.).

Limited development of the seed industry has been shown to be a major barrier to the adoption of improved sorghum varieties in Sub-Saharan Africa (Ahmed *et al.* 2000). In Ethiopia, sorghum has received relatively little

attention in formal seed sector multiplication and distribution (Mulatu 2000). Distortions in seed marketing have been identified as a barrier to more wide-spread adoption of modern crop varieties (Rashid *et al.* 2006; Byerlee, *et al.* 2007). The Ethiopian Seed Enterprise (ESE) until recently had a monopoly on the production of improved varieties released from the agricultural research and development sector. The production and storage capacity of the institute is quite limited. The primary focus of MV seed production has primarily been on wheat, followed by maize. Mulatu (2000) finds that for several years, ESE produced less than 1 percent of the total potential seed requirements for improved varieties in the country, using an estimation based on area sown, seeding rate, and replacement rates.

Adoption rates of MV sorghum varieties in Ethiopia are not well meas-ured, but there seems to be agreement that they are low (Mulatu 2000; McGuire 2005). One obvious reason may be a lack of supply due to the low production levels cited above. However, ESE has reported problems selling their stock of improved sorghum seed, even at the low levels of multiplication noted above. Pricing is an important issue. The sales price for modern sor-ghum varieties increased 130 percent over the period 1992–2000 with a major increase in the 1999–2000 production season (Mulatu 2000). At the same time, problems with seed quality and timely delivery have been identified as a problem for farmers using the seed supplied by the formal sector (Lipper *et al.* 2006; Byerlee *et al.* 2007). Access to credit is another potential con-straint farmers face in obtaining improved sorghum varieties. In Ethiopia, farmers commonly obtain the seeds of improved varieties, as well as other production inputs via credit packages from the government extension service.

2.2 The demand for sorghum varieties

The choice to use an improved variety or landrace for Ethiopian farmers' sorghum crop is driven by demand as well as supply. If an improved variety does not provide the attributes farmers want, they are not likely to adopt it. A key issue affecting the demand for improved varieties is their performance under marginal conditions, without the use of complementary inputs, which is frequently the situation on many Ethiopian farms.

Early maturity is a variety trait that may provide farmers with an ex ante means of coping with drought, by virtue of the short rainy season required for production. Short maturing varieties provide a means of 'drought escape' by allowing a crop to be produced under a growing season shortened by drought. Another trait farmers may demand is drought tolerance, which refers to the capacity of the plant to adjust water use efficiency over a produc-tion season (Tuberosa and Salvi 2006). Landrace sorghum varieties have drought tolerance characteristics such as dormancy, which is one reason they are adapted to the area. Early maturing varieties are unable to respond to growing conditions in good production years, e.g. when the rains do not fail. Thus, farmers often sow varieties with both early and late maturity to cope

with uncertainty (Ahmed *et al.* 2000). Early maturing varieties may be demanded by farmers who wish to replant after a failure of rains in the initial phase of the production season. Farmer demands for early maturing varieties then are affected by their perception of the risk of rainfall failure, as well as their expectations of replanting.

Several studies have indicated high private values of landraces in Ethiopia across a range of crops (Mulatu 2000; Unruh 2001; Benin *et al.* 2006; Lipper *et al.* 2005; McGuire 2005; Gebremedhin *et al.* 2006). While the specific traits demanded vary by crop, insights on what might drive demand for sorghum landraces can be obtained by looking at what drives variety demand for other crops as well. Attributes such as desirable consumption characteristics and stalk (rather than grain) productivity are shown to be important drivers of the demand for sorghum landraces, as well as yield potential under stressed or marginal production conditions. Unruh (2001) discusses the importance of landraces in managing risk in the Ethiopian highlands and posits that the highly risky production environment in Ethiopia necessitates frequent replanting in response to crop failure. He argues that landraces are better suited to replanting due to their adaptation to local environments.

A final factor influencing the demand for sorghum crop varieties in Ethiopia is the high degree of production variability. Farms in Ethiopia are small and spread across highly heterogeneous agro-ecologies with high variability over time of climatic and production conditions. This highly heterogeneous production environment gives rise to a demand for diversity of varieties, as specific crop or variety can meet the variety of needs of the farm household. Gebremedhin *et al.* (2006) have found that adopters of improved varieties in the northern Ethiopian highlands also continued growing their maize and wheat landraces. They conclude that since improved varieties have limited adaptation and farmers face many economic constraints in these areas, improved varieties are likely to supplement, rather than replace landraces. This demand may lead to partial adoption along with landraces, much as Ahmed *et al.* (2000) found in other areas of Sub-Saharan Africa.

Farmer demand for seed is driven by the net returns to the input, as well as specific traits. The demand for seed is sensitive to the net returns to crop production, which is affected by the vagaries of the grain markets. Ethiopian grain markets are disarticulated, resulting in radical drops in grain prices in good production years and a consequent decline in crop returns (Lipper *et al.* 2005). Sorghum is a crop that is largely grown for consumption by farm households. Farmers do market portions of their harvest in good years for cash income, and thus low marketed surplus and output prices are likely to discourage investment in improved seeds. Highly variable market returns also increase the risk of inability to repay production loans for farmers. Repayment of such loans is enforced using extension agents and a degree of coercion by local administrative officials (Byerlee *et al.* 2007). Furthermore, farmers who default on loans are excluded from credit programs for any crop and can lose a proportion of their assets (Dercon and Christiansen, 2007).

Taking into consideration these supply and demand factors, we now turn to conceptually addressing the question of how risky environments impact on farmers' decisions to adopt improved varieties in the context of sorghum in Ethiopia.

3 Conceptual approach linking risk and adoption of improved varieties

The question explored in this chapter is how risk affects the decision of Ethiopian farmers to adopt improved varieties of sorghum, given a highly risky production environment with limited capacity to either insure ex ante, or smooth consumption ex post against risks of crop failure from drought. The conceptual framework for addressing the question is rooted in the literature on household technology adoption under uncertainty (Just 1974; Feder 1980; Feder *et al.* 1985; Shively 1997; Dercon and Christiansen 2007). The literature indicates that risk management is an important factor affecting technology adoption, and predicts that adoption of inputs that increase risks to household incomes will be underutilized. The loss in efficiency will be particularly high for risk averse households with limited capacity for ex post consumption smoothing (Dercon and Christiansen 2007).

The conceptual model used here is motivated by a random utility model and previous literature on farmers' adoption of technology under risk. Improved varieties of sorghum were developed specifically to reduce exposure to drought risk. At the same time their adoption involves assuming credit repayment risks as well as risk of poor performance under marginal conditions. As commented earlier, early maturing modern sorghum varieties have been shown to be an effective ex ante means of coping with drought in some areas of Sub-Saharan Africa, either by planting them together with landraces at the beginning of the production season, or when replanting the crop in the wake of an initial rainfall failure. In the first case the farmer is adopting the technology under greater environmental uncertainty; in the second case, partial information about the lack of rainfall early in the production season is available and the farmers know that the length of the production season has been reduced, although uncertainty over production conditions over the remaining production period remains.

We expect that farmers with higher risk aversion and the least capacity for ex post consumption smoothing would be most likely to adopt a technology that reduces risk. However, whether improved sorghum varieties increase or reduce risk to Ethiopian farm households is not immediately apparent. Improved varieties may reduce the risk of crop failure through their capacity to mature quickly, however they may also increase production risk if used in marginal areas and without complementary inputs. Increased consumption risk associated with credit default in the face of a failure is another consideration. Therefore, one important question to explore is how effective improved sorghum varieties are in reducing risk. If improved sorghum varieties are

found to be a risk-reducing technology, then we would expect to find higher rates of adoption among those most vulnerable to shocks.

Likewise with replanting, the implications for variety choice are somewhat unclear. Unruh (2001) argues that the replanting is most likely to be with a traditional variety—as these are more likely to have attributes which address the production problem. However, in the case of sorghum, since improved varieties are shorter maturing than the traditional varieties, it may be the case that improved varieties would be associated with lower risk under a shortened production season. In this case one would expect to find a positive relationship between MV adoption and replanting in the wake of rainfall failure.

A third consideration in assessing farmers' choice of sorghum varieties is the constraints they may face in accessing them. Improved variety adoption depends on accessibility to inputs, including access to credit as well as supply outlets, and the price of the inputs relative to potential returns. Evidence from Ethiopia suggests these could be a constraint to would-be adopters of improved varieties. The belief that capital inputs are required for modern variety adoption would be supported by positive correlation with soil fertility, because adoption would not be beneficial on poorer soils. Likewise, complementary inputs, such as fertilizers and water, are less likely to be used on hillsides, so that modern variety adoption is expected to be negatively associated with sloping fields.

4 Data, methods and results

4.1 The data

The farm household survey used in this study is part of a larger case study of the impacts of a seed system intervention implemented by the Hararghe Catholic Secretariat (HCS), a non-governmental organization, in the drought-prone Hararghe area of Ethiopia. The seed intervention involved selecting, multiplying and distributing local landraces of wheat and sorghum to seed-insecure households. Seeds were provided under a credit arrangement which required repayment in the form of seed with a 15 percent interest charge.

The case study involved sample household and community level surveys, agro-morphological characterization of sorghum and wheat varieties on farms, market surveys on sorghum and wheat prices over the production season and community focus group surveys on local crop diversity for the selected crops. A total of 720 households were surveyed in 30 Peasant Associations. Of these, about 50 percent were HCS participants. Of the remaining 50 percent, about half were non-participants residing in participant communities, and half non-participants in non-participant communities. The sample was limited to uplands and midlands area in order to reduce the degree of variation arising from agro-ecological factors and to better isolate the impacts of the project. The non-project participant households (e.g. the

control group) were selected to match the characteristics of HCS project participants to the extent possible. The agro-morphological and community focus group surveys were used to collect information for measuring crop genetic diversity and for validating variety names. The market survey involved the weekly collection of quantities and prices of varieties sold in marketplaces over a period of two months. Finally, the community survey provided data on road and marketing infrastructure, development interventions within the community and general information common to the entire community where households reside.

The household survey was conducted in two rounds: the first was in August 2002 after the planting of the main crop of the year, and the second was in February 2003 after the harvest. The survey was designed to collect information from farmers to measure household well-being as well as farmers' preferences towards varieties and sources of seeds in addition to indicators of on farm diversity. Farm-level data necessary to control for land endowments, and agro-ecological conditions were also collected as well as information on seed acquisition, including the means of acquiring seeds, the criteria for seed selection, source and price of purchase and access to varieties and to seeds, formal and informal seed markets. Finally, data included the varieties planted, seed acquisition sources, seed information sources, and the household's perception of positive and negative characteristics of different varieties.

4.2   *The empirical approach*

We are interested in understanding which households are more likely to suffer a crop failure and which households are more likely to re-plant after a crop failure. We realize that the decision to plant improved varieties is an important predictor of both of these decisions, but want to correct for any correlation between modern variety adoption and the other variables in our data set. We create an instrument for modern variety adoption at the household level, and use the adoption instrument in our failure and replant equations. Instrumental variable techniques correct for endogeneity of modern variety adoption on crop failure and replanting, but there remains the possibility that failure and replant could determine modern variety adoption. This possibility remains and is the focus of further study. We then proceed with estimating three separate reduced form equations. The predicted levels of the dependent variable in the first equation (sorghum modern variety adoption) serve as an instrument for modern variety adoption in the subsequent estimations on crop failure and crop replanting. To analyze these three questions, we first use probit models for binary dependent variables. The models offer the information about, respectively: (1) the probability of adopting improved varieties of sorghum; (2) the probability of sorghum crop failure; and (3) the probability of replanting after a sorghum failure.[2]

Characteristics of the farm, farmer, and farm household were included as

explanatory variables in the regressions and their impacts on those probabilities assessed. The regression on sorghum improved variety adoption included explanatory variables at the farm level on the size of the farm in terms of operated area (i.e. land owned, land rented in and land rented out). Two variables on landholdings are used: the size of holdings and the size of holdings squared, in order to capture potential differences in behavior of smallest and largest landholders. Landholding is an indicator of household assets, and expected to be positively correlated with improved variety adoption and replanting (Feder 1980; Feder *et al.* 1985; Zegeye *et al.* 2001). A set of variables measuring the physical characteristics of the plots were included, including farmer-reported average slope of the land, irrigated area, and the average fertility of the land (farm values were calculated as a weighted average of plot-reported variables). Better quality lands are expected to be positively associated with improved variety adoption due to the higher potential improved variety performance under these conditions, but negatively associated with crop failure(Feder *et al.* 1985; Zegeye *et al.* 2001; Benin *et al.* 2006). Two geographic farm descriptions are also used regarding the location of the farm defined both by the municipal association and in terms of altitude. Lower elevations are reported to be more favorable to the adoption of useful improved varieties of sorghum (Mulatu 2000; McGuire 2000). In addition, the location of the farm relative to nearest market was used as an indicator of the household integration into input and output marketing activities, which is expected to be positively associated with improved variety adoption (Benin *et al.* 2006).

Variables measuring farmer characteristics include age of the household head and years of education. Both variables are expected to be positively associated with improved variety adoption due to their association with higher levels of asset accumulation and access to information. A variable indicating whether the household had participated in the HCS seed system intervention was also added, expected to be positively associated with improved variety adoption and replanting but negatively associated with crop failure. Finally, in the improved variety adoption estimation, another variable is added and refers to whether the household grows wheat, which is a crop widely grown in the area, generally with improved varieties. Farmers who have access to improved varieties of wheat might also have greater access to improved sorghum varieties, however, improved varieties of wheat could also serve as a substitute for improved sorghum varieties, thus the expected relationship with improved sorghum variety adoption is ambiguous (Lipper *et al.* 2006).

From the modern variety adoption equation, we estimate two auxiliary regressions on the propensity to experience a sorghum crop failure and propensity to replant a subsequent crop after a sorghum failure. These regressions make use of many of the same variables included in the 'predicted' value from the modern variety adoption equation, as well as additional variables for the purposes of separately identifying the failure and the replant

equations. The sorghum failure equation includes a variable on past crop failures, assumed positive, and both the failure and replant estimations include a variable measuring the total number of sorghum varieties grown, assumed to be negatively associated with crop failure but positively associated with replanting (Unruh 2001).

We test the hypothesis that households growing modern sorghum varieties are more likely to have a crop failure than those who grow landraces, assuming that landraces are adapted to local conditions and are also adaptable to intra-year variability in weather patterns. We also test whether households that choose to replant are more likely to use a modern variety of sorghum because improved varieties are quicker to mature. Because replanting is by definition carried out in shortened growing seasons, we expect the correlation between improved varieties and replanting to be positive.

4.3 Description of the variables

In this section, descriptive statistics of key variables of interest used for the analysis are presented as complement to the interpretation of later regression results. We start with descriptive statistics on dependent variables as reported in Table 11.1 while explanatory variables are reported in Table 11.2.

Table 11.1 indicates that most of the sorghum growers in the sample grow only sorghum landraces (88 percent) but 12 percent of the farmers are improved variety adopters; a higher rate than reported for overall sorghum improved variety adoption in Ethiopia (McGuire 2005). Also, 91 percent of the farmers who reported a failure in their sorghum crop and 95 percent of those who replanted sorghum after an initial failure, use landrace seeds for the crop. The differences decline, however, if we look at each group separately. Of improved variety adopters, 20 percent reported a crop failure, compared with 24 percent of landrace producers. 6.25 percent of improved variety adopters replanted as compared with 13.75 percent of landrace producers.

Table 11.2 indicates the sample population is comprised of small average size of landholdings, but also considerable variation in size among the sample farmers. Very low levels of formal education are found among head of households (average less than two years of formal schooling). The mean age of household head is approximately 40 years old, similar to findings of Benin

Table 11.1 Distribution of improved varieties and landrace for sample farm households in planting, crop failure and replanting

	All sorghum growers		Sorghum MV grower		Landrace only	
	No.	*(%)*	*No*	*(%)*	*No.*	*(%)*
Sorghum planted	498	(100)	59	(12)	439	(88)
Sorghum failed	185	(100)	16	(9)	169	(91)
Sorghum replanted	102	(100)	5	(5)	97	(95)

Table 11.2 Descriptive statistics, Hararghe region, Ethiopia

Variable name	Description	Mean	SD
Planted sorghum improved varieties	Dummy = 1 if yes, else 0	0.118	0.32
Total Area operated	in timmad (1 timmad = 1/8 of a hectare)	3.221	2.97
Totareasq	Total area squared	19.191	49.85
Age of household head	Years	39.716	12.62
Age of household squared	Years squared	1736.45	1165.03
Average slope across all plot	1= gentle; 4 = steep	2.409	1.11
Average fertility across all plots	1= low; 3 = good	1.761	0.67
Poverty index*	1 = rich; 2 = medium; 3 = poor	2.598	1.445
Avg. years education, adults	average number of years of education (adults)	1.150	1.53
Total number of adults	Total adults in household	3.39	1.56
Irrigated	dummy = 1 if any operated plot irrigated, else 0	0.330	0.47
Failure	dummy = 1 if any crop planted has failed, else 0	0.383	0.49
Kmtomkt	Distance to nearest market in km	9.385	8.81
Wheat	dummy = 1 if HH grows wheat, else 0	0.383	0.49
HCSparticipa	dummy = 1 if Hh participates in HCS program, else 0	0.781	0.41
Altitude	Altitude of village in meters	2054.685	330.13
_Iwor_2	Meta woreda	0.524	0.50
_Iwor_3	Dire Dawa Woreda	0.137	0.34
totsorgvar	Total number of sorghum varieties grown by household	1.17	0.40

* The poverty index is constructed applying principal component analysis to main assets and house characteristics.

et al. (2006) for other areas of Ethiopia. Land quality is on average poor with steep slopes and poor soils, although again considerable variation exists in the sample. We found relatively little variance in the poverty index: most households in the sample are poor.

In Table 11.3 we turn to the issue of seed supply constraints as a possible explanation for MV adoption behavior. The results are somewhat surprising as only 20 percent of the sorghum improved variety adopters indicated some difficulty in getting seeds, compared with 30 percent of the sorghum landrace producers. Generally we expect that access to modern varieties is more constrained than for landraces (Mulatu 2000; McGuire 2000), however, the fact that this sample was constructed around participation in an NGO program designed to facilitate access to MVs is perhaps one explanation for the lower difficulty in obtaining seeds reported by MV adopters.

Table 11.4 gives insights into the means by which seeds are obtained. Again, results are somewhat surprising, indicating high rates of cash pur-

Table 11.3 Difficulty obtaining seeds: sorghum improved varieties vs. landraces

Degree of difficulty	All sorghum growers	Sorghum MV grower	Landrace only
% HH reporting no problem obtaining sorghum seeds	347 (71%)	47 (80%)	300 (70%)
% HH reporting problems obtaining sorghum seeds	141 (29%)	12 (20%)	129 (30%)
Total	488 (100%)	59 (100%)	429 (100%)

Table 11.4 Means of acquiring seeds: sorghum MV vs. landrace

Means of seeds acquisition	Sorghum (HHs)		
	Total	Improved	Landraces
Purchased paying cash (%)	47 (52%)	7 (55%)	40 (50%)
Purchased through loan (%)	3 (3%)	1 (9%)	2 (3%)
Exchange (%)	12 (13%)	2 (18%)	10 (13%)
Gift (%)	29 (32%)	2 (18%)	27 (34%)
Total (%)	91 (100%)	11 (100%)	79 (100%)

chases—for landraces as much as improved varieties. Since improved varieties are acquired through the formal system which generally includes production credit, they may actually be easier for some credit constrained farmers to obtain. Table 11.4 indicates, however, that relatively little credit is used for obtaining seeds in either the formal or informal sector. Gifts are the second most common form of seed acquisition, and landraces are more commonly used in this form of exchange. Tables 11.3 and 11.4 indicate that access to landraces is not necessarily greater than for MV for this sample population.

These results on accessibility of improved varieties vs. landrace seeds need to be interpreted with caution. Response rates to the questions shown in Table 11.4 were quite low (14–18 percent of producers) and not representative of the entire sample. The data indicate that the group of farmers who have adopted improved varieties have relatively low problems in obtaining access to the varieties, however, they do not give insights into the perceptions of non-MV adopters into the difficulties of obtaining the variety. If access to the variety varies within the farming community by characteristics of the household, which indeed the literature on market failures suggests (de Janvry and Sadoulet 2003), then we may be seeing a situation where farmers with

privileged access to MV seeds report no problems with sourcing the seeds, where nonetheless a constraint on access to less favored groups within the community exists.

4.4 Results

Regression results for all three equations are shown in Table 11.5. Adoption of improved varieties of sorghum is shown to be positively correlated with the very largest and smallest size farms, proximity to market and more urban areas (Dire Dawa), better land quality and educational level of the household. High adoption rates among small-scale farmers is somewhat surprising, however, these may be holdings of part-time farmers whose main source of income is non-agricultural. The results also indicate that improved variety adoption is associated with wealthier farmers on relatively high potential lands. The results suggest that poorer farmers and those on relatively poor quality lands with greater vulnerability to downside risk to food security are less likely to adopt modern varieties. In general, these findings are consistent with the literature on technology adoption and specifically MV adoption. The findings of a negative relationship between MV adoption and land quality, and a positive relationship with wealth are consistent with those of the literature (Ahmed *et al.* 2000). Vulnerability to downside risk has been found to be negatively associated with technology adoption in other studies (Shively 1997; Dercon and Christiansen 2007). However, studies on sorghum MV adoption have indicated that they can be effective in reducing downside risk (Matlon 1990; Ahmed *et al.* 2000), indicating that incentives exist for their adoption among vulnerable populations, however, no specific finding indicating a positive relationship between vulnerability and adoption has been reported.

   The results on the crop failure estimation call into question the degree to which improved varieties actually reduce downside risk. The predicted probability of adoption of improved sorghum varieties, estimated at the household level, was found to be weakly positively associated with sorghum crop failure (significant with 90 percent level of confidence). The result is somewhat nuanced. Small to medium-size farms, with low fertility and sloped fields operating at lower elevations and with relatively low levels of formal education among household heads, were found to be significantly more likely to experience a crop failure. The question arises whether crop failure associated with improved variety adoption is linked to land quality. Are the adopters on poor quality lands the most vulnerable to failure, and do sorghum improved varieties need to be produced under relatively good conditions in order to reduce downside risk? If so, early programs to extend early maturing sorghum varieties in areas of high risk vulnerability would need to be designed to focus only on high potential areas, otherwise they could actually increase, rather than decrease downside risk. In order to explore this issue we created a variable measuring the interaction between land quality and MV

Table 11.5 Estimation results

	Planted modern variety of sorghum	Sorghum crop failed	Replanted after crop failure
Timmads operated	−0.188	0.207	0.78
	[2.45]**	[2.57]**	[2.38]**
Timmads operated squared	0.008	−0.007	−0.044
	[2.13]**	[1.51]	[1.74]*
Age of household head	0.029	−0.005	0.203
	[0.93]	[0.20]	[1.21]
Age of head squared	0	0	−0.002
	[0.79]	[0.09]	[1.12]
Altitude	0	−0.001	−0.001
	[0.71]	[2.39]**	[0.80]
Average slope across all plot	−0.186	0.168	0.24
	[2.04]**	[2.14]**	[0.88]
Average fertility across all plots	0.19	−0.46	−0.066
	[1.54]	[3.96]***	[0.17]
Years of education of adults	0.124	−0.13	−0.313
	[2.43]**	[2.32]**	[1.37]
Kilometers to closest market	−0.044		
	[3.48]***		
Irrigated land	0.085		
	[0.46]		
Household grows wheat	−0.258		
	[1.12]		
HCS participant community	−0.127	0.753	
	[0.54]	[4.03]***	
Chiro Woreda	−0.163	0.392	3.551
	[0.56]	[1.75]*	[3.33]***
Meta Woreda	0.82	−1.105	2.21
	[2.47]**	[4.44]***	[2.24]**
Predicted MV adoption		1.962	−3.519
		[1.75]*	[0.71]
Number of crop failures last 10 years		−0.052	0.521
		[1.00]	[2.23]**
Number on-farm sorghum vars.		0.186	1.081
		[1.09]	[1.99]**
Poverty index, derived			−0.006
			[0.34]
Total number of adults within the HH			−0.508
			[2.09]**
Constant	−1.941	0.954	−9.071
	[1.50]	[0.89]	[1.79]*
Observations	496	445	320
Pseudo R2	0.1303	0.1515	0.4719

Notes: Absolute value of z-statistics in brackets.
* significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent, levels.

adoption. The addition of this variable does not greatly change any of the coefficients in the estimations however, and the interaction term is not significant, indicating that the MV crop failures cannot be linked solely to land quality, but rather a more complex set of factors is at work. Farmers located in areas where HCS operated were significantly more likely to have a crop failure, which is indicative of the strategy the NGO uses to select participant communities; those at greatest risk of food insecurity. Location, however, is an important determinant of crop failure which is not surprising given the highly variable pattern of rainfall in the area. Households in Meta Woreda were significantly more likely to have a crop failure in sorghum and those in Dire Dawa less so. Educational levels of the household head were also found to be significant and negatively correlated with crop failure.

Location and farm size were important in determining which households replanted in the wake of crop failure as well. In general, medium-sized farms, and farms with poorer soils, particularly in the Meta region, seem to be the most likely to replant. Households in the Dire Dawa region are significantly less likely to replant, which may either be due to drier conditions or possibly the greater availability off-farm coping strategies for crop failure. The results also indicate that farm households located in a community where HCS was also located, the NGO involved in providing access to both modern and traditional sorghum seed varieties, are also more likely to replant, which is likely due to the availability of needed inputs. As would have been expected, results indicate that farmers reporting a higher frequency of crop failures in the last five years are also more likely to replant. Notably, the probability of growing a modern sorghum variety does not have an influence on the likelihood of replanting, and the sign on the coefficient is negative.

5 Conclusions

Our analysis suggests that sorghum improved variety adoption is not an effective means of coping with drought for farmers in the study site, despite the fact they were developed to allow drought evasion (e.g. short season). The results also indicate that improved sorghum varieties are generally adopted for planting in relatively higher potential areas (defined by land quality and market access) and they are associated with a higher rate of crop failure than landraces in a year with widespread crop failure from drought. One possible explanation is that the reduction in rainfall was so severe in the 2002–2003 year, as to be insufficient for even short season varieties to provide a harvest and different results may be obtained in milder drought years. These results do not allow us to draw generalizable results on the relationship of MV adoption to crop failure under all drought conditions, and this is a question for further research. Drought tolerance may well be in higher demand than drought escape for sorghum varieties among Ethiopian farmers, and the results here indicate that landraces are more likely to provide this trait. Also, under the production conditions of eastern Ethiopia, a cross-over effect

seems to be occurring where landraces perform better than improved varieties due to marginal production conditions and limited use of complementary inputs. With these results at hand, we suggest that improved variety adoption is likely to be risk increasing, rather than reducing.

Supply side constraints may also be an issue in adopting improved sorghum varieties although here the evidence is somewhat mixed. The results on the analysis of improved variety adoption indicate that households with higher quality and quantity of land and educational levels are more likely to grow improved varieties, which may suggest that access to these varieties is determined by wealth. However, the descriptive statistics on seed sourcing indicate that access may be a problem for landraces as well. This calls into question the notion that access in the informal seed sector is relatively less problematic than the formal; this study indicates that farmers face problems in obtaining landraces and they are frequently acquired through cash purchases. This may be a result of changes and disruptions in the informal sector due to increased use of markets for agricultural inputs and outputs as well as migration, civil disturbances and extreme poverty.

Apparently, sorghum improved varieties do not play an important role in farmers' decision to replant the crop in the wake of a crop failure as we had expected. The negative sign on improved varieties in the replant regression is somewhat unexpected, since these varieties can be planted late into the season and thus would be expected to be a good replant candidate for farmers with crop failure. This is an issue that needs further exploration with follow-up interviews in the field. Our results seem to support Unruh's (2001) argument of the importance of landraces in the decision to replant crops, suggesting the importance of the availability of local crop genetic diversity as both a means and outcome of replanting.

What seems to be quite clear is that location is a critical determinant of the choice to replant sorghum; producers located in more isolated areas (Meta versus Dire Dawa) seem to be a critical determinants of the replanting strategy. Measures of poverty were not found to be significant predictors of the choice of replanting as a coping strategy. The limited variation in poverty found in our sample, together with the limited number of options available for ex post risk management in the area may be the basis for this finding.

If the focus on the short maturing varieties proved to be an ineffective way to cope with drought under the production conditions found in the area, would a shift towards other types of improved sorghum varieties with greater drought tolerance be more effective in these conditions? Since the crop is used primarily for subsistence purposes, with low rates of complementary input use and low farm level returns, the potential for improved varieties to outperform landraces is limited (Ahmed *et al.* 2000). For the same reasons commercial development of the seed sector is likely to remain limited. Thus development of improved sorghum varieties for commercial distribution appears unlikely to be an effective strategy for coping with drought. In addition, improving educational levels among farmers appears to be one

important way to reduce exposure to drought risk, based on the significant and negative relationship between formal educational levels and crop failure. Human capital appears to be a key asset in reducing vulnerability to risk, by increasing farmers' capacity to manage and select technologies that will allow them to avoid failures. The results also suggest that better access to the rich local diversity of sorghum varieties adapted to local production conditions may be important as well.

A strategy for reducing the risk associated with sorghum production accessible to poor farmers requires a broader look at the potential for managing the crop genetic diversity in the area. Di Falco *et al.* (2007) have recently found that on-farm diversity as measured by the number of crop varieties is an important way of reducing downside risk in Ethiopian highlands. Promoting the accessibility to a diverse range of crop varieties is an important part of facilitating farmer capacity to manage their risk. Strategies that enhance the performance and accessibility of local crop genetic resources, such as participatory plant breeding, and the selection and multiplication of desirable sorghum landraces may, in fact, be a more effective breeding strategy for this crop in this area.

A final point to note is the potential impacts of sorghum improved variety adoption on crop genetic erosion. The results presented here indicate that at this point in time, with the current production and marketing conditions found in the area, the adoption of improved sorghum varieties increases rather than reduces on farm diversity. Farmers who planted improved sorghum varieties maintained their landraces as well, essentially expanding the set of potential attributes they could obtain from the sorghum crop. Given the limited effectiveness of improved varieties relative to landraces for coping with drought, farmer demands for such varieties are likely to remain fairly small, thus genetic erosion from the development of these varieties is not likely to be an issue. Problems in this regard are more likely to arise from improvements in varieties of other crops that could potentially substitute for sorghum, although this does not appear to be the case so far.

Acknowledgements

Notes

1 In this chapter we use the term improved varieties interchangeably with modern varieties (MVs) to refer to crop varieties that are the result of a process of scientific breeding programs.
2 In order to test for the presence of endogeneity between the dependent variables of MV adoption, crop failure and the replanting decision, we also ran a set of bivariate probit models with sorghum crop failure and replanting as the dependent variables with a predicted value of MV adoption as explanatory variable. The results

obtained indicated that endogeneity could be rejected; the likelihood ratio test on 'rho' parameter gave a zero value.

References

Ahmed, M.M., Sanders, J.H. and Nell, W.T. (2000) 'New sorghum and millet cultivar introduction in Sub-Saharan Africa: impacts and research agenda', *Agricultural Systems* 64(1): 55–65.

Bellon, M.R. (2004) 'Conceptualizing interventions to support on-farm genetic resource conservation', *World Development* 32(1): 159–172.

Bellon, M.R. (2006) 'Crop research to benefit poor farmers in marginal areas of the developing world: a review of technical challenges and tools', *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 2006(1) No. 070.

Benin, S., Smale, M. and Pender, J. (2006) 'Explaining the diversity of cereal crops and varieties grown on household farms in the Highlands of Northern Ethiopia,' in M. Smale (ed.) *Valuing Crop Biodiversity: On Farm Genetic Resources and Economic Change*. Wallingford: CABI.

Bramel, P. J., Nagado, S., Haugegen, J.M., Adugna, D., Dejene, T., Bekele, T. and Tore Traedal L. (2004) 'Relief seed assistance in Ethiopia', in L. Sperling, T. Remington, J. Haugen and S. Nagoda (eds) *Addressing Seed Security in Disaster Response: Linking Relief with Development*. Cali: International Center for Tropical Agriculture.

Brush, S. B. (1995) 'In situ conservation of landraces in centers of crop diversity', *Crop Science* 35(2): 346–354.

Byerlee, D., Spielman, D. Alemu, D. and Gautam, M. (2007) *Policies to Promote Cereal Intensification in Ethiopia: A Review of Evidence and Experience*. IFPRI Discussion Paper 00707 Development Strategy and Governance Division. Washington, DC: IFPRI.

Ceccarelli, S. and Grando, S. (2002) 'Plant breeding with farmers requires testing the assumptions of conventional plant breeding: lessons from the ICARDA Barley Program', in D.A. Cleveland and D. Soleri (eds) *Farmers, Scientists and Plant Breeding Integrating Knowledge and Practice*. New York: CABI International.

de Janvry, A. and Sadoulet, B. (2003) 'Progress in the modeling of rural households' behavior under market failures', in A. de Janvry and R. Kanbur (eds) *Poverty, Inequality and Development: Essays in Honor of Erik Thorbecke*. Dordrecht: Kluwer.

Dercon, S. (2001) 'Economic reform, growth and the poor: evidence from rural Ethiopia', The Centre for the Study of African Economies Working Paper Series. Working Paper 146. Available HTTP: http://www.bepress.com/csae/paper146/

Dercon, S. and Christiaensen, L. (2007) 'Consumption risk, technology adoption and poverty traps: evidence from Ethiopia', World Bank Policy Research Working Paper 4257, June. Washington, DC: World Bank.

Devereux, S. (2000) 'Food insecurity in Ethiopia: a discussion paper for DFID', *IDS Sussex*. Available HTTP: http://www.ids.ac.uk/ids/pvty/pdf-files/FoodSecEthiopia4.pdf

Di Falco, S., Chavas, J.P. and Smale, M. (2007) 'Farmer management of production risk on degraded lands: the role of wheat variety diversity in Tigray Region, Ethiopia', *Agricultural Economics* 36: 147–156.

FAO (1998) *The State of the World's Plant Genetic Resources for Food and Agriculture*. Rome: FAO.

Feder, G. (1980) 'Farm size, risk aversion and the adoption of new technology under uncertainty', *Oxford Economic Papers* 32: 263–283.

Feder, G., Just, R. and Zilberman, D. (1985) 'Adoption of agricultural innovations in developing countries: a survey', *Economic Development and Cultural Change* 33(2): 255–298.

Frankel, O. H. (1970) 'Genetic dangers in the green revolution', *World Agriculture* 19(3): 9–13.

Gebremedhin, B., Smale, M. and Pender, J. (2006) 'Determinants of cereal diversity in villages of Northern Ethiopia', in M. Smale (ed.) *Valuing Crop Biodiversity: On Farm Genetic Resources and Economic Change*. Wallingford: CABI.

Harlan, J.R. (1992) *Crops and Man*. Madison, WI: American Society of Agronomy, Crop Science Society of America.

Harlan, J.R., de Wet, J. M. J., and Glen Price, E. (1973) 'Comparative evolution of cereals' *Evolution*, 27, (2): 311–325.

Hawkes, J.G. (1983) *The Diversity of Crop Plants*. Cambridge, MA: Harvard University Press.

Just, R.E. (1974) 'An investigation of the importance of risk in farmers' decisions', *American Journal of Agricultural Economics* 56: 14–25.

Lipper, L., Cavatassi, R. and Winters, P.C. (2005) 'Seed systems, household welfare and crop genetic diversity: an economic methodology applied in Ethiopia', available HTTP: http://www.fao.org/docrep/008/af843e/af843e00.HTM

Lipper, L., Cavatassi, R. and Winters, P. (2006) 'Seed supply and the on-farm demand for diversity: a case study from Eastern Ethiopia', in M. Smale (ed.) *Valuing Crop Biodiversity: On Farm Genetic Resources and Economic Change*. Wallingford: CABI.

Matlon, P.J. (1990) 'Improving productivity in sorghum and pearl millet in semi-arid Africa', in *Food Research Institute Studies*, Vol. XXII, No. 1. Palo Alto, CA: Stanford University Press.

Matlon, P.J. and Spencer, D. (1984) 'Increasing food production in Sub-Saharan Africa: environmental problems and inadequate technological solutions', *American Journal of Agricultural Economics* 66 (5): 671–676.

McGuire, S. (2000) 'Farmers' management of sorghum diversity in eastern Ethiopia', in C. Almekinders and W. de Boef (eds) *Encouraging Diversity: The Conservation and Development of Plant Genetic Resources*. London: Intermediate Technology Publications.

McGuire, S. (2005) *Getting Genes: Rethinking Seed System Analysis and Reform for Sorghum in Ethiopia*. Wageningen: Wageningen University.

MEDAC (Ministry of Economic Development and Planning) (1999) *Survey of the Ethiopian Economy: A Review of Post-Reform Developments (1992/93–1997/98)*. Addis Ababa: MEDAC.

Mulatu, E. (2000) 'Seed systems and small-scale farmers: a case study of Ethiopia', PhD thesis, University of the Free State, South Africa.

Perales, Rivera H.R., Brush, S.B. and Qualset, C.O. (1998) 'Agronomic and economic competitiveness of maize landraces and *in situ* conservation in Mexico', in M. Smale (ed.) *Farmers, Gene Banks and Crop Breeding: Economic Analyses of Diversity in Wheat Maize and Rice*. Boston: Kluwer, pp. 109–126.

Rashid, S., Assefa, M. and Ayele, G. (2006) 'Distortions to agricultural incentives in

Ethiopia', Agricultural Distortions Research Project Working Paper, October 2006. http://siteresources.worldbank.org/INTTRADERESEARCH/Resources/544824–1163022714097/Ethiopia_1007.doc

Sanders, J.H., Shapiro, B. and Ramaswamy, S. (1996) *The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa*. Baltimore MD: Johns Hopkins University Press.

Shiferaw, B. and Holden, S. T. (1997) 'A farm household analysis of resource use and conservation decisions of smallholders: an application to Highland farmers in Ethiopia', Discussion Paper #D-03/1997, Department of Economics and Social Sciences, Agricultural University of Norway (AUN), Ås.

Shiferaw, B. and Holden, S. (1999) 'Soil erosion and smallholders'conservation decision in the highlands of Ethiopia', *World Development* 27: 739–752.

Shively, G. (1997) 'Consumption risk, farm characteristics, and soil conservation adoption among low-income farmers in the Phillipines', *Agricultural Economics* 17 (2–3): 165–177.

Smale, M. (2006) 'Concepts, metrics and plan of the book', in M. Smale (ed.) in *Valuing Crop Biodiversity: On Farm Genetic Resources and Economic Change*. Wallingford: CABI.

Tuberosa, R. and Salvi S. (2006) 'Genomics-based approaches to improve drought tolerance of crops', *Trends in Plant Science* 11 (8): 405–412.

Unruh, J. D. (2001) 'The dilemma of african agrobiodiversity: Ethiopia and the role of food insecurity in conservation', paper presented at the conference Managing Biodiversity in Agricultural Ecosystems, 8–10 November 2001, Montreal, Canada. Available HTTP : http://www.unu.edu/env/plec/cbd/Montreal/papers/Unruh.pdf

USDA (2005) *Food Security Assessment, GFA 16*. S. Shapouri and S. Rosen, editors. Text and data accessed at http://hwww.ers.usda.gov/publications/GFA16/GFA16fm.pdf. Washington, DC : Economic Research Service, May 2005.

Vavilov, N.I. (1956) 'The origin, variation, immunity, and breeding of cultivated plants', in *Selected writings of N. I. Vavilov*, *Chronica Botanica*, 13: 1–16.

Weijenberg, J., Dagg, M., Kampen, L., Kalunda M., Mauilu, A.M., Ketema, S., Navarro, L. and Abdi-Noor, M. (1995) 'Strengthening national agricultural research systems in Eastern and Central Africa', World Bank Technical Paper 290, Washington, DC: The World Bank.

World Bank (2006) *Ethiopia: Policies for Pro-Poor Agricultural Growth*. Washington, DC: World Bank.

Zegeye, T., Taye, G., Tanner, D., Verkuijl, H., Agidie, A., and Mwangi, W. (2001) *Adoption of Improved Bread Wheat Varieties and Inorganic Fertilizer by Small-scale Farmers in Yelmana Densa & Farta Districts of Northwestern Ethiopia*. Agricultural Research Organization (EARO) and International Maize and Wheat Improvement Center (CIMMYT), Mexico, D.F: Ethiopia, pp. 12–13.

12 A trade-off analysis between rangeland health and income generation in southern Namibia

Stéphanie Domptail, Alexander Popp and Ernst-August Nuppenau

1 Introduction

In this chapter we deal with the problem of appropriate objectives and modeling procedures in bio-economic modeling to identify the behavior of farmers[1] with respect to the environment. The choice of objectives is crucial for the identification of behavior. In the agricultural economics literature there is a tendency to classify farmers in two groups, i.e. as traditional and commercial farmers, who show different behavior and are modeled applying different objectives. Modelers generally consider traditional farmers as being focused on food security and on sustaining their environment, whereas commercial farmers are expected to maximize their income, which means that they have a tendency to exploit resources. Yet farming is a process and we suggest here that, to a certain extent, commercial farmers also pay attention to the qualitative aspects of their range. As reported in this chapter, which reflects recent work done in Southern Namibia, we find some clues that processes of natural resource degradation, which means in our case the degradation of rangeland quality, might be important to farmers. Commercial farmers in Namibia serve as an example to find empirical evidence about our hypothesis according to which farmers have several objectives, caring for nature being one of them. Our clues suggest that farmers, even commercial farmers, farm owners or managers, are not pure income-maximizing entities. Rather, they seek to conserve their natural resources, their environment and the nature surrounding them, and thus they adapt their management objectives to the degradation threats. It is the aim of this schapter to make a contribution at the methodological level, concerning the modeling of private farmers' strategies when in the presence of degradation processes. We especially want to shed light on theoretical and empirical aspects of the debate around the definition of appropriate objective functions and the conjectural modeling of maximizing behaviors. In order to do so we develop a bio-economic modeling approach to find strategies and corresponding objectives for practical farm management which take into account ecological objectives. We consider this process to be a step towards the understanding of sustainable management.

The issue addressed here is also related to an increased scientific interest in

range and farm management under volatile natural resource conditions. We want to merge new knowledge on range dynamics with the above discussion on farm behavior and practices, because in our opinion this is a fruitful way to deliberate new strategies that are conducive to farmers concerned about sustainability of the rangeland ecosystem. Since the early 1990s, rangeland scientists have tended to use non-equilibrium theories to explain phenomena like thresholds and non-linearity observed in the ecological dynamics of semi-arid to arid rangelands, as opposed to succession theories more applicable under other climates.[2] For the most part, non-equilibrium theories rely on evidence that grassland ecology and productivity are more correlated with external abiotic factors— like interaction between soil, vegetation, rainfall and temperature—than with biotic factors such as grazing pressure (Ellis and Swift 1988; Illius and O'Connor 1999; Sullivan and Rhode 2002; Vetter 2004). One such application is the State-and-Transition model, in which ecosystems are assumed to be attracted towards stable states, but flips can occur, making the ecosystem switch from one stable state to another. Reversibility of such shifts in an ecological state is not self-evident (Westoby *et al.* 1989; Bestelmeyer *et al.* 2003; Stringham *et al.* 2003; Janssen *et al.* 2004). Implications for the management of rangeland are considerable and are described by Westoby *et al.* (1989). In order to avoid undesirable flips of the system, pastoralists must consider both abiotic and biotic interactions. For instance, according to Stephan *et al.* (1996), the level of biomass yearly left *in situ* after grazing influences range condition in the long run. Grazing has thus still a recognized impact on range dynamics (Batabyal 2004) and we will reveal that this is known to farmers. It means that the management of controllable biotic factors by farmers (e.g. domestic grazing) must take into account both threats (e.g. droughts) and opportunities (e.g. high rainfall events) created by interactions of abiotic factors. Successful management is a challenge since it involves finding the combination of 'right' objectives, eco-system knowledge and foresight, and since mistakes can have dramatic consequences. Thus, modeling is necessary to detect responses to natural conditions as well as degradation of the biota. Expressed as high adaptability in stocking, a good strategy reveals skills of the farmer such as knowledge of eco-system behavior, animal husbandry and financial management.

Finally, Namibia has high stakes in the maintenance of its natural resource. Indeed, natural resources and in particular rangeland use are a source of occupation for an important part of the population. Beside the developing sector of green tourism, the more traditional livestock sector employs 8 percent of the total working population, and 68 percent of the population derive their livelihood directly or indirectly from agriculture (Wardell-Johnson 2006). Parallel to this situation, authorities and the scientific community are concerned with rangeland degradation, characterized by its loss of biodiversity and productivity, possibly leading to desertification in the south of Namibia (Strohbach 2000).[3]

The chapter is organized as follows: After describing the study area, we

present evidence of the existence of an objective of rangeland conservation by farmers, using the case study of dwarf shrub savannah of Nama Karoo in Namibia. Then we present a multi-objective bio-economic model and show how preferences for income or conservation impact on farming strategies. The results are also compared to our empirical findings describing farming practices in the study area. We finally discuss how observations can be linked to preferences for agrobiodiversity conservation.

2 Case study: farms in the Nama Karoo of southern Namibia

2.1 Ecological and land use characteristics of the study area

The study area is located in the dwarf shrub savanna biome of Namibia where grasses, dwarf shrubs and high bushes constitute most of the vegetation. Perennial grasses are mostly *Stipagrostis* species, Characteristic shrubs are *Rhigozum trichotomum, Catophractes alexandri, Accacia nebrownii, Tetragonia shenkii, Monechma genistisifolium, Petalidium linifolium* and *Zygophyllum spp*. All shrubs are of value as fodder, some varieties being more palatable than others. Degradation implies a change in the vegetation composition of the range. Vegetation changes involve the replacement of perennial grasses by annual ones and an increase of the bare areas. Degraded areas can be also subject to bush encroachment by less desirable shrubs such as *Zygophyllum spp*. on lime soils or by *Rhigozum trichotomum* (own and farmer observations). The median annual rainfall in the study area is between 120 and 140 mm. In addition, the erratic characteristic of rainfalls leads to variations in yearly biomass production reaching 95 percent.

In total, the study area occupies 700,000 ha around the town of Keetmanshoop, Karas region, of which 535,000 ha are privately owned and farmed. Interviews done with 20 farmers between March and June 2005 allowed covering 50 percent of this area (Figure 12.1). Pretests were conducted on four farms with highly differing activities (goat, sheep and game). The intention was to cover all agricultural domains. We proceeded with structured interviews with mostly open-ended questions, with the following goals: (1) an explorative description of the farming system; (2) identification of farmers' management options and stocking behavior; and (3) the identification of productivity parameters.

Due to the suburban location of the study area only ten farms out of 20 relied solely on farming to match their household needs. Farmers farm predominantly with Dorper sheep for meat production but on most farms goats are kept as well. Not only Dorper are bred in the area, but also smaller sheep breeds such as Karakul or Damara[4].

The government of Namibia has developed maps of the carrying capacity of its rangelands. The official carrying capacity for most farms of the study area is of 1 small stock unit (SSU) for 5 ha (map, MAWF 2000). Farms have 10,000 ha in size on average. Converted in ewe numbers, this carrying
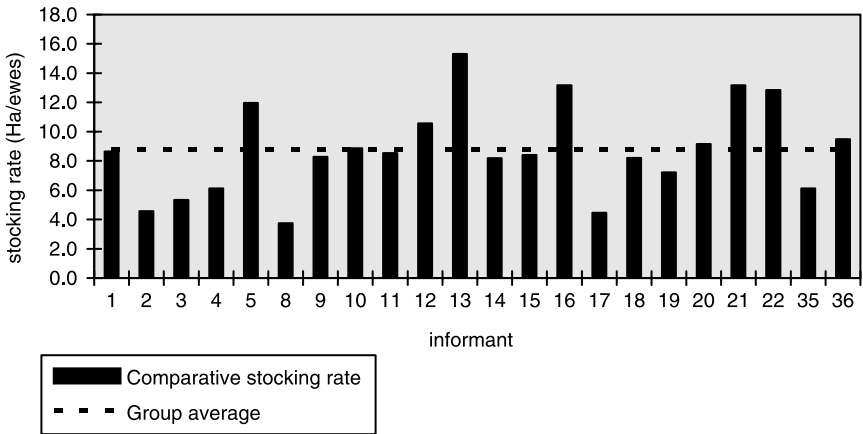
Figure 12.1 Variety of stocking rates practiced on 20 commercial farms in the study area as well as two commercial farms in the Karas mountains, 2005.

capacity of 1/5 indicates that a herd of about 1,200 Dorper ewes can be sustained on a 10,000 ha farm, which corresponds to a stocking rate of one ewe for every 8 hectares. On average, we found that farmers stick to this rule. A more detailed look, however, reveals a large variation in the stocking rates practiced on the farms of the study area. Stocking rates vary for both, full- and part-time farmers, independent of the income source (8.1 ha per SSU on average and 8.3 respectively).[5]

2.3 *Farmers have multiple objectives for their farming activities*

Usually it is assumed that the objective of commercial farmers is to maximize income, which is directly correlated to herd size (Buss 2006; Drechsler and Wätzold 2004). However, we explored the idea and the consequences of farmers having not only the objective of income maximization but also, to a certain extent, the objective of rangeland quality and thus agro-biodiversity conservation. Along this idea we built the conceptual framework of this chapter. Our first goal was to gather information through an explorative approach which should help in the modeling of pastoralists' decisions. The concept arose with the consideration of the following two arguments and two findings.

First, we argue from observation that consequences of range degradation are not purely an externality because farmers bear the costs of degradation nearly instantly. Their cash flow is limited and they are financially fragile, so that land degradation, even if it is short run, can become a threat to farming.

Second, we argue from literature (Roe 1997) that farmers appreciate the value of good range condition apart from its productive aspect using the concept of high reliability seeking systems. Indeed, as Roe points out,

pastoralists have the goal of maintaining a reliable production in a context of highly varying rainfall events. This means that pastoralists strive not to achieve the highest possible production but rather they strive for control over the variation of output (income). Pastoral activities under varying rainfall should seek to maintain the resilience of the system. The high reliability theory provides us with a new context to understand farmers' practices. For instance, fluctuations in rainfall and biomass are easier to manage with small stock herds (versus cattle) because they can be marketed easily and are prolific. Also ranges in good condition help to manage highly variable rainfall by buffering its effect on biomass production: perennial grasses and shrubs, characteristics of good condition range, are able to produce fodder even in case of (small) droughts whereas annual species produce more biomass in cases of rainfall but none in case of drought. If perennial species disappear, the system becomes less stable and reliable. Thus a reliable production system is a densely covered and bio-diverse system, which constitutes our second argument for considering rangeland conservation as a goal of farmers.

An illustration of this concept for our study area follows. Farmers associate a range of different grasses and bush species with specific rangeland conditions. Results of our interviews with farmers in 2005 reveal that important characteristics of 'good range' for farmers include the balance between shrubs and grass cover as well as the diversity of shrubs (Appendix 1). Shrubs are usually a source of fodder in the after-season, a source of minerals and tannins important for both health and reproduction of the herd (personal communication with several farmers, 2005). What turns out to be important for farmers is the possibility to have a variety of shrubs and grasses to ensure the fulfillment of nutrient requirements in the winter time (dry season) thanks to the presence of shrubs. Thus biodiversity is important to maintain a herd in a healthy state, thereby reducing costs and guaranteeing a high productivity, as well to maintain productivity in both high and after season, thereby securing the cash flow.

Aside from theory-driven insights, we found further evidence that farmers pay particular attention to rangeland condition in their daily farm management. First, farmers were questioned about the indicators they use to determine the appropriate timing to move the animals from one camp (/paddock) to the other. In the survey, vegetation-related indicators were cited 68 percent of 44 cited in total. Only 20 percent of the citations concerned livestock. This shows that management is directed at maintaining rangeland health first (not meat production). The following statement of one farmer best illustrates the issue: 'I am not farming with animals, I am farming with the veld [the rangeland]. With my new system it is a pleasure to see the veld improve year after year.' In this statement the farmer explicitly indicates the keystone of his management, rangeland quality, showing his emphasis on managing the natural range, as priority.

Second, besides, farmers were asked whether they would invest in the improvement of their range if they had one or several degraded areas on their

farm. Answers could be summed up into a classification of four criteria of decision-making, characterizing farmers in their inclination to undertake regenerative actions. These are (i) personal values especially concerning the role of the farmer as a land manager, (ii) the economic benefits derived from regeneration activities, (iii) the ecological feasibility of such actions, and finally (iv) the farmer's perception on the financial and economic feasibility (see detailed statements in Appendix 2). While some farmers expressed a direct desire to improve rangeland condition whenever possible, others decided in terms of economic benefit, having income as a prime objective.

To summarize, these clues lead us to form the hypothesis that farmers have multiple objectives. Although this is nothing new when considering communal farmers, it is a new argument in the case of commercial farmers. In addition, the fact that one farmer objective would be derived from an ecological inclination and may allow quantifying the ecological output of the farming system is a new concept. We thus argue that rangeland and agro-biodiversity conservation *per se* constitutes one of the farmers' objectives and income maximization another one.

2.3 Farmers differ in their land use strategies

For an operational approach, an essential prerequisite for modeling farmer reactions to variations in resource availability is the identification of management options. Farmers' reactions to variations in inputs are manifold. We asked farmers how they react to the threats and opportunities that droughts and high rainfall events represent. Strategies in high rainfall years include actions ranging from the purchase of ewes, the increase in herd size through an increase in the number of replacement lambs kept, to special actions taken. If we interpret such actions with the concept of rainfall-tracking strategies vs. conservative strategies, one can consider the options to range from highly reactive to static. Replacement and purchase are key regulatory variables that are available to the model and which reflects the option to react to changes in the natural resource environment.

Strategies in drought years include options ranging from decreasing herd size, purchasing fodder to no special action taken at all. The time dimension also plays a role: whether the first reaction is to decrease herd size and the second one is to purchase fodder, if the drought persists is interpreted differently from the reverse strategy. Farmers' choices concerning the sequence of actions to be taken in both situations were coded and allowed the definition of behavioral patterns.

The combination of choices in both types of events leads to five fuzzy groups of farmers with specific behavioral patterns (Table 12.1.).

Our point here is that a diversity of farmers and related strategies already exists in a small sample of farmers. We suggest that we have to take this diversity into account in our analysis.[6] We suggest that this diversity can be related at least partly to the relative importance of income versus range

Table 12.1 Classification of behavior according to farmers' actions in case of drought and extreme rainfall events

Behavioral category	Keyword	Behavior description
Category 1	Threat avoider	Operating with land of high carrying capacity, but lower stocking rates; are very reactive to droughts (immediate herd reduction, eventually all animals can be sold or sent to another farm) and rather static in case of high rainfalls
Category 2	Opportunity seizer	Operating with land having a good carrying capacity, rather static in cases of drought (partial reduction in herd size, fodder purchase) and reactive to high rainfalls; indicators for rangeland management are based on vegetation
Category 3	Less flexible strategy	Rather static group, following a moderately tracking strategy (occasional purchase of fodder, low variability in animal numbers), with stocking rates sticking to recommended carrying capacity.
Category 4	Static strategy	Conservative and static strategy with maintenance of animal numbers, operating at rather low stocking rates (19 has a low stocking rate in absolute terms)
Category 5	Highly reactive strategy	Immediate adjustment in herd size by drought (all animal can be sold or sent to another farm) and high rainfall events (increase number of female lambs kept and purchase of ewes).

conservation as a goal for farming. In the next section we use a bio-economic multi-objective model in order to test this hypothesis.

3   The bio-economic model

Many studies based on bio-economic approaches use mathematical programming following an optimal control approach (Costanza and Neumann 1997; Batabyal 1999; Bach 1999; Duraaippah and Perkins 1999; Wossink *et al.* 2001; van Wenum *et al.* 2004; Okumu *et al.* 2004; Börner 2004). Optimization programs describe the evolution of a system over a time horizon and determine optimal levels of decision variables over time and under constraints. In our case, farmers' decisions on stocking density on the rangeland involve the careful balancing of immediate benefits obtained from livestock sales and immediate investment in rangeland conservation on which the future benefits (future sales) depend. The optimal solution defines the sequence of inputs (biomass consumed) and outputs (income) in time, taking into account short and long term gains.

3.1 The multi-objective bio-economic model and its structure

We use a multi-objective (MOP) model to depict strategies of managers over time and to evaluate trade-offs occurring between the two objectives of a representative farmer, i.e. generating income and conserving the range in a good condition.[7] Lately, MOP models have been used to include both social goals such as resource conservation or environmental damage reduction and private goals usually associated with income or utility maximization in the search for optimal land use practices (Giasson *et al.* 2002; Thankappan *et al.* 2006). Traditionally, such models are useful to find a solution when decision makers pursue two conflicting goals (Romero and Rehman 1989). One challenge of the management of non-equilibrium systems is the manager's knowledge of the interactions between both economic and ecological systems. As theoretically demonstrated by Finnoff *et al.* (2005), feedback from the ecological system to the economic system is crucial in the case of imperfect knowledge of the decision maker. In the case of complex and ever changing systems such as arid rangelands it is recommended to focus on the explicit modeling of this feedback. Therefore, we include the impact of grazing on range condition in the model, which allows a dynamic feedback. The approach uses a constant damage function as done in most bio-economic models (Abel 1997; Bach 1999, Kreuter and Workman 1994; Costanza and Neuman 1997; Wossink. *et al.* 2001; Bulte *et al.* 2003; Börner 2004; van Wenum *et al.* 2004) and is not influenced internally by the system, contrary to recent work done by Finnoff and Tschirhart (2003). However, because the model is dynamic, changes in the resource affect farmer practices, which in turn affect the state of the system. We model a complete interaction of the two subsystems.

We have chosen to model activities at the level of the farm for a time period of 30 years because farmers most often plan to hand the farm over to their children (Buss 2006). Pastoral activities include goats and meat sheep (Dorper) breeding. In the modeling exercise, one distinguishes between several types of variables and parameters: (1) s*tate variables* which describe the state of the system at any given time. Here the most important are the number of animals and the area of rangeland defined according to its health condition (*s*); (2) *control variables* are time dependent and determined by the decision-maker: here we consider livestock sales and purchases in number of ewes, as well as the number of female lambs kept that would enter the herd 12 months after birth; and (3) the system is also affected by external *parameters:* here, rainfall. The optimization problem involves finding a suitable way of using stocking rates (ST) and livestock breeds (P) by allocating land and labor, under varying rainfall conditions, while meeting requirements in terms of overhead costs and at the same time optimizing the two objectives P_1 and P_2 of income generation and rangeland/biodiversity conservation. Table 12.2 summarizes the optimization problem.

Table 12.2 Main activities in the linear programming model and requirements of resource for each activity

Resource	Dorper	Goats	Rest	Borehole construction	Limits
Labor (hours per year per SSU)	5	10	0	0	= < 7680 (3 Working Units)
Land (ha)	3, 5, 7 SSU/ha, depending on stocking rate	3, 5, 7 ha per ha, depending on stocking rate	400 ha (size of an average camp)	1250 ha (area that 1 borehole can supply water to)	= <10 000
Biomass (Kg dry matter per year)	712	854	0	0	= < Depends on rainfall (linear relationship)
Income (N$)	350 (lamb)	400 (lamb)	0	– 35 000	> = 0
Income (N$)	350 (lamb)	400 (lamb)	0	– 35 000	Maximization
Range condition					Maximization of rangeland area with high biodiversity

The two maximands *P1* and *P2:*

$$P'_1 = \sum_t (\text{Balance}_t + \text{Fingains}_t + \text{Landvaluve} + \text{Selfcons}) * \left(\frac{1}{1 + IR}\right)^t \quad (12.1)$$

P1 sums up over time (*T*) all economic and financial incomes of the farm, where *'Balance'* refers to the discounted sum of the receipts minus payments; *'Fingains'* codes the financial gains or losses resulting from yearly cash flow excess or deficit; *'Landvalue'* reflects the value of the land associated with a different quality status of the range, including all potential uses at the end of the simulation period, and it is given by a shadow price (Buss 2006). *'Selfcons'* is the discounted value of home consumed animals and *'IR'* reflects the discount rate.

The second expression (*P2*) sums up over time (*t*) the total area (*'HAstates*$_{s1'}$ + *HAstates*$_{s2'}$*') in good condition (states 1 and 3) of the modeled farm. This follows Batabyal (2004), who suggests that farmers tend to minimize the time that their rangeland is in a moderate condition with a risk of shifting to a worse one, or the time it is in bad condition. Maximizing *P2* means that the optimal solutions give the best possible level of conservation of biodiversity of rangeland plant species.

$$P_2 = \sum_t Hastates_{"s1",t} + Hastates_{"s1",t}) * \left(\frac{1}{1+IR}\right)^t \tag{12.2}$$

Both functions are discounted because of private time preference and the dynamic character of the model. We chose to discount both functions at the same rate *IR* of 14 percent, which is the rate applied to commercial loans. Although we are aware of the discussion around social discounting rates (Weitzman 1994) when dealing with environmental goods and social welfare, we opt for a more simple consideration, i.e. that both objectives are private. We also introduce a constraint to define the minimum level of activity:

$$P_1 \geq I \tag{12.3}$$

where *I* is the sum of the fixed, variable and household costs summed up over time.

The model further includes four sub-systems: (1) farm resources and biomass production; (2) rangeland dynamics; (3) herd dynamics; and (4) farm economics (see Appendix 4 for a detailed description of the model's equations).

3.2 Including agro-biodiversity in a bio-economic model: the state and transition concept

The model includes an explicit module that simulates the changes in range condition as a result of rainfall and stocking intensity (stocking rate) and the livestock breed chosen. In return, the new state of the rangeland affects the production of biomass and thus the maximum number of livestock that can be kept on the farm in the following years. In a joint interdisciplinary effort with Namibian rangeland experts and inspired by Milton and Hoffman (1994), six states are defined according to vegetation cover, where we differentiate between herbaceous and bush vegetation layer (Table 12.3).

States 1 and 3 are highly productive. Farmers expect them to find a series of good shrubs that they appreciate for their fodder and other values. Both

Table 12.3 Description of the six stable states for rangeland identified in the study area and simplified denomination in the chapter (rangeland condition)

State	Rangeland condition	Percent of grass cover	Percent of bush cover
S1	Good	50–100	0–39
S2	Bush dominated	10–49	0–39
S3	good	30–100	40–100
S4	Annual grass dominated	0–29	40–100
S5	poor	0–9	10–49
S6	poor	0–9	0–9

states are considered as good condition rangeland by farmers and show the highest biodiversity. They correspond to what farmers call 'range in good condition.' State 2 is dominated by high shrubs, whereas in State 4, annual grasses dominate. State 5 has only little vegetation left. State 6 is bare of vegetation. All four states have been classified as intermediary or poor condition, depending on the farmers. Here, we simplify by considering States 5 and 6 to be in poor condition, while States 4 and 2 are referred to as the annuals- and bush-dominated respectively.

These states vary in productivity as well (Figure 12.2). They are to be understood as stable ecological states towards which the range is attracted. Under certain circumstances though, the range might switch from the one to the other. The probability that this happens we call *transition probability* and it depends on, first, rainfall and, second, on land use (domestic livestock breed and stocking intensity). Both states' productivity parameters and transition probabilities are calculated over thousands of repetitions using a dynamic and spatially explicit vegetation model, parameterized especially for the study area (Popp 2008). Transition probabilities were calculated for; (1) each activity (goats, dorper or resting); (2) different stocking rates (from very extensive to very intensive stocking); and (3) four rainfall classes (from high to low). We model the interaction between pastoral activities and degradation by including these probabilities in the bio-economic model using a damage function, by associating a damage factor to each activity. In the model, it is assumed that farmers have complete knowledge of the potential damage, i.e. they can plan their stocking rates before the damages occur.

4 Results

4.1 Trade-offs analysis

In order to focus on the trade-offs between the two objectives of rangeland conservation and income maximization, we use the constraint programming method (Romero and Rehman 1989; Thankappan *et al.* 2006). The idea is to optimize one objective, while using the second objective as a constraint. The value of the constraint varies between its 'ideal' and an 'anti-ideal' point,[8] identified in the calculation of the pay-off matrix. The process is then reversed and a series of points belonging to the Pareto optimal solution set are obtained.[9] The Pareto solutions are used to draw the efficiency frontier of our ecological-economic production system (Figure 12.3).

A numerical calculation of the marginal values for this efficiency curve provides the trade-off values between the two objectives. Similarly, one can calculate the rate of change of the trade-off values. The highest rates deliver inflection points of the efficiency frontier. These points are turning points where the nature of the trade-off changes. These can be used as benchmarks to observe the change in activities and strategies (Thankappan *et al.* 2006). On the trade-off curve (Figure 12.3), D represents the maximum income, C
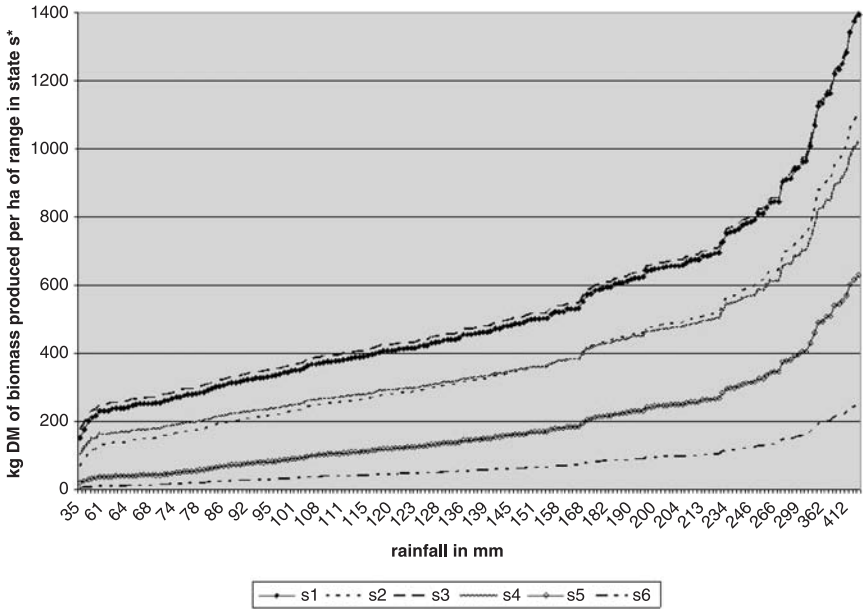
Figure 12.2 Biomass production per ha of range in the various conditions defined.
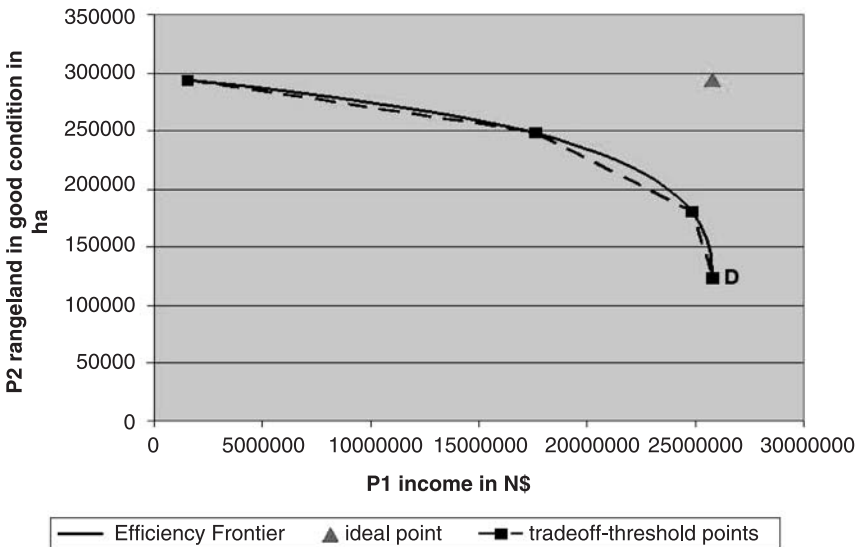

Figure 12.3 Frontier efficiency for a typical full-time farm in the area of Keetmanshoop.

and B are turning points and A is the maximum area of range in good condition. The steep slope between points D and C corresponds to a tradeoff value of 14 NAD[10] per ha of range in good condition state 1 and State 3 and indicates that a small sacrifice in income will lead to an important improvement of the range's condition. From C to B and then to A the trade-off value increases to values such as 352 NAD per ha of range in good condition, suggesting that any improvement in rangeland condition will only be achieved at great costs. Tradeoff values can be interpreted as the price the farmer accepts to pay to conserve an additional ha of rangeland in good condition on his farm for one year. It is a monetary reflection of his preference for rangeland conservation.

4.2 Strategy analysis

Our results show that the strategy used at each benchmark point changes accordingly. Table 12.4 presents a detailed description by providing modeling results for all important control and output variables at each benchmark point of the efficiency frontier.

Rangeland in State 1 and State 3 are summed up under the term good condition range. Range in state 5 and state 6 are described as range in poor condition associated with the idea that they reduce farm productivity in the

Table 12.4 Objective, activities and control variables, given as averages over the simulation period of 30 years at the four benchmark points of the efficiency frontier

	Unit	A	B	C	D
Objectives					
Income	NAD**	6772	671548	821396	873104
Lambs sold	#	726	1556	1865	2192
Range good condition	HA	7825	6550	5650	4249
Range poor condition	HA	206	1554	2552	3415
Activities					
Stocking rate	SSU*/HA	1/9	1/4,5	¼	1/3,5
Goat does	#	145	213	194	292
Sheep ewes	#	534	1173	1444	1584
Total ewes	#	679	1386	1638	1876
Control variables					
Ewes sold (% total herd size)	%	0.33	0.19	0.18	0.14
Ewes bought (% total herd size)	%	0.071	0.009	0.009	0.009
Replacement rate in % total female lambs	%	0.30	0.23	0.21	0.19
Standard variation of herd size	# ewes	**449**	**394**	**360**	**256**
Total fodder purchased (over the 30 years simulation period)	tons	0	1	191	878

Notes: *SSU: Small Stock Unit. ** NAD: Namibia Dollars. 1€ = 9 NAD.
Source: Own modeling.

long term. The following paragraph describes the main output results and control variables for the strategies A (objective of range conservation), B, C and D (objective of income maximization (table 4).

Output variables

As suggested by the changing trade-off values along the curve, degradation levels (reflected by the area in poor condition) are not proportional with income levels and average stocking rates. A small difference in stocking rates, as between case D and C, can reduce the degradation level as much as the bigger difference in average stocking rate between B and A. Again, this result suggests that a small commitment towards conservation can deliver already important benefits in terms of biodiversity conversation, as also suggested in the study by Buss (2006), where it was demonstrated that a reduction of 20 percent of the optimal income of ranchers of mid-Namibia would lead to the maintenance in a good quality of an important portion of the farmland.

Let us confront the stocking rate results to the stocking rates issued by the MAWF as recommended values for maximum carrying capacity of 1 SSU / 5 ha to 1/10 in some areas (MAWF 2000). Only stocking rates of strategy A fall into this category. This suggests that recommended stocking rates express a clearly biodiversity conservative strategy of the government, which is an important result of this study. However, those are only recommendations; both Section 2 of this chapter and our model results highlight that different farmers apply different strategies, described in the following section.

Control variables

First, conservation strategies appear to involve more frequent herd size reduction than income-oriented strategies. Indeed, we have defined a lower bound of 13 percent for the variable 'ewes sold,' simulating the fact that all ewes older than 7 years must be sold because of their decreased productivity. Figures above 13 percent indicate an important reduction of herd size. As expected, this variable shows higher values in strategies where rangeland conservation is given a priority.

Second, replacement is higher in conservation strategies (A), where the average stocking rate is low. Keeping replacement ewe lambs is strategic when working at low stocking rates since female lambs kept for replacement allow for endogenous herd growth (breeding). In addition, purchase of ewes on the market appears to be characteristic of conservation strategies rather than income-oriented strategies (D). Indeed, in order to achieve peak production whenever the opportunity through a high rainfall event occurs, conservation strategies must maintain the potential to increase a herd, whereas the income-oriented strategies rather simply maintain the size of the herd. The standard deviation of the yearly herd size shows that more variation exists in range-conserving strategies, with a standard deviation in strategy A being nearly

twice as high as strategy D. Conservation strategies (A) are rather dynamic, whereas income-oriented strategies (D) are static. Thus, tracking stocking strategies seem to be characteristic for farmers with high preferences for rangeland conservation.

However, the high stocking rates with little variation in animal numbers of strategy D is only possible thanks to the purchase of fodder. A look at Figure 12.4 reveals that while no extra fodder is purchased in cases A and B, 200 t of fodder are purchased in C and nearly five times the amount in case D. Fodder is purchased at every occasion if rainfall is below average in strategy D, whereas in C, fodder is only purchased at the end of a drought period. Fodder purchases enable farmers to keep animals on a farm although the range does not supply enough biomass for their maintenance. Thus herd size and range capacity become de-coupled: abiotic factors alone do not determine the stocking rate. Pressure of grazers is sustained and this results in higher degradation probabilities. In addition, degraded areas produce less biomass so that the purchase of fodder is needed to maintain stock level. Thus a risk of entering a spiral of degradation arises if the reliance on external fodder is high. However, occasional reliance on fodder can be beneficial as it helps farmers to maintain a higher income in severe drought situations such as in strategy B.

Our bio-economic modeling results can be summarized as follows. First, reliance on fodder and its de-coupling effect has a negative impact on
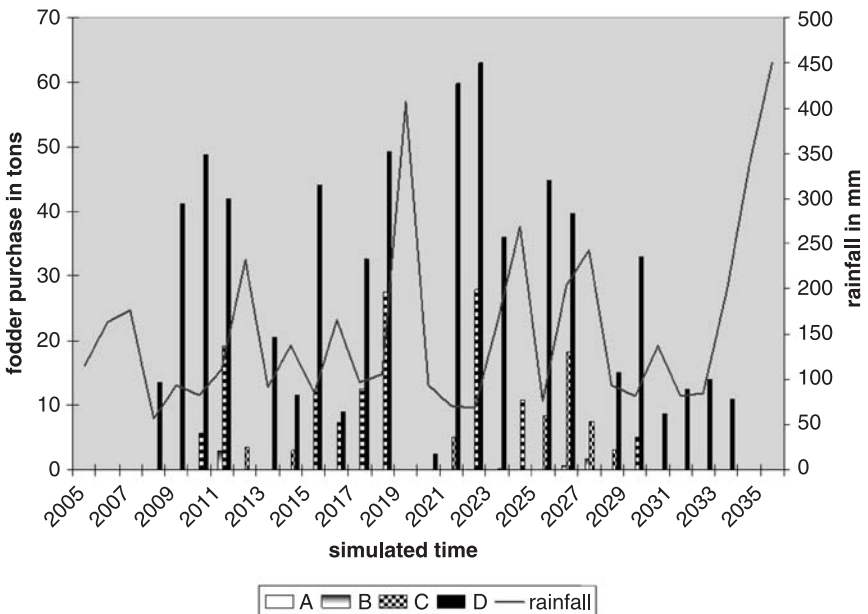

Figure 12.4 Simulation results: example of a time series for fodder purchase plotted with rainfall.

rangeland condition (that is expected in the range dynamic conceptual framework this work builds on). Second, assuming that income and stocking rates are proportional, as our results suggest, stocking rates below the recommended 1 SSU per 5 ha will not contribute to a drastic improvement in range condition under the actual farming system; rather, they could limit the possibilities of farmers to invest in necessary infrastructures such as water points and fence maintenance. Third, it seems that recommended stocking rates are supporting the objective of range conservation. Fourth, the relative importance of income and range condition has a big impact on the optimal strategy and the level of degradation of the range.

4.3 Confrontation of observed and modeled strategies

By summarizing the control variables we draft the strategies represented by each benchmark point on the efficiency frontier and check for similarities with the behavior categories identified thanks to our field work (Table 12.5).

Importantly, Table 12.5 does not aim at directly associating each farmer of the behavioral categories with the patterns of land degradation found along

Table 12.5 Strategy profiles, consequences on veld condition and similar farmer behavior categories

Benchmark points	Main state and control features of strategy	Similarities to categories found in empirical research
A	Very average low stocking rate. Herd size variations: high (Figure 12.1). High replacement rate. Important purchases of ewes. No purchase of fodder. Biomass is not a binding variable.	Category 5: Highly reactive farmer
B	Stocking rate near the recommended 1SSU / 5 ha. Herd size variation: high. Lowest reliance on purchase of ewes. Resort to purchase of fodder rare.	Category 1: Threat avoider
C	Stocking rate of 1SSU/ 4 ha. Herd reduction takes place by selling but also relies on regular fodder purchase.	Towards category 2: Opportunity seizer
D	High stocking rate, above 1 SSU / 4 ha. Herd size variation is low; towards a static strategy. These elements indicate reluctance to sell in droughts. Reliance on fodder is high.	Category 3: Less flexible strategy

the efficiency frontier, as we lack data on long-term stocking rates at the farm level. However, we want to stress that modeling income-maximizing farmers (as opposed to multi-objective farmers) only delivers one strategy and it is not the dominant one in the study area. By including another dimension in the objective function, we can model a diversity of strategies based on the reactivity of the strategy with regards to rainfall. We can see similarities between some modeled and observed strategies, although categories 2 and 4 are not mirrored independently by the modeling exercise. Most probably, our representation of a farmer (having only two objectives) is simplistic; other elements can be of importance in shaping farming systems and responses to rangeland condition and rainfalls, such as for example loss aversion behaviors in the realm of behavioral economics (Chen *et al.* 2006).

5 Conclusions

This chapter has shown that commercial farmers are very diverse in the way they manage their rangeland. Although only few control variables are available to them in terms of adjustments of stocking rate to rainfall, they are flexible and follow different strategies. Grazing strategies are mainly adjusted with respect to the dynamic effects on range quality, which means biomass is not always fully used. The variety of responses of farmers to threats and opportunities has been addressed by a multi-objective approach under the high-reliability paradigm. Under this paradigm, both range condition and income are part of the objective function. Our work includes two research strategies. The qualitative analysis, which was conducted first, revealed that there is a diversity of strategies among farmers of the study area. Then, the multiple objective programming approach delivered complementary information because it enabled us to make a link between strategy and resulting range degradation or conservation. Similarities exist between results of both methods: qualitative results, which illustrate the existence of the various farm behaviors, and quantitative results, which are at various points of an efficiency frontier (see Figure 12.3 for illustration). Limitations and strength of our approach are the following. Since the modeling exercise is done for an isolated farm, contacts with the economy of the outside world are omitted. This means that prices are assumed static and the interactions between farms are neglected. Rainfall variability has been modeled successfully, but not yet its stochasticity. Thus the 'model farmer' is able to plan ahead knowing what rainfall and risk he will encounter. In addition, as explicated by Thankappan *et al.* (2006), linear models are far from being able to mirror the complexity of farmer decision-making and all interactions taking place in complex ecological-economic interactions and systems. One strength of this approach is that it delivers a monetary value of importance (a valuation) of the objective of range conservation through the value of the trade-offs. From a social welfare point of view, one could consider the trade-off value as the necessary investment in resource conservation needed in order to maintain constant

consumption from income, as suggested by the Hartwick rule (Hediger 2003; Asheim *et al.* 2003).

Basically, in the chapter, we have argued and shown that income maximization has severe impacts on rangeland quality, that farmers know this, and some reconsider range quality as a long-term goal. But also, to the contrary, other farmers act rather as income securers and tend not to invest in the quality of their range. It appears that even a majority of modern commercial farmers are more than mere income-maximizing units. It would be wrong if we overlooked this aspect when considering management of natural resources. The level of the investment in range quality seems to be affected by many factors; most are economic, but a few can surely be attributed to the social context of the farmers and their environmental concerns.

As Leeuwis (2004) has argued, perceived values shape frameworks for farmers' practices. For example, the concept of duty of care, emerging in range research in Australia (Stoeckel *et al.* 1997), points to the moral obligation of land users to maintain the quality of the resource they use. Rolston (2006) summarizes this issue: 'Economics does not enable us to choose between diverse options, all of which are economically possible' and 'What kind of planet ought we humans wish to have? One we resourcefully manage for our benefits? Or one we hold in loving care? Science and economics can't teach us that; maybe religion and ethics can.' However, this is normative. Pursuing the idea that there is a missing dimension in our framework to analyze human resource use, Becker (2006) proposes the idea of a *homo ecologicus* who would pursue a respectful and sympathetic relationship with nature. We human beings recognize nature as an entity and we are guided by her creativeness. Interestingly, one farmer has stressed this creative trait of nature that pushes him to be creative as well: 'You can't always do the same thing; you have to change, try things.' In addition, most farmers would agree that degradation is taking place, but not on their farm. This has a special context. As severe overgrazing and degradation are associated with farming practices in communal areas (perception supported by the work of Hongslo and Benjaminsen (2002), there is a *social pressure* among farmers not to 'turn landscapes into *nothing*'.

Finally, we want to stress that commercial farmers in Southern Namibia rely on very little inputs that could substitute nature's services on the farm. Farmers work with a natural ecosystem so that ecosystem dynamics is something they must understand and work with. However, the question of how land should be managed is not new. Liebig and Marx shared the same idea that farming should be a process where what is taken out of the land should be returned to it (Mayumi 2001). And we think Namibian farmers are aware of this. Like traditional farmers, for instance the Gedeo farmers in Ethiopia, many farmers interviewed in context of this study are aware of this cycle and exchange with nature. They want to develop techniques to maintain fertility using agro-ecology. As in the Gedeo system, there are no 'weeds' for them,

as all plants are left in place to return the fertility to the soil (Kippie 2002). Two farmers also mentioned the pleasure derived from having range in good condition, which is corresponding to the findings of Shaw (2002), according to which farmers are more satisfied when they find themselves in a regenerative system.

Appendix 1 Characteristics and plant species cited by farmers to be typical of rangeland in good and in poor condition

Importance*	Characteristics of a range in good condition	Importance*	Characteristics of a range in poor condition
3.1	grass quantity	2.12	no grass left
1.9	shrub quality	2	annual grasses
1.8	shrub quantity	1.7	bare ground
1.7	high quality veld regarding animal needs	1.44	dry vegetation
1.5	grass quality	1.41	no rain
		1.41	no vegetation
		1.39	bare small bushes

Note: *Importance = Frequency of citation / sr(sum of ranking coefficients).
This coefficient primarily reports the frequency of citation, but balances the results using the ranking of citation: being cited as a first characteristic in the interview confers more importance to the item.

Citation frequency	Afrikaans and botanical names of shrubs and bushes cited more than once and associated with range in good condition	Citation frequency	Afrikaans and botanical names of shrubs and bushes associated with range in poor condition
8	Perdebos (*Monechma genistisifolium*)	5	Driedorn (*Rhigozum trichotomum*) Skilpadbossies (*Zygophyllum pubescens* or
7	Gabbabos (*Catophractes alexandrii*)	4	*dregeanum*)
7	Driedorn (*Rhigozum trichotomum*)	4	Soetdorring (*Accacia Nebrownii*)
6	Gannabos (*Salsola spp.*)	2	Gabbabos (*Catophractes alexandrii*)
5	Brosdorn (*Phaeloptilum spinescens*)	1	Noeniebos (*Boscia foetida*)
5	Kooibos (Tetragonia schenkii)	1	Vermeerbos
4	wolbos (*Leucosphera bainsii*)		
2	Klapperbos (*Nymania capensis*)		
2	wolfdoring (*Lyceum oxicarpum*)		

Citation frequency	Afrikaans and botanical names of shrubs and bushes cited more than once and associated with range in good condition	Citation frequency	Afrikaans and botanical names of shrubs and bushes associated with range in poor condition
6	Bushman lang been (*Stipagrostis ciliata*)	5	suurgras (*Schmidtia kalahariensis*)
6	Bushman kort been (*Stipagrostis obtusa*)	1	devilkiss (*Harpagophytum procumbens*)
4	Bloubuffelgras (*S. namaquensis*)	1	gift Straupe
3	Gemsbock tail (*Stipagrostis*)		
2	8-day grass		
1	Blanksaadgras (*Stipagrostis uniplumis*)		
1	Bushman breitblätrige (*S. brevifolia*)		
1	torra bushman grass (*S. anomala*)		

Appendix 2 Paraphrases of farmer statements: Answers to the question, "Would you try to regenerate/rehabilitate a camp of your farm that is degraded and why?"

YES, because
Personal values:
"attitude towards farming: business vs. way of life",
"for the children (heritage)"
"because of sentiments"
"it is a way of life".

If economic benefits are expected:
"to increase productivity"
"if there are benefits"

In case of ecological opportunity:
"if rain creates the opportunity"
"if ecologically possible"

NO because:
Productivity too low to afford investment in regenerative management actions
"cannot afford to invest in regeneration"
"not if forced to use the range"
"dependence on farm income matters"

Appendix 3 Constitution of fuzzy groups of behavior among interviewed farmers (data gathered during semi-structure questionnaires among 22 farmers in 2005)

The classification is based on announced reaction of farmers to drought and high rainfall events. The information is matched with information on stocking rates practiced and indicators constituting the base of rangeland management (see Section 2.2.).

Sets are fuzzy since some farmers could belong to more than one group (Figure 12.A1). Grouping was done thanks to the meaningful coloring of coded answers and visual analysis.
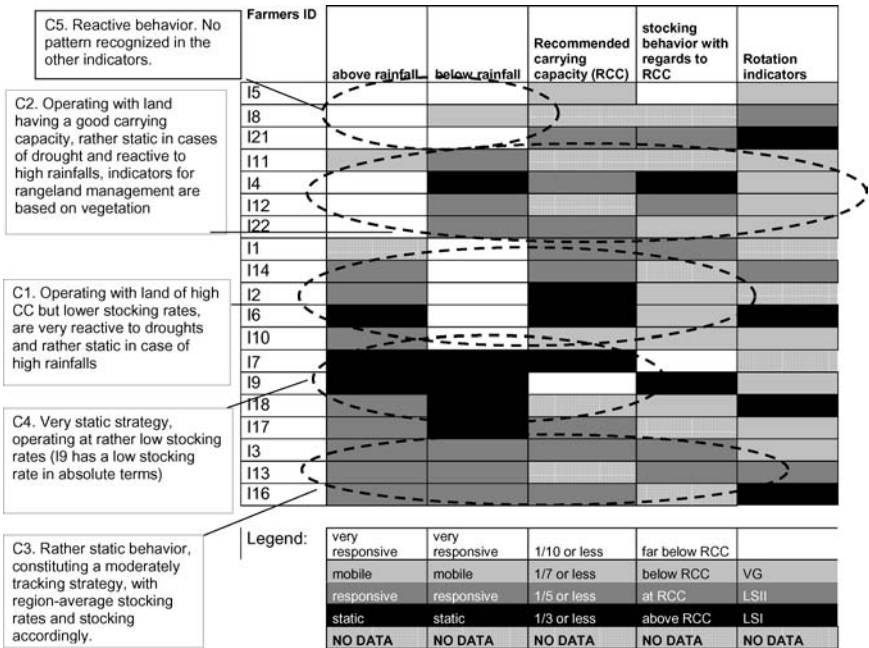

Figure 12.A1 Constitution of fuzzy groups of behavior among farmers interviewed.

Appendix 4 The bio-economic model

Model sets

St set for the different possible stocking rate or intensities of grazing per ha: st3 (1 small stock on 3 ha), st5 (1 small stock on 5 ha), st7 (1 small stock on 7 ha).

S   set of the different ecological states of the rangeland: s1, s2, s3, s4, s5, s6

Sfin Alias (s,sfin)

P   different breeds: goats, dorper
Re   veld regeneration activities, here only resting
T   time /2005 * 2035/
LY   set designating the 2 vegetation layers: grass and shrubs

Calibration and parameterization

First, the model is parameterized to allow a simulation of farmer practices under the actual highly capitalized farming system. All parameters describing input–output relationships are associated with the arithmetic mean of the variables found in the study area. These include parameters determining herd dynamics, variable and fixed costs and product prices. While all the data gathered was used in the descriptive statistics (Available Case Analysis), missing information on prices was approximated in the case of income and cost calculations, using the average of the group (Toutenburg *et al.* 2004). Parameters have also been exposed to the opinion of at least one local expert in a cross-checking process, especially with regard to the most important production-related parameters, i.e. yearly fixed costs and number of market-able lambs produced per ewe per year. Calibration was done with the help of expert interviews; two individual and two group interviews with local experts guided the elaboration of the model by evaluating the plausibility of the outcome.[11] These discussions guided the definition of the levels for unknown parameters, such as the economic value of self consumed lambs or the economic cost of buying stock from outside the farming system.[12] This conforms to parameterizing and calibrating practices seen elsewhere for farm modeling (Buss 2006; Unterschultz, pers. communication).

Farm resources and biomass production

Rainfall is the most important variable in the considered agro-ecological system. According to Du Pisani from the Ministry of Agriculture, Water Resources and Forestry (Pers. comm. March 28, 2005) the rainfall distri-bution for South Namibia follows an incomplete gamma distribution: there are more below average rainfall years than above average rainfall years. We approximate the gamma distribution using a logarithmic transformation of rainfall data in combination with a normal distribution.

$$RAINTER = 1\mathrm{n}(Rain) \tag{A.1}$$

where*: Raintr* is the transformed rainfall and

   Rain the rainfall data of the Keetmanshoop station.

Moments of normal distribution were calculated for the transformed rainfall data.

$$RAINTER = F\{\sigma(RAINTER), \mu(RAINTER)\} \tag{A.2}$$

where:

$\sigma(Raintr)$ is the standard deviation of the transformed rainfall data

$m(Raintr)$ is the mean of the transformed rainfall data.

The opposite transformation provides us with simulated rainfalls approximating the gamma distribution, which are used as a stochastic parameter in the model. In practice, moments of the transformed data for a normal distribution are $(m, \sigma) = (4.7588; 0.63768)$. We incorporate the "incompleteness" of the gamma distribution of real rainfalls by adding 20 to computed rainfall values. Biomass calculations are done using a linear distribution depending on rainfall.

$$biomass_{t\_ly} = restbiom_{t-1\_ly} *BIOMLOSS + \sum_{s}$$

$$(Rain_t biomassCoef_{s\_ly} * HAstate_{st} \tag{A.3}$$

where:

$biomasst_{t,ly}$	the amount of biomass available as fodder in year t given in tons
$restbiomt_{t,ly}$	the amount of biomass left on the veld after grazing at the end of the year t-1 and potentially available for the next year t.
$BIOMLOSS$	coefficient of biomass lost from one year to the other.
$Hastates_{s,t}$	the amount of land on the farm in each ecological state given in ha and for year t.
$RAINt_t$	the rainfall in year t in mm
$biomassCoefs_{s,ly}$	coefficient of biomass growth for an assumed linear relationship between biomass growth and rainfall. Source: Vegetation model by A. Popp (2007).

Fodder can be purchased by a model farmer as an alternative for biomass to satisfy the needs of the herd, so that the biomass constraint is not completely binding.

$$biomass_{t\_ly} + (fodder_t / FODNEEDS) > \tag{A.4}$$

$$\sum_{P}\left(\left(\sum_{st,s} animIntens_{Pst,s,t}\right) * (BIONEEDS * lyFEEDING_{P,ly})\right)$$

where

$Fodder_t$	the total amount of fodder purchased yearly
FODNEEDS	needs in fodder per animal per year
$animIntens_{P,st,s,t}$	number of animals kept at different stocking rates st in year t. The sum over P gives the total amount of animal of each breed.
BIONEEDS	needs in biomass per animal per year
$lyFEEDING_{P,ly}$	coefficient determining the share of browse and graze in the diet

The number of water-supplying boreholes on the farm depends on boreholes stocks, built in a year and the "Breakdown Borehole Coefficient": one borehole infrastructure has a life expectancy of 10 years.

$$boreholes_t = boreholes_{t-1} + boreholebau_t - DryBorehole \qquad (A.5)$$

where:

$boreholest_t$	the total number of boreholes on the farm
$borehol baut_t$	number of boreholes bored in year t
Dryborehole	scalar for the number of boreholes that fall out of order each year

The number of boreholes constrains the stock that can be kept on the farm by reducing the grazeable area, since land without water points cannot be used in the considered labor-extensive farming system (Duraiappah and Perkins, 1999).

$LA_{borehole}$	amount of land around a borehole which can be grazed if the borehole is functioning, in ha.

$$boreholes_t * LA_{borehole} > \sum_{P,st,s} (animIntens_{P,st,s,t} * LANDREQ_{st} \qquad (A.6)$$

Rangeland dynamic

The following equation describes the yearly transitions taking place for the rangeland as a result of the grazing and resting activities carried on. The probability to switch from one condition to the next is specific to the activity carried on and the initial condition of the range.

$$
\begin{aligned}
Hatransformed_{sfin,t} = &\sum_{P} \sum_{st} \sum_{s} (animIntens_{P,st,s,t} * LANDREQ_{st} \\
&* TRANSITION_{P,st,s,sfin,t} \\
&+ \sum_{re} \sum_{s} regeact_{re,s,t} * TRANSIREST_{s,sfin,t}
\end{aligned}
\qquad (A.7)
$$

where

$Hatransformed_{sfin,t}$	area in each state given in ha at the end of the transition from initial to final state as reaction to use and rainfall, summed up for year t.
$LANDREQ_{st}$	land required per small stock at each stocking rate : st3 3 ha, st5 5 ha, st7 7 ha.
$TRANSITION_{P,st,s,sfin,t}$	transition coefficients of a state(s) to another state (sfin), depending on animal type (P), intensity of use (st), initial state (s) and yearly rainfall (rainfall in t).
$Regeact_{re,s,t}$	resting activity.
$TRANSIREST_{s,sfin,t}$	transition coefficients of a state to another state, depending on rainfall and initial state if it is rested.

The stock of land in each quality thus changes in time as defined by the following equation:

$$HAstates_t = HAtransfoFIN_{s,t} + HAstates_{s,t} \qquad (A.8)$$

$$-\left[\sum_P \sum_{st} (animIntens_{P,st,s} * LANDREQ_{st}) + \right.$$

$$\left. \sum_{re} (Regeact_{re,s,t} * RegeActCOEF_{\text{"land"},re}) \right]$$

where:

$HAstates_{s,t}$	amount of land in ha in each range quality or state at time t
$RegeActCOEF_{\text{"land"},re}$	amount of land rested at once (1 unit = 400 ha)

Herd dynamic

The number of breeding ewes ($ewesfin_{P,t}$) and thus of animals on the farm fluctuates with the number of ewes marketed ($eweSell_{P,t}$), ewes purchased ($ewebuy_{P,t}$), the number of ewe lambs kept for replacement in the previous years ($lambuse_{P,\text{"replace"},t-1}$), as described in equation (A.9)

$$ewesfin_{P,t} = ewesfin_{P,t-1} + lambuse_{P,\text{'replace'},t-1} - ewessell_{P,t} + ewebuy_{P,t} \quad (A.9)$$

Farm economics

As commercial farmers have full access to financial markets they use credit possibilities quite commonly to cope with the high variability of production

patterns following rainfall. The value of capital *fingainst* is taken into account by an "interest rate" *CR*, which we use to give the costs or gains of having a negative or respectively positive balance in the bank (Buss 2006) at the end of the year's activities. This rate was estimated at 4 percent, mirroring interests made in a savings account.

$$FINGAINS_t = CR * Bankaccount_t \qquad (A.10)$$

The commercial farmer has two possible strategies to ensure maximum peak production: maximize the number of animals (Roe *et al.*, 1997) and maximize the financial gains at the bank.

Notes

1 Please note that in this chapter the word farmer refers to ranch managèrs and not to cropping activities.
2 Until the 1990s the succession model was used to depict the ecological behavior of rangeland in arid and semi-arid climates. The succession model is based on the idea that changes in the state of the system are reversible and linear. In particular, in the case of grassland, the dominance of the herbaceous layer is the result of an interaction between grazers and the vegetation and constitutes a climax.
3 Desertification designates the process of degradation of semi-arid and arid eco-systems that leads to desert formation (Natural Conservation Service, Ministry of Agriculture, USA, 1999).
4 Karakul sheep are kept for skin production: the lamb is slaughtered when they are 1 day old and the skins are exported to Copenhagen. Damaras are indigenous meat sheep which develop slower than Dorper. Dorper is an cross-bred sheep, bred for improved meat production, as dwarf stem wheat during the Green Revolution, and has higher needs in fodder.
5 The data were gathered for one year only, 2005; at that time herds were recovering from the drought of 2002–2003. Due to constant variability of herd sizes in time, these results are only descriptive.
6 This has been the object of much research. See for a detailed and mathematical analysis Boyd and Richerson (1985), Chapter 4.
7 We use GAMS to program a dynamic linear optimization model of a typical farm in the study area.
8 The ideal point has the maximum possible value of each objective as coordinates in a two dimension plan. It indicates an ideal but impossible situation where both objectives are at their maximum value. The anti-point has the minimum possible values of each objective as coordinates on a two dimension plan.
9 The Pareto solution is defined by achieving the best score possible associated with one objective without making the other objective worse off (Ponce-Hernandez *et al.* 2004).
10 NAD: Namibian Dollars are worth between 1/7th and 1/10th of a Euro.
11 As group and individual interviews are considered complementary for qualitative and quantitative data collection (Kaplowitz 2001; Frey and Fontana 1993), we attempted to gather farmers in small groups and complemented those with individual interviews with farmers who did not attend group meetings.
12 The calibration of such parameters was done according to qualitative and quantitative statements made by experts concerning the behavior of control variables (numbers of replacement ewes and bought ewes) and optimizing income only.

References

Abel, N. (1997) 'Mis-measurement of the productivity and sustainability of African communal rangelands: a case study and some principles from Botswana,' *Ecological Economics* 23: 113–133.

Asheim, G.B., Buchholz, W. and Withagen, C. (2003) 'The Hartwick rule: maths and facts,' *Environmental and Resource Economics* 25: 129–150.

Bach, C.F. (1999) 'Economic incentives for sustainable management: a small optimal control method for tropical forestry,' *Ecological Economics* 30: 251–265.

Batabyal, A.A. (1999) 'Aspects of the optimal management of cyclical ecological-economic systems,' *Ecological Economics* 30: 285–292.

Batabyal, A.A. (2004) '*Stochastic Modeling in Range Management: Selected essays*. New York: Nova Science Publishers.

Becker, C. (2006) 'The human actor in ecological economics: philosophical approach and research perspectives,' *Ecological Economics* 60: 17–23.

Bestelmeyer, B.T., Brown, J.R., Havstad, K.M., Alexander, R., Chavez, G. and Herrick, J.E. (2003) 'Development and use of state-and-transition models for rangelands,' *Journal of Range Management* 56: 114–126.

Börner, J. (2004) 'Modeling the impact of technology and policy innovations on farm-households,' in '*Smallholders in the Amazon: Interactions between Ecosystem and Social System in the Use and Protection of Tropical Rainforests*.' SHIFT-Socio-economica Final Report Phase III (2001–2004).

Boyd, R. and Richerson, P.J. (1985) *Culture and the Evolutionary Process*. Chicago: The University of Chicago Press.

Bulte, E.H., Horan, R.D. and Shogren, J.F. (2003) 'is the Tasmanian tiger extinct? A biological-economic re-evaluation,' *Ecological Economics* 45: 271–279.

Buss, H.J. (2006) *Land Use Options of Namibian Farms. Optimal Management Strategies Proposed by Bioeconomic Models*. Kiel: Agrarökonomische Studien.

Chen, M.K., Lakshminarayanan, V. and Santos, L.R. (2006) 'How basic are individual biases? Evidence from Caouchin monkey trading behavior,' *Journal of Political Economy*.

Costanza, V. and Neuman, C.E. (1997) 'Managing cattle grazing under degraded forests: an optimal control approach,' *Ecological Economics* 21: 123–139.

Duraiappah, A.K. and Perkins, J.S., (1999) 'Sustainable livestock management in the Kalahari: an optimal livestock rangeland model (OLR),' Working Paper No 23, CREED.

Drechsler, M. and Wätzold, F. (2004) 'Ecological- economic modelling for designing and evaluating biodiversity conservation policies,' discussion paper, UFZ, Leipzig, Germany.

Ellis, J. and Swift, D. (1988) 'Stability of African pastoral ecosystems: alternate paradigms and implication for development,' *Journal of Range Management* 41: 450–459.

Finnoff, D., Shogren, J.F., Leung, B., and Lodge, D. (2005) 'The importance of bioeconomic feedback in invasive species management,' *Ecological Economics* 52: 367–381.

Finnoff, D. and Tschirhart, J. (2003) 'Protecting an endangered species while harvesting its prey in a general equilibrium ecosystem model,' *Land Economics* 70(2): 160–180.

Frey, J.H and Fontana, A. (1993). 'The group interview in social research,' in D.L.

Morgan (ed.) *Successful Focus Groups: Advancing the State of the Art*. London: Sage, pp. 20–34.

Giasson, E., Bryant, R.B., and Bills, N.L. (2002) 'Environmental and economic optimization of dairy manure management: a mathematical programming approach,' *Agronomy Journal* 94: 757–766.

Hediger, W. (2003) 'Sustainable farm income in the presence of soil erosion: an agricultural Hartwick rule,' *Ecological Economics* 45: 221–236.

Hongslo, E. and Benjaminsen, T.A. (2002) 'Turning landscapes into "nothing": a narrative on land reform in Namibia,' *Forum for Development Studies* 29(2): 321–347.

Illius, A. and O'Connor, T. (1999) 'On the relevance of non-equilibrium concepts to semi-arid grazing systems,' *Ecological Applications* 9: 798–813.

Janssen, M.A., Anderies, J.M. and Walker, B.H. (2004) 'Robust strategies for managing rangelands with multiple stable attractors,' *Journal of Environmental Economics and Management* 47: 140–162.

Kaplowitz, M.D. and Hoehn, J.P (2001) 'Do focus groups and individual interviews reveal the same information for natural resource valuation?' *Ecological Economics* 36: 237–247.

Kippie, T. (2002) *Five Thousand Years of Sustainability? A Case Study on Gedeo Land Use (Southern Ethiopia)*. Treebook n§5. Heelsum, the Netherlands: Treemail Publishers.

Kreuter, U.P. and Workman, J.P. (1994) 'Costs of overstocking on cattle and wildlife ranches in Zimbabwe,' *Ecological Economics* 11: 237–248.

Leeuwis, C. and van den Ban, A. (2004) *Communication for Rural Innovation: Rethinking Agricultural Extension*. Oxford: Blackwell Science.

MAWF Namibia (2000) 'Carrying capacity of Namibian rangelands' (proposed map October 2000). Windhoek, Namibia, Ministry of Water Affairs and Forestry.

Mayumi, K. (2001) *The Origins of Ecological Economics: The Bioeconomics of Georgescu-Roegen*. London and New York: Routledge.

Milton, S.J. and Hoffman, M.T, (1994) The application of state-and-transition models to rangeland research and management in arid succulent and semi-arid grassy Karoo, South Africa. *African Journal Range for Science*, 11: 18–26 pp.

Okumu, B.N., Russell, N., Jabbar, M.A., Colman, D., Mohamed Saleem, M.A. and Pender, J. (2004) 'Economic impacts of technology, population growth and soil erosion at watershed level: the case of the Ginchi in Ethiopia,' *Journal of Agricultural Economics* 55: 503–523.

Popp, A., Blaum, N. and Geltsch, F. (2008) Ecohydrological feedback mechanisms in arid rangelands: Simulating the impacts of topography and landuse. To appear in *Basic and Applied Ecology*.

Roe, E. (1997) 'Viewpoint: on rangeland carrying capacity,' *Journal of Range Management* 50: 467–472.

Roe, E., Huntsinger, L. and Labnow, K. (1998) 'High reliability pastoralism,' *Journal of Arid Environment* 39: 39–55.

Romero, C. and Rehman, T. (1989) *Multiple Criteria Analysis for Agricultural Decisions: Development in Agricutlture Economics*. Amsterdam: Elsevier.

Rolston, H. (2006) 'Caring for Nature: what science and economics can't teach us but religion can,' *Environmental Values* 15: 307–313.

Shaw, J. (2002) *Let Them Eat Grass: Understanding Pasture-finished Beef Cattle*

Farms in the American Appalachians. Heelsum, the Netherlands: Treemail Publishers.

Stephan, T., Jeltsch, F., Wiegand, T., Wissel, C., and Breiting, H.-A. (1996) 'Die Gamis-Farm in Namibia: Analyse einer Weidewirtschaftsstrategie mit Hilfe eines Computersimulationsmodells,' *Verhandlung der Gesellschaft für Ökologie* 26: 455–461.

Stoeckel, A., Breckwoldt R. and Hughes, P. (1997) *Sustainable Natural Resource Management in the rangelands*. Canberra: Centre for International Economics.

Stringham, T.K., Krueger, W.C. and Shaver, P.L. (2003) 'State and transition modeling: an ecological process approach,' *Journal of Range Management* 56: 106–113.

Strohbach, B.J. (2000) 'Vegetation degradation in Namibia,' Paper presented at 75th Congress of the Namibia Scientific Society, Windhoek.

Sullivan, S. and Rohde, R. (2002) 'On non-equilibrium in arid and semi-arid grazing systems,' *Journal of Biogeography* 29: 1595–1618.

Thankappan, S., Midmore, P., and Jenkins, T. (2006) 'Conserving energy in small-holder agriculture: a multi-objective programming case-study of northwest India,' *Ecological Economics* 56: 190–208.

Toutenburg, H., Heumann, C. and Nittner, T. (2004) *Statistische Methoden bei unvollständigen Daten*. München: Department für Statistik, Universität München.

Unterschultz, J.R., Miller, J. and Boxall, P.C. (2003) 'The on-ranch economics of riparian zone cattle grazing management,' *Environmental Management* 33: 664–676.

van Wenum, J.H., Wossink, G.A.A. and Renkema, J.A. (2004) 'Location-specific modeling for optimizing wildlife management on crop farms,' *Ecological Economics* 48: 395–407.

Vetter, S. (2004) 'Equilibrium and non-equilibrium in rangelands: a review of the debate,' in S. Vetter (ed.) *Rangelands at Equilibrium and Non-Equilibrium: Recent Developments in the Debate around Rangeland Ecology and Management*. PLAAS (Programme for Land and Agrarian Studies), University of Western Cape, pp. 5–15.

Wardell-Johnson, G. (2006) 'Biodiversity and conservation in Namibia – into the 21st century,' in B. Fuller and I. Prommer (eds) *Population-Development-Environment in Namibia*. IIASA., pp. 17–45.

Weitzman, M.L. (1994) 'On the "environmental" discount rate,' *Journal of Environmental Economics and Management* 26: 200–209.

Westoby, M. and Noy-Meir, I. (1989) 'Opportunistic management for rangelands not at equilibrium,' *Journal of Range Management* 42: 266–274.

Wossink, G.A.A., Oude Lansink, A.G.J.M. and Struik, P.C. (2001) 'Non-separability and heterogenity in integrated agronomic-economic analysis of nonpoint-source pollution,' *Ecological Economics* 38: 345–357.

13 Estimating the interactions of soil biota with agricultural practices

Sébastien Foudi

1. Introduction

An ecosystem consists of the set of species living in a given space, the set of interactions among species and between species and their physical environment, and the matter and energy that flows through the species and their environment. Biodiversity is commonly perceived as a generator of this ecosystem. Nevertheless, the ecosystem is not fixed in time and its evolution is driven by the evolution of species, and also, directly or indirectly, by the impact of human activities. The agro-ecosystem is a particular ecosystem. Agro-ecosystems are influenced by agricultural practices, which result in a more simplified, artificial environment. Currently, the loss of biodiversity raises questions about how to attain more sustainable agricultural ecosystems. Answers to these questions will include an understanding of the interactions between natural species and agricultural practices.

The preservation of soil functions in agriculture is the basis of the sustainability of the agricultural systems. These functions are themselves based on the fauna of the soil and its diversity. The soil biota includes all plants and animal life of a particular space. The productive biota (crops and livestock), the resource biota (decomposers) and the destructive biota (pests) are grouped under soil biota. Soil biota is influenced by the agricultural practices of farmers, which emphasize the maximization of productive biota at the expense of the two other categories. However, resource biota is the basis of ecosystem resilience. As decomposers, microorganisms participate in the creation of vegetable mould. As regulators of nutrient cycling, they enhance the efficiency of nutrient acquisition by plants and may reduce nitrogen run off.

The impact of agricultural practices on resource biota appears through disturbances in land uses, the preparation of fields, and the use of xenobiotic compounds such as pesticides and fertilizers. Scientists are now identifying soil biodiversity, recognizing its functions in the ecosystems, and quantifying the interactions between agricultural production and soil biota.

Research by both economists and biologists is necessary to develop policies for natural resource conservation. Yet, the fact that economists and biologists study problems on different scales makes policy formulation difficult.

Biologists conduct research in the laboratory or on micro-plots, while economists implement analyses at the scale of the farm or region. As noted by Swift *et al.* (2004), it is possible that functions and species change across space.

The aim of this chapter is to estimate the interactions between soil biota and agricultural production in several agro-ecosystems and test whether results are relevant for biological research. I propose a structural model, estimating interactions with data on land allocations and use of crop inputs in a two-step econometric procedure. The first step is to estimate the evolution of the resource biota as a function of the stock and the use of xenobiotic compounds. In the second step, crop-specific fertilizers and the predicted levels of resource biota are used to estimate the magnitude of these two inputs in the production of the agro-ecosystem. The contribution of the chapter is to quantify the magnitude of the relationship of agriculture with soil biota and propose an econometric method to estimate this relationship. An approach of this type can generate information to support the design of resource conservation policies.

Section 2 presents the findings of biological research that explains the relationship of soil resources with agricultural production, highlighting the limitations of this research. The structural model is presented in Section 3. Section 4 presents results of bio-econometric estimations. Conclusions are drawn in the final section.

2 Biology and agriculture

In the biodiversity concept viewed from the perspective of the agro-ecosystem, a distinction must be established between the direct and indirect consequences of the decisions of farmers. The first type of diversity, termed 'planned diversity' (Swift *et al.* 2004), is represented by the suite of plants and livestock that are deliberately selected, imported, maintained and managed by farmers. The second type of diversity is the 'associated biota' (plant, animal and microbial). Associated biota is strongly influenced by the composition and the diversity of planned biota. While 'planned diversity' obeys economic decisions and biological considerations, the impact of agricultural practices on associated biota is the crucial issue in biodiversity conservation.

Swift and Anderson (1993) defined three categories of biota on the basis of the contribution of each to agricultural ecosystem productivity: (1) the productive biota (crops and livestock); (2) the resource biota (cover crops, decomposer organisms); and (3) the destructive biota (pests, weeds). Even when endowed with property rights on all three groups, farmers concentrate on maximizing productive biota at the expense of the other two. This simplification has generated the definition of agro-ecosystems – ecosystems that have been deliberately simplified by people for the purpose of producing specific goods of value to humans (Swift *et al.* 2004).

The three sets of biota are interrelated. Loss of the resource biota when

maximizing the productive biota may leave space for more destructive biota, which in turn reduces the productive biota. In response, farmers may use techniques that eradicate the destructive biota, which will negatively affect the resource biota that determines a part of the productive biota. Biologists are now documenting the complexity of these interactions. One emerging question concerns the effect of the resource biota on the productive biota and to what extent conserving the resource biota benefits the productive biota. Next, I summarize the related evidence.

Beare *et al.* (1997) conducted a detailed review of the literature on the impact of decomposer biota on soil biodiversity and agricultural intensification. The literature illustrates the complexity of interactions that drives soil fertility, including: interactions among decomposers, interactions between plants and microorganisms, effects of decomposers on soil properties (N transformations), effects of crop quality residues on the density and diversity of decomposers and on the rates of residue decomposition, effects of the means by which crop residues are disposed on the size, composition and activity of soil biological communities, as well as on the rates of decomposition of organic matter. Decomposer biota participates in the synthesis and decomposition of soil organic matter, but also regulates water infiltration and retention (Swift *et al.* 2004). When identified, the function of this fauna in the ecosystem is heavily ecosystem-specific and species-specific. For example, the function of the earthworm in improving water infiltration is perceived as damage by farmers cultivating rice (Joshi *et al.* 1999). Similarly, the conversion of Amazonian rainforest to grassland has led to the extinction of a native earthworm species, which was replaced by an exotic species that compacts the soil and negatively affects pasture productivity (Chauvel *et al.* 1999).

Soil fauna is classified into three groups: (1) microfauna (nematodes, protozoa) that are quite well known by biologists; (2) mesofauna (mites, collembola) that are poorly known; and (3) macrofauna (earthworms, ants, termites, millipedes), also well known. Almost all are referred to as regulators of nutrient cycling. They change the decomposition processes that influence the release and retention of nutrients, and enhance the efficiency of nutrient acquisition by plants.

Each of the three groups plays its own role in the ecosystem but all contribute to soil fertility at different scales, directly or indirectly. Some studies (Tian 1998) suggest that promoting the colonization and the activity of soil macrofauna may be important for restoring the decomposition function of degraded soils. Among macrofauna family, earthworms might be the most studied species (Lavelle *et al.* 1992). It is known among biologists that many earthworm species contribute to nutrient cycling through the production of nutrient-rich casts. Their production is estimated to be around 50–100kg per hectare in humid tropical pastures. Researchers have also shown that earthworms' casts contain more organic carbon, total nitrogen, and available phosphorus from which the casts are derived. The casts produced by

earthworms are rich in organic matter. The higher rates of mineralization found in these casts enhance the supply of nutrients to roots in the surrounding area and to superficial roots which can absorb these nutrients after they leach from the litter layer (Anderson *et al.* 1983, in Fragoso *et al.* 1997). In tropical grasslands, about 25–150kg per hectare of mineral nitrogen may be released annually by a species of earthworms (Lavelle *et al.* 1992). It is also estimated that 50 kg per hectare of mineral phosphorus could be released into the soil. Fragoso *et al.* (1997) find that 'This nutrient may be rapidly assimilated by plants if released at a time when a nutrient sink is present and if not, may be stored or made inaccessible to plant roots by leaching, surface runoff, soil erosion or others processes.' However, whereas agricultural intensification reduces the diversity of organisms involved in nutrient cycling, there is no evidence that a higher diversity of these organisms can produce significant effects on decomposition and mineralization processes (Swift *et al.* 2004). This lack of evidence illustrates the complexity of the relationships among soil biodiversity, agro-ecosystem functions and agricultural practices.

The impacts of agricultural practices on soil biodiversity have also been studied but quantification of this impact is rare. Beare *et al.* (1997) identify three factors associated with agricultural intensification: (i) an increase in the frequency and magnitude of disturbances that result from land-use change and site preparation (deforestation, burning and removal of residues); (ii) a reduction in the quantity of organic resources returned to the soil; (iii) the use of xenobiotic compounds such as industrial fertilizers and pesticides. Moreover, land use choices have also an effect on soil biodiversity. Indeed, land use changes consisting in converting native forest or grassland systems to arable cropping systems result in a decline of soil biodiversity (Lavelle *et al.* 1992).

Regarding the effects of agrochemical herbicides on soil biodiversity, researchers have shown that non-selective agrochemicals can be detrimental for long-run soil management and maintaining soil fertility. Insecticides and herbicides reduce the density, diversity and biomass of earthworms.

Despite these advances, the role of soil fauna in maintaining soil fertility is poorly understood in quantitative terms. Even less well known is the effect of soil organisms on production. Lavelle *et al.* (1992) have shown that the earthworm species they studied enhanced maize yields. Gilot (1994) observed an increase of 18 per cent and 12 per cent in maize grain and stalk production, respectively, when an earthworm species was introduced into 1.28 m^2 microplots. However, Gilot also found that the survival rates of the species after the harvest was very low, indicating that results were not robust.

Integrating economic and biological models of soil fertility conservation poses a challenge because of differences in the spatial scale of analysis. This challenge is illustrated in a statement by Beare *et al.* (1997; 91) based on the work of Franklin (1993): 'When discussing the implications of changes in soil biodiversity [for] ecosystem function it is important to identify the taxonomic

resolution used to describe diversity and the spatial scale at which diversity-function relationships are considered.' Indeed, while economists deal with aggregate phenomena, biologists deal with micro plots (or laboratory chamber) and specific species or member of species. There is a possibility that the functions and species change across space (Swift *et al.* 2004), so that aggregation would generate misleading results. Finally, the objectives of economics and biologists differ. Economists are concerned about productivity and how to derive soil conservation policies that could improve the social welfare. Biologists seek to understand the contribution of soil fauna to soil fertility, the interactions among soil organisms, and the role of soil fauna and soil biodiversity on ecosystem functions. Given the knowledge constraints identified above, I propose a structural model which facilitates the estimation of some interactions among agricultural practices and soil natural resources.

3 Natural resource exploitation by agriculture

3.1 The structural model

The farm represents a heterogeneous space formed of different plots or fields indexed by c. Each plot characterizes a different land use and a different crop (wheat, maize, grassland). On this space lives the biotic resource (denoted by B) representing the resource biota. This resource is a renewable resource whose evolution is described by a logistic form. Consistent with the discussion in the preceding section, B is negatively affected by the agricultural effort (E) which is exerted by the farmer on the land. This effort represents the use of chemical fertilizers and other pesticides and xenobiotic compounds.

The damage produced by the effort takes the form of a Shaefer function, $H(E_{ct}, B_{ct}) = \varphi_c E_{ct} B_{ct}$ where φ_c is a mortality coefficient due to the effort.

The evolution of this resource is then:

$$B_{ct} = B_{c,\,t-1} + B_{c,\,t-1}\left[r_c\left(1 - \frac{B_{c,\,t-1}}{\kappa_c}\right)\right] - H(E_{c,\,t-1}, B_{c,\,t-1}) \tag{13.1}$$

where r_c is the intrinsic growth rate of the patch and κ_c is the carrying capacity of the patch.

With respect to economic decision-making, the farmer uses two kinds of inputs for the production: the renewable resource, B and the agricultural effort, E. The agricultural production $Q(B_{ct}, E_{ct})$ on land c is assumed to be described by a quadratic functional form:

$$Q(B_{it}, E_{it}) = \psi_0 + \psi_{1B}B_{it} + \frac{1}{2}\psi_{2B}B_{it}^2 + \psi_{2E}E_{it} + \frac{1}{2}\psi_{2E}E_{it}^2 + \psi_{BE}B_{it}E_{it} \tag{13.2}$$

4 Econometric estimations

The database is an unbalanced panel data of 7,650 observations from 1995 to 2001, issued by the Farm Accountancy Data Network of the European Union (FADN). Farmers represented in the database work in three different regions: Midi-Pyrenees (38 per cent), Pays de la Loire (37 per cent) and Rhône-Alpes (25 per cent). The analysis considers two cash crops (wheat and maize) and one semi-natural land-use (non-permanent grasslands). Farmers can manage these three land-uses simultaneously.

Table 13.1 presents descriptive statistics for the land uses examined. Eighty-eight per cent of farmers cultivated wheat, 84 per cent managed grasslands and 40 per cent grew maize. The average farmer allocates space first to grasslands, and then to wheat and to maize crops. There is major dispersion in the data and there are significant regional differences in land use patterns.

Crop-specific expenditures on inputs (part of E) were not included in the database. Only total expenditures (over all land uses) for mineral nitrogen and for biocides (insecticides, fungicides and herbicides) were reported. To approximate crop-specific fertilizer and biocide use, I consulted the regional database of Agreste (a statistical office of the French Minister of Agriculture), in which the shares of nitrogen and biocides applied to each type of land use are reported for each of the three regions in 2001. Assuming that the behaviour of farmers in term of nitrogen use is uniform and reproduces the regional decomposition of nitrogen use (unit per hectare) among the different crops, I computed the nitrogen quantity spread on each type of fields. The same procedure was employed to calculate quantities of biocides applied by land use.

Table 13.1 Descriptive statistics

	Mean	*SD*
Land (ha)		
Wheat	18.10	21.99
Maize	17.96	26.65
Grassland	35.40	27.80
Cash crop production (100kg)		
Wheat	1075.73	1470.15
Maize	1769.69	2602.58
Grassland	NA	NA
Mineral nitrogen (Kg)		
Wheat	440.61	701.27
Maize	95.81	295.01
Grassland	119.07	129.53
Pesticides (Kg)		
Wheat	35.65	44.56
Maize	3.97	10.88
Grassland	NA	NA

The population of farmers represented in the data is characterized by preferences for mixed land uses. About three-quarters of the farmers surveyed mix wheat cultivation and grasslands. Grassland is not a cash crop, so that data on the production of that semi-natural land uses are included.

Dynamic panel data enable the biological parameters of the model to be estimated because they capture temporal evolution. Moreover, panel data capture unobserved heterogeneity that could reflect the ecosystem-specific effect in the production process. A two-step method is proposed to estimate the model. In the first step, the parameters of the law of motion of the natural resource are estimated. The predicted values of this variable are then used in the second step as a regressor in the production function.

4.1 Biological estimations: dynamic panel data

Each of the three land uses is studied independently of the others because the review of the biological literature showed that soil natural resources are highly crop-specific. Moreover, it is assumed that there is no migration of the resource from one patch to the other.

The law of motion of the natural resources of the soil c is described by equation (13.1):

$$B_{ct} = B_{c,\,t-1} + B_{c,\,t-1}\left[r_c\left(1 - \frac{B_{c,\,t-1}}{\kappa_c}\right)\right] - H\left(E_{c,\,t-1},\,B_{c,\,t-1}\right)$$

where B_{ct} is the natural resource of the soil c at time t, r_c is the natural growth rate of the resource on soil c, κ_c is the carrying capacity of the soil c and $E_{c,\,t-1}$ refers to the agricultural effort synthesized by the mineral nitrogen and biocides spread over soil c. φ_c is the mortality coefficient of the natural resource due to the agricultural effort.

This equation cannot be estimated because the database does not contain the natural resource variable. The variable can be generated with information contained in the data. One can assume that the natural resource is a function of the land on which it is living, meaning that it is a function of its habitat. Rosenzweig (2001) shows that at the scale of the whole earth and its major bio-geographical provinces, the steady states in species diversity respond linearly to available area. A simple way to formalize this relationship is to take a linear function of the land. The resource variable can then be expressed as:

$$B_{ct} = \theta_c L_{ct} \tag{13.3}$$

where L_{ct} is the land under land use c at time t and θ_c is a crop-specific, non-negative and time-invariant parameter.

Under equation (13.3), the crop specific form of equation (13.1) for the agroecosystem or farm i is:

$$L_{it} = \beta L_{i,\, t-1} + \omega L_{i,\, t-1}^2 + \varphi L_{i,\, t-1} E_{i,\, t-1} + u_{it} \tag{13.4}$$

where $u_{it} = a_i + \varepsilon_{it}$ and a_i is the farm- or agro-ecosystem-specific parameter and, ε_{it} is the traditional error term.

The hypothesis stated by equation (13.3) implies that none of the biological parameters can be recovered. Indeed, if the growth rate of the resource can be recovered as $\beta - 1$, the carrying capacity parameter cannot be recovered as long as θ is unknown. From the regressions, it is expected that the parameters β associated with $L_{i,\, t-1}$ are larger than one. If so, a non-negative natural growth rate can be recovered. The parameter associating ω with $L_{i,\, t-1}^2$ is expected to be negative so that the carrying capacity is positive. The parameter φ is expected to be negative, representing the mortality effect of the agricultural effort on the resource.

By construction, the lagged variable $L_{i,\, t-1}$ is correlated with the residual term since the farm-specific component a_i is correlated with the residual term ε_{it}. One way to eliminate this endogeneity is to estimate the model in first differences, removing the farm-specific parameter. First differences introduce a second source of endogeneity arising from correlation between $\Delta L_{i,\, t-1}$ and $\Delta \varepsilon_{it}$ (Δ is the first difference operator). To correct for this endogeneity, Arellano and Bond (1991) use the dependent variable lagged at least twice as an instrument. The estimator is based on the Generalized Method of Moments. The moment conditions hold and the estimators are consistent if the error terms are not serially correlated, at order 1 and at order 2. Serial correlation of order 2 is rejected by the data for all of the estimated equations presented in Table 13.2

Table 13.2 presents the estimated results of the first stage, for single land uses and an aggregate land use representing cash crops. In each equation, the test of over-identifying restrictions does not lead to rejection of the specification of the model. Thus, the instruments used are valid for correcting endogeneity. All parameters have the expected sign in the equations of single land uses. The chemical inputs, nitrogen (N) and biocides (P) affect the growth of the natural resource significantly and negatively. The equation for the aggregate cash crop (wheat-maize) illustrates why regressions should be estimated for specific crops rather than globally. Pesticide use has no significant effect on the habitat, although its effect is significantly negative in single habitats. This result is consistent with the findings of biological research regarding the importance of scale in the examination of ecosystems functions.

4.2 Production function estimation

Production is assumed to fit a quadratic form as a function of the soil biotic resource (B) estimated in step 1 and the level of chemical inputs [E = (N, P)] used on the land, as described in equation (13.2). Under the assumption stated by equation (13.3), the production for a given crop can be rewritten as:

Table 13.2: Biological estimation results

Variables[a,b]	Grassland	Wheat		Maize		Wheat and Maize	
	M1	M1	M2	M1	M2	M1	M2
constant	0.63**	0.079	0.04	0.95**	0.91**	0.22**	0.17**
	(0.09)	(0.07)	(0.06)	(0.15)	(0.16)	(0.06)	(0.06)
$L_{i,t-1}$	1.25**	1.62**	1.64**	1.12**	1.13**	1.36**	1.28**
	(0.36)	(0.48)	(0.49)	(0.26)	(0.25)	(0.45)	(0.46)
$L^2_{i,t}$	−0.015**	−0.028**	−0.028**	−0.022**	−0.026**	−0.026**	−0.025**
	(0.004)	(0.007)	(0.007)	(0.007)	(0.008)	(0.006)	(0.006)
$L_{i,t-1}N_{i,t-1}$	−0.008**	−0.009**	−0.008**	−0.035**	−0.033**	−0.004**	−0.003**
	(0.003)	(0.003)	(0.002)	(0.008)	(0.008)	(0.001)	(0.001)
$L_{i,t}-1P_{i,t-1}$			−0.058**		−0.8**		−0.008
			(0.017)		(0.31)		(0.009)
Tests[c]							
Sargan	12.2 (0.6)	17.6 (0.22)	16.3 (0.29)	17.5 (0.22)	18.07 (0.2)	22.1 (0.07)	21.2 (0.09)
Autocovariance of order 1	−2.4 (0.01)	−3.8 (0.00)	−3.8 (0.00)	−3.3 (0.00)	−3.3 (0.00)	−3.1 (0.00)	−3.01 (0.00)
Autocovariance of order 2	0.75 (0.45)	0.18 (0.85)	0.35 (0.72)	0.27 (0.78)	0.39 (0.69)	0.38 (0.7)	0.28 (0.77)

Notes: ** and * : parameters significant at 95% and 90% confidence levels, respectively.
[a] N stands for Nitrogen and P stands for biocides.
[b] standard deviation in parentheses.
[c] *p*-value in parentheses.

$$Q(\hat{L}_{it}, E_{it}) = \psi_0 + \psi_{1L}\hat{L}_{it} + \frac{1}{2}\psi_{2L}\hat{L}_{it}^2 + \psi_{1E}E_{it} + \frac{1}{2}\psi2_E E_{it}^2 + \psi_{LE}\hat{L}_{it}E_{it} + v_{it}$$

(13.5)

with $v_{it} = \eta_i + \varepsilon_{it}$, $\psi_{1L} = \theta\psi_{1B}$, $\psi_{2L} = \theta^2\psi_{2B}$ and $\psi_{LE} = \theta\psi_{BE}$.

As discussed in the review of biological literature and confirmed in the estimations in step one, soil biota is a dynamic and site-specific phenomenon. In that sense, the fluctuation of the resource over time and space should be accounted for when estimating the agricultural production function. This point is verified in the data. Hausman tests led to the use of a fixed effects estimator, treating individual effects as parameter in the model (Table 13.3), using time variation within each cross-section.

Table 13.3 presents two regressions for each land use. In model M1, two inputs are used in production (the natural resource, L and mineral nitrogen, N). Model M2 assumes the use of three inputs (biocides, P in addition to those in M1). Results indicate that the production functions are well-behaved, increasing and concave in their arguments. The chemical inputs, nitrogen and pesticides, have a significant effect on production. The effect of the natural resource input generated in step one is significant only for the production functions that include wheat, without biocides. The cross-products or the single-output equations indicate that the three inputs are complements. The complementarity of mineral nitrogen and pesticides in the production process comes from the fact that they are not used in pursuit of the same goal; the latter is used to control pests and the former to improve the growth of the plant. The complementarity of the nitrogen and the soil species deals with the nutrient cycle since some species of the soil fix mineral nitrogen. Fixing mineral nitrogen avoids leaching and immobilization,[1] improving the efficiency of nitrogen acquisition by the plant. Finally, the complementarity between the natural resource and biocides may reflect the influence of biocides in the competition between species: the pesticides are used to target species that damage the crop and become too abundant, leaving space for the proliferation of other, non-damaging species, which constitute the natural resource input in this model.

The analysis of the aggregate crop function shows that the wheat crop influences the aggregate crop, and thus the maize crop is less important. Nevertheless, these results should be interpreted with caution since censoring has not been taken into consideration in the second step. The bias may be small for wheat and the non-continuous wheat-maize rotation. Respectively, 88 per cent and 91 per cent of the farmers produced these crops. The bias could be more important for maize, which was cultivated by only 40 per cent of the farmers.

5 Conclusion

This chapter has presented an empirical analysis that illustrates the interactions of soil resource biota with agricultural production. The model is

Table 13.3 Quadratic production function

Variables[a]	Wheat		Maize		Wheat & Maize	
	M1	M2	M1	M2	M1	M2
constant	112.7** (26.1)	31.07 (28.3)	81.43* (44.7)	15.54 (46.7)	235.4** (31.5)	185.6 (37.9)
Resource	4.09** (1.91)	2.29 (1.93)	7.98 (6.21)	6.18 (5.32)	6.16** (2.52)	1.94 (2.72)
Resource^2	-0.29** (0.08)	-0.32** (0.08)	-0.35 (0.47)	-0.74 (0.40)	-0.06 (0.12)	-0.15 (0.13)
Nitrogen	0.87** (0.09)	0.67** (0.09)	6.99** (0.50)	4.82** (0.59)	0.64** (0.06)	0.59 (0.06)
Nitrogen^2	-0.00** (0.00)	-0.001** (0.00)	-0.01** (0.00)	-0.009** (0.00)	-0.00** (0.00)	-0.00** (0.00)
Pesticides		5.03 (0.93)		43.23** (10.47)		2.08** (0.8)
Pesticides^2		-0.06** (0.00)		-1.74** (0.42)		-0.02** (0.00)
Resource x Nitrogen	0.006* (0.00)	0.007* (0.00)	0.014 (0.01)	0.012 (0.01)	-0.003** (0.00)	-0.005** (0.00)
Resource x Pesticides		0.05 (0.03)		0.8** (0.36)		0.12** (0.02)
Pesticides x Nitrogen		0.007** (0.00)		0.05** (0.00)		0.0001 (0.00)
R-square	0.587	0.636	0.594	0.595	0.623	0.601
Specification Tests[b]						
Individual effect (F test)	6.3 (0.00)	6.02 (0.00)	5.9 (0.00)	6.01 (0.00)	10.9 (0.00)	9.99 (0.00)
Global validity (F test)	86.1 (0.00)	75.9 (0.00)	62.2 (0.00)	43.2 (0.00)	73.5 (0.00)	49.0 (0.00)
Hausman	198.3	153.2	114.2	77.7	496.3	285.4

Notes: ** and * : parameters significant at 95% and 90% confidence levels, respectively.
[a] standard deviation in parentheses.
[b] p-value in parentheses.

motivated by findings reported in the biological literature, which demonstrate the way that farmers' practices influence the biotic resources of the soil and the impact of these resources on productivity in the agroecosystem. While documented by scientists, these interactions have rarely been quantified. The complexity of ecosystem function makes quantifying these effects difficult. Nonetheless, knowing the magnitude of interactions is important for the design of efficient conservation policies.

Thus, I have proposed a simple econometric procedure to estimate the relationship between farm production and the agro-environment. The approach provides an opportunity to test empirically whether biological results can be supported by an economic data base. A two-step procedure was applied to a panel database, accounting for unobserved heterogeneity, site-specific effects, and the dynamic evolution of a natural resource. Under the hypothesis that the stock of the resource biota is a linear function of its habitat, the evolution of the resource biota is estimated in the first step as a function of past levels and the mortality that results from farmers' use of xenobiotic compounds. In the second step, the predicted level of resource biota is used as a regressor to estimate production functions in different agroecosystems.

The database to which the model was applied represents farmers in three agroecosystems (wheat, maize, grassland) in several heterogeneous regions of France, for the period 1995–2001. The heterogeneity of the studied regions supports a general analysis of the impacts of some agri-envrionmental policies.

The estimated equations could be used to simulate the effect of natural resource conservation policies such as agri-environmental schemes aiming at reducing the level of nitrogen in the soil. Introducing soil biota in the equations permits a more accurate estimation of the effect of a policy aimed at reducing the level of industrial fertilizers in the soil, and of the cost of compensation, because it includes interaction terms. Incorporating soil and production interactions reveals that part of the production loss will be counteracted by an increase in the level of the natural resource in the soil. This finding supports the case for less compensation.

Note

1 Nitrogen immobilization is the process by which mineral nitrogen becomes organic nitrogen, which is useless for the growth of the plant unless it undergoes a mineralization process.

References

Arellano, M. and Bond, S. (1991) 'Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations', *The Review of Economic Studies*, 58: 277–297.

Beare, M.H., Vikram Reddy, M., Tian, G. and Srivastava, S.C. (1997) 'Agricultural

intensification, soil biodiversity and agroecosystem function in the tropics: the role of decomposer biota', *Applied Soil Ecology* 6: 87–108.

Black, H.I.J. and Okwakol, M.J.N, (1997) 'Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of termites', *Applied Soil Ecology* 6: 37–53.

Chauvel, A., Grimaldi, M., Barros, E., Blanchart, E, Sarrazin, M. and Lavelle, P. (1999) 'Pasture degradation by an Amazonian earthworm', *Nature* 389: 32–33.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K. *et al.* (1997) 'The value of the world's ecosystem services and natural capital', *Nature* 387: 253–260.

Feller, C., Brown, G.G., Blanchart, E., Deleporte, P. and Chernyanskii, S.S. (2003) 'Charles Darwin, earthworms and the natural sciences: various lessons from past to future', *Agriculture, Ecosystems and Environment* 99: 29–49.

Fragoso, C., Brown, G.G., Patron, J.C., Blanchart, E., Lavelle, P., Pashanasi, B., Senapati, B. and Kumar, T. (1997) 'Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of earthworms', *Applied Soil Ecology* 6: 17–35.

Franklin, J.F. (1993) 'Preserving biodiversity: species, ecosystems, or landscapes?' *Ecological Applications* 3: 202–205.

Gilot, C. (1994) 'Effets de l'introduction du ver gophage tropical Millisonia anomala omodeo en systèmes cultivés sur les caractéristiques des sols et la production végétales en moyenne Côte d'Ivoire', PhD thesis, INRA Paris-Grignon.

Hole, D.G., Perkins, A.J. Wilson, J.D., Alexander, I.H. Grice, P.V. and Evans, A.D. (2005) 'Does organic farming benefit biodiversity?', *Biological Conservation* 122: 113–130.

Joshi, R.C., Matchoc O.R.O., Cabigat, J.C. and James, S.W. (1999) 'Survey of earthworms in the Ijugao rice terraces, Philippines', *Journal of Environmental Science Management* 18(2): 1–12.

Lavelle, P., Melendez, G., Pashanasi, B. and Shaefer, R. (1992) 'Nitrogen mineralization and reorganization in casts of the geophagous tropical earthworm Pontoscolex corethurus', *Biology and Fertility of Soil* 14: 49–53.

Ministère de l'agriculture et de la pêche (2004) *Enquête sur les pratiques culturales en 2001, Agreste chiffres et Données Agriculture*, N159.

Munyanziza, E., Kehri, H.K. and Bagyaraj, D.J. (1997) 'Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of mycorrhiza in crops and trees', *Applied Soil Ecology* 6: 77–85.

Rosenzweig, M.L. (2001) 'Loss of speciation rate impoverish future diversity', *Proceedings of National Academy of Sciences of the USA*, N98, pp. 5404–5410.

Skonhoft, A. (1999) 'On the optimal exploitation of terrestrial animal species', *Environmental and Resource Economics*, 13: 45–57.

Swift M.J. and Anderson J.M. (1993) 'Biodiversity and ecosystem function in agricultural systems'. E-D. Schulze and H.A. Mooney (eds) *Biodiversity and Ecosystems Function*. Berlin: Springer, pp. 15–41.

Swift, M.J., Izac, A-M.N. and van Noordwijk, M. (2004) 'Biodiversity and ecosystem service in agricultural landscapes: are we asking the right questions?', *Agriculture, Ecosystems and Environment* 104: 113–134.

Tian, G. (1998) 'Effect of soil degradation on leaf decomposition and nutrient release under humid tropical conditions', *Soil Sciences* 163: 897–906.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C. *et al.* (2001) 'Forecasting agriculturally driven global environmental change', *Science* 292: 281–284.

Zaller, J.G. and Arnone, J.A. (1999) 'Earthworms and soil moisture effects on the productivity and structure of grasslands communities', *Soil Biology and Biochemistry* 31: 517–523.

14 Estimating the value of *milpa* diversity and genetically modified maize to farmers in Mexico

A choice experiment approach

Ekin Birol and Eric Rayn-Villalba

1 Introduction

The *milpa* is a complex intercropping system of maize, beans, and squash, traditionally cultivated by Mexican farmers. Approximately 2 million farm households across Mexico continue to cultivate *milpa*s on around 6 million ha of land every year, and most are dependent on the produce for their food security, diet quality and livelihoods (Bellon and Berthaud 2004).

In addition to the private benefits *milpa*s provide for the farmers that manage them, *milpa*s generate global public benefits. *Milpa*s are considered to be one of the last reservoirs of maize genetic resources for humanity (Bellon and Berthaud 2004). These diverse and complex poly-cropping ecosystems generate crop genetic resources (CGR) in individual crops, especially the genetic diversity found in maize landraces[1] (OECD 2002; Bellon and Berthaud 2004; Van Dusen and Taylor 2005). Maize landraces may be a source of unique traits needed by plant breeders, such as genetic resistance to certain plant diseases, pests and abiotic stresses. A valuable resource for future crop improvement, maize landraces contribute to global food security in maize, the most globally important staple crop after wheat (Fowler and Hodgkin 2004).

Even though continued management of the *milpa* is crucial for *in situ* conservation of maize genetic resources, there is considerable uncertainty with regards to the long-run sustainability of *milpa* management in Mexico (Van Dusen and Taylor 2005). Increasing rates of off-farm employment, including migration, threatens the continued management of *milpa* systems (Van Dusen 2006). Moreover, maize is a cross-pollinating species, and some experts believe that there are potential threats to maize landraces from the flow of transgenes in genetically modified (GM) maize. Although cultivation of GM maize is currently prohibited in Mexico, the presence of transgenic constructs was reported in maize landraces in the state of Oaxaca in 2001 (Dalton 2001). Since then, the potential effects of transgenic maize on maize landraces and wild relatives of maize in Mexico has been the topic of public debate (Dyer and Yunez-Naude 2003).

The aim of this chapter is to estimate the private value (to Mexican farmers) of the most important components of agrobiodiversity found in the *milpa* system. These components include inter-crop diversity (diversity among crop species), infra-crop diversity (diversity among maize varieties), and crop genetic diversity (whether or not a maize landrace is grown). In addition, we estimate the disutility (utility) of GM maize cultivation to Mexican farmers. A stated preference, non-market valuation method is employed to estimate the values of agrobiodiversity components and the option to cultivate GM maize, for two reasons. First, most of the agrobiodiversity supplied by the *milpa* system is not traded in markets (Van Dusen and Taylor 2005). Second, cultivation of GM maize is currently prohibited.

Data were collected from 420 farm households in the states of Jalisco, Michoacán and Oaxaca. Econometric analysis was conducted with the random parameter logit model including interactions, which can detect for unobserved and observed sources of heterogeneity in the sample. The locations and profiles of farmers who value the agrobiodiversity of *milpas* the most are identified. These farmers would constitute least-cost targets for programmes to conserve *milpas* on farms, *in situ*. Also, the location and characteristics of those farm households who derive the least disutility from cultivation of GM maize are identified. These findings could prove helpful in understanding the potential impact of removing the prohibition of GM maize in Mexico.

This chapter makes three contributions to the literature. First, only a few studies have investigated the social and economic factors that affect *milpa* and maize diversity in Mexico, and these have mainly employed the model of the agricultural household, a revealed preference framework (e.g., Smale *et al.* 2001; Van Dusen and Taylor 2005; Van Dusen 2006). Second, this study adds to the growing literature that employs the choice experiment method, an approach borrowed from environmental economics, to estimate the value of agrobiodiversity to farmers (e.g., Scarpa *et al.* 2003a, 2003b; Ndjeunga and Nelson 2005; Birol *et al.*, 2006; Ruto *et al.* 2008). Finally, the analysis is one of the relatively few that employs the choice experiment method to value non-market goods in a developing country context (e.g., Othman *et al.* 2004).

The next section describes the choice experiment method and the econometric approach employed. Section 3 explains the choice experiment design and the survey administration. Section 4 describes characteristics of the study sites and farmers surveyed. Section 5 reports the econometric results, comparing the private value of *milpa* diversity and GM maize among types of farmers and sites. The final section concludes the chapter and draws policy implications for *in situ* conservation of agrobiodiversity in Mexican *milpa*s, and for potential adoption of GM maize.

2 The choice experiment approach

The economic benefits that the *milpa* system generates accrue primarily to farmers in non-market use values, or utility. The preferences of farmers determine the implicit values they derive from their *milpa* and its agrobiodiversity (Scarpa *et al.* 2003a; Birol *et al.* 2006). *Milpa* farmers are both producers and consumers of agrobiodiversity.

Of the range of environmental valuation approaches, the choice experiment method is most appropriate for valuing *milpas*, considering that the *milpa* comprises multiple agrobiodiversity components. With the choice experiment approach, the implicit value of each agrobiodiversity component can be estimated in addition to the total value of the *milpa*. The relative rank of each component, and the trade-offs among components can be assessed, in addition to the value of changing more than one component at a time (Hanley *et al.* 1998; Bateman *et al.* 2003). Moreover, because it is based on hypothetical choices, the choice experiment provides a means of predicting the value of an attribute which is currently outside the farmers' set of experiences (Adamowicz *et al.* 1994). In this case, that attribute is GM maize.

The choice experiment (CE) method has its theoretical grounding in Lancaster's model of consumer choice (Lancaster 1966), and its econometric basis in random utility theory (RUT) (Luce 1959; McFadden 1974). Lancaster proposed that consumers derive satisfaction not from goods themselves but from the attributes they provide. To illustrate the basic model behind the CE presented here, consider a farmer's choice of a *milpa*. Assume that utility depends on choices made from a choice set C, which includes all possible *milpa* alternatives. The farmer has a utility function of the form:

$$U_{ij} = V(Z_{ij}) + e(Z_{ij}). \tag{14.1}$$

For any farmer i, a given level of utility will be associated with any *milpa* alternative j. Utility derived from any of the *milpa* alternatives depends on the attributes of the *milpa* (expressed in vector Z), such as the levels of the different components of agrobiodiversity it provides.

RUT is the basis for integrating behaviour with economic valuation in the CE method. According to RUT, the utility of a choice is comprised of a deterministic component (V) and an error component (e), which is independent of the deterministic part and follows a predetermined distribution. The error component implies that predictions cannot be made with certainty. Choices made between alternatives will be a function of the probability that the utility associated with a particular *milpa* option j is higher than with other alternatives. Assuming that the relationship between utility and attributes is linear in the parameters and variables function, and that the error terms are identically and independently distributed with a Weibull distribution, the probability of any particular *milpa* alternative j being chosen can be expressed in terms of a logistic distribution. Equation (14.1) can be estimated

with a conditional logit model (CLM) (McFadden 1974; Greene 1997; Maddala 1999).

The assumptions about the distribution of error terms that are implicit in the use of the CLM impose a particular condition known as the independence of irrelevant alternatives (IIA) property. IIA states that the relative probabilities of two options being chosen are unaffected by introduction or removal of other alternatives. If the IIA property is violated then CLM results will be biased. A second limitation of the CLM is that it assumes homogeneous preferences across farmers. As is well known in consumer theory, preferences are generally heterogeneous. Accounting for this heterogeneity enhances the accuracy and reliability of estimates of demand, participation, marginal and total welfare (Greene 1997). Furthermore, accounting for heterogeneity enables prescription of policies that take equity concerns into account. An understanding of who will be affected by a policy change in addition to understanding the aggregate economic value associated with such changes is necessary (Boxall and Adamowicz 2002).

Compared to the CLM, the random parameter logit model (RPLM) does not require the IIA assumption and can also account for unobserved, unconditional heterogeneity in preferences across respondents. The random utility function in the RPLM is given by:

$$U_{ij} = V(Z_j(\beta + \eta_i)) + e(Z_j). \tag{14.2}$$

Similarly to the CL model, utility is decomposed into a deterministic component (V) and an error component stochastic term (e). Indirect utility is assumed to be a function of the choice attributes (Z_j), with the utility parameter vector β, which due to preference heterogeneity may vary across farmers by a random component η_i. By specifying the distribution of the error terms e and η, the probability of choosing j in each of the choice sets can be derived (Train 1998). By accounting for unobserved heterogeneity, the random parameter logit model (RPLM) takes the form:

$$P_{ij} = \frac{\exp(V(Z_j(\beta + \eta_i)))}{\displaystyle\sum_{h=1}^{C} \exp(V(Z_h(\beta + \eta_i)))} \tag{14.3}$$

Since this model is not restricted by the IIA assumption, the stochastic part of utility may be correlated among alternatives and across the sequence of choices via the common influence of η_i. Treating preference parameters as random variables requires estimation by simulated maximum likelihood. Procedurally, the maximum likelihood algorithm searches for a solution by simulating k draws from distributions with given means and standard deviations. Probabilities are calculated by integrating the joint simulated distribution.

Recent applications of the RPLM have shown that this model is superior to the CLM in terms of overall fit and welfare estimates (e.g., Lusk *et al.*, 2003). Even if unobserved heterogeneity can be accounted for in the RPL model, however, this model fails to explain the *sources* of heterogeneity (Boxall and Adamowicz 2002).

One solution to detecting the sources of heterogeneity while accounting for unobserved heterogeneity could be to include interactions of farmer specific household, farm and market characteristics with choice-specific attributes in the utility function. The RPLM with interactions can pick up preference variation in terms of both the unconditional heterogeneity of tastes (random heterogeneity) and individual characteristics (conditional heterogeneity), improving the fit of the model (e.g., Revelt and Train 1998). When the interaction terms are included, the indirect utility function that is estimated becomes:

$$V_{ij} = \beta + \beta_1 Z_1 + \beta_2 Z_2 + \ldots + \beta_n Z_n + \delta_1 S_1 + \delta_2 S_2 + \ldots + \delta_l S_m. \qquad (14.4)$$

β is the alternative specific constant (ASC), which captures the effects on utility of any attributes not included in choice specific *milpa* attributes, n is the number of *milpa* attributes considered and the vector of utility parameters β_1 to β_n are attached to the vector of attributes (Z). In this specification, m is the number of farmer-specific household, farm and market participation characteristics that explain the choice of *milpa*, and the vector of coefficients δ_1 to δ_l correspond to the vector of interaction terms (S) that influence utility. Since farmer-specific household, farm and market participation characteristics are constant across choice occasions for any given farmer, they only enter as interaction terms with the *milpa* attributes. Interaction terms help to capture heterogeneity across farmers, minimising the error component η_i.

3 Choice experiment design, administration and data

3.1 *Choice sets*

A choice experiment is a highly 'structured method of data generation' (Hanley *et al.* 1998), relying on carefully designed tasks or 'experiments' to reveal the factors that influence choice. Experimental design theory is used to construct profiles of the *milpa* in terms of its attributes and levels of these attributes. Profiles are assembled in choice sets, which are presented to the farmers, who are asked to state their preferred *milpa* profile in each choice occasion.

The first step in choice experiment design is to define the *milpa* in terms of its attributes and levels taken by these attributes. The most important *milpa* attributes and their levels were identified in consultation with experts and agricultural scientists at the Instituto Nacional de Ecología (Mexican National Institute of Ecology, INE), drawing on the results of informal

interviews with *milpa* farmers in the study sites, and previous research on *milpa* cultivation. The selected attributes and levels are reported in Table 14.1.

The first three attributes characterise the various components of agrobiodiversity found in the *milpa*. The first attribute, crop species diversity, represents inter-crop species diversity. In particular, this attribute refers to the intercropping of maize, beans and squash that is a defining feature of the *milpa*. It is important to take the secondary crops of global importance (beans and squash) as well as multiple maize varieties into consideration, since competition among, as well as within species affects agrobiodiversity in the *milpa*. Focusing on only a single species or variety could bias econometric estimates and mislead policy prescriptions (Van Dusen and Taylor 2005).

The second attribute, maize variety diversity, represents infra-species diversity. Numerous studies have found that in order to meet certain agronomic requirements, match varieties to soil types, and provide for the range of maize dishes consumed in Mexican villages, *milpa* farmers grow multiple maize varieties simultaneously. These may include landraces, as well as advanced generations of improved varieties that farmers deliberately select and mix with their local landraces in order to incorporate useful traits (Louette *et al.* 1997; Smale *et al.* 2001; Bellon 2004; Bellon and Berthaud 2004; Brush and Perales 2007).

The third attribute, presence of a maize landrace, represents maize genetic diversity. While any maize variety is genetically diverse due to the cross-pollinating properties of the crop, there is a major difference in the structure of diversity between, for example, a maize landrace and a maize hybrid. Notably, all GM maize grown in the U.S. is hybrid maize.

Table 14.1 Milpa attributes and attribute levels used in the choice experiment

Milpa attribute	*Definition*	*Attribute levels*
Crop species diversity	The total number of crops that are grown in the *milpa*.	1 (only maize), 2 (maize and bean or squash), 3 (maize, bean and squash)
Maize variety diversity	The total number of maize varieties that are grown in the *milpa*.	1, 2 or 3
Maize landrace	Whether or not the *milpa* contains a maize variety that has been passed down from the previous generation(s) and/or has not been purchased from a commercial seed supplier.	*Milpa* contains a landrace vs. *Milpa* does not contain a landrace
GM maize	Whether or not the *milpa* contains genetically modified maize.	*Milpa* contains GM maize vs. *Milpa* does not contain GM maize
Yield	% of the expected maize yield relative to current *milpa*	130, 115, 100, 85, 70

The fourth component included in the choice set is the option to grow GM maize. This attribute was defined by the INE scientists following various workshops held with farmers in Oaxaca and Michoacán sites from 2001 to 2003. GM maize was defined as a different type of maize (*clase de maíz*) which has 'new genetic information'. It was explained that genetic material (DNA) is similar to a book of instructions used to build living organisms such as humans, plants and animals, and biotechnology enables inserting a paragraph from the book of one organism into the book of another. The enumerators did not specify any (positive or negative) traits pertaining to GM maize, in order not to bias farmers' choices.

The last attribute, maize yield, characterises production in the hypothetical *milpa* as a percentage of the farmers' current production. This attribute is a proxy for a monetary variable and is included in order to estimate welfare changes. An indirect measure is preferred over a direct measure because on most farms the outputs and functions of the *milpa*s are not traded in the markets, but consumed by farm families themselves.

A large number of unique *milpa* descriptions can be constructed from this number of attributes and levels.[2] Statistical design methods (see Louviere *et al.* 2000) were used to structure the presentation of the levels of the five attributes in choice sets. More specifically, an orthogonalisation procedure was employed to recover only the main effects, consisting of 24 pair-wise comparisons of *milpa* profiles. These were randomly blocked to four different versions with 6 choice sets. Each farmer was presented with 6 choice sets, each containing two *milpa* profiles and an option to 'opt out' by selecting neither of the *milpa* profiles presented to them. In 'opt out', the farmer would continue to cultivate his current *milpa*. When farmers chose to 'opt out', enumerators recorded attribute levels of current *milpas*. This option can be considered as a status quo or baseline alternative, whose inclusion in the choice set is instrumental to achieving welfare measures that are consistent with demand theory (Louviere *et al.* 2000; Bateman *et al.* 2003).[3]

In addition, the 'opt out' option can in this case be used to measure participation levels. Given that one of our aims is to assess if *milpa* production could be threatened by the adoption of GM maize, this option provides information on whether or not some farm households would prefer to continue cultivating their *milpa* when presented with the opportunity to cultivate GM maize.

The choice experiment study was implemented in October and November 2004 with face-to-face interviews with farmers who have been producing maize for at least the last two harvesting seasons. An introductory section explained to respondents the context in which choices were to be made and described each attribute. The respondents were reminded that there were no right or wrong answers and that we were only interested in their opinions. In addition to the choice sets, respondents were also asked about their knowledge, perceptions and attitudes with regards to biotechnology, genetically

modified crops and food. Social and economic information on farm house-holds and *milpa* decision-makers was also collected.

3.2 Study sites

A total of 420 randomly selected farm households were interviewed across 17 communities in three states of Mexico. The three sites included four com-munities of the Sierra de Manantlán District in the state of Jalisco; five in the Lago de Patzcuaro District in the state of Michoacán and eight in the Ixtlan de Juarez District in the state of Oaxaca.

The sites are named after the states in the remainder of the chapter. These three sites were selected in order to represent different agro-ecologies, micro-climates, and levels of economic deprivation. All three sites are considered to be centres of maize diversity according to INE, and in each site, *milpa* cultiva-tion is still prevalent. In 2001, traces of transgenic constructs were found in maize landraces in the Oaxaca site (Dalton 2001).

The Jalisco site is the largest and least densely populated of the three. Com-munities sampled in Jalisco are officially recognised as indigenous communities *(comunidades indígenas)* and have a traditional form of government (*usos y costumbres*), although the percentage of the population who speak an indigen-ous language is the lowest (1.2 per cent) of the sites. The percentage of the active population employed in the primary sector is the highest in Jalisco, and the percentages employed in the secondary and tertiary sectors are the lowest. The percentage of adults who are illiterate (over 20 per cent) is also the highest in Jalisco. On average, the communities in this site do not have good access to commercial markets, and are the farthest from the main highway. According to the marginality index[4] constructed by CONAPO (2001), communities in Jalisco are the most marginalised among those included in this study.

The Michoacán site is the smallest in area and is the most densely populated. Communities included in this study have an indigenous form of government, with 13.4 per cent of the population speaking an indigenous language. Illiterate inhabitants make up almost a fifth of the population. The unemployment rate is the highest in Michoacán. The majority of the active population is employed in the secondary sector, followed by primary and tertiary sectors. Compared to the other sites, communities in this site are nearest to the main highway.

The communities in the Oaxaca site also have an indigenous form of gov-ernment, and over a third of the population speaks an indigenous language. The unemployment rate is lowest in this site. The highest percentage of the population is employed in the primary sector, followed by tertiary and sec-ondary sectors. The percentage of the population who are illiterate is the lowest in the Oaxaca site. The average distance of communities to the main highway is larger than in Michoacán site, but only about a fourth as great as in the Jalisco site. Communities in Oaxaca are the least marginalised across the three sites (CONAPO 2001).

3.3 *Farm families and* **milpa** *management*

The average characteristics of the households and *milpa* decision- makers in each state are reported in Table 14.2. Only statistically significant differences are reported below.

Milpa decision-makers in Oaxaca have fewer years of farming experience compared to those in the other two sites. *Milpa* decision-makers in Michoacán have more education compared to those in Jalisco. Farm families in Jalisco are smaller in size than those in the other two sites. A higher percentage of households in Oaxaca have at least one household member working off farm. Hence, these households have higher average levels of off-farm income compared to those in Michoacán and Jalisco.

Characteristics of *milpa* management and agrobiodiversity are reported in Table 14.3. Area cultivated in maize is larger in Jalisco and smaller in Oaxaca than in Michoacán. Farm families in Oaxaca manage the greatest diversity of crop species and those in Michoacán the lowest. On average, 1.4–1.5 maize varieties are managed in each site, and over 90 per cent of farm households cultivate at least one maize landrace. No statistically significant differences were found among the three sites with respect to these two characteristics.

The number of *milpa* participants is significantly smaller in Jalisco compared to the other two sites. A higher percentage of *milpas* in Oaxaca have good quality soil, followed by Jalisco and Michoacán. Finally, a lower percentage of farm households in Oaxaca sell some of their *milpa* produce in markets, compared to Michoacán and Jalisco.

Table 14.2 Farm household characteristics by site

Variable	Definition	Jalisco (N = 126)	Michoacán (N = 161)	Oaxaca (N = 133)
		Mean (s.d.)		
Experience***	Farming experience of *milpa* decision-makers in years	38.78 (16.55)	38.51 (15.10)	29.80 (15.98)
Education**	Education of *milpa* decision-makers in years	4.52 (3.51)	5.25 (2.25)	4.96 (2.56)
Household size***	Number of households members	2.69 (1.41)	3.14 (1.43)	3.20 (1.56)
Income***	Monthly households' income in Mexican Pesos	1806.94 (1184.86)	1957.21 (940.66)	3126.07 (1531.62)
		Percent		
Off farm employed***	At least one member of the family works off-farm	19	29	44

Source: Encuesta sobre las percepciones de los productores de maíz en comunidades rurales con respecto a la liberación de materiales transgénicos dentro de alimentos y cultivos, y su impacto en la diversidad de su cultivo. Programa de Bioseguridad GEF/CIBIOGEM-INE, 2004. T-tests and Pearson Chi square tests show significant differences among at least one pair of regions (**) at 5% significance level, and (***) at 1% significance level.

Table 14.3 Milpa characteristics by site

Variable	Definition	Jalisco (N = 126)	Michoacán (N = 161)	Oaxaca (N = 133)
		Mean (s.d.)		
CSD***	Number of different crop species in the *milpa*	1.79 (0.76)	1.64 (0.78)	2.53 (0.87)
MVD	Number of maize varieties in the *milpa*	1.51 (0.75)	1.40 (0.65)	1.50 (0.63)
Area***	*Milpa* area managed by the household in hectares	7.35 (8.97)	3.93 (5.52)	1.27 (1.13)
Participants***	Number of *milpa* cultivation participants in the household	1.83 (1.09)	2.61 (1.47)	2.45 (1.25)
		Percent		
Landrace	*Milpa* has at least one landrace maize variety	92	96	95
Soil***	*Milpa* with good quality soil	35	25	42
Sell***	Some of the *milpa* produce is sold	58	49	28

Source: Encuesta sobre las percepciones de los productores de maíz en comunidades rurales con respecto a la liberación de materiales transgénicos dentro de alimentos y cultivos, y su impacto en la diversidad de su cultivo. Programa de Bioseguridad GEF/CIBIOGEM-INE, 2004. T-tests and Pearson Chi square tests show significant differences among at least one pair of regions (***) at 1% significance level.

4 Results

Several aspects of the data are worth noting to facilitate interpretation of the findings. First, the data were coded according to the levels of the attributes. Attributes with two levels entered the utility function as binary variables coded as 1 for 'yes' and −1 for 'no' (Adamowicz *et al.* 1994; Louviere *et al.* 2000). Data for the attributes with three and five levels were entered in cardinal-linear form. The attributes for the option 'Neither *Milpa*, I prefer my current profile' were coded with the values that farmers reported in the survey. Second, since this choice experiment involves generic instead of labelled options, ASC was equalled to 1 when either *milpa* A or B was chosen and to 0 when the farmer chose his own *milpa* profile (Louviere *et al.* 2000). The ASC was also specified to account for the proportion of farmers choosing to adopt a different *milpa* system. A relatively more negative and significant ASC indicates a higher propensity of farmers to choose the status quo.

4.1 Conditional and random parameter logit models

The CE was designed with the assumption that the observable utility function would follow a strictly additive form. The model was specified so that the probability of selecting a particular *milpa* was a function of *milpa* attributes

and the ASC. Using the 2,520 choices elicited from 420 respondents, eight conditional logit models (CLM) with logarithmic and linear specifications for the attributes with three and five levels were estimated and compared using LIMDEP 8.0 NLOGIT 3.0. The highest value of the log-likelihood function was found for the specification with all attributes in linear form.

As hypothesised in the survey design and supported by the descriptive statistics, farm households in the three sites are likely to value *milpa* attributes differently. The null hypothesis that the separate effects of sites are equal to zero was rejected with a Swait Louviere log-likelihood ratio test at the 0.5 per cent significance level, based on regressions with the pooled and separate site samples. When the same test was carried out to make pair-wise comparisons, the largest differences in preferences were found between Oaxaca and Michoacán, followed by Jalisco and Michoacán. These results suggest that underlying parameters are distinct for each site and that separate regressions should be estimated.

To confirm that the RPLM is appropriate, the Hausman and McFadden (1984) test for the IIA property was conducted for each site-level regression estimated with CLM. In each site, the results of the test indicate that the IIA property cannot be accepted at the 1 per cent level. Therefore, a less restrictive model specification, such as the random parameter logit model (RPLM), should be employed.

The RPLM was estimated using LIMDEP 8.0 NLOGIT 3.0. All of the *milpa* attributes except yield were specified to be normally distributed (Train 1998; Revelt and Train 1998). Simulations of distributions were based on 1000 draws. For each of the three sites, the Swait–Louviere log-likelihood ratio test rejects the null hypothesis that the regression parameters for the CLM and RPLM are equal at the 0.5 per cent significance level. Values of McFadden's ρ^2[5] are significantly higher for the RPLM than for the CLM specifications. Thus, model fit was improved through use of the RPLM.

4.2 *Random parameter logit model with interactions*

Even though the RPLM can incorporate and account for heterogeneity by allowing model parameters to vary randomly by individual (e.g., Train 1998), it is not well suited to explaining the *sources* of heterogeneity in preferences. In many cases these sources relate to the characteristics of the individuals (Boxall and Adamowicz, 2002).

Six farmer-specific characteristics were selected by calculating Variance Inflation Factors.[6] The characteristics selected include: (1) years of experience in farming; (2) number of family members who participate in *milpa* cultivation; (3) whether or not at least one family member is employed off-farm; (4) whether or not the family sells some of its *milpa* produce; (5) maize area cultivated and (6) distance between the main highway and the community in which the household is located. These were interacted with the five *milpa* attributes in order to investigate sources of heterogeneity (equation 14.4 above).

As in the basic RPLM, all of the *milpa* attributes except yield were specified to be normally distributed, and simulations of distributions were based on 1000 draws. In each site-level regression, the null hypothesis that the regression parameters for the RPLM and RPLM with interactions were equal was rejected at the significance level of 0.5 per cent with a Swait-Louviere log-likelihood ratio test. Again, McFadden's ρ^2 for the RPLM with interactions was significantly higher than for the basic RPLM, suggesting that use of the model with interaction terms improves model fit.

The results of the RPLM with interactions are shown for the three sites in Table 14.4.

Findings for the site in Jalisco are shown in the second column. The standard deviation for crop species diversity coefficient is insignificant, indicating that on average, farmers in Jalisco prefer *milpas* with higher levels of crop species diversity. However, neither the maize variety diversity nor the maize landrace attribute has a statistically significant effect on the utility of the average farmer, and the standard deviations of the coefficients of these attributes are significant and large. Thus, there is considerable heterogeneity across the sub-sample drawn in Jalisco, with some farmers preferring lower and some higher levels of these attributes. This heterogeneity causes the mean coefficient to be statistically insignificant.

Farmers with more experience prefer maize landraces, but lower levels of maize variety diversity. Previous studies have also demonstrated that older and more experienced farmers are more likely to grow landraces but not necessarily to grow a higher number of varieties (e.g., Meng 1997; Van Dusen and Taylor 2005; Smale 2006; Birol *et al.* 2006). Often, they do not have the labour force needed to manage more labour-intensive components of agrobiodiversity. To the extent that managing more varieties requires more labour, older farmers may be more constrained than younger farmers. Older, more experienced farmers in the Jalisco site do not prefer a *milpa* with GM maize.

The hypothesis that agrobiodiversity management is labour-intensive is also supported by the finding that farm households with higher numbers of *milpa* participants were more likely to choose to cultivate more maize varieties. Similarly, those households with at least one member working off-farm are less likely to choose maize landrace. As has been shown in other studies, off-farm employment competes for time with agrobiodiversity management on farms (e.g., Brush *et al.* 1992; Meng 1997; Smale *et al.* 2001; Van Dusen and Taylor 2005; Smale 2006; Birol *et al.* 2006).

Larger households in Jalisco also prefer *milpa*s with GM maize. This result could reflect a preoccupation with meeting staple food needs through farm production, since most of these farms are located in communities that are far away from markets. Those households whose members are employed off-farm do not prefer GM maize, even though they are more likely to prefer *milpas* with higher yields. It may be that they have been exposed to more negative information about GM maize. Farmers who sell at least some of their *milpa* produce are less likely to prefer either maize landraces or GM

Table 14.4 RPLM with interactions estimates, by site

Variable	Jalisco Coeff. (s.e)	Michoacán Coeff. (s.e)	Oaxaca Coeff. (s.e)
ASC	−2.26*** (0.27)	−1.36*** (0.17)	−1.2***(0.2)
Crop species diversity (Mean coefficient)	0.27*** (0.9)	0.68***(0.17)	0.44***(0.18)
Crop species diversity (St. dev. of coefficient)	0.18 (0.42)	0.17 (0.35)	0.06 (0.22)
Maize variety diversity (Mean coefficient)	0.13 (0.27)	−1.12***(0.40)	0.18** (0.1)
Maize variety diversity (St. dev. of coefficient)	0.62*** (0.31)	0.24 (0.48)	0.04 (0.23)
Maize landrace (Mean coefficient)	−0.06 (0.8)	1.8***(0.66)	0.86*** (0.25)
Maize landrace (St. dev. of coefficient)	3.18*** (0.76)	2.28*** (0.67)	0.31 (0.66)
GM maize (Mean coefficient)	0.55 (0.55)	−1.37***(0.43)	0.13 (0.23)
GM maize (St. dev. of coefficient)	0.33 (1.09)	1.5***(0.5)	0.02 (0.31)
Yield	0.08*** (0.01)	0.99***(0.17)	0.05***(0.01)
Crop species diversity* area	–	0.05*** (0.02)	–
Crop species diversity* sell	–	–	0.68***(0.18)
Crop species diversity* off farm	–	–	0.67***(0.17)
Crop species diversity* participation	–	–	0.2***(0.08)
Maize variety diversity* experience	−0.01** (0.006)	0.01* (0.01)	–
Maize variety diversity* participation	0.24*** (0.09)	0.09* (0.06)	–
Maize variety diversity* sell	–	−0.6*** (0.18)	–
Maize variety diversity* distance	–	0.78***(0.29)	–
Maize landrace* experience	0.04*** (0.02)	–	–
Maize landrace* participation	–	–	0.35** (0.18)
Maize landrace* off farm	−2*** (0.8)	0.66*(0.4)	–
Maize landrace* sell	−1.46*** (0.59)	−0.6* (0.39)	–
Maize landrace* area	–	−0.05*(0.03)	0.24* (0.15)
GM maize* experience	−0.03*** (0.01)	–	–
GM maize* participation	0.22* (0.14)	−0.18**(0.09)	−0.28***(0.09)
GM maize* off farm	−0.72* (0.5)	–	–
GM maize* sell	−0.61*** (0.29)	–	–
GM maize* area	−0.06*** (0.02)	–	−0.38***(0.11)
Yield* experience	–	−0.001***(0.0004)	–
Yield* off farm	0.04*** (0.02)	−0.04***(0.01)	−0.03***(0.01)
Yield* area	–	0.005***(0.002)	0.02***(0.007)
Sample size	126	161	133
ρ^2	0.325	0.372	0.462
Log likelihood	−555.99	−647.55	−447.14

Source: Encuesta sobre las percepciones de los productores de maíz en comunidades rurales con respecto a la liberación de materiales transgénicos dentro de alimentos y cultivos, y su impacto en la diversidad de su cultivo. Programa de Bioseguridad GEF/CIBIOGEM-INE, 2004.
(*) 10% significance level; (**) 5% significance level; (***) 1% significance level two-tailed tests.

maize. These farmers may seek to specialise in high yielding varieties (HYVs) for market sales, but would rather not grow GM maize due to the negative attitudes of Mexican consumers towards GMOs (Cuellar 2004). The larger the *milpa* area cultivated by the household, the lower is the probability that the decision-maker prefers to cultivate GM maize. This finding might be explained by the fact that most of those households who manage larger fields already cultivate HYVs. These farmers might consider GM maize to be inferior to the HYVs they currently grow because of seed costs are higher or other aspects of the seed are less attractive.

The results for the RPLM with interactions are reported for the Michoacán site in the third column of Table 14.4. In Michoacán, the standard deviation for crop species diversity coefficient is insignificant, demonstrating that all farmers in this site, like those in Jalisco, prefer higher levels of crop species diversity. As in Jalisco, the standard deviation of maize variety diversity co-efficient is statistically insignificant. Coupled with the significant and negative coefficient on the mean of this attribute, these results suggest that farmers in Michoacán prefer lower levels of maize variety diversity. The standard deviation for maize landrace is significant and large, indicating that some farmers might prefer not to cultivate maize landraces. The standard deviation for GM maize is also significant and large, which implies, by comparison, that some farmers in this site might prefer to cultivate GM maize.

Significant interaction terms show that in Michoacán, older *milpa* decision-makers with more experience prefer higher levels agrobiodiversity in the form of maize variety diversity. However, they prefer *milpas* with lower yields, perhaps because they prefer less intensive production. Households with higher numbers of *milpa* participants are more likely to choose *milpa* profiles with more maize varieties. They are also more likely to choose not to grow GM maize. Since these families tend to have more children, this finding may be a consequence of perceptions concerning the health risks of GMOs. Households with at least one family member working off-farm are more likely to choose a *milpa* with a maize landrace and less likely to choose one with higher yields. In this case, off-farm income may enable families to substitute for farm production with market purchases. Those farm households who sell at least some of their *milpa* produce prefer to cultivate more maize varieties but not to manage a maize landrace. Households who manage larger *milpa* areas prefer higher levels of crop species diversity and yield, but they are less likely to choose *milpa* profiles that include a maize landrace. Those households located further away from the main highway are more likely to prefer higher numbers of maize varieties. This result is similar to those of Brush *et al.* (1992), Meng (1997) Smale *et al.* (2001), Van Dusen and Taylor (2006), Smale (2006), Birol *et al.* (2006) who find a positive relationship between distance markets and the demand for agrobiodiversity on household farms.

The results of RPLM with interactions for Oaxaca site are reported in the last column of Table 14.4. In Oaxaca, as compared to the other two sites, standard deviations of the coefficients on crop species diversity, maize variety

diversity and maize landrace are statistically insignificant, implying that farmers in this site prefer higher levels of all three attributes. As in the other sites and previous studies, the significant interactions between farmer characteristics and *milpa* attributes suggest that farm households with higher number of *milpa* participants choose more agrobiodiversity. As in the site of Michoacán, larger households, which are younger and more likely to include young children, choose *milpa* profiles without GM maize. Findings with respect to off-farm employment are the same as those observed in Michoacán. Households that sell some of their produce prefer more diverse crop species in their *milpas*. Households who cultivate larger *milpa* areas are more likely to choose a *milpa* with higher yields, since they are more likely to sell their produce in the markets. They are also more likely to choose to grow a maize landrace, but less likely to choose to grow GM maize. Attitudes against GM maize are thought to be especially strong in this area of Mexico.

4.3 Welfare estimates

The CE method is consistent with utility maximisation and demand theory (Bateman *et al.* 2003). Welfare measures can be calculated from the parameter estimates by using the following formula:

$$CS = \frac{\ln \sum_i \exp(V_{i1}) - \ln \sum_i \exp(V_{i0})}{\alpha} \tag{14.5}$$

where CS is the compensating surplus welfare measure, α is the marginal utility of income (represented by the coefficient of the monetary attribute in the choice experiment, which is yield in this case) and V_{i0} and V_{i1} represent indirect utility functions before and after the change under consideration.

For the linear utility index, the marginal value of change in a single *milpa* attribute can be estimated as a ratio of coefficients. The ratio represents the marginal rate of substitution between yield and the *milpa* attribute in question, or the marginal welfare measure (willingness to accept compensation) for a change in any of the attributes. For *milpa* attributes with three levels, equation (14.5) reduces to a part-worth (or implicit price) formula

$$W = -1 \left(\frac{\beta_{attribute}}{\beta_{monetary\ variable}} \right) \tag{14.6}$$

The demand functions conditional on the farm household characteristics reported in Table 14.4 can be used to calculate the value assigned by the farm household to *milpa* attributes that have three levels (Scarpa *et al.* 2003a; Birol *et al.* 2006), by modifying Equation (14.6):

$$W = -1 \left(\frac{\hat{\beta}_{attribute} + \delta_{attribute} \times S_1 \ldots + \delta_{attribute} \times S_6}{\hat{\beta}_{monetaryattribute} + \delta_{monetaryattribute} \times S_1 + \ldots + \delta_{monetaryattribute} \times S_6} \right) \tag{14.7}$$

Table 14.5 Valuation of agrobiodiversity components in the *milpa*, by site

	Jalisco	Michoacán	Oaxaca
Crop species diversity	3	12.5	7.7
	(1.9–4.1)	(10.6–14.4)	(6.1–9.3)
Maize variety diversity	1.6	—	2.8
	(0.4–2.7)		(1.3–4.2)
Maize landrace	—*	42.4	32.8
		(35.9–48.9)	(28.4–37.3)
GM maize	−20	−51.4	−31.1
	(−22.6− −17.4)	(−55.4− −46.6)	(−33− −29.2)

Notes: Valued as average % change in yield (95% C.I.)
*— indicates that the Wald procedure resulted in insignificant welfare estimates for this attribute.

Variables S_{1-6} are the six farmer-specific characteristics under consideration. For the effects-coded, binary attributes the formula becomes

$$W = -2 \left(\frac{\hat{\beta}_{attribute} + \delta_{attribute} \times S_1 \ldots + \delta_{attribute} \times S_6}{\hat{\beta}_{monetaryattribute} + \delta_{monetaryattribute} \times S_1 + \ldots + \delta_{monetaryattribute} \times S_6} \right) \quad (14.8)$$

Using the Wald Procedure (Delta method) in LIMDEP 8.0 NLOGIT 3.0, the private value of the components of agrobiodiversity in the *milpa* was calculated for the average farm household in each site. Results are reported in Table 14.5.

Across the three sites, crop species diversity is valued most highly by farmers located in Michoacán and least by farmers located in Jalisco. Farmers in Oaxaca derive the largest values from higher levels of maize variety diversity, followed by Jalisco. On average, farm households in Michoacán do not value this attribute significantly. Having a maize landrace in the *milpa* is valued most highly by farmers in Michoacán, followed by Oaxaca. Farmers located in Jalisco do not value this attribute significantly. Farmers located in Michoacán derive the highest disutility from the GM maize attribute, followed by Oaxaca and Jalisco, respectively. Overall, Oaxacan farmers value the *milpa* system the most, as they derive significant values from all of the three agrobiodiversity components of the *milpa*.

5 Conclusion

This chapter provides estimates of the private use value of agrobiodiversity attributes and the option to cultivate GM maize in the *milpa* system of Mexico. A choice experiment was conducted through personal interviews with a random sample of 420 farm households located in 17 villages in the states of Jalisco, Michoacán, and Oaxaca. A random parameter logit model with interactions was applied to analyze the data.

In all three sites, farmer demand for higher maize yields and higher levels of crop species diversity attests to the fact that *milpa* cultivation continues to

be an important economic activity. Findings with respect to maize variety diversity and maize landrace cultivation are more mixed across sites. On average, farmers in the sample choose to cultivate 1.5 maize varieties (*clases de maíz*). Although most farmers grow more than one maize variety simultaneously in Mexico, this average is similar to that found in previous studies, and there appears to be limited variation in the numbers of varieties grown (Louette *et al.* 1997; Smale *et al.* 2001; Bellon 2004; Van Dusen 2006). Earlier research indicates that Mexican farmers still cultivate several maize varieties because of their demand for specific production and consumption attributes that no single variety can provide, such as adaptation to soil, earlier maturity, and suitability for special dishes. To the extent that maize varieties differ in timing and nature of management practices, cultivating different maize varieties can be more labour-intensive.

Two important results emerge when heterogeneity among farmers in the study sites is investigated through the application of the random parameter logit model. Heterogeneity has implications for conservation programmes. First, in Michoacán and Jalisco, the least cost targets for conservation are smaller-sized households with elderly decision-makers who are located in the most isolated communities. This finding is consistent with a number of case studies conducted elsewhere, raising concerns about the future of the conservation efforts as economies develop and younger generations leave farming (e.g., Meng 1997; Van Dusen and Taylor 2005; Smale 2006; Birol *et al.* 2006). Findings in Oaxaca are not so simply interpreted. In the Oaxaca site, there are two prototypes for least cost targets. One consists of smaller-sized households with younger decision-makers whose members work off-farm. A second prototype includes larger households whose members work off-farm and sell some maize, and who cultivate larger *milpa* areas. Data collected for this study indicate only whether farmers sell any of their produce and if any of the farm family members is employed off-farm. More detailed information regarding the value of sales and the relative magnitudes of farm and off-farm income would deepen our understanding of these findings.

The second important result is that farmers are clearly averse to cultivating GM maize. Most of the farmers in the sample stated that they are willing to sacrifice substantial proportions of their harvest in order not to cultivate this type of maize. The two groups who derive the greatest disutility from the option to grow GM maize are older decision-makers with smaller families who are located in more isolated villages and decision-makers with larger families who participate in output and labour markets. This first group are probably more attached to maize landraces and unwilling to pay the higher costs of GM seed. The second group may also be unwilling to pay higher seed costs, and may also be more aware of the anti-GM attitudes of some Mexican consumers (Cuellar 2004).

Findings concerning GM maize should be interpreted with caution. The purpose of including the option to grow GM maize in this choice experiment was to explore farmers' attitude towards genetic modification, and

hypothetically, how these attitudes might affect their behaviour. So far, approval for introduction of GM varieties and their adoption by farmers in developing countries have been largely driven by evidence of the performance of these varieties in mitigating yield losses from pests or diseases (e.g, insect-resistant maize and cotton). If the Mexican government were considering the approval of GM maize, a more complete choice experiment analysis would include specific traits as well as an analysis of consumer preferences.

Acknowledgements

Notes

1 Definitions of crop landraces are numerous in the international scientific literature (Zeven 1998). Landraces are variants, varieties, or populations of crops, with plants that are often highly variable in appearance, whose genetic structure is shaped by farmers' seed selection practices and management, as well as natural selection processes, over generations of cultivation (Smale *et al.* 2001).

2 The number of *milpa*s that can be generated from 5 attributes, 2 with 2 levels, 2 with 3 levels and one with 5 levels is $3^2*2^2*5=160$.

3 Note that in this context, it is not realistic to ask the subsistence *milpa* farmers not to manage *milpas* at all (Louviere *et al.* 2000).

4 Marginality index assesses the relative deficiencies across the communities in the country using four structural dimensions (education, housing, income from labour and population distribution).

5 The ρ^2 value in conditional logit models is similar to the R^2 in conventional analysis except that significance occurs at lower levels. Hensher *et al.* (2005: 338) comment that values of ρ^2 between 0.2 and 0.4 are considered to be extremely good fits.

6 Correlations and multicollinearity between these characteristics were tested using correlation matrices and calculating Variance Inflation Factors (VIF) for each variable, and no evidence of multicollinearity or correlation between these characteristics were found.

References

Adamowicz, V., Louviere, J. and Williams, M. (1994) 'Combining stated and revealed preference methods for valuing environmental amenitie*s', Journal of Environmental Economics and Management* 26: 271–292.

Bateman, I.J., Carson, R.T., Day, B., Hanemann, W.M., Hanley, N., Hett, T., Jones-Lee, M., *et al.* (2003) *Guidelines for the Use of Stated Preference Techniques for the Valuation of Preferences for Non-market Goods*. Cheltenham: Edward Elgar.

Bellon, M.R. (2004) 'Conceptualizing interventions to support on-farm genetic resource conservation', *World Development* 32(1): 159–172.

Bellon, M.R. and Berthaud, J. (2004) 'Transgenic maize and the evolution of landrace diversity in México, the importance of farmers' behavior', *Plant Physiology* 134: 883–888.

Birol, E., Smale, M. and Gyovai, Á. (2006) 'Using a choice experiment to estimate farmers' valuation of agricultural biodiversity on hungarian small farms', *Environmental and Resource Economics* 34(4): 439–469.

Boxall, P.C. and Adamowicz W.L. (2002) 'Understanding heterogeneous preferences in random utility models: a latent class approach' , *Environmental and Resource Economics*, 23: 421–446.

Brush, S.B. and Perales H.R. (2007) 'A maize landscape: ethnicity and agro-biodiversity in Chiapas Mexico', *Agriculture, Ecosystems and Environment* 121(3): 211–221.

Brush, S., Taylor, E. and Bellon, M. (1992) 'Technology adoption and biological diversity in Andean potato agriculture', *Journal of Development Economics*, 39(2): 365–387.

Consejo Nacional de Población (CONAPO) (2001) *Índices de marginación, 2000*. December.

Cuellar, M. (2004) 'Mexican consumer preferences for biotechnology and retail food outlets', unpublished thesis, Washington State University.

Dalton, R. (2001) 'Transgenic corn found growing in Mexico'. *Nature*, 413: 337.

Dyer, G. and Yunez-Naude, A. (2003) 'NAFTA and conservation of maize diversity in Mexico', paper prepared for The Second North American Symposium on Assessing the Environmental Effects of Trade, Commission for Environmental Cooperation.

Fowler, C. and Hodgkin, T. (2004) 'Plant genetic resources for food and agriculture: assessing global availability', *Annual Review of Environmental Resources*, 29: 143–179.

Greene, W.H. (1997) *Econometric Analysis,* 3rd Edition, Englewood Walls. NJ: Prentice Hall.

Hanley, N., Wright, R. E. and Adamowicz, W. (1998) 'Using choice experiments to value the environment', *Environmental and Resources Economics* 11(3–4): 413–428.

Hausman, J.A. and McFadden, D. (1984) 'Specification tests for the multinomial logit model', *Econometrica* 52: 1219–1240.

Hensher, D., Rose, J. and Greene, W. (2005) *Applied Choice Analysis: A Primer*. Cambridge: Cambridge University Press.

Lancaster, K. (1966) 'A new approach to consumer theory', *Journal of Political Economy* 74: 132–157.

Louette, D., Charrier, A. and Berthaud, J. (1997) 'In situ conservation of maize in Mexico, genetic diversity and maize seed management in a traditional community', *Economic Botany* 51: 20–39.

Louviere, J. J., Hensher, D.A., Swait, J.D. and Adamowicz, W.L. (2000) *Stated Choice Methods: Analysis and Applications* Cambridge: Cambridge University Press.

Luce, D. (1959) *Individual Choice Behaviour*. New York: John Wiley.

Lusk, J.L., Roosen, J. and Fox, J.A. (2003) 'Demand for beef from cattle administered growth hormones or fed genetically modified corn: A comparison of consumers in

France, Germany, the United Kingdom and the United States', *American Journal of Agricultural Economics* 85(1): 16–29.

Maddala, G.S. (1999) *Limited Dependent and Qualitative Variables in Econometrics*. Cambridge: Cambridge University Press.

McFadden, D. (1974) 'Conditional logit analysis of qualitative choice behaviour', in P. Zarembka (ed.) *Frontiers in Econometrics*. New York: Academic Press.

Meng. E. (1997) 'Land allocation decisions and *in-situ* conservation of crop genetic resources: the case of wheat landraces in Turkey'. PhD thesis, UC Daris, CA, Department of Agricultural and Resource Economics.

Ndjeunga, J. and Nelson, C. H. (2005) 'Toward understanding household preference for consumption characteristics of millet varieties: a case study from western Niger', *Agricultural Economics* 32 (2): 151–165.

OECD (2002) *LMOS and the Environment: Proceedings of an International Conference*, ed. Craig R. Roseland. Paris: Organisation of Economic Cooperation and Development.

Othman, J., Bennett, J. and Blamey, R. (2004) 'Environmental values and resource management options: a choice modelling experience in Malaysia'. *Environment and Development Economics* 9: 803–824.

Revelt, D. and Train, K. (1998) 'Mixed logit with repeated choices: households' choice of appliance efficiency level', *Review of Economics and Statistics* 53: 647–657.

Ruto, E., Garrod, G. and Scarpa, R (2008) 'Valuing animal genetic resources: a choice modeling application to indigenous cattle in Kenya', *Agricultural Economics* 38 (1): 89–98.

Scarpa, R., Drucker, A., Anderson, S., Ferraes-Ehuan, N., Gomez, V., Risopatron, C.R. and Rubio-Leonel, O. (2003a) 'Valuing animal genetic resources in peasant economies: the case of the box Keken creole pig in Yucatan', *Ecological Economics* 45 (3): 427–443.

Scarpa R., Ruto, E.S.K., Kristjanson, P., Radeny, M., Drucker, A.G. and Rege, J.E.O. (2003b) 'Valuing indigenous cattle breeds in Kenya: an empirical comparison of stated and revealed preference value estimates', *Ecological Economics* 45(3): 409–426.

Smale, M. (ed.) (2006) *Valuing Crop Biodiversity: On Farms Genetic Resources and Economic Change*. Wallingford: CAB International.

Smale, M., Bellon, R.M. and Aguirre Gomez, J.A. (2001) 'Maize diversity, variety attributes, and farmers' choices in Southeastern Guanajuato, México', *Economic Development and Cultural Change* 50(1): 201–225.

Train, K.E. (1998) 'Recreation demand models with taste differences over people', *Land Economics* 74 (2): 230–239.

Van Dusen, M.E. (2006) 'Missing markets, migration and crop biodiversity in the *Milpa* systems of Mexico: a household-farm model', in M. Smale, (ed.) *Valuing Crop Biodiversity: On Farms Genetic Resources and Economic Change*. Wallingford: CAB International.

Van Dusen, M.E. and Taylor, J.E. (2005). 'Missing markets and crop diversity: evidence from Mexico', *Environment and Development Economics* 10(4): 513–531.

Zeven, A. C. (1998) 'Local crop varieties: a review of definitions and classifications', *Euphytica* 1.

15 Can greening markets help conserve landraces in situ?

Eggplants in India

Vijesh V. Krishna and Unai Pascual

1 Introduction

There is an active debate surrounding the relationship between dissemination of high yielding modern varieties (MVs) and erosion of plant genetic diversity, as the former is often argued to have the potential to induce genetic uniformity rather than crop diversity. While there is a line of thought that MVs are having an important role in maintaining and enriching genetic diversity (Wood and Lenne 1997), their introduction is also associated with an increase in farmers' opportunity cost to cultivate landraces. The present study examines a least-cost option for landrace conservation under the potential challenge from MV dissemination, through the creation of so-called market based instruments (MBIs). Least-cost conservation strategies would be best suited in those sites which are highly ranked in terms of both public as well as private benefits from in situ agrobiodiversity conservation (Smale *et al.* 2004).

Cultivating landraces would entail relatively lower per-unit cost, where they are better adapted to the local agro-climatic conditions in comparison to the MVs. In the absence of such natural incentives, market segmentation for landrace products is hypothesized to facilitate *de facto* conservation through enhanced private value of these landrace varieties for the farming community. In addition, evolving consumer preferences coupled with economic growth is creating emergent conditions for an increased demand for eco-friendly products. Such 'green consumerism' may have the potential to help conserve landraces in situ by transferring the price premium of such green products directly to farming communities. The domestic market for eco-friendly (green) products in developing economies is still rather small due to slow moving consumer preferences and the limited responsiveness of producers and suppliers (Grote 2002). Nevertheless, there can be a significant potential for green markets in emerging economies such as India, even though the existing markets are highly informal in catering the needs of eco-friendly consumers. In this regard it is necessary to develop conceptual models on market segmentation for landrace products at different levels of maturity in order to shed light on

the potential of green consumerism as associated with landrace traits in emergent economies.

The focus of this chapter is on eggplant. It is one of the most important vegetable crops and is highly heterogeneous in India with respect to its varieties. Differentiation can be made by fruit characteristics, viz. shape, colour, variegation and spines, which helps meet the diversified consumer demand. In addition, market prices vary across different varieties of eggplant fruits, which are moderated by consumer tastes and preferences. In fact, identification of landraces is relatively easy in the eggplant market and thus the fruit characteristics act as a good proxy for formal labelling schemes. This product heterogeneity makes a case for the existence of differential markets which in turn can overcome the basic difficulty of imperfect information to some degree. In this case, and provided that consumer preferences vary according to landrace attributes, it should be possible to identify the level of price increment for eggplant products due to their landrace traits.

Given the rapidly evolving seed markets in India, the eggplant production sector is also congenial for the analysis of the impacts of agricultural development policy strategies on in situ landrace conservation outcomes. It should be noted that the F_1 hybrids are being widely cultivated in southern India and in addition eggplant is also being genetically modified to express pest resistance in order to reduce pesticide dependence in crop production and ultimately enhance the farm profitability (Krishna and Qaim 2007). While at the same time the biotech thrust in eggplant crops continues in India, consumer demand for indigenous and diverse vegetables can be thought of as a key factor defining such technology adoption and diffusion patterns, and in turn, their associated welfare impacts on farming communities. Keeping these issues in mind, this chapter presents and analyses primary data on production and consumption of eggplant to draw inference on the likely impacts of potentially emerging green markets (for eggplant products) on technology adoption and varietal diversity conservation.

The chapter is organized as follows. The forthcoming section reviews the debate about the impact of market development on conservation of plant genetic resources (PGRs). Section 3 addresses the rationale behind selecting eggplant production system in India. Then, Section 4 describes the case study, sampling procedure and data collection, while Section 5 reports and discusses the empirical results based on the hedonic price models based on farm-gate prices, as well as on consumer preferences for eggplant attributes. The final section concludes and draws some policy implications.

2 Market development and PGR conservation

2.1 Market instruments for PGR conservation

There is an array of MBIs that may be designed to incorporate the external cost of production or consumption activities, for instance, by pricing

processes or products, or by creating property rights and facilitating the establishment of proxy markets associated to environmental services. In addition, market-friction instruments (MFIs) can be used to improve the operation of existing (imperfect) markets (Cutbush 2006; Whitten *et al.* 2007). Among the MFIs, labelling and certification are being used to connect the demand and supply sides of the market and to establish an advantage for those who are in a position to help conserve biodiversity by labelling their products as such. The evolving global market for biodiversity-conserving 'shade coffee' is an example (CEC 1999) and this is also the case with labelling proposals with regard to the potential introduction of genetically modified (GM) foods in India (Bansal 2007).

MFIs work through exogenous economic factors that are pivotal in determining consumer preferences. For example, as disposable per capita income rises, consumer preferences for quality are increasingly expressed in various food markets (Zilberman and Lipper 2005). Surveys in both developed and developing economies have found that consumers are willing to pay higher prices for 'environment-friendlier' products (Shams 1995; Florax *et al.* 2005; Krishna and Qaim 2008). Nevertheless, there exists the challenge of translating the growing concern for the environment and related consumers' willingness to pay (WTP) into MFIs that would be conducive to in situ conservation of PGRs. Niche markets allowing for the emergence of green price premiums through certification and labelling are gaining relevance in this juncture (Basu *et al.* 2003). As an example, new marketing opportunities are being sought by the growing consumer awareness for 'organic' production processes and demand for specialty foods in developed economies (Grote 2002; Garibay and Jyoti 2003). In this context, the emerging question is whether using MFIs to identify the traits of landraces/cultivars for important crops help the conservation of PGRs by farmers themselves, through price premium incentive mechanisms.

Much work has been done to shed light on valuing and identifying consumer preferences for agricultural products with specific attributes, such as the use of GM organisms in food production (e.g. Kontoleon and Yabe 2006; Rigby and Burton 2006), and the cultivation of landraces by farmers themselves (cf. Birol and Rayn-Villalba, Chapter 14 in the volume). However, there is still much to be learnt about consumer preferences and values assigned to landrace products by non-farmer food consumers in developing countries. Shedding light on this issue would help to better design and support incipient MFIs linked to local food markets that in turn may provide the right incentives to farmers for in-situ conservation of PGRs (Brush 2000; 2004). Furthermore, while there are interesting studies on the management of on-farm crop diversity that addresses farmers' perceptions and choices regarding morphological traits (Birol *et al.* 2006; Birol and Rayn-Villalba, Chapter 14 in this volume), this literature tends to neglect the important role of non-farmer buyer preferences especially when food products linked to landraces are associated only with informal market chains.

This is the case in most developing countries, where product differentiation occurs without formal certification and labels. Instead, consumer knowledge about phenotypic characteristics of products along with trust on farmers/ sellers may act as proxies for labelling. However, getting rid of market frictions is challenging due to the existing information asymmetry between farmers and consumers especially as regards the value of the landrace attribute of the food crop. In this juncture, informal markets can be seen as prematurely linking the demand and supply for such green products.

2.2 A conceptual framework of MFIs for landraces

The conservation of landraces during the diffusion process of improved (modern) varieties (MVs)[1] is associated with a considerable opportunity cost, OC, to farmers, which is the difference between the gross margin per unit area of the MVs, denoted as GM^M, and landraces, GM^L. Assuming that variable costs of producing MVs and landraces are equal, then, $OC = Y^M P^M - Y^L P^L$, where $Y^M(Y^L)$ and $P^M (P^L)$ denote the yield and the unit market price of MVs (landraces), respectively. In addition, assuming that $P^M = P^L$ and $Y^M \leq Y^L$, the opportunity cost of conserving landraces would be the value of the potential incremental yield of MVs. In other words, in the absence of a price premium of landraces when farmers' utility does not depend on either cultivating MV or landraces and it is expected that profit-maximizing farmers would switch production from landraces to MVs.

Given exogenous consumers' preferences, products derived from landraces may be associated with various attributes that are superior to MVs (e.g., taste, cooking quality, etc.), thus having an additional direct use value to MVs. In addition, landrace products may have non-use values given some consumers' cultural attitudes towards conserving local crop varieties. Here, we illustrate this point to understand the possible impacts of market development for landraces when they compete with MVs for a share of total consumer demand for the crop. Following Van Dusen (2006), Figure 15.1 is adapted to depict the production possibility frontier (PPF) representing the efficient production mix between the higher yielding MVs and landraces by a representative farming community under the best available technology.

Farmers' decisions regarding the mix of MV and landrace cultivation are guided by many factors, including exogenous market price signals (Pascual and Perrings 2007). In Figure 15.1, the slope of the price lines UV and WX equals the ratio of the price of landrace products to the price of products of MVs. In this starting case, we assume that no price differentiation can be made when consumers cannot differentiate MVs from landrace derived products in the market stalls, i.e., $P^{L0} = P^M$ with P^{L0} indicating the starting price of the landrace product; the 45° price line UV has a slope of minus one. When both landrace and MVs products are indistinguishable in appearance and are unlabelled, consumers are not able to recognize landrace products from MVs in the market. In this simple case, and unless the landraces respond
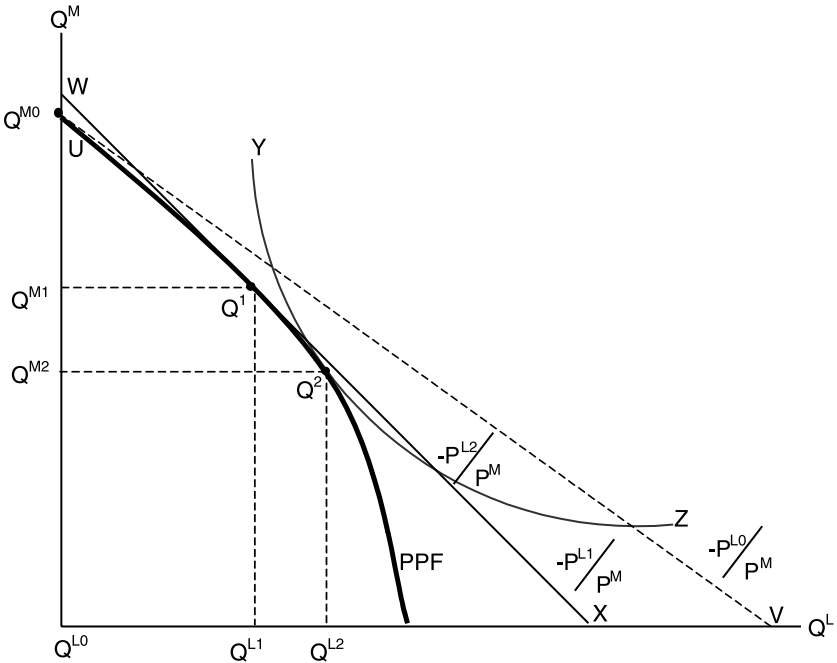
Figure 15.1 Production possibility frontier (PPF) for landraces and modern varieties with outputs Q^L and Q^M under different market conditions.

differently to the local agro-climatic conditions and turn more productive than MVs, optimality is associated with the corner solution, $(0, Q^{M0})$, where production is entirely allocated to MVs. This is a simple and expected story, similar to the interaction between dominant and recessive genes in genetics. In the simple case depicted above, the MV is the 'dominant' crop and the landrace is the 'recessive' crop; the market thus favours the dominant one by the decentralized decision of individual, private maximizing, farmers.

But when farmers also consume their own produce and their utility levels depend on whether the consumption derives from landraces or MVs, the simple genetics complicates. Rather than market prices, shadow prices need to be estimated and any model needs to take into account that production and consumption decisions become endogenous by the farmers. Thus, even if $P^{L0} = P^M$, the outcome would be associated with a residual level of production of landraces in order to meet farm households' tastes for landraces. However, given that the focus is upon the entire market demand in which non-farm consumers make up almost all of it, farmers' marginal consumption level is neglected in the analysis.

Notwithstanding this simplification, it should be noted that even when the market segmentation between MVs and landraces is imperfect (due to non-existing formal labelling schemes), a share of the total of non-farmer

consumers are often able to recognize the landrace produce as it is usually the case that certain product attributes can be revealed, though not perfectly, through for instance, external appearance of the product. This revelation in turn may depend, for instance, on consumers' experience through repeated purchases of such products or through the proximity to the cultivation centres. This consumer information would make the realized demand of landrace products to increase, and, given a static supply, would make the price of landraces to increase from P^M to P^{L1}. The new price line becomes WX with slope $-P^{L1}/P^M$. When the possibility of revealing certain proxies for the superiority of a given landrace attribute exists, the farming community would shift the optimal production mix to level (Q^{M1}, Q^{L1}), corresponding to the new point of tangency between the price line WX and the PPF.

However, not all consumer households may be able to completely identify the landrace products from MVs. Hence, consumers' imperfect information prevents the market from allocating MVs and landraces in a way that is socially optimal. This information gap leads to typical market information problems in the form of adverse selection and moral hazard, originally described by Akerlof (1970). In this pervasive situation, MVs would be over-represented to the detriment of landraces. The socially optimal production mix would correspond to the point of tangency between the consumer community's virtual price curve YZ and the PPF. It is noteworthy that a price curve arises as the shadow price for landraces, P^{L2}, is associated with the marginal utility of consumption of society, which in turn changes depending on the level of landraces already demanded. The new shadow price is higher than the price farmers obtain under existing imperfect information levels, i.e. $P^{L2} > P^{L1} > P^{L0}$. This situation can be readdressed by the use of MFIs such as labels and certification schemes allowing consumer information to be translated into a price premium for landrace products. This in turn would be translated to a higher demand for landraces which would need to be met by farmers by further cultivating landraces if these are paid a price premium (at Q^{L2}). At the same time, this would curtail the diffusion of MVs falling from Q^{M0} to Q^{M2}. It should be noted, though, that the level (Q^{L2}, Q^{M2}) is determined by consumers' attitude towards development and landrace cultivation. This is depicted by the possibility that the indifference curve YZ shifts downwards as society moves away from its 'productivity perspective' towards a more 'conservative perspective' (Heisey *et al.* 1997; Pascual and Perrings 2007).

3 Landrace conservation and emergence of MVs in the eggplant production sector of India

India has made significant progress in recent years towards setting up a legal regime for the management of its PGRs (Biber-Klemm *et al.* 2005).[2] However, agricultural development policies are increasingly focused on development and dissemination of high yielding MVs with limited genetic diversity

(Krishna and Qaim 2007). This situation exemplifies the agricultural development versus PGR conservation political dichotomy or clash of interests, which is explicit in the case of eggplant crop in India.

India is the second largest producer of eggplant in the world (FAOSTAT 2006). Production is dominated by small-scale and marginal farmers, and hence the crop is often described as the 'poor man's vegetable'. Traditionally eggplant farmers have maintained and supplied the crop seeds, resulting in special varieties adapted to the region's environment as well as local consumers' tastes. The three most common cultivated eggplant varieties in India are *Solanum melongena* var. *esculentum* (round/egg-shaped fruits), *S. m* var. *serpentinum* (long, slender fruits) and *S. m* var. *depressum* (dwarf plants) (Bose *et al.* 2002). Further, in addition as food crop, a number of wild relatives of eggplant are identified in indigenous medicine systems as having medicinal properties (Daunay *et al.* 2000). Also, eggplant landraces and their wild relatives have been documented as being valuable due to their resistance against pests and diseases (Sridhar *et al.* 2001). Additionally, some landraces have non-use values. For example, the *Matti Gulla* variety of eggplant grown in villages of Karnataka is believed to be 'divine'.

Notwithstanding the array of different values associated with eggplant landraces, we focus on the narrower, but significant, consumptive value of eggplant varietal diversity. Given its high diversity, it is not surprising to find that consumer preference for eggplant fruits are expressed according to characteristics such as taste, colour, size, spiny-calyx, shape, etc.

Such preferences become complex to analyze due to the large combination of the fruit's characteristics that in turn has historically led to the cultivation of eggplant varieties with very diverse phenotypes.[3] In the face of such diversity, there has also been a significant adoption of eggplant MVs in the country (Krishna and Qaim 2007). Since the 1980s, an increasing number of the F_1 eggplant hybrid varieties bred by private seed companies are being commercialized. More specifically, hybrids are being widely cultivated in the southern states of Karnataka, Andhra Pradesh, and Maharashtra. By contrast, in eastern parts of India (especially West Bengal and Orissa states, which together account for around 50 per cent of the total eggplant area in the country), the adoption of hybrid seeds is marginal as the landraces are more adapted to the local soil and climatic conditions (ibid).

The MV-adopting states were highly diverse in terms of eggplant landrace varieties before the massive introduction of hybrid seeds two decades ago. Since then, a gradual shift by farmers from cultivating landraces to hybrids has been observed due to policy interventions that facilitate increased private investment in the seed industry and state government incentives directly influencing farmers' decision to cultivate MVs. For example, the government of Andhra Pradesh provides subsidies to vegetable farmers to adopt hybrids seed in order to increase productivity (Rao 2006). The resulting productivity increase due to MV adoption has been noticeable. For instance, average yield of eggplant in Karnataka, where hybrids are widely adopted, is 58 per cent

higher compared to West Bengal, where adoption of such MVs is marginal (Krishna and Qaim 2007).

Apart from the conventional breeding sector, modern biotechnology poses new challenges to on-farm varietal conservation. Recognizing the economic relevance of resistant breeds, GM eggplant hybrids and open pollinated varieties are currently developed under unique public-private sector research collaboration in India (ibid). Adoption of high-yielding varieties like GM eggplant is often perceived both to foster agricultural development and to undermine the diversity in PGRs. Critics call attention to the displacement of genetic diversity and transgenic escape (due to natural out-crossing) as amongst the potential environmental threats associated with GM crops (Ervin *et al.* 2001; Greenpeace India 2006).[4] In this context, the Task Force on Application of Biotechnology, set up by the Indian Ministry of Agriculture to develop a national framework for biosafety, has recommended that the critical areas with respect to agri-biodiversity should be protected and ear-marked as 'agro-biodiversity sanctuaries', where the cultivation of GM crops should be prohibited (GoI 2004). In the face of such government rhetoric, the drivers of GM technology adoption are complex. Besides being critically determined by public attitude towards such technology (Nielsen *et al.* 2003; Zilberman and Lipper 2005), it also depends on the extent to which public policy moulds under the pressures from pro- and anti-GM organizations, and on the extent of farmers' attitude towards experimentation with GM crops as recently pointed out by Gupta and Chandak (2005). Regarding the consumers' broad attitudes towards introduction of GM foods, there are some recent studies that have attempted to predict these for the Indian consumers and have indicated a general positive attitude (Anand *et al.*, 2007 Krishna and Qaim 2008). However, the evidence is not fully settled as the responses of consumers to attitude surveys are under hypothetical conditions, which can be slightly or highly removed from the revealed preference through their purchasing behaviour. In addition, Bansal (2007) observes that the importance of labelling and consumer preferences varies with social groups. Further, with a rather limited awareness of GM foods by the general public, media exposure and formal education has been seen to reduce the acceptance by consumers of GM foods (Krishna and Qaim, 2008). There is a possibility that once the GM eggplant comes to be marketed in India, the consumers' knowledge and perception, which need not be objective or scientific, may alter significantly. The present study gains significance in this juncture, by providing an insight into the potential welfare changes due to consumer aversion towards a production technology. The conventional hybrids and GM varieties are expected to have a positive impact on farm productivity even though they may be less favoured from the consumers' perspective.

4 The case study

We use primary data from eggplant producers and consumers in India. The study combines the revealed preference of society for landrace products using data on farm price realized by eggplant cultivators and stated preference from consumers' perspective. Data on eggplant cultivation were collected from a cross-section of 240 farm households in 2005 from Andhra Pradesh and Karnataka, two leading eggplant-producing states in South India. The survey covered the major eggplant-growing tracts within the selected states, most of which are located in the river belts – Krishna in Andhra Pradesh, and Cauveri in Karnataka. Using a stratified random sample, six districts and 13 *taluks* (revenue subdivisions within each district) were selected deliberately based on the area under eggplant cultivation. Villages and farm households were selected randomly. Some 36 per cent of the sampled households cultivate eggplant landraces, implying an adoption rate of MV technology of 64 per cent in the study area.

Farm economic data were gathered from these households, including yields, variable production costs and farm prices obtained for eggplant fruits. In addition, information about the attributes of the marketed eggplant fruits were gathered from each farmer, including the skin colour, size, percentage of borer infestation in the marketed eggplant lot and presence of spines of fruit calyx. Such information is complemented with data on socio-economic characteristics of the farm household through structured surveys. Due to their close proximity to the perennial rivers, eggplant farmers of survey do not face major problems of water shortage. Often, farms even have more than one source of irrigation. The average land holding of the sampled farms is 4.96 acres, and the mean per capita household income is estimated to be around 20,000 rupees (US$500). The respondents received limited formal education, with the average being less than five years of schooling. This sampling framework does not include households that grow only a few vegetable plants in their kitchen gardens for own consumption.

In addition, data from vegetable consumers were also collected in 2006 from five important urban locations in India: New Delhi, Bangalore, Kolkata, Kolar, and Barddhaman. The first three are among the largest cities of India and administrated by municipal corporations, whereas Kolar and Barddhaman are two district headquarters in the states Karnataka and West Bengal respectively, and are in close proximity to important eggplant production regions.

The information about consumers in each of these urban areas also corresponds to a stratified random sample design and corporation wards and consumer households were selected randomly from each of these urban areas. In total, the sample of consumers makes up 629 individuals (each from a different household) from 61 corporation wards. In comparison to the sample of the farm survey, the consumer respondents show higher levels of education and income, with an average of about 10 years of formal schooling

and about Rs.30,000 (US$747) as per capita income. The survey was designed to gather information about consumers' preferences and attitudes towards different eggplant characteristics, including those of landrace fruits. In a second stage, for those individuals who indicated a clear preference for landraces over hybrids, a dichotomous choice question on their willingness to purchase landrace products was posed against hypothetical price increments, in order to estimate the consumptive (use-) value of eggplant landraces.[5]

5 Eggplant landrace production, pricing and consumption attitudes in South India

5.1 Productivity analysis

Table 15.1 provides information about yields, total and per-unit cost and return structure of eggplant (landrace vs. hybrid) cultivation in South India. Eggplant hybrids show a marked superiority over landraces with respect to yield. The average marketed yield is 95 versus 122 quintals (Q) per acre for landraces and hybrids, respectively.[6] It should also be noted that the marketable yield is not very different in both cases as farm households' consumption of eggplant is negligible. The per-unit cost of hybrid cultivation is about 29 per cent lower (albeit statistically insignificant) in comparison with landraces. On the other hand, the farm price obtained for landraces

Table 15.1 Economics of eggplant cultivation in south India

	Mean (Std. deviation)		Difference of hybrids over landraces (%)
	Landraces (N = 86)	Hybrids (N = 154)	
Variable cost (thousand Rs/acre)	18.98 (12.43)	17.29 (7.38)	−9.77
Yield (Q/acre)[+]	95.28 (58.33)	111.99 (78.21)	14.92*
Per unit cost of production (Rs/Q)	199.13 (330.81)	154.44 (125.12)	−28.94
Market price (Rs/Q)	501.25 (151.03)	383.47 (147.39)	−30.71**
Gross revenue (thousand Rs/acre)	47.76 (32.59)	42.94 (33.39)	−11.22
Net revenue (thousand Rs/acre)	28.79 (33.94)	25.65 (31.75)	−12.24

Notes: *, **: Significant at 0.10 and 0.01 levels, respectively.
[+] Quintal (Q) is equivalent to 100kg.
42.60 Rs = 1US$ on June 2008.

(Rs.501/Q) is around 31 per cent higher in comparison with the hybrid products (Rs. 383/Q).

As one would have expected, due to similar cropping techniques, there is no significant difference regarding the total variable and per-unit cost of cultivation of landraces versus hybrids. However, the cost structure varies between the two as shown in Table 15.2. The main difference is that in the study area, landraces are mostly cultivated in leased-in land and the associated rent raises the total cost. Labour cost is also higher for landrace cultivation, mainly because hybrid adoption and seedling purchase – the practice that eliminates the labour expenses associated with nursery raising – are often found associated in the study area. In the case of hybrid production, however, the cost of material inputs (viz. as seeds, fungicides, manures, and fertilizers) is higher. The hybrid seeds, generally, are found to be highly responsive to the chemical inputs, which may be partly attributed to this difference. On the other hand, the farm and household characteristics which enhance the adoption of hybrid seeds could be responsible for higher use of purchased inputs. As can also be seen from Table 15.1, landrace eggplants are associated with a significant higher price of about 30 per cent. This partly circumvents its productivity disadvantage with respect to the hybrid varieties. In fact, the higher price earned by landraces is responsible for the similar economic performance of

Table 15.2 Cost structure of eggplant cultivation in south India

	Mean (Std deviation)		Difference in mean (Std deviation)
	Hybrids	Landraces	
Variable costs (Rs/acre) on			
Planting material	1348.91	166.02	1182.89***
	(1323.73)	(649.74)	(152.13)
Manures	2002.01	1217.35	784.66***
	(2157.05)	(1721.99)	(270.91)
Chemical fertilizers	3944.63	2929.62	1015.01***
	(1936.66)	(1582.09)	(244.75)
Fungicides	270.39	163.85	106.53**
	(399.66)	(282.55)	(48.76)
Insecticides	2010.53	1897.63	112.90
	(2072.31)	(2012.64)	(276.11)
Hired human labour	6017.83	7071.38	−1053.55**
	(3827.85)	(6168.68)	(645.72)
Machine and animal labour	520.13	943.40	−423.27***
	(603.52)	(884.17)	(96.45)
Other costs	1180.55	4586.28	−3405.73***
	(2452.58)	(7039.02)	(625.09)
Total variable cost (Rs/acre)	17294.98	18975.53	−1680.55*
	(7380.94)	(12425.78)	(1278.25)

Notes: ***, **,*: Statistically significant at 0.10, 0.01 and 0.05 per cent respectively (one tail t-test). 42.60 Rs = 1US$ on June 2008.

hybrids and landraces. The question is whether the price differential is due to the supply structure of hybrids in the incompletely segmented market, or whether it also has to do with the way consumers perceive the product attributes and thus there may be a demand component too. This is akin to the hypothesis that consumers have attitudes and preferences that favour landrace attributes.

5.2 Price analysis

According to Lancaster's (1966) theory of the demand for 'characteristics' or intrinsic quality features, consumption is an activity in which goods and services, singly or in combination, are inputs and in which the output is a collection of characteristics. This theory lays the framework of the hedonic pricing method used to examine the price structure of different agricultural products (e.g., Unnevehr 1986; Dalton 2004; Edmeades 2007; Huang and Lin 2007). Here we follow this tradition to assess the effects of both product attributes and farmer characteristics in determining the market price of eggplant fruits in Southeast India.

The farm price of eggplant fruits is hypothesized as a function of fruit, regional, seasonal, farm and household characteristics. We adopt a linear Box-Cox transformation of the hedonic price function, after testing the significance of model selection over alternatives through likelihood ratio tests. The linear Box-Cox transformation requires the dependent variable $DEP(\theta)$ to be scaled by a factor θ, such that (Cropper *et al.* 1988):

$$DEP(\theta) = \frac{DEP^{\theta} - 1}{\theta}.$$

The dependent variable for hedonic function is eggplant price (Rs/Q) obtained by the farmers of the study area. The model turns out to be linear when $\theta = 1$, inverse if $\theta = -1$, and semi-log when $\theta = 0$. Using our data, the likelihood ratio test statistics rejects the null hypotheses of $\theta = 1$, $\theta = -1$, and $\theta = 1$, implying that linear, inverse and semi-log specifications would not be appropriate. The marginal implicit prices (MIP) are calculated as $c(x/\text{þ})$, where c is the estimated coefficient, and x and þ are the mean values of the explanatory and dependent variables.

The estimation of the hedonic model was carried out employing the Box-Cox models in two steps. First, the model (Model I) is estimated just with the product and farming attributes as explanatory variables. Model II was estimated, which differs from Model I by the addition of five household characteristics. If the product attributes (like hybrid status) were endogenously determined by the farm household characteristics, they might cause a simultaneity problem, and correlation between explanatory variables and the error term would render the estimates inconsistent. However, the likelihood ratio test suggests that Model II fits the data better than the previous one (at 0.05 level), and the superior model only is shown in Table 15.3.

Table 15.3 Results of the hedonic price estimation: Box-Cox regression

	Coefficient (chi^2)	MIP
Intercept	11.733	
Dummy for hybrid eggplant	−0.452**	−85.80
	(4.211)	
Share of borer infested fruits in the marketed lot (%)	0.021	
	(0.359)	
Dummy for purple fruits	−0.439**	−81.93
	(4.666)	
Dummy for small or medium fruits	0.046	
	(0.043)	
Dummy for spiny calyx	0.580***	241.45
	(9.175)	
Dummy for Rabi season of cultivation	−0.502***	−132.83
	(8.585)	
Dummy for Summer season of cultivation	−0.820***	−397.73
	(14.041)	
Dummy for Andhra Pradesh	0.364	
	(1.360)	
Time taken to transport the produce to market (hours)	−0.150*	−7.51
	(3.042)	
Experience of farmer in eggplant cultivation (years)	0.173***	3.20
	(6.774)	
Years of schooling obtained by farmer	0.008	
	(0.089)	
Dummy for mass media exposure	0.305*	136.47
	(2.925)	
Size of farm owned by the household (acres)	−0.085*	−3.11
	(2.815)	
Θ	0.195*	
	(0.114)	
Log likelihood	−1514.92	
LR Chi^2 (13)	64.74	
Prob. > Chi^2	0.00	

Notes: MIP: Marginal Implicit Price (42.60 Rs = 1US$ on June 2008).
*, **, *** : Significant at 0.10 and 0.01 levels, respectively.

From the analysis it can be seen that hybrid eggplants are associated, a marginal implicit farm price of minus Rs.86/Q in comparison to landraces. It is already observed that the average absolute price difference between landrace and hybrid products is Rs.118/Q (cf. Table 15.1). This difference could be due to the product characteristics of landraces that are not common in hybrid eggplants, or due landrace status itself. Farmer characteristics that determine his/her bargaining power while selling the product is also hypothesized to have impact on farm price. By incorporating fruit and household characteristics together in the model, the hedonic function indicates that 73 per cent of the aforementioned farm price gap is due to the landrace attribute,

whereas the 27 per cent (Rs.32/Q) is attributed to the fruit characteristics that are not common in hybrids and farmer characteristics. In case of other fruit characteristics, one can see that the purple fruits are cheaper in the market by Rs.82/Q compared to the green/white skinned ones. Hybrids and landraces of eggplant are available in both colours, showing that the green landraces would be highly expensive for the vegetable consumers in comparison to purple fruits of hybrids. In addition, the presence of spines in the fruit calyx is found to enhance the farm price by Rs.241/Q. Though certain hybrids are possessed with spiny calyx, consumers commonly associate this attribute with landrace status. Hence, adverse selection due to this information asymmetry might be one of the reasons for the associated high marginal implicit price of spiny calyx.

There are other important variables that should also be considered. For instance, there exists significant seasonal variation in eggplant prices. The data show that the per-quintal farm price during *Kharif* season (that starts with the onset of the southwest monsoon in July, and ends with it on October) is Rs.133 and Rs.398 higher in comparison to the *Rabi* (winter) and summer seasons, respectively. Another important variable is the effective distance to market, as indicated by the time taken to transport the produce to the market place. It appears that the longer the time that is needed during transportation, the lower the final price is, reflecting the effect on the freshness of fruits.

The model also shows that when looking at farmers' characteristics, experience in eggplant farming is positively determining the farm price, with a marginal effect of Rs.3/Q per year of experience. It can thus be hypothesized that additional farming experience may provide better information about the complex eggplant market and its price structure and this effect may influence the bargaining power. Similar effects on bargaining power were observed by Harding *et al.* (2003) in a different context. Lastly, as it would be expected through economics of scale, the farm size owned by the farmer is associated with a negative MIP, with a unit increase in acreage reducing the market price by Rs.3/Q.

These results indicate that the landrace attribute *per se* provides a significantly higher price for the cultivators, and that the market is differentiated to a certain degree for catering the needs of consumers. Having said this, information asymmetries and market imperfections are present. Due to numerous middle-men in Indian vegetable markets, consumer prices are actually much higher than the farm prices (Gandhi and Namboodiri 2004). Such transaction costs might be playing a crucial role in the transmission of the value consumers attach with the landrace trait to the cultivator. In the complete absence of labels, transaction costs in keeping the eggplant market segmented for landraces rises with the number of market agents. This creates a drift in the supply function and thus transfers only a fraction of consumers' WTP to the hands of farmers. In addition, there are also consumers who are not able to differentiate the products, i.e., landraces vs. hybrids, as no formal labelling

scheme exists indicating this important characteristic of the produce. The situation is similar to that represented by point Q^1 in Figure 15.1. This would imply that albeit the associated price for eggplant landraces is higher, this may not be linked to consumer demand to a full extent. As explained earlier, the optimal mix of cultivation of landraces versus modern hybrid varieties, as denoted by point Q^2 in Figure 15.1, can be found only by knowing consumers' preferences, that is, by directly obtaining the willingness to pay estimate that consumers attach to the landrace attribute. This step is explained next based on a consumer survey carried out in urban India.

5.3 Analysis of consumer preferences

The majority of surveyed consumers (79 per cent) stated that landrace products are distinguishable from the hybrid ones in the eggplant market. Their preference for the eggplant type – hybrids or landraces – is elicited for the case where there is no price difference between them. While on average 75 per cent of all sampled consumers preferred products of landrace eggplant, only 13 per cent showed a preference for hybrids, the rest being indifferent between landrace and hybrid eggplants (Table 15.4). It is also observed that the preference for landraces is high in Kolkata and Barddhaman, the cities is surrounded by landrace-growing tracts. Similar reasoning can be traced out for the comparatively high preference for hybrid eggplant (around 20 per cent among respondents) in New Delhi and Bangalore, as these cities are located far from the production locations or surrounded by hybrid eggplant-growing tracts.

In order to shed light on consumers' strict preference of eggplant landrace products over hybrids, a probit model is estimated (Table 15.5). The data suggest that older individuals show a more positive attitude towards landrace eggplants, which is unsurprising as the habit of consumption is a major factor behind preferences. Additionally, the proxies of information

Table 15.4 Consumer preferences for hybrid vs. landrace eggplants in urban India in 2006

Preference	Number of households in					
	New Delhi	Bangalore	Kolar	Kolkata	Barddhaman	Total
Hybrids	34	29	11	7	0	81
(%)	(22.08)	(18.95)	(13.92)	(4.27)	(0.00)	(12.88)
Indifferent	24	19	7	18	18	86
(%)	(15.58)	(12.42)	(8.86)	(10.98)	(22.78)	(13.67)
Landraces	96	105	61	139	61	462
(%)	(62.34)	(68.63)	(77.22)	(84.76)	(77.22)	(73.45)
Total	154	153	79	164	79	629
(%)	(100.00)	(100.00)	(100.00)	(100.00)	(100.00)	(100.00)

Table 15.5 Factors contributing to consumer preference and WTP for landrace eggplant fruits

Variable	Probit model: Preference of landraces over hybrid eggplant fruit		WTP model
	Coefficient (Std. Error)	Marginal effect	Coefficient (Std. Error)
Intercept	0.618 (0.416)		−2.140* (1.136)
Dummy for female respondent	−0.065 (0.155)		0.006 (0.410)
Age of respondent (years)	0.014*** (0.006)	0.003	0.017 (0.014)
Number of members in the household	−0.023 (0.029)		0.067 (0.082)
Dummy for households with children below 14 years	0.072 (0.157)		0.449 (0.416)
Years of schooling by respondent	0.030* (0.016)	0.005	0.134*** (0.043)
Dummy for respondent's ability to identify the landrace products	0.265* (0.155)	0.055	1.965*** (0.429)
Average price paid by the household for eggplant (Rs/kg)	−0.062*** (0.018)	−0.010	−0.120** (0.051)
Annual per capita income of the household (thousand Rs), PCAI	0.010 (0.012)		0.125*** (0.031)
Square of PCAI	−8E-05 (1E-04)		−6E-04** (3E-04)
Dummy for respondent from Kolar and Barddhaman	0.310* (0.183)	0.051	0.341 (0.444)
Sigma			3.775 (0.193)
Log likelihood	−219.44		−681.43
LR *Chi²* (10)	44.26		108.85
Prob. > *Chi²*	0.00		0.00

*, **, ***: Statistically significant at 0.10, 0.50 and 0.01 per cent respectively

availability, viz. education and consumers' skills to distinguish landrace products in the market, appear to be important. The landrace preference is controlled for the actual price of the currently purchasing eggplant product. Consumers were paying Rs.10.49/kg of eggplant on average in the retail market, which is 2.49 times higher the selling price obtained by the farmers in the survey. There is significant inter-household variation in the retail price of eggplant, which mainly depends on the source from which the households purchase the vegetables. The current retail market price has a significant effect on the likelihood of purchasing landraces over hybrid fruits, while the

household disposable income appears not to impact. That is, higher the market price of the eggplant fruit currently paid by the consumer, the lower would be likelihood to select landraces, as these are already associated of being more expensive. It is also interesting to show that those consumers from smaller towns are more inclined towards landrace consumption.

From the above evidence, it appears that there is a sizeable proportion of urban consumers who perceive eggplant landraces as having some superior characteristics when compared with hybrids. This suggests that in principle it should be possible to assess the strength of such perceptions and preferences through a monetary metric. By doing so, we could shed light on understanding which of these attributes could actually induce some kind of market segmentation for the landrace product in order to create a new market that could be conducive to reward farmers for conserving such agrobiodiversity in situ. We attempt to do so by employing a stated preference model on consumers' willingness to pay (WTP) for the landrace attribute of the eggplants that they purchase in the food markets in the urban regions of New Delhi, Bangalore, Kolar, Kolkata and Barddhaman.

Urban consumer's WTP for landrace eggplants (P^*) is estimated using a random utility framework (Bateman *et al*. 2002). Consumers preferring landrace varieties at the market price are asked whether they would be willing to purchase it at a higher price (P^H). The bid structure utilized in the study is derived based upon a smaller-scale pilot survey and the price increments are then varied randomly across all surveyed consumers from 0.5 to 8 rupees per kilo in equal intervals of Re. 0.5. Accordingly, there are four possible response groups: (G1) those consumers who prefer hybrid fruits at the existing market price, i.e., $P^* < 0$; (G2) those who are indifferent among landraces and hybrids at market price, i.e., $P^* = 0$; (G3) those who prefer landraces at the market price but are not willing to pay a price premium for the product, i.e., $0 \leq P^* < P^H$; and (G4) those who are willing to pay a price premium above the market price in order to be able to consume the landrace product, i.e., $P^* \geq P^H$ In order to estimate these price premiums, we apply an interval-censored model using maximum likelihood techniques (Cameron 1988). The [lower, upper] limits of the interval, provided as the dependent variable in the model, are [$-\infty$, 0] for (G1), [0,0] for (G2), [0, P^H] for (G3), and [P^H, $+\infty$] for (G4). It is assumed that WTP is influenced by a vector of explanatory variables x. Hence, WTP = $\beta x + \varepsilon$, where β is a vector of coefficients, and ε is a normally distributed random error with mean zero and variance σ^2. The estimated coefficients can be directly interpreted as the marginal effects of the explanatory variables.

The estimation results of the WTP model appear in the right column of Table 15.5. Since the dependent variable is measured as the price premium over the current market price of eggplant and there exists a wide variation in the price across the surveyed households, the model also includes the information of such market prices as an additional explanatory variable, which not surprisingly, shows a negative association with the stated WTP

for the price premium elicited to the sampled individuals. According to the model, if the current retail market price increases by one rupee per kilo of the eggplant, the WTP premium for landrace attribute would decline by Rs.0.12/kg.

The personal characteristics of respondents, except income and education, are found to have no statistically significant effect upon consumers' stated WTP value. For instance, while age significantly contributes to forming the consumer preference towards landrace eggplants as shown in the probit model, it becomes not significant in determining the WTP value. By contrast, consumer households' annual per capita income, which proxies their ability to pay, is found to raise the demand for the landrace attribute though at a declining rate; a Rs1000 increase in per capita income would be associated with a price premium of Rs.2.93/kg (which is equivalent to 28 per cent of the current average retail market price) and indicates that economic growth and higher income levels may help consumers to accept a higher price premium in the eggplant market. This result confirms other similar ones found in valuation studies on organic products (e.g., Florax *et al*. 2005). Lastly, formal education is also found to have a positive effect, with an additional year of schooling indicating an increase of the stated WTP for the price premium of Rs.0.13/kg.

Availability of information can foster the development of green markets significantly as in the case of labelled eco-products in developed countries (IFAV 2001). In the Indian eggplant case, we find that consumers' ability to differentiate landrace products from that of hybrids is associated positively with their WTP, i.e., those consumers being more able to differentiate the landrace eggplants from the hybrid ones are WTP in the order of Rs.1.96/kg (19 per cent of the retail market price). This positive association between information and consumers' WTP indicates that future market development for landraces can be fostered, if unbiased information is provided through labelling and certification.

Figure 15.2 shows the distribution of the estimated consumer WTP values. Using the results from Table 15.5, the mean WTP for landrace eggplant fruits among the urban consumers in India is estimated as a price premium of Rs.3.87/kg in comparison to their hybrid counterpart. The median, Rs.3.82/kg, is close to the mean value, indicating that the WTP distribution is relatively symmetric.

These values imply that the average price premium that consumers would be willing to pay for the landrace attribute is as much as 37 per cent of the hybrid vegetable price. It also shows that at first sight the price premium farmers currently obtain (31 per cent; cf. Table 15.1) is comparable with the consumers' WTP in percentage terms. However, in absolute terms there is a wide gap between the market price premium that farmers obtain for landrace products and the consumers' WTP for such premium. The price increment currently available for farmers is just Rs.1.18/kg, whereas consumers are willing to pay up to Rs.3.87/kg, i.e., the potential consumer premium is three
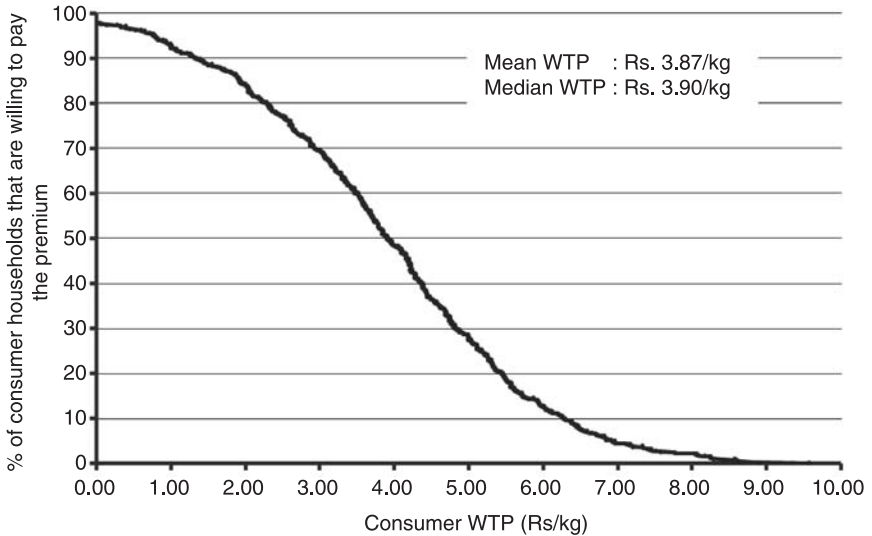
Figure 15.2 Consumer WTP for landrace eggplant.

times greater than the price premium currently realized by farmers. The difference between actual price margin obtained for the landrace cultivators and WTP stated by the consumer households could be explained as the difference existing between production situations Q^1 and Q^2 in Figure 15.1. The price associated with Q^2, i.e., where the consumer's WTP is fully accounted for by the market, would be higher than that at Q^1, i.e., the current situation faced by farmers with incomplete information by consumers.

The above results indicate that the evolution of reliable marketing channels facilitating the distribution and a formal labelling system for landrace products could help bridge this gap. Shams (1995) indicated that the consumers in developing countries could adopt environment-friendlier products as they grow more aware about the environmental risks posed by rapid economic development. However, in the case study presented in this chapter, the empirical evidence shows that the significant use value of landraces for vegetable consumers can be seen as a potentially major determinant for helping on-farm conservation in farmers' fields (if such premium were transferred to farmers to cultivate landraces) even with environmentalism still yet to surface in major Indian urban zones.

6 Conclusion

This chapter has explored the potentials of market development for in situ conservation of indigenous vegetable crop varieties and as a means to ensure the optimal co-existence of landraces and modern varieties. The chapter has addressed the supply as well as demand sides of landrace trait, taking the case

of eggplant in India. It should be stated that the introduction of MV eggplants into food production has been realized with only a partial success, as the perception about the quality of the crop produce is inferior from the consumers' perspective. This is an important reason why landrace eggplant still are marketed in urban India.

Along with the increase in consumers' awareness about the environmental externalities of intensive crop production, there has been a timid rise in the demand for green products in India (Parrott and Marsden 2002; Anand 2007). However, the potential to fully exploit niche markets for green products has often been considered as limited to wealthy nations, and rather small due to limited responsiveness of producers and suppliers in developing countries (Grote 2002; Basu *et al.* 2003; Shushmul 2005). But against this widespread opinion, the present study reports a potential demand for landrace products in new emergent economies, such as India, even though the current food market is not yet responding in order to meet the needs and preferences of eco-friendly consumers. Without a formal labelling system, the market still relies on trust towards vegetable farmers and sellers and knowing about fruit characteristics depicting landrace status. Such informal eco-labelling is clearly inefficient and this study shows that under relatively low transaction costs, markets for landraces could potentially emerge.

An examination of the supply and demand of eggplant in the country indicates the existence of an informal market segmentation for landraces, which helps farmers attain a higher price premium for growing landraces, at least as regards eggplants. Although hybrid eggplants are performing better in terms of yield, the market price is higher for landraces (about one-third greater as compared with products from hybrid eggplants). Such price advantage of landraces eclipses to a large extent the yield advantage of hybrids. Four groups of reasons can be cited as price-determining for eggplant fruits: (1) the quality of landrace origin (consumers consider the landrace eggplant is having medicinal properties, for example); (2) the fruit characteristics (such as size, colour, spiny calyx, etc.) which are preferred by the consumers and commonly found associated with the landrace products; (3) regional and seasonal factors; and (4) the farmer characteristics as the sale is often associated with a bargain between farmer and buyer in the market place. The hedonic price model employed suggests that the landrace status alone explains around 70 per cent of the farm price gap between landrace and hybrid products. Other fruit characteristics (such as fruit colour), seasonal and farmer characteristics were also found to be significant in determining the market price. Although the market is differentiated to a certain degree for catering the diversified needs of consumers, information asymmetries still prevails in the system as the fruit attributes only inadequately substitute for labels and certificates. Hence, a contingent valuation model is estimated in order to elicit the total economic value of the landrace attribute from the perspective of the eggplant consumers in urban areas of India.

The results from the state preference model suggest that when the

consumer WTP for the landrace attribute is compared with the farm price incentive, the price farmers obtain currently for landrace trait is just a small fraction of the value consumers attach to this same characteristic. The results from the WTP model also suggest that socio-economic variables along with the current market price significantly impact the potential niche market development for landrace products. Additionally, better quality information, for instance through signalling and labelling of products, is found to increase consumers' WTP further.

Of course, the optimal co-existence of landraces and modern varieties can only be assured if consumers' preferences through adequate pricing are transferred to farmers through a price incentive to grow landraces instead of modern varieties. The policy implication is quite straightforward. Developing practical schemes such as compulsory or voluntary labelling and certification to enhance information by consumers about the landrace attributes of vegetables and setting appropriate low cost marketing channels to transfer part of the price premium back to farmers could help farmers sustain the adoption of landraces against modern varieties. This is just one way to help conserve in situ agrobiodiversity in rural India with regard to crop varieties.

Notes

1 As in other chapters in this book we also use the term improved varieties interchangeably with modern hybrid varieties to refer to crop varieties that are the result of a process of scientific breeding programs.
2 In the recent past, India has made significant progress in setting up a legal regime for the management of PGRs, in three separate legislative instruments: (i) the Protection of Plant Varieties and Farmers' Rights Act, (ii) the Biodiversity Bill, and (iii) the Patents (Amendment) Act of 2002. The separation of various elements into three legislations is partly due to India's international legal obligations, viz. the Trade related aspects of Intellectual Property Rights (TRIPs) Agreement and the Convention on Biological Diversity (CBD).
3 Due to the limitations of existing literature on eggplant production and marketing in India, these observations are made from an expert survey among the scientists of Indian Horticultural Research Institute (Bangalore) and Indian Institute of Vegetable Research (Varanasi) as well as District Horticultural Officers of Karnataka and Andhra Pradesh.
4 It should be noted that while selective breeding generated 'green revolution'-type seed varieties by introducing distinct genetic material from those of traditional varieties, biotechnology alters existing seed varieties by modifying a few genes. It has been pointed out that the extent of loss in agrobiodiversity due to the introduction of transgenics depends on the degree in which local transgenics are adopted rather than on a single generic GM variety (Zilberman *et al.* 2004).
5 Detailed information about farmer and consumer households are available from Krishna and Qaim (2007; 2008), respectively.
6 In India, the quintal is equivalent to 100 kg, and is a standard measurement of mass for agricultural products.

Acknowledgements

References

Akerlof, A.G. (1970) 'The market for lemons: quality, uncertainty and the market mechanism', *Quarterly Journal of Economics* 84: 488–500.

Anand, S. (2007) 'Retailers spur organic food sales', *The Times of India*, 27 December.

Anand, A., Mittelhammer, R.C. and McCluskey, J.J. (2007) 'Consumer response to information and second generation genetically modified food in India', *Journal of Agricultural and Food Industrial Organization*, 5(8).

Bansal, S. (2007) 'The economics of GM food labels: an evaluation of mandatory labeling proposals in India', discussion paper 00704, Environment and Production Technology Division. The International Food Policy Research Institute (IFPRI), Washington, DC.

Basu, A.K., Chau, N.H. and Grote, U. (2003) 'Eco-labeling and stages of development', *Review of Development Economics* 7(2): 228–247.

Bateman, I.A., Carson, R.T., Day, B., Hanemann, M., Hanley, N., Hett, T., Jones-Lee, M. *et al.* (2002) *Economic Valuation with Stated Preference Techniques: A Manual*. Cheltenham: Edward Elgar.

Biber-Klemm, S., Cottier, T., Cullet, P. and Berglas, D.S. (2005) 'The current law of plant genetic resources and traditional knowledge', In S. Biber-Klemm, T. Cottier and D.S. Berglas (eds.) *Rights to Plant Genetic Resources and Traditional Knowledge*. Wallingford: CAB International.

Birol, E., Smale, M. and Gyovai, A. (2006) 'Using a choice experiment to estimate farmers' valuation of agricultural biodiversity on Hungarian small farms', *Environmental and Resource Economics* 34(4): 439–469.

Bose, T.K., Kabir, J., Maity, T.K., Parthasarathy, V.A. and Som, M.G. (2002) *Vegetable Crops*. Calcutta: Naya Prakash.

Brush, S.B. (2000) 'The issues of *in situ* conservation of crop genetic resources', in S.B. Brush, (ed.) *Genes in the Field: On-Farm Conservation of Crop Diversity*. Boca Raton, FL: RRIDRC/IPGRI/Lewis Publishers.

Brush, S.B. (2004) *Farmers' Bounty: Locating Crop Diversity in the Contemporary World*. New Haven, CT: Yale University Press.

Cameron, T.A. (1988) 'A new paradigm for valuing non-market goods using referendum data: maximum likelihood estimation by censored logistic regression', *Journal of Environmental Economics and Management* 15: 355–379.

CEC (1999) *Measuring Consumer Interest in Mexican Shade-grown Coffee: An Assessment of the Canadian, Mexican and US Markets*. Montreal: Commission for Environmental Cooperation.

Cropper, M.L., Deck, L.B., and McConnell, K.E. (1988) 'On the choice of functional form for hedonic price functions', *Review of Economics and Statistics*, 70(4): 668–675.

Cutbush, G. (2006) 'Incentives for natural and cultural heritage conservation', paper prepared for the Australian State of the Environment Committee, Department of

the Environment and Heritage, Canberra, 2006. http://www.deh.gov.au/soe/2006/emerging/incentives/index.html

Dalton, T.J. (2004) 'A household hedonic model of rice traits: economic values from farmers in West Africa', *Agricultural Economics* 31(2–3): 149–159.

Daunay, M.C., Lester, R.N., Hennart, J.W. and Duranton, C. (2000) 'Eggplants: present and future', *Capsicum Eggplant Newsletter* 19: 11–18.

Edmeades, S. (2007) 'A hedonic approach to estimating the supply of variety attributes of a subsistence crop', *Agricultural Economics* 37 (1): 19–28.

Ervin, D., Batie, S., Welsh, R., Carpentier, C.L., Fern, J.I., Richman, N.J. and Schulz, M.A. (2001) *Transgenic Crops: An Environmental Assessment*. Policy Studies Report No. 15. Arlington, VA: Henry A. Wallace Center for Agricultural and Environmental Policy.

FAOSTAT (2006) Available at www.faostat.fao.org (accessed September 2006).

Florax, R.J.G.M., Travisi, C.M. and Nijkamp, P. (2005) 'A meta-analysis of the willingness to pay for reductions in pesticide risk exposure', *European Review of Agricultural Economics* 32: 441–467.

Gandhi, V.P. and Namboodiri, N.V. (2004) 'Marketing of fruits and vegetables in India: A study covering the Ahmedabad, Chennai and Kolkata markets', IIMA Working Paper Number 2004–06–09, Indian Institute of Management, Ahmedabad, India.

Garibay, S.V. and Jyoti, K. (2003) *Market Opportunities and Challenges for Indian Organic Products*. Bern: Swiss State Secretariat of Economic Affairs.

GoI, (2004) *Report of the Task Force on Application of Agricultural Biotechnology*. New Delhi: Ministry of Agriculture, Government of India.

Greenpeace India (2006) 'Genetically engineered brinjal: Safe for the country? Safe for you?' Available at http://www.greenpeace.org/raw/content/india/press/reports/genetically-engineered-brinjal.pdf.

Grote, U. (2002) 'Eco-labelling in the agricultural sector: an international perspective', in *Proceedings of the High-Level Pan European Conference on Agriculture and Biodiversity*. Strasbourg: European Council.

Gupta, A. K. and Chandak, V. (2005) 'Agricultural biotechnology in India: ethics, business and politics', *International Journal of Biotechnology* 7: 212–227.

Harding, J.P., Rosenthal, S.S. and Sirmans, C.F. (2003) 'Estimating bargaining power in the market for existing homes', *The Review of Economics and Statistics* 85(1): 178–188.

Heisey, P.W., Smale, M., Byerlee, D. and Souza, E. (1997) 'Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan', *American Journal of Agricultural Economics* 79: 726–737.

Huang, C.L. and Lin, B.H. (2007) 'A hedonic analysis of fresh tomato prices among regional markets', *Review of Agricultural Economics* 29(4): 783–800.

IFAV 2001 *Recherche: Verbraucherverhalten beim Lebensmittelkauf*. Cologne: Institut für Angewandte Verbraucherforschung e.V. (IFAV).

Kontoleon, A. and Yabe, M. (2006) 'Market segmentation analysis of preferences for GM derived animal foods in the UK', *Journal of Agricultural and Food Industrial Organization* 4(1): 1–38.

Krishna, V.V. and Qaim, M. (2007) 'Estimating the adoption of Bt eggplant in India: Who benefits from public-private partnership?' *Food Policy* 32: 523–543.

Krishna, V.V. and Qaim, M. (2008) 'Consumer attitudes towards GM food and pesticide residues in India', *Review of Agricultural Economics* 30(2): 233–251.

Lancaster, K. (1966) 'A new approach to consumer theory', *Journal of Political Economy* 74: 132–157.

Nielsen, C.P., Thierfelder, K. and Robinson, S. (2003) 'Consumer preferences and trade in genetically modified foods', *Journal of Policy Modeling* 25: 777–794.

Parrott, N. and Marsden, T. (2002) *The Real Green Revolution*. London: Greenpeace Environmental Trust, UK.

Pascual, U. and Perrings, C. (2007) 'Developing incentives and economic mechanisms for *in situ* biodiversity conservation in agricultural landscapes', *Agriculture, Ecosystems and the Environment* 121: 256–268.

Rao, G.V.R. (2006) 'Extended summer delays vegetable cultivation', *The Hindu*, 20 June.

Rigby, D. and Burton, M. (2006) 'Modeling disinterest and dislike: a bounded Bayesian mixed logit model of the UK market for GM food', *Environmental and Resource Economics* 33: 485–509.

Shams, R. (1995) 'Eco-labeling and environmental policy effects in developing countries', *Inter-economics* 30(3): 143–149.

Shushmul, M. (2005) *Food Processing Market in India*. New Delhi: RNCOS.

Smale, M., Bellon, M.R., Jarvis, D. and Sthapit, B. (2004) 'Economic concepts for designing policies to conserve crop genetic resources on farms', *Genetic Resource and Crop Evolution* 51: 121–135.

Sridhar, V., Vijay, O.P. and Naik, G. (2001) 'Field evaluation of brinjal (*Solanum spp*) germplasm against shoot and fruit borer (*Leucinodes orbonalis* Guen.)', *Insect Environment*, 6(4): 155–156.

Unnevehr, L. J. (1986) 'Consumer demand for rice grain quality and returns to research for quality improvement in south-east Asia', *American Journal of Agricultural Economics* 68: 634–641.

Van Dusen, M. E. (2006) 'Missing markets, migration and crop biodiversity in the *Milpa* system of Mexico: a household-farm model', in M. Smale, (ed.) *Valuing Crop Biodiversity*: On farm *Genetic Resources and Economic Change*. Wallingford: CAB International Publishing, UK.

Whitten, S.M., Coggan, A., Reeson, A. and Gorddard, R. (2007) 'Putting theory into practice: market failure and market based instruments (MBIs)', CSIRO Working Paper Series 2007–02, Commonwealth Scientific and Industrial Research Organisation, Australia.

Wood, D. and Lenne, J.M. (1997) 'The conservation of agrobiodiversity on-farm: questioning the emerging paradigm', *Biodiversity and Conservation* 6: 109–129.

Zilberman, D., Ameden, H., Graff, G. and Qaim, M. (2004) 'Agricultural biotechnology: productivity, biodiversity and intellectual property rights', *Journal of Agriculture and Food Industrial Organization* 2(3): 1–16.

Zilberman, D. and Lipper, L. (2005) 'Major processes shaping the evolution of agriculture, biotechnology, and biodiversity', in J. Cooper, L.M. Lipper and D. Zilberman (eds) *Agricultural Biodiversity and Biotechnology in Economic Development*. Berlin: Springer.

Part III

Market and non-market institutions for agrobiodiversity conservation

16 Agro-biodiversity as natural insurance and the development of financial insurance markets

Stefan Baumgärtner and Martin F. Quaas

1 Introduction

Farmers traditionally grow a variety of crops in order to decrease the adverse impact of uncertain environmental and market conditions. That is, they use agro-biodiversity as a form of natural income insurance. In this chapter, we study how risk-averse farmers manage their portfolio of agro-biodiversity to hedge their income risk from uncertain environmental conditions, and how this management decision is being affected by the availability of financial insurance. Obviously, the two options—natural insurance through agro-biodiversity and financial insurance from the market—are substitutes for risk-averse farmers (Baumgärtner 2007). So, the price of financial insurance has an impact on the level of agro-biodiversity cultivated on the farm for risk-management purposes: as financial insurance becomes cheaper, it drives out agro-biodiversity as a form of natural insurance.

In the trade-off between financial insurance and natural insurance through agro-biodiversity, a market failure problem arises from the fact that agro-biodiversity not only provides private on-farm benefits, but also gives rise to public benefits such as improved pollination or control of pests or diseases, i.e. reduced income risk, on neighboring farms. As a general result, the privately determined level of on-farm agro-biodiversity is lower than the socially optimal one (Heal *et al.* 2004). In particular, such market failure stems from the risk-changing characteristics of agro-biodiversity and risk-averse behavior of private farmers (Baumgärtner 2007, Quaas and Baumgärtner, 2008). In this chapter, we study whether this risk-related market failure in the allocation of agro-biodiversity is worsened or lessened by improved access to financial insurance.

Agro-biodiversity's private and public insurance function, and its interrelation with financial insurance from the market, has different economic dimensions. Our analysis therefore builds upon, and combines, different strands in the economic literature.

1.1 Agro-biodiversity as a form of natural insurance

A number of studies have analyzed the contribution of crop diversity to the mean and variance of agricultural yields (Smale *et al.* 1998; Schläpfer *et al.* 2002; Widawsky and Rozelle 1998, Zhu *et al.* 2000) and to the mean and variance of farm income (Di Falco and Perrings 2003, 2005; Di Falco *et al.* 2007). One result is that agro-biodiversity may increase the mean level, and decrease the variance, of crop yields. This result is perfectly in line with evidence that emerged from recent theoretical, experimental and observational research in ecology about the role of biodiversity for the provision of ecosystem services (Hooper *et al.* 2005; Kinzig *et al.* 2002; Loreau *et al.* 2001, 2002). It has been conjectured that risk averse farmers use crop diversity in order to hedge their income risk (Birol *et al.* 2006a, 2006b; Di Falco and Perrings 2003). Since agro-biodiversity has an insurance value for farmers, they tend to employ a higher level of agro-biodiversity in the face of uncertainty (Baumgärtner 2007; Quaas and Baumgärtner, 2008). The extent to which farmers rely on agro-diversity as a natural insurance may be affected by agricultural policies such as subsidized crop yield insurance or direct financial assistance (Di Falco and Perrings, 2005). In this respect, agro-biodiversity plays a similar role for risk-averse farmers as other risk- changing production factors, such as e.g. nitrogen fertilizer or pesticides (Horowitz and Lichtenberg 1993, 1994a, 1994b).

1.2 Interaction of natural and financial insurance

Instead of making use of natural insurance, farmers can also buy financial insurance to hedge their income risk. For example, in the USA for over one hundred years, crop yield insurance has been offered to manage agricultural risk. Since traditional crop yield insurance is particularly vulnerable to classical insurance problems such as moral hazard or adverse selection (e.g. Luo *et al.* 1994), considerable effort has recently been spent on developing alternative possibilities of financial insurance for farmers, e.g. index-based insurance contracts (Miranda and Vedenov 2001; Skees *et al.* 2002; World Bank 2004).

While this effort to develop instruments of financial insurance is motivated by the idea that reducing income risk is beneficial for farmers, some studies have shown that financial insurance tends to have ecologically negative effects. Horowitz and Lichtenberg (1993, 1994a, 1994b) show that financially insured farmers are likely to undertake riskier production—with higher nitrogen and pesticide use—than uninsured farmers do. A similar result is pointed out by Mahul (2001), assuming a weather-based insurance. Wu (1999) empirically estimates the impact of insurance on the crop mix and its negative results on soil erosion in Nebraska, USA.

The underlying economic reason is that agro-biodiversity as a form of natural insurance and financial insurance from the market are substitutes, so that improved access to the latter drives out the former (Baumgärtner 2007).

In the insurance economics literature, the analysis of the trade-off between 'self insurance' (by acting such as to reduce a potential income loss) or 'self protection' (by acting such as to reduce the probability of an income loss) on the one hand, and 'market insurance' on the other hand goes back to Ehrlich and Becker (1972). One standard result is that self insurance and market insurance are substitutes, with the result that market insurance, as it becomes cheaper, may drive out self insurance.

1.3 Underprovision/overuse of public good

Since agro-biodiversity has not only a private insurance function but provides public insurance benefits as well, there is a potential public good problem associated with the private provision of agro-biodiversity (Heal *et al.* 2004). For example, the extent of genetic diversity in food crops is important as it affects the risk of attack by pathogens. A drop in diversity increases this risk. Farmers may not take this into account when making crop choices, leading to what from a social perspective is an inadequate level of agro-diversity.

The conventional wisdom on the use (or provision) of a public good under uncertainty seems to be that the more uncertainty and the higher the risk aversion of individual decision-makers, the less severe is the problem of overuse (or under-provision) of the public good (Bramoullé and Treich 2005; Sandler and Sterbenz 1990; Sandler *et al.* 1987). In a sense, this literature suggests that private uncertainty and risk-aversion increase the efficiency of the private provision of public goods. The focus in this literature is on the properties of the utility function, while the production of the public good (or public bad) is typically modelled in a trivial way, i.e. one unit of money spent on providing the public good equals one unit of the public good provided.

Quaas and Baumgärtner (2008) have shown that in realistic settings, in which the production of a public good—such as a public insurance function—is generated in a complex system—such as a multi-scale ecosystem— things become ambiguous. They find that ecosystem management and environmental policy depend on the extent of uncertainty and risk-aversion as follows: (1) Individual effort to increase the level of biodiversity unambiguously increases. However, the free-rider problem may decrease or increase, depending on the characteristics of the ecosystem and its management; in particular; (2) the size of the externality may decrease or increase, depending on how individual and aggregate management effort influence biodiversity; and (3) the welfare loss due to free-riding may decrease or increase, depending on how biodiversity influences ecosystem service provision.

If agro-biodiversity has not only a private but also a public insurance value, the interrelationship between natural and financial insurance becomes more complex, too. Quaas and Baumgärtner (2008) have shown that while improved access to financial insurance leads to a lower level of agro-

biodiversity, the effect on the public-good problem and on overall welfare is ambiguous and determined by agro-ecosystem properties.

In this chapter, we bring together the various ideas about agro-biodiversity and financial insurance, and analyze them in a unified formal framework. We analyze how a risk-averse farmer makes use of the natural insurance function of agro-biodiversity and of financial insurance. In particular, we study the question of how availability of financial insurance affects the underprovision of agro-biodiversity and social welfare when on-farm agro-biodiversity generate both a private benefit and, via ecological processes at higher hierarchical levels, also public benefits.

The analysis is based on a conceptual ecological-economic model. Crop yield is random because of exogenous sources of risk (e.g. weather, diseases or pests); its statistical distribution (mean and variance) is determined by the level of agro-biodiversity. The level of on-farm agro-biodiversity not only determines the distribution of farm income, but also generates external benefits. The farmer is risk-averse and chooses the level of agro-biodiversity so as to maximize the expected utility of farm income. When making this choice, he has also access to financial income insurance.

We show that natural insurance through agro-biodiversity and financial insurance are substitutes. Hence, availability of financial insurance reduces the demand for natural insurance through agro-biodiversity and, thus, leads to a reduction in agro-biodiversity. In particular, the lower the costs of financial insurance are (i.e. the more actuarially fair the risk premium of financial insurance is), the lower is the resulting level of agro-biodiversity. Yet, the effects of an improved access to financial insurance on the market failure problem (due to the external benefits of on-farm agro-biodiversity) and on welfare are ambiguous. We derive a specific condition on agro-ecosystem functioning under which, if financial insurance becomes more accessible, welfare in the absence of regulation increases or decreases.

These results are highly policy relevant. While at first sight the introduction of, or improved access to, financial and insurance markets seems to be beneficial to farmers from a welfare point of view, our results demonstrate that—depending on agroecosystem properties—it may have adverse welfare effects.

The chapter is organized as follows. In Section 2, we specify the ecological-economic model. The analysis and results are presented in Section 3, with all proofs and formal derivations contained in the Appendix. Section 4 discusses the results and concludes.

2 Ecological-economic model

We consider a farmer who manages an agro-ecosystem for the service, i.e. crop yield, it provides. Due to stochastic fluctuations in environmental conditions the provision of the agro-ecosystem service is uncertain. Its statistical distribution depends on the state of the agro-ecosystem in terms of agro-biodiversity, which is determined by the farmer's management decision. As a

result, the statistical distribution of agroecosystem service and, hence, of income depend on ecosystem management. We capture these relationships in a stylized ecological-economic model as follows.

2.1 Agro-ecosystem management

The farmer chooses a level v of agro-biodiversity, say by selecting a portfolio of different crop varieties. Given the level of agro-biodiversity v, the agro-ecosystem provides the farmer with the desired service, i.e. total crop yield, at a level s which is random. For simplicity we assume that the agro-ecosystem service directly translates into monetary income and that its mean level $\varepsilon s = \mu$ is independent of the level of agro-biodiversity and constant.[1] The variance of agroecosystem service depends on the level of agro-biodiversity v as follows

$$\text{var } s = \sigma^2(v) \quad \text{where} \quad \sigma^{2\prime}(v) < 0 \text{ and } \sigma^{2\prime\prime}(v) \geq 0. \tag{16.1}$$

For illustrative purposse, we will consider the following specific example:

$$\sigma^2(v) = \sigma_0 v^{1-\eta} \quad \text{with} \quad \eta > 1. \tag{16.2}$$

The constant η parameterizes the natural insurance capacity of the agro-ecosystem:[2] the larger η, the stronger does the variance of agro-ecosystem service (total crop yield) decline with the level of agro-biodiversity.

2.2 Financial insurance

In order to analyze the influence of availability of financial insurance on the farmers' choice of agro-biodiversity, we introduce financial insurance in a simple and stylized way. We assume that the farmer has the option of buying financial insurance under the following contract: (1) The farmer chooses the fraction $a \in [0, 1]$ of insurance coverage. (2) He receives (pays)

$$a(\varepsilon s - s) \tag{16.3}$$

from (to) the insurance company as an actuarially fair indemnification benefit (insurance premium) if his realized income is below (above) the mean income.[3] In order to abstract from any problems related to informational asymmetry, we assume that the statistical distribution as well as the actual level s of agro-ecosystem service are observable to both insurant and insurance company. (3) In addition to (16.3), the farmer pays the transaction costs of insurance. The costs of insurance over and above the actuarially fair insurance premium, which are a measure of the 'real' costs of insurance to the farmer, are assumed to follow the cost function

$$\delta \, a \, \text{var } s, \tag{16.4}$$

where the parameter $\delta \geq 0$ describes how actuarially unfair is the insurance contract. The costs increase linearly with the insured part of income variance. This captures in the simplest way the idea that the costs of insurance increase with the 'extent' of insurance. Throughout the analysis we assume $\delta < \rho$ to exclude corner solutions where a change in δ would have no effect on the farmer's behavior.

The main focus of our analysis will lie in the comparative statics with respect to the parameter δ. Thereby we interpret a decrease in δ as an improvement in the access to, or reduction of the costs of, financial insurance.[4]

2.3 Farmer's income, preferences and decision

The farmer chooses the level of agro-biodiversity v and financial insurance coverage a. A higher level of agro-biodiversity carries costs $c > 0$ per unit of agro-biodiversity. These costs may be due to increased cropping, harvesting and marketing effort, and are purely private. Adding up income components, the farmer's (random) income y is given by

$$y = (1 - a)\, s - cv + a\varepsilon s - \delta a \operatorname{var} s. \tag{16.5}$$

Since the agro-ecosystem service s is a random variable, net income y is a random variable, too. The uncertain part of income is captured by the first term in Equation (16.5), while the other components are certain. Obviously, increasing a to one allows the farmer to reduce the uncertain income component down to zero.

The mean εy and the variance $\operatorname{var} y$ of the farmer's income y are determined by the mean and variance of agro-ecosystem service, which depends on the level of agro-biodiversity (Equation 16.11),

$$\varepsilon y = \mu - cv - \delta a \sigma^2(v) \quad \text{and} \tag{16.6}$$

$$\operatorname{var} y = (1 - a)^2 \sigma^2(v). \tag{16.7}$$

Mean income is given by the mean level of agro-ecosystem service μ, minus the costs of agro-biodiversity cv and the costs of financial insurance $\delta\, a\, \sigma^2(v)$. For an actuarially fair financial insurance contract ($\delta = 0$), mean income equals mean net income from agro-ecosystem use, $\mu - cv$. The variance of income vanishes for full financial insurance coverage, $a = 1$, and equals the full variance of agro-ecosystem service, $\sigma^2(v)$, without any financial insurance coverage, $a = 0$.

The farmer is assumed to be non-satiated and risk-averse with respect to his uncertain income y. There exists empirical evidence on how agro-biodiversity influences the mean and variance of agro-ecosystem services, but hardly on the full statistical distribution. This restricts the class of risk

preferences which can meaningfully be represented in our ecological-economic model to utility functions which depend only on the first and second moment of the probability distribution, i.e. on the mean and the variance. Specifically, we assume the following expected utility function, where $\rho > 0$ is a parameter describing the farmer's degree of risk aversion (Arrow 1965, Pratt 1964):[5]

$$U = \varepsilon y - \frac{\rho}{2}\,\mathrm{var}\,y. \tag{16.8}$$

2.4 External benefits of agro-biodiversity

The farmer's private decision on the level of agro-biodiversity v affects not only his private income risk, as expressed by the variance of on-farm agro-ecosystem service, var s (Equation 16.1), but also causes external effects. Assume that $B(v)$ captures the sum of external benefits of on-farm agro-biodiversity v, such as improved pollination or control of pests or diseases, i.e. reduced income risk, on neighboring farms.[6] In particular, we shall assume that the external benefit of agro-biodiversity essentially consists in a reduction of public risk, i.e. in a reduction of the variance of some public ecosystem service:

$$\varepsilon B(v) = \Upsilon \tag{16.9}$$

$$\mathrm{var}\,B(v) = \Sigma^2(v) \quad \text{where} \quad \Sigma^{2\prime}(v) < 0 \text{ and } \Sigma^{2\prime\prime}(v) \geq 0. \tag{16.10}$$

The external welfare effect of on-farm agro-biodiversity is

$$\varepsilon B - \frac{\Omega}{2}\,\mathrm{var}\,B, \tag{16.11}$$

where $\Omega > 0$ is a parameter describing the degree of social risk aversion. Furthermore, we assume that the private and the public risks associated with v are uncorrelated. The total (i.e. private plus external) welfare effect of on-farm agro-biodiversity, thus, is:[7]

$$W = \varepsilon y + \varepsilon B - \frac{\rho}{2}\,\mathrm{var}\,y - \frac{\Omega}{2}\,\mathrm{var}\,B. \tag{16.12}$$

3 Analysis and results

The analysis proceeds in four steps: First, we identify agro-biodiversity's private and public insurance value (Section 3.1) Next, we discuss the laissez-faire allocation which arises if the farmer maximizes his expected private utility from farm income (Section 3.2). Then, we study the efficient allocation which

is obtained by maximizing social welfare (Section 3.3). Finally, we investigate how policy measures to internalize the externalities and welfare are influenced by the access to financial insurance, as described by the parameter δ (Section 3.4).

3.1 The insurance value of agro-biodiversity

In order to precisely define the insurance value of agro-biodiversity, recall that by choosing the level of agro-biodiversity v and the fraction of financial insurance coverage a the farmer actually chooses a particular income lottery, which in our model is characterized by the mean $\varepsilon y = \mu - cv - \delta\, a\, \sigma^2\,(v)$ and variance var $y = (1-a)^2\, \sigma^2(v)$ (Equations 16.6, 16.7). These are determined by v and a and, therefore, one may speak of 'the lottery (v, a)'.

One standard method of valuing the riskiness of a lottery to a decision-maker is to calculate the *risk premium R* of the lottery, which is defined as the amount of money that leaves the decision-maker equally well off, in terms of utility, between the two situations of (1) receiving for sure the expected pay-off from the lottery εy minus the risk premium R, and (2) playing the risky lottery with random pay-off y (e.g. Dasgupta and Heal 1979: 381; Kreps 1990: 84). With utility function (16.8), the risk premium R of a lottery with mean pay-off εy and variance var y is simply given by:

$$R = \frac{\rho}{2}\, \text{var } y. \tag{16.13}$$

In the model employed here the risk premium of the farmer's income lottery thus depends on the level of agro-biodiversity v and of financial insurance coverage a:

$$R(v, a) = \frac{\rho}{2}\,(1-a)^2\, \sigma^2(v). \tag{16.14}$$

The insurance value of agro-biodiversity can now be defined based on the risk premium of the lottery (v, a) (Baumgärtner 2007).

Definition 1

The insurance value V^v of agro-biodiversity v is given by the change of the risk premium R of the lottery (v, a) due to a marginal change in the level of agro-biodiversity v:

$$V^v(v, a) := -\frac{\partial R(v, a)}{\partial v}. \tag{16.15}$$

Thus, the insurance value of agro-biodiversity is the marginal value of agro-biodiversity in its function to reduce the risk premium of the farmer's income risk from harvesting uncertain agro-ecosystem services. Being a marginal value, it depends on the existing level of agro-biodiversity v. It also depends on the actual level of financial insurance coverage a. The minus sign in the defining Equation (16.15) serves to express agro-biodiversity's ability to *reduce* the risk premium of the lottery (v, a) as a *positive* value. Applying Definition 1 to Equation (16.14) one obtains the following result for the insurance value of agro-biodiversity in this model.

Proposition 1

The insurance value $V'(v, a)$ of agro-biodiversity is given by

$$V'(v, a) = -\frac{\rho}{2}(1 - a)^2 \sigma^{2\prime}(v) > 0. \tag{16.16}$$

From Equation (16.16) it is apparent that the insurance value of agro-biodiversity has an objective, a subjective and an institutional dimension. The objective dimension is captured by the sensitivity of the variance of agro-ecosystem services to changes in agro-biodiversity, $\sigma^{2\prime}$; the subjective dimension is captured by the farmer's degree of risk aversion, ρ; and the institutional dimension is captured by the farmer's extent of financial insurance coverage, a, which depends on institutional conditions (see below). The insurance value of agro-biodiversity V' increases with the sensitivity of the variance of agro-ecosystem services to changes in agro-biodiversity, $|\sigma^{2\prime}|$, and with the degree ρ of the farmer's risk aversion. It decreases with the farmer's extent of financial insurance coverage, a. In the extreme, for vanishing subjective risk-aversion, $\rho = 0$, or for full financial insurance coverage, $a = 1$, agro-biodiversity's insurance value vanishes. As a function of the level v of agro-biodiversity, the insurance value $V'(v, a)$ decreases: as agro-biodiversity becomes more abundant (scarcer), its insurance value decreases (increases).

In the example of specification (16.2), agro-biodiversity's insurance value $V'(v, a)$ is isoelastic with respect to changes in the level of agro-biodiversity v, and η expresses this elasticity.[8] That is, an increase of agro-biodiversity by 1 percent always leads to an increase of its insurance value by η percent. This motivates the interpretation of η as the agro-ecosystem's natural insurance capacity.

One can also define the insurance value of financial insurance as

$$V^a(v, a) := -\frac{\partial R(v, a)}{\partial a}. \tag{16.17}$$

With Expression (16.14) for the risk premium of the income lottery (v, a), the insurance value $V^a(v, a)$ of financial insurance is thus given by

$$V^a (v, a) = \rho (1 - a) \sigma^2 (v). \tag{16.18}$$

From Equation (16.18) it is apparent that the insurance value of financial insurance also has an objective, a subjective and an institutional dimension. The objective dimension is captured by the variance of agro-ecosystem services, σ^2, which represents the extent of potential environmental risk; the subjective dimension is captured by the farmer's degree of risk aversion, ρ; and the institutional dimension is captured by the farmer's extent of financial insurance coverage, a, which depends on institutional conditions (see below). The insurance value of financial insurance V^a increases with the variance of agro-ecosystem services, σ^2, i.e. with environmental risk, and with the degree ρ of the farmer's risk aversion. It decreases with the farmer's extent of actual financial insurance coverage, a. In the extreme, for vanishing subjective risk-aversion, $\rho = 0$, vanishing environmental risk, $\sigma^2 = 0$, or for full financial insurance coverage, $a = 1$, the value of financial insurance vanishes.

So far, we have been discussing agro-biodiversity's *private* insurance value to an individual farmer, based on the private risk premium $R(v, a)$ (Equation 16.14) of the farmer's private income lottery. Beyond that, agro-biodiversity also has a *public* insurance value. On-farm agrobiodiversity has an additional risk-reducing value due to its external benefit (16.11), i.e. there exists a public risk premium,

$$R^{pub} (v) = \frac{\Omega}{2} \operatorname{var} B = \frac{\Omega}{2} \Sigma^2 (v), \tag{16.19}$$

which is in addition to the private one, giving rise to a public insurance value of

$$V^{pub} (v) = - \frac{\partial R^{pub} (v)}{\partial v} = - \frac{\Omega}{2} \Sigma^{2\prime} (v) > 0. \tag{16.20}$$

The total insurance value of on-farm agro-biodiversity then is the sum of the private and the public insurance value.

3.2 Laissez-faire allocation

As laissez-faire allocation (v^*, a^*) we consider the allocation in which the farmer individually chooses the level of agro-biodiversity v and financial insurance coverage a so as to maximize his expected private utility (Equation 16.8) subject to constraints (16.6) and (16.7). Formally, the farmer's decision problem is

$$\max_{v,a} U = \mu - cv - \delta a \sigma^2 (v) - \frac{\rho}{2} (1 - a)^2 \sigma^2 (v). \tag{16.21}$$

The laissez-faire allocation has the following properties.

Proposition 2

An (interior) laissez-faire allocation exists and is unique. It is characterized by the following necessary and suffcient conditions:

$$V^v(v^*, a^*) - \delta a^* \sigma^{2\prime}(v^*) = c \qquad (16.22)$$

$$V^a(v^*, a^*) = \delta \sigma^2(v^*) \qquad (16.23)$$

The laissez-faire levels of both agro-biodiversity and financial insurance coverage increase with the degree of risk-aversion:

$$\frac{dv^*}{d\rho} > 0 \quad \text{and} \quad \frac{da^*}{d\rho} > 0. \qquad (16.24)$$

The laissez-faire level v^* of agro-biodiversity increases, and the laissez-faire level a^* of financial insurance coverage decreases, with the costs of financial insurance:

$$\frac{dv^*}{d\delta} > 0 \quad \text{and} \quad \frac{da^*}{d\delta} < 0. \qquad (16.25)$$

Proof: see Appendix A.1.

Condition (16.22) states that the farmer will choose the level of agro-biodiversity so as to equate the marginal benefits and the marginal costs of agro-biodiversity. The marginal costs are given by the constant unit costs c on the right-hand side. The marginal benefits are given by the expression on the left-hand side and comprise two terms: the insurance value of agro-biodiversity and the reduction in payments for financial insurance that results from the reduced variance of agro-ecosystem service due to a marginal increase in agro-biodiversity.

Likewise, Condition (16.23) states that the level of financial insurance coverage is chosen so as to equate the marginal benefits and the marginal costs of financial insurance, where the marginal benefit is the insurance value and the marginal costs are the (marginal) transaction costs. This condition can be rearranged into

$$a^* = 1 - \frac{\delta}{\rho}, \qquad (16.26)$$

which states that the farmer will choose the level of financial insurance coverage as follows. In the absence of transaction costs, i.e. for $\delta = 0$, he chooses

full coverage by financial insurance, i.e. $a^* = 1$. As transaction costs of financial insurance increase, i.e. for $\delta > 0$, he chooses partial coverage by financial insurance, $0 < a^* < 1$, and if transaction costs are so high that $\delta = \rho$ he chooses no financial insurance coverage, $a^* = 0$.[9]

Both the level of agro-biodiversity and the level of financial insurance coverage increase with the degree of the farmer's risk-aversion (Result 16.24), since both instruments allow him to hedge his income risk. As different forms of insurance the two are substitutes: as financial insurance becomes more expensive, i.e. δ increases, the farmer reduces his demand for financial insurance coverage and increases his level of agro-biodiversity (Result 16.25). Put the other way: as financial insurance becomes cheaper, it drives out agro-biodiversity as the natural insurance. In any case, with financial insurance available, the farmer will choose a level of agro-biodiversity which is below the one that he would choose if financial insurance was not available.[10]

3.3 Effcient allocation

The effcient allocation $(\hat{v}, \hat{a})$ is derived by choosing the level of agro-biodiversity v and financial insurance coverage a so as to maximize total welfare (Equation 16.12), subject to Constraints (16.6), (16.7), (16.9) and (16.10):

$$\max_{v,\, a} W = \mu + Y - cv - \delta\, a\, \sigma^2(v) - \frac{\rho}{2}(1-a)^2\, \sigma^2(v) - \frac{\Omega}{2}\Sigma^2(v). \qquad (16.27)$$

The effcient allocation has the following properties.

Proposition 3

An (interior) solution to problem (16.27) exists and is unique. It is characterized by the following necessary and suffcient conditions:

$$V^v(\hat{v}, \hat{a}) + V^{pub}(\hat{v}) - \delta\, \hat{a}\, \sigma^{2\prime}(\hat{v}) = c \qquad (16.28)$$

$$V^a(\hat{v}, \hat{a}) = \delta\, \sigma^2(\hat{v}) \qquad (16.29)$$

The effcient levels of both agro-biodiversity and financial insurance coverage increase with the degree of individual risk-aversion:

$$\frac{d\hat{v}}{d\rho} > 0 \quad and \quad \frac{d\hat{a}}{d\rho} > 0. \qquad (16.30)$$

The effcient level of agro-biodiversity increases with, and the effcient level of financial insurance coverage is unaffected by, the degree of social risk-aversion:

$$\frac{d\hat{v}}{d\Omega} > 0 \quad and \quad \frac{d\hat{a}}{d\Omega} = 0. \tag{16.31}$$

The effcient level $\hat{v}$; of agro-biodiversity increases, and the effcient level $\hat{a}$ of financial insurance coverage decreases, with the costs of financial insurance:

$$\frac{d\hat{v}}{d\delta} > 0 \quad and \quad \frac{d\hat{a}}{d\delta} < 0. \tag{16.32}$$

Proof: see Appendix A.2

The properties of the effcient allocation are very similar in structure to those of the laissez-faire allocation (cf. Proposition 2). The difference between the effcient and the laissez-faire allocation is that in the effcient allocation the positive externality, which a private farmer's effort has on society at large in terms of a reduced variance of public benefits, is fully internalized: first-order condition (16.28), which demands equality of marginal benefits and costs of agro-biodiversity, includes not only the private insurance value but also the public insurance value, i.e. the total insurance value, of agro-biodiversity.

   This changes the effect that an increase in the transaction costs of financial insurance has on the management effort and financial insurance coverage in magnitude, but not in sign. Hence, the same arguments hold which support Proposition 2: with increasing transaction costs δ of financial insurance it is optimal to substitute financial insurance by natural insurance.

   As in the laissez-faire allocation, the effcient levels of agro-biodiversity, $\hat{v}$, and financial insurance coverage, $\hat{a}$, increase with the degree of individual risk aversion, ρ.

3.4 Welfare effects of improved access to financial insurance

Comparing the laissez-faire allocation (cf. Proposition 2) with the effcient allocation (cf. Proposition 3), it becomes apparent that there is market failure: Due to the external benefit of on-farm agro-biodiversity, the laissez-faire allocation is not effcient. In the laissez-faire allocation a private farmer chooses a level of agro-biodiversity that is too low compared to the socially optimal level, because he does not take into account the positive externality on society at large. As a result, welfare is lower in the laissez-faire allocation than in the effcient allocation.

Proposition 4

The laissez-faire level of agro-biodiversity is lower than the effcient level, while the level of financial insurance coverage is the same in both allocations.

As a result, laisser-faire welfare is lower than welfare in the effcient allocation.

$$v^* < \hat{v}, \qquad\qquad\qquad (16.33)$$

$$a^* = \hat{a}, \qquad\qquad\qquad (16.34)$$

$$W^* < \hat{W}. \qquad\qquad\qquad (16.35)$$

Proof: see Appendix A.3

In order to implement the effcient allocation, a regulator could impose a Pigouvian subsidy on agro-biodiversity. Denoting by τ the subsidy per unit of v, the optimization problem of a private farmer under such regulation then reads

$$\max_{v,\, a} U = \mu - cv - \delta\, a\, \sigma^2\,(v) - \frac{\rho}{2}\,(1 - a)^2\,\sigma^2\,(v) + \tau v. \qquad (16.36)$$

Comparing the first order conditions for the effcient allocation (Problem 16.27) and for the regulated allocation (Problem 16.36), we obtain the optimal subsidy $\hat{\tau}$.

Proposition 5

The effcient allocation is implemented if a subsidy $\hat{\tau}$ on agro-biodiversity is set with

$$\hat{\tau} = -\frac{\Omega}{2}\,\Sigma^{2\prime}\,(\hat{v}) > 0. \qquad\qquad (16.37)$$

The optimal subsidy increases with the degree Ω of social risk aversion, and decreases with the degree ρ of individual risk aversion and with the costs δ of financial insurance:

$$\frac{d\hat{\tau}}{d\Omega} > 0\,, \quad \frac{d\hat{\tau}}{d\rho} < 0, \quad \frac{d\hat{\tau}}{d\delta} < 0. \qquad\qquad (16.38)$$

Proof: see Appendix A.4

The Pigouvian subsidy $\hat{\tau}$ captures the positive externality of on-farm agro-biodiversity on society at large. It is exactly given by agro-biodiversity's public insurance value (Equation 16.20). Hence, the optimal subsidy is higher, the higher the public insurance benefits of agro-biodiversity are.

The optimal subsidy $\hat{\tau}$ can be interpreted as a measure of the extent of regulation necessary to internalize the externality, i.e. to solve the public-

good problem. Thus, it can also be interpreted as a measure of the size of the externality.

Clearly, the size of the externality depends on the costs δ of financial insurance. The effect of higher costs of financial insurance on the market failure is unambiguous. Condition (16.38) states that increasing costs of financial insurance decrease the market failure.

After having studied the effect of financial insurance on the size of the externality, we now turn to the question of how increased costs of financial insurance influence welfare. In a first-best economy, where the external effect is perfectly internalized, e.g. by the Pigouvian subsidy (16.37), the answer to this question is simple: higher costs of financial insurance are always welfare decreasing in a first-best world.[11]

This is not necessarily the case in the second-best world of the laissez-faire allocation where the externality of on-farm agro-biodiversity is present. Whether welfare in the laissez-faire allocation (Equation 16.12)

$$W^* \equiv \mu + \Upsilon - cv^* - \delta\, a^*\, \sigma^2\, (v^*) - \frac{\rho}{2} (1 - a^*)^2\, \sigma^2\, (v^*) - \frac{\Omega}{2} \Sigma^2\, (v^*) \quad (16.39)$$

increases or decreases with the costs of financial insurance, δ, depends on the relative size of two effects: (1) the direct effect of increased insurance costs is always negative (this is the only effect present in the first best); (2) the indirect effect that increased costs of financial insurance lead to an increased level of agro-biodiversity is positive (Proposition 2). The condition for whether one or the other effect dominates is given in the following proposition.

Proposition 6

With increasing costs of financial insurance welfare in the laissez-faire allocation decreases / is unchanged / increases, i.e. $dW^* / d\delta \lesseqqgtr 0$, if and only if

$$-\frac{\Omega}{2} \Sigma^{2\prime}\, (v^*) \frac{dv^*}{d\delta} \lesseqqgtr a^*\, \sigma^2\, (v^*), \quad (16.40)$$

which is equivalent to

$$V^{pub}\, (v^*) \lesseqqgtr (Vv\, (v^*, a^*) - \delta\, a^*\, \sigma^{2\prime}\, (v^*))\, \frac{\sigma^2\, (v^*)\, \sigma^{2\prime\prime}\, (v^*)}{[\sigma^{2\prime}\, (v^*)]^2} \quad (16.41)$$

Proof: see Appendix A.5

The right-hand side of Condition (40) expresses the direct effect that expenditures for financial insurance increase with δ. This effect decreases welfare. The left-hand side of Condition (16.40) captures the indirect effect

that on-farm biodiversity increases with δ (Proposition 2). Welfare is improved by the increase in $v*$ weighted by a factor of $-\dfrac{\Omega}{2}\Sigma^{2\prime}(v*) > 0$ which quantifies the positive externality of the private choice of on-farm agro-biodiversity on society at large. The overall welfare effect depends on the balance between these two effects. In particular, if the indirect effect is sufficiently large welfare in the laissez-faire even increases with the costs of financial insurance.

Condition (16.40) can be expressed in the fundamental parameters of the model, and in terms of the private and public insurance value of agro-biodiversity (Condition 16.41). On the left-hand side is the public (marginal) benefit, i.e. the public insurance value, of agro-biodiversity. On the right-hand side is the private (marginal) benefit of agro-biodiversity, i.e. the private insurance value plus the indirect benefit of reduced costs of financial insurance, weighted by a factor of $\sigma^2(v*)\sigma^{2\prime\prime}(v*)/[\sigma^{2\prime}(v*)]^2$ which expresses the agro-ecosystem's natural insurance function. In the example of an agro-ecosystem with isoelastic natural insurance function (Equation 16.2) this factor becomes

$$\frac{\sigma^2(v*)\,\sigma^{2\prime\prime}(v*)}{[\sigma^{2\prime}(v*)]^2} = \frac{\eta}{\eta - 1} = const. \tag{16.42}$$

As η increases from 1 to infinity, this factor decreases from infinity to 1. So, the larger the agro-ecosystem's natural insurance capacity, the smaller is this factor.

With this, Condition (16.41) states that laissez-faire welfare $W*$ decreases with the costs δ of financial insurance if the agro-ecosystem is characterized by a low natural insurance capacity, the private insurance value of agro-biodiversity is high, and its public insurance value is low. Under these circumstances, the negative direct effect of financial insurance costs to private farmers dominates over its positive indirect effect of increased agro-biodiversity. So, an increase in private insurance costs decreases total welfare. Interestingly, the reverse may also happen in the second-best world where the agro-biodiversity externality is not internalized: an increase in private insurance costs may increase total welfare. This holds for a situation in which the agro-ecosystem is characterized by a high natural insurance capacity, the private insurance value of agro-biodiversity is low, and its public insurance value is high. Under these circumstances, the positive indirect effect, i.e. an increase in the level of agro-biodiversity and the associated public and private insurance value, outweighs the negative direct effect of increased costs of financial insurance.

After having studied the effect of improved access to financial insurance on laisez-faire welfare, we now look at how improved access to financial insurance affects the welfare loss from the market failure, which is due to the

external benefits of agro-biodiversity. The welfare loss in the laisez-faire allocation compared with the efficient allocation is given by

$$\hat{W} - W^* = -c\hat{v} - \delta\,\hat{a}\,\sigma^2\,(\hat{v}) - \frac{\rho}{2}\,(1-\hat{a})^2\,\sigma^2(\hat{v}) - \frac{\Omega}{2}\,\Sigma^2\,(\hat{v})$$

$$- \left[-cv^* - \delta\,a^*\,\sigma^2\,(v^*) - \frac{\rho}{2}\,(1-a^*)^2\,\sigma^2\,(v^*) - \frac{\Omega}{2}\,\Sigma^2\,(v^*) \right], \tag{16.43}$$

where $v^* < \hat{v}$ and $a^* = \hat{a}$ so that $\hat{W} - W^* > 0$ (Proposition 4). The properties of the welfare loss are as follows:

Proposition 7

With increasing costs of financial insurance the welfare loss from market failure in the allocation of agro-biodiversity increases / decreases / is unchanged, i.e. $d(\hat{W} - W^*)\,/\,d\delta \gtreqqless 0$, if and only if

$$\frac{d}{d\delta}\,(\hat{W} - W^*) \gtreqqless 0$$

$$\Leftrightarrow V^{pub}\,(v^*) \gtreqqless (V^v\,(v^*, a^*) - \delta\,a^*\,\sigma^{2\prime}\,(v^*))\left(1 - \frac{\sigma^2(\hat{v})}{\sigma^2(v^*)}\right)\frac{\sigma^2\,(v^*)\,\sigma^{2\prime\prime}\,(v^*)}{[\sigma^{2\prime}\,(v^*)]^2} \tag{16.44}$$

Proof: see Appendix A.6

Condition (16.44) about the welfare loss $\hat{W} - W^*$ is essentially the same as Condition (16.41) about the laissez-faire welfare level W^*, amended by a factor of $1 - \sigma^2(\hat{v})/\sigma^2(v^*)$, which may take on values between zero and one depending on the agro-ecosystem's natural insurance capacity. So, essentially all interpretations of Proposition 6 carry over to the interpretation of Proposition 7. The additional factor of $1 - \sigma^2(\hat{v})/\sigma^2(v^*)$ in Condition (16.44) implies that the larger the deviation of the laissez-faire level of agro-biodiversity v^* from its efficient level $\hat{v}$, the greater are the chances that the welfare loss increases with the costs of financial insurance.

4 Conclusion

We have analyzed how a risk-averse farmer manages his portfolio of agro-biodiversity so as to hedge his income risk. The ecological-economic model captures two stylized facts: (1) Onfarm agro-biodiversity provides benefits not just at the farm level, but also provides external benefits. (2) The variance of private and public benefits decreases with the level of agro-biodiversity. Thus, agro-biodiversity has a natural insurance function.

Financial insurance is a substitute for natural insurance from

agro-biodiversity. As a consequence, higher costs of financial insurance lead to a higher demand for natural insurance, and thus, to a higher level of agro-biodiversity. Put the other way around, introducing institutions for, or improving access to, financial insurance leads to a lower level of agro-biodiversity, as farmers substitute natural insurance from agro-biodiversity by financial insurance.

Due to the external benefits of on-farm agro-biodiversity, the laissez-faire allocation is not efficient. In order to study how this market failure is affected by the availability of financial insurance we have analyzed how (1) the extent of regulation necessary to implement the efficient allocation and (2) how welfare in the laissez-faire allocation depend on the transaction costs of financial insurance.

We found that the Pigouvian subsidy, as a measure of the extent of efficient regulation in a firstbest world, unambiguously decreases with the costs of financial insurance. We also found that in a secondbest world where such regulation does not exist, or is not properly enforced, it is even possible that improved access to financial insurance decreases welfare. While this is, in principle, well-known from second-best theory, we have derived a specific condition on agro-ecosystem functioning under which this happens (Conditions 16.41 and 16.44): improved access to financial insurance will have a negative impact on total welfare if the agro-ecosystem is characterized by a high natural insurance capacity, the private insurance value of agro-biodiversity is low, and its public insurance value is high.

These results are highly relevant for agricultural, environmental and development policy. In so far as it is one aim of development policy to introduce, and improve access to, financial and insurance markets, our analysis shows that such a policy has unambiguously negative implications for agro-biodiversity. Furthermore, our results highlight that properties of agro-ecosystems determine whether welfare increases or decreases under such a policy. Unless a sound agro-biodiversity policy is in place, which should internalize the public benefits of agro-biodiversity for private farmers, improving farmers' access to financial and insurance markets regardless of agro-ecosystem properties may have adverse welfare effects.

Acknowledgments

A Appendix

A.1 Proof of proposition 2

Written down explicitly, the first order conditions (22) and (23) for the interior solution of problem (21), which are obtained as $\partial U/\partial v = 0$ and $\partial U/\partial a = 0$, are

$$-\left[\frac{\rho}{2}(1 - a^*)^2 + \delta\, a^*\right] \sigma^{2\prime}(v^*) = c \tag{A.1}$$

$$\rho\,(1 - a^*)\,\sigma^2(v^*) = \delta\,\sigma^2(v^*) \tag{A.2}$$

Condition (A.2) can be solved to

$$a^* = 1 - \frac{\delta}{\rho} \tag{A.3}$$

Differentiating (A.1) with respect to ρ and using (A.3) yields

$$-\left[\frac{\rho}{2}(1 - a^*)^2 + \delta\, a^*\right] \sigma^{2\prime\prime}(v^*)\,\frac{dv^*}{d\rho} = \frac{1}{2}(1 - a^*)^2\,\sigma^{2\prime}(v^*) \tag{A.4}$$

$$\frac{dv^*}{d\rho} = -\frac{\delta}{\rho}\,\frac{1}{2\rho - \delta}\,\frac{\sigma^{2\prime}(v^*)}{\sigma^{2\prime\prime}(v^*)} > 0 \tag{A.5}$$

Differentiating (A.1) with respect to δ and using (A.3) yields

$$-\left[\frac{\rho}{2}(1 - a^*)^2 + \delta\, a^*\right] \sigma^{2\prime\prime}(v^*)\,\frac{dv^*}{d\delta} = a^*\,\sigma^{2\prime}(v^*) \tag{A.6}$$

$$\frac{dv^*}{d\delta} = -\frac{a^*}{\dfrac{\rho}{2}(1 - a^*)^2 + \delta\, a^*}\,\frac{\sigma^{2\prime}(v^*)}{\sigma^{2\prime\prime}(v^*)} \tag{A.7}$$

$$\frac{dv^*}{d\delta} = -\frac{1}{\delta}\,\frac{\rho - \delta}{\rho - \dfrac{\delta}{2}}\,\frac{\sigma^{2\prime}(v^*)}{\sigma^{2\prime\prime}(v^*)} > 0 \tag{A.8}$$

Differentiating (A.3) with respect to ρ and δ is straightforward and yields expressions for $da^*/d\rho$ and $da^*/d\delta$.

A.2 Proof of proposition 3

Written down explicitly, the first-order conditions (16.28) and (16.29) for the interior solution of problem (16.27), which are obtained as $\partial W/\partial v = 0$ and $\partial W/\partial a = 0$, are

$$-\left[\frac{\rho}{2}(1-\hat{a})^2 + \delta\,\hat{a}\right]\sigma^{2\prime}(\hat{v}) - \frac{\Omega}{2}\Sigma^{2\prime}(\hat{v}) = c \tag{A.9}$$

$$\rho\,(1-\hat{a})\,\sigma^2(\hat{v}) = \delta\,\sigma^2(\hat{v}) \tag{A.10}$$

Condition (A.10) can be solved to

$$\hat{a} = 1 - \frac{\delta}{\rho} \tag{A.11}$$

Differentiating (A.9) with respect to ρ and using (A.11) yields

$$-\left\{\left[\frac{\rho}{2}(1-\hat{a})^2 + \delta\,\hat{a}\right]\sigma^{2\prime\prime}(\hat{v}) + \frac{\Omega}{2}\Sigma^{2\prime\prime}(\hat{v})\right\}\frac{d\hat{v}}{d\rho} = \frac{1}{2}(1-\hat{a})^2\,\sigma^{2\prime}(\hat{v}) \tag{A.12}$$

$$\frac{d\hat{v}}{d\rho} = \frac{-\dfrac{1}{2}\dfrac{\delta^2}{\rho^2}\,\sigma^{2\prime}(\hat{v})}{\delta\left(1 - \dfrac{\delta}{2\rho}\right)\sigma^{2\prime\prime}(\hat{v}) + \dfrac{\Omega}{2}\Sigma^{2\prime\prime}(\hat{v})} > 0 \tag{A.13}$$

Differentiating (A.9) with respect to Ω and using (A.11) yields

$$-\left\{\left[\frac{\rho}{2}(1-\hat{a})^2 + \delta\,\hat{a}\right]\sigma^{2\prime\prime}(\hat{v}) + \frac{\Omega}{2}\Sigma^{2\prime\prime}(\hat{v})\right\}\frac{d\hat{v}}{d\Omega} = \frac{\Omega}{2}\Sigma^{2\prime}(\hat{v}) \tag{A.14}$$

$$\frac{d\hat{v}}{d\Omega} = \frac{-\dfrac{1}{2}\Sigma^{2\prime}(\hat{v})}{\delta\left(1 - \dfrac{\delta}{2\rho}\right)\sigma^{2\prime\prime}(\hat{v}) + \dfrac{\Omega}{2}\Sigma^{2\prime\prime}(\hat{v})} > 0 \tag{A.15}$$

Differentiating (A.9) with respect to δ and using (A.11) yields

$$-\left\{\left[\frac{\rho}{2}(1-\hat{a})^2 + \delta\,\hat{a}\right]\sigma^{2\prime\prime}(\hat{v}) + \frac{\Omega}{2}\Sigma^{2\prime\prime}(\hat{v})\right\}\frac{d\hat{v}}{d\delta} = \hat{a}\,\sigma^{2\prime}(\hat{v}) \tag{A.16}$$

$$\frac{d\hat{v}}{d\delta} = \frac{-\left(1 - \dfrac{\delta}{\rho}\right)\sigma^{2\prime}(\hat{v})}{\delta\left(1 - \dfrac{\delta}{2\rho}\right)\sigma^{2\prime\prime}(\hat{v}) + \dfrac{\Omega}{2}\Sigma^{2\prime\prime}(\hat{v})} > 0 \tag{A.17}$$

Differentiating (A.11) with respect to ρ, Ω and δ is straightforward and yields expressions for $d\hat{a}/d\rho$, $d\hat{a}/d\Omega$ and $d\hat{a}/d\delta$.

A.3 Proof of proposition 4

(i) From Conditions (A.3) and (A.11) it is apparent that $a^* = \hat{a}$.

(ii) As $a^* = \hat{a}$, Conditions (16.22) and (16.28) can be interpreted as equations of functions of the single variable v that determine the levels of v^* and $\hat{v}$, respectively. Both conditions have as their right-hand side the constant c, and as their left-hand side a strictly decreasing function of v, so that v^* and $\hat{v}$ are uniquely determined. As the term $V^{pub}(v) = \dfrac{\Omega}{2}\Sigma^{2\prime}(v)$ is strictly positive for all v, the left-hand side of Condition (16.28) is strictly greater than the left-hand side of Condition (16.22) for all v. As a result the value of v that equates the left-hand side with the right-hand side is strictly greater for Condition (16.28) than for Condition (16.22), i.e. $\hat{v} > v^*$.

(iii) $\hat{W} \geq W^*$ by definition of the efficient allocation as the allocation that maximizes W. Strict inequality follows from strict concavity of W in $\hat{v}$ and $\hat{v} > v^*$.

A.4 Proof of Proposition 5

The first-order conditions for the interior solution of Problem (16.36), which are obtained as $\partial U/\partial v = 0$ and $\partial/\partial a = 0$, are

$$-\left[\frac{\rho}{2}(1 - a^*)^2 + \delta\, a^*\right]\sigma^{2\prime}(v^*) + \tau = c \tag{A.18}$$

$$a^* = 1 - \frac{\delta}{\rho} \tag{A.19}$$

Comparison of Condition (A.18) with Condition (A.9) reveals that

$$v^* = \hat{v} \qquad \text{for} \qquad \tau = \hat{\tau} = -\frac{\Omega}{2}\Sigma^{2\prime}(\hat{v}) \tag{A.20}$$

Employing results (A.13), (A.15) and (A.17), the comparative statics of $\hat{\tau}$ are

$$\frac{d\hat{\tau}}{d\Omega} = -\frac{1}{2}\Sigma^{2\prime}(\hat{v}) - \frac{\Omega}{2}\Sigma^{2\prime\prime}\,\hat{v}\,\frac{d\hat{v}}{d\Omega}$$

$$= -\frac{1}{2}\Sigma^{2\prime}(\hat{v})\left\{1 - \frac{\dfrac{\Omega}{2}\Sigma^{2\prime\prime}(\hat{v})}{\delta\left(1 - \dfrac{\delta}{2\rho}\right)\sigma^{2\prime\prime}(\hat{v}) + \dfrac{\Omega}{2}\Sigma^{2\prime\prime}(\hat{v})}\right\} > 0 \tag{A.21}$$

$$\frac{d\hat{\tau}}{d\rho} = -\frac{\Omega}{2}\Sigma^{2\prime\prime}(\hat{v})\frac{d\hat{v}}{d\rho} < 0 \tag{A.22}$$

$$\frac{d\hat{\tau}}{d\delta} = -\frac{\Omega}{2} \Sigma^{2\prime\prime} (\hat{v}) \frac{d\hat{v}}{d\delta} < 0 \tag{A.23}$$

A.5 Proof of proposition 6

Differentiating W^* (Equation 16.39) with respect to δ yields

$$\frac{dW^*}{d\delta} = -a^* \, \sigma^2 \, (\hat{v}^*) - \frac{\Omega}{2} \Sigma^{2\prime} (v^*) \frac{dv^*}{d\delta}. \tag{A.24}$$

$$\frac{dW^*}{d\delta} \lesseqqgtr 0 \Leftrightarrow -\frac{\Omega}{2} \Sigma^{2\prime} (v^*) \frac{dv^*}{d\delta} \lesseqqgtr a^* \, \sigma^2 \, (\hat{v}^*) \tag{A.25}$$

Employing (A.7), (16) and (20), this condition can be expressed explicitly as

$$-\frac{\Omega}{2} \Sigma^{2\prime} (v^*) \frac{dv^*}{d\delta} \lesseqqgtr a^* \, \sigma^2 \, (v^*) \tag{A.26}$$

$$-\frac{\Omega}{2} \Sigma^{2\prime} (v^*) \lesseqqgtr -\left(\frac{\rho}{2} (1 - a^*)^2 + \delta \, a^* \right) \frac{\sigma^2 \, (v^*) \, \sigma^{2\prime\prime} \, (v^*)}{\sigma^{2\prime} \, (v^*)} \tag{A.27}$$

$$V^{pub} \, (v^*) \lesseqqgtr (v^v \, (v^*, a^*) - \delta \, a^* \, \sigma^{2\prime} \, (v^*)) \frac{\sigma^2 \, (v^*) \, \sigma^{2\prime\prime} \, (v^*)}{[\sigma^{2\prime} \, (v^*)]^2} \tag{A.28}$$

A.6 Proof of Proposition 7

Differentiating the welfare loss (Equation 43) and using $a^* = \hat{a}$ (Proposition 4) yields

$$\frac{d}{d\delta} (\hat{W} - W^*) = a^* \, [\sigma^2(v^*) - \sigma^2(\hat{v})] + \frac{\Omega}{2} \Sigma^{2\prime} (v^*) \frac{dv^*}{d\delta} \tag{A.29}$$

Employing (A.7), (16) and (20), one thus has

$$\frac{d}{d\delta} (\hat{W} - W^*) \gtreqqless 0 \Leftrightarrow$$

$$-\frac{\Omega}{2} \Sigma^{2\prime} (v^*) \frac{dv^*}{d\delta} \gtreqqless a^* \, [\sigma^2(v^*) - \sigma^2 \, (\hat{v})] \tag{A.30}$$

$$-\frac{\Omega}{2} \Sigma^{2\prime} (v^*) \gtreqqless -\left(\frac{\rho}{2} (1 - a^*)^2 + \delta \, a^* \right) \frac{[\sigma^2(v^*) - \sigma^2(\hat{v})] \, \sigma^{2\prime\prime}(v^*)}{\sigma^{2\prime}(v^*)} \tag{A.31}$$

$$V^{pub} \, (v^*) \gtreqqless (V^v \, (v^*, a^*) - \delta \, a^* \sigma^{2\prime} \, (v^*)) \frac{[\sigma^2(v^*) - \sigma^2 \, (\hat{v})] \, \sigma^{2\prime\prime}(v^*)}{[\sigma^{2\prime}(v^*)]^2} \tag{A.32}$$

$$V^{pub}(v^*) \lesseqgtr (V^v(v^*, a^*) - \delta a^* \sigma^{2'}(v^*)) \left(1 - \frac{\sigma^2(\hat{v})}{\sigma^2(v^*)} \right) \frac{\sigma^2(v^*)\,\sigma^{2''}(v^*)}{[\sigma^{2'}(v^*)]^2} \quad \text{(A.33)}$$

Notes

1 Empirical evidence suggests that μ may depend on v (see Section 1). We explored the impact of such relationships in previous versions of the model. Here, we neglect such a dependence of μ on v as it complicates the analysis while not adding further insights into the insurance dimension of the issue under study.

2 For a formal motivation in terms of agro-biodiversity's *insurance value*, see Section 3.1.

3 This benefit/premium-scheme is actuarially fair, because the insurance company has an expected net payment stream of $\varepsilon[a\,(\varepsilon s - s)] = 0$. This model of insurance is fully equivalent to the traditional model of insurance (e.g. Ehrlich and Becker 1972: 627) where losses compared with the maximum income are insured against and the insurant pays a constant insurance premium irrespective of actual income. In this traditional model, the *net* payment would exactly amount to (16.3); for a formal proof see Quaas and Baumgärtner (2008, Appendix A.1).

4 The parameter δ could be treated as a policy variable, as it could be influenced by subsidies or taxes. Yet, in this chapter we treat δ as an exogenous parameter.

5 More general utility functions of the mean-variance type would complicate the analysis without generating further insights.

6 Quaas and Baumgärtner (2008) provide an explicit model of many farmers that shows how public benefits may arise from individual biodiversity management.

7 In case of coorrelated private and public risks Equation (16.12) would generalize to $W = \varepsilon y + \varepsilon B - \dfrac{\rho}{2} \text{var} y - \dfrac{\Omega}{2} \text{var} B - \gamma \text{covar}(y, B)$

8 Formally, $-v\,\dfrac{\partial V^v(v, a)}{\partial v} / V^v(v, a) \equiv \eta$.

9 Recall that we assume $\delta \leq \rho$ throughout in order to focus on interior solutions. For $\delta > \rho$, the optimization problem (16.21) would have a corner solution, $a^* = 0$, with $da^*/d\rho = da^*/d\delta = 0$.

10 This level can be determined from setting $a = 0$ in Problem 16.21 and maximizing over v. It is strictly smaller than v^* for all $\delta < \rho$ and equals v^* for $\delta \geq \rho$, i.e. in cases where financial insurance is so expensive that an optimizing farmer would not buy it.

11 This follows from applying the envelope theorem on total welfare (16.12) with respect to δ.

References

Arrow, K. J. (1965) Aspects of the theory of risk-bearing. Yrjö Jahnssonin Säätio Lecture. Reprinted with modifications in: K. J. Arrow, *Essays in the Theory of Risk Bearing*, Chicago: Markham, 1971.

Baumgärtner, S. (2007) 'The insurance value of biodiversity in the provision of ecosystem services', *Natural Resource Modeling* 10(1): 87–127.

Birol, E., Kontoleon, A. and Smale, M. (2006a) 'Farmer demand for agri-cultural biodiversity in Hungary's transition economy: a choice experiment approach', in M. Smale (ed.), *Valuing Crop Biodiversity on Farms during Economic Change*, Wallingford, UK: CAB International Publishing.

Birol, E., Smale, M. and Gyovoi, A. (2006b) 'Using a choice experiment to estimate farmers' valuation of agrobiodiversity on Hungarian small farms', *Environmental and Resource Economics* 34: 439–469.

Bramoullé, Y. and Treich, N. (2005) 'Can uncertainty alleviate the commons problem?' Discussion Paper, University of Toulouse.

Dasgupta, P.S. and Heal, G.M. (1979) *Economic Theory and Exhaustible Resources, Cambridge*: Cambridge University Press.

Di Falco, S., Chavas, J.-P. and Smale, M. (2007) 'Farmer management of production risk on degraded lands: wheat diversity in Tigray region, Ethiopia', *Agricultural Economics* 55(4): 459–466.

Di Falco, S. and Perrings, C. (2003) 'Crop genetic diversity, productivity and stability of agroecosystems: a theoretical and empirical investigation', *Scottish Journal of Political Economy* 50(2): 207–216.

Di Falco, S. and Perrings, C. (2005) 'Crop biodiversity, risk management and the implications of agricultural assistance', *Ecological Economics* 55(4), 459–466.

Durrett, R. and Levin, S. (1996) 'Spatial models for species-area curves', *Journal of Theoretical Biology* 179: 119–127.

Ehrlich, J. and Becker, G. S. (1972) 'Market insurance, self-insurance and self-protection', *Journal of Political Economy* 80: 623–648.

Heal, G., Walker, B., Levin, S., Arrow, K., Dasgupta, P., Daily, G., Ehrlich, P., *et al.* (2004) 'Genetic diversity and interdependent crop choices in agriculture', *Resource and Energy Economics*, 26: 175–184.

Hooper, D. U., Chapin III, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J. H., *et al.* (2005) 'Effects of biodiversity on ecosystem functioning: a consensus of current knowledge', *Ecological Monographs* 75(1): 3–35.

Horowitz, J.K. and Lichtenberg, E. (1993) 'Insurance, moral hazard and chemical use in agriculture', *American Journal of Agricultural Economics* 75: 926–935.

Horowitz, J.K. and Lichtenberg, E. (1994a) 'Crop insurance and agricultural chemical use', in D. Hueth and H. Furtan (eds) *Economics of Agricultural Crop Insurance: Theory and Evidence*. Norwell, MA: Kluwer.

Horowitz, J.K. and Lichtenberg, E. (1994b) 'Risk-increasing and risk-reducing effects of pesticides', *Journal of Agricultural Economics* 45(1): 82–89.

Kinzig, A., Pacala, S. and Tilman, D. (2002) *The Functional Consequences of Biodiversity: Empirical Progress and Theoretical Extensions*. Princeton, NJ: Princeton University Press.

Kreps, D.M. (1990) *A Course in Microeconomic Theory*. New York: Harvester Wheatsheaf.

Loreau, N., Naeem, S. and Inchausti, P. (2002) *Biodiversity and Ecosystem Functioning: Synthesis and Perspectives*. Oxford: Oxford University Press.

Loreau, N., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J. P., Hector, A., Hooper, D.U., Huston, M. A. *et al.* 'Biodiversity and ecosystem functioning: current knowledge and future challenges', *Science* 294: 804–808.

Luo, H., Skees, J. R. and Marchant, M. A. (1994) 'Weather information and the potential for intertemporal adverse selection', *Review of Agricultural Economics* 16: 441–451.

Mahul, O. (2001) 'Optimal insurance against climatic experience', *American Journal of Agricultural Economics* 83: 593–604.

Miranda, M. J. and Vedenov, D. V. (2001) 'Innovations in agricultural and natural disaster insurance', *American Journal of Agricultural Economics* 83: 650–655.

Pratt, J. W. (1964) 'Risk aversion in the small and in the large', *Econometrica* 32(1–2): 122–136.

Quaas, M. F. and Baumgärtner, S. (2008) 'Natural vs. financial insurance in the management of public-good ecosystems', *Ecological Economics* 65(2): 397–406.

Sandler, T. and Sterbenz, F. P. (1990) 'Harvest uncertainty and the tragedy of the commons', *Journal of Environmental Economics and Management* 18(2): 155–167.

Sandler, T., Sterbenz, F. P. and Posnett, J. (1987) 'Free riding and uncertainty', *European Economic Review* 31(8): 1605–1617.

Schläpfer, F., Tucker, M., and Seidl, I. (2002) 'Returns from hay cultivation in fertilized low diversity and non-fertilized high diversity grassland', *Environmental and Resource Economics* 21: 89–100.

Skees, J. R., Varangis, P., Larson, D. and Siegel, P. (2002) 'Can financial markets be tapped to help poor people cope with weather risks?' Technical report, World Bank, Washington DC.

Smale, M., Hartell, J., Heisey, P.W. and Senauer, B. (1998) 'The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan', *American Journal of Agricultural Economics* 80: 482–493.

Tilman, D. (1997) 'Distinguishing between the effects of species diversity and species composition,' *Oikos* 80: 185.

Widawsky, D. and Rozelle, S.D. (1998) 'Varietal diversity and yield variability in Chinese rice production', in M. Smale (ed.) *Farmers, Gene Banks, and Crop Breeding: Economic Analyses of Diversity in Wheat, Maize, and Rice*. Boston: Kluwer, pp. 159–172.

World Bank (2004) 'Mongolia—Index-Based Livestock Insurance Project', Technical report, World Bank, Washington, DC.

Wu, J. J. (1999) 'Crop insurance, acreage decisions, and nonpointsource pollution', *American Journal of Agricultural Economics* 81: 305–320.

Zhu, Y., Chen, H., Fan, J., Wang, Y., Li, Y., Chen, J. , Fan, J.X., *et al.* (2000) 'Genetic diversity and disease control in rice', *Nature* 406: 718–722.

17 Determinants of collaborative conservation costs of *Coffea arabica*'s wild population in montane rainforest of southwestern Ethiopia

Aseffa Seyoum, Bezabih Emana,
Franz W. Gatzweiler and Belaineh Legesse

1 Introduction

Ethiopia is endowed with biodiversity due to variation in its altitude and climate. There are about 6,500 to 7,000 species of flowering plants, conifers and ferns in Ethiopia, of which 12 per cent are endemic (Tedla and Gebre 1998). The country serves as a source of genetic resources of different species of crops such as coffee. Coffee is the most important agricultural commodity in Ethiopia, both economically and socially. It is one of the most important export crops. The country ranks ninth in coffee exports which generate over 60 per cent of the country's foreign earning (EEA 2000: 257). Despite its importance, the wild population of *Coffea arabica* is increasingly endangered as a result of deforestation, production of alternative crops, and settlement of immigrants. High population pressure and continuing declining in soil fertility in farm areas have been the major reasons for this ecosystem degradation. To the local community, forest land serves as their main means of livelihood in order to meet their subsistence requirement while it also has a risk buffering role (Ejigie 2005: 89) in that provides the means for smoothing income fluctuations. This creates a commonly observed conflict between the efforts for biodiversity conservation on the one hand and the need of forest land conversion and exploitation on the other. This conflict unavoidably puts biological diversity in danger of extinction.

The extent of degradation of the natural resource is severe. Loss of *Coffea arabica* genetic resource ultimately has considerable economic loss both for Ethiopia but also globally, especially with the current prevalence of specific biotic and abiotic[1] agricultural problems (Gole 2003: 2). Hence, there is a need to develop suitable conservation strategies to safeguard coffee genetic diversity along with the entire spectrum to maintain its ecological, social and economic value to the community, to the nation and to the world.

There are two basic strategies for biodiversity conservation: ex situ and in situ (Conrad and Salas 1993: 404). Ex situ and in situ conservations cannot

be an alternative means of achieving the same goal (Brush 2000: 3). There is a recognition that these methods address different aspects of genetic resource conservation, and neither of them alone is sufficient to conserve the whole range of genetic resources that exist. The former has the advantage of easy accessing and good documentation for breeders. The latter conservation approach serves as a continuous source of germplasm for ex situ conservation (Gole 2003: 24). It enables to preserve the evolutionary process that generates new germplasm under conditions of natural selection to maintain those components in living and viable ecosystems (Swanson and Goeschl 2000: 167).

Currently, FARM Africa[2] is implementing a major collaborative conservation project to attain sustainable conservation of natural forest with its biodiversity through the establishment of forest users groups. However, there is hardly any empirical evidence on the costs of this programme nor on the determinants of farmer's willingness to participate in the conservation of these natural resources. Therefore, the objective of the present study was fill this void and to estimate the costs incurred by the local people by participating in this collaborative conservation project of wild varieties of *Coffea arabica* in the montane rainforest of Ethiopia. Further we identified the factors that explain participation of the local people in the specific collaborative conservation project as well as the determinants of its conservation cost.

2 Conceptual and empirical framework

One can classify approaches for the conservation of biodiversity into two broad categories: strict protection and economic incentives. Under strict protection approaches, the policy instruments specify standard regulations that aim at internalizing the negative externalities imposed on genetic resources and stipulate a range of penalties for non-compliance. While in case of economic incentives, the policy instruments aim at reducing losses of biodiversity through their effect on resource value. The latter approach uses a range of instruments such as market based schemes and social incentives to achieve sustainable conservation of biodiversity (Mburu 2004: 1–5). The collaborative conservation concept is an economic incentive approach to in situ conservation of biodiversity enabling economically viable and ecologically suitable levels of resource extraction, particularly in the so-called 'buffer zone' of a protected area.

The viability of collaborative *Coffea arabica* genetic resource conservation in montane forest depends on the net benefits that local people perceive to gain from their participation in the scheme. Therefore, the participation decision of the household depends on their benefits of participation as compared to the cost of non-participation. The benefits to the household's participation in the scheme are derived from the timber and non-timber forest products that they are entitled to harvest by virtue of being a member of the forest user group. Whereas costs of the strategy includes the opportunity costs,

transaction costs[3] and costs due to wildlife attacks on household's property within the conservation area (Ferraro 2001: 7; Mburu *et al.* 2003: 61).

Opportunity cost of conservation is the value of whatever other economically important activities are foregone in order to preserve biological diversity in natural habitats (Richards *et al.* 2003: 29). It is the benefit that the local community loses under the conservation strategy and can be estimated using measures of either the additional expenditure spent to maintain the status quo (Kramer *et al.* 1995: 25) or of the loss of benefits due to the absence of the resources which provide that services. In addition, households experience various transaction costs that cause disparity in the costs incurred under different conservation strategies. There are different conceptions of transaction costs in the literature in the context of genetic resource conservation. For instance, Sexena *et al.* (2004: 9) considers these as costs associated with different transaction activities related to keeping germplasm in gene banks while Mburu *et al.* (2003: 61) defined transaction cost as costs incurred in the establishment and implementation of institutional arrangements necessary for conservation programmes. In our case, these costs comprise of time and labour spent for participation in conservation activities such as afforestation of open spaces, meetings, and patrolling.

Generally, the costs of in situ conservation to the local people depend on their socio-economic characteristics, their resource endowment, conservation area characteristics, and level of participation (Zegeye 2004: 149). Moreover, Mburu *et al.* (2003: 69) identified that conservation benefits to farm households depends on stated socio-economic factors which in turn impact on households' participation in conservation activities. Accordingly, the inter-relationships between costs of collaborative conservation, levels of participation in the strategy, and their relationships with the socio-economic characteristics of the local people is conceptualized in Figure 17.1.

2.1 Definition of variables and working hypotheses

The dependent variable in the first stage of the empirical analysis is the household participation decision in the conservation programme. Participation in the collaborative strategy means that the household is a member of the forest user group which was established to take the responsibility of conserving and proper utilization of the forest. The model used to analyze the determinants of participating is a binary discrete choice model, with the dependent variable taking the value one for participating households and zero otherwise. In the second stage, the dependent variable is the total cost in Ethiopian Birr (ETB) that the farm household incurs due to collaborative conservation of *Coffea arabica*. This is a continuous variable estimated per household.

The explanatory variables that were hypothesized to influence the participation decision of farm households' participation and total cost of the programme for the conservation of *Coffea Arabica* were based on *a priori*
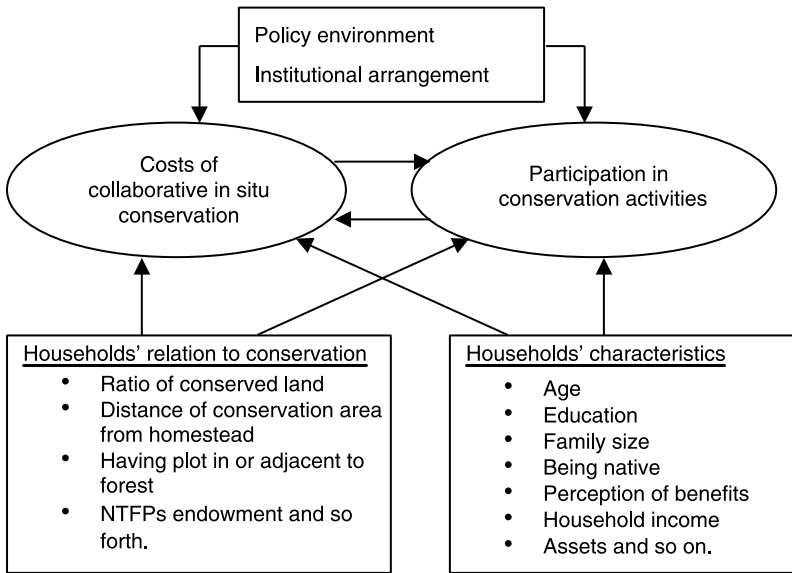
Figure 17.1 Conceptual framework of in situ conservation costs of *Coffea arabica*.
Source: Own formulation.

knowledge and the conceptual framework developed above. These include demographic features of the household such as family size, age and education of the household head, resource endowment, the level of dependency on the natural forest and conservation area characteristics such as its distance from household residence.

Family size is measured as the total number of people living in the same home. It is a continuous variable used as a proxy variable for household labour supply. Households with a large family size are expected to participate more in collaborative conservation and this is expected to enhance the benefit the household receives from the conservation area and reduces its costs. Moreover, an older household head is assumed to be more conservative and less likely to participate in conservation intervention (Featherstone and Goodwin 1993: 76). This type of household may also not have sufficient labour to harvest forest products from the conservation area and may be less dependent on natural forest such that the variable may be negatively related to the cost of conservation (Mburu *et al.* 2003: 70).

Educated farmers are expected to have more contact with forestry experts and have better understanding of the benefits of conservation (Mburu *et al.* 2003: 69). Native people living in the conservation area are expected to be more concerned about the natural forest because of a stronger 'sense of place' and social attachment. Hence, these variables are hypothesized to be related positively to participation in conservation and negatively to cost of conservation. Location of household in relation to the forest area such as

walking distance to the forest (Ejigie 2005: 85), whether or not a household has farming plot adjacent to the conservation area, households' perception of expected benefit, and intensity of damage on their properties (crop and livestock) from wildlife that come from the conservation area are expected to influence household participation decisions as well as its costs of conservation.

The household benefits (in ETB per year) from harvesting of forest products from the conservation area (including non-timber forest products) before its demarcation as protected area are expected to negatively influence participation in conservation activities and positively conservation costs (Konyar and Osborn 1990). Current demand for farm inputs and timber forest products from a given conservation area is also expected to positively influence the participation in collaborative conservation. In addition, household resource endowment such as livestock, forest coffee and cropland holdings, as well as total household income are hypothesized to affect conservation costs that accrue to households. Total income of household refers to the revenue from farm and off-farm activities for the year 2003/04, measured in local currency, Ethiopian Birr (ETB).

3 The study

3.1 Site characteristics

The study was conducted in Bonga forest located 440 Km southwestern of the country. The forest area is located in the Southern Nation, Nationalities and People's (SNNP) Region, which is one of the nine regional states of Ethiopia in the Kaffa administrative zone. Bonga forest stretches over a total area of about 161,424 ha. The altitude ranges from 1000 to 3350 m above sea level (Bekele 2003: 1). Part of Bonga forest found in Gimbo district, the specific study area, covers about 22,539 ha. It is a broad-leaved tropical forest designated as a National Forest Priority Area. The dominant species comprising the natural vegetation at the canopy level are *Aningeria adolfi, Friedericii, Ficus spp, Olea welwitschii, and Cordia africana Schefflere abyssinica*. Moreover, the middle canopy species are *Phoenix reclinata, Maesa lanceolata* and *Milletia feruginea*. The very important undergrowth species that constitutes a considerable part of the natural forest are *Coffea arabica, Aframomum korerima* and *Piper capense* (FARM Africa 2002: 14).

The natural forest in the study area remains a very important source of farm inputs and timber for local construction. In addition, resettlement and investment activities (organic coffee production) have been carried out in the area. These activities did not take into consideration the degradation of natural forest and loss of wild population of *Coffea arabica*. The study area was, therefore, selected deliberately for two reasons. First, there is conflict between the interests of the local community and the global objective of biological diversity conservation. Second, there is the implementation of collaborative

scheme for sustainable conservation of natural forest with wild population of *Coffea arabica*. Accordingly, there are six forest user groups established in the area. These user groups are at different stages of development. *Agama*, *Wacha*, and *Baka* forest user groups are well organized and certified as forest conservation and development cooperatives. While the remaining three forest-user groups (*Matapa*, *Obera* and *Dara*) are at early stages of establishment.

3.2 Data collection

The study was based on both primary and secondary data sources. The primary data were collected from households located in Bonga coffee forest of Gimbo district. Then, a two-stage random sampling technique was adopted to identify sample respondents from this purposively identified district. Based on first-hand information from a pilot survey, four sample PAs were drawn in the first stage while 99 households were selected randomly, in the second stage, using probability proportional sampling techniques.

Primary data were collected through focus group discussions, and face-to-face interviews with randomly sampled household heads. A structured questionnaire consisting of socio-economic variables, land holding and use, coffee ownership under different management practices, benefits received by households before and after establishment of conservation strategies, etc. was used for data collection. In addition, transaction costs of participation and other relevant information in relation to the area under conservation were obtained.

Moreover, the information generated through the structured questionnaire was supplemented by focus group discussions (FGD) made with the local people and secondary data collected from FARM Africa. Field data collection was undertaken from October to December 2004.

The analytical model

In order to meet the objectives of the study, both descriptive and econometric analyses were used. First, costs of collaborative in situ conservation activities were estimated. Then, econometric models were fitted to identify the factors influencing household participation in the conservation activity and determinants of conservation costs incurred by farm households. Since the costs incurred by the farm household depend on whether or not the farm households participate in *Arabica* coffee conservation while at the same time the household participation decision also depends on the costs they incur due to their participation, we have a likely endogeneity problem (Smith and Blundell 1986: 679).

This endogeneity problem can be handled econometrically through 'treatment effect' model. This model is estimated using a two-stage least squares (2SLS) method (Greene 2003: 787). The two-stage method consists

of successive estimation of qualitative and quantitative aspects of the model. In Equation (17.1), *I* implies the presence or absence of a treatment effect, which in our case is the status of participation. Thus, in the first stage, the determinants of participation decision were estimated using a binary probit regression model. According to Maddala (1983: 22) the probit model is specified as:

$$I_i^* = a + \delta X_i + \varepsilon_{1i} \tag{17.1}$$

Where

I$_i$ = 1 if I$_i^*$ > 1, the farmer participates in *Coffea arabica* conservation
I$_i$ = 0 if I$_i^*$ ≤ 0, otherwise.
X_i are exogenous variables where i = 1, 2,. . . .,16, as shown in Table 17.1.
δ is vector of parameters to be estimated;
α is the intercept term;
ε_{1i} is the disturbance term.

In the second stage, determinants of costs that accrue to farm households from collaborative conservation of montane rainforest with arabica coffee were identified using Equation (17.2). Participation in conservation was included as an explanatory variable in the identification of the determinants of the cost incurred by farm households.

$$C = f(X_i, I_i) \tag{17.2}$$

Following Greene (2003: 787), the regression model can be further specified as:

$$C = \gamma + \beta_i X_i + \nu I_i + \varepsilon_{2i} \tag{17.3}$$

Where *C* is total cost incurred by households due to in situ conservation of *Coffea arabica*;

X_i = Explanatory variables as defined earlier in Equation (17.1)
I$_i$ = Participation in conservation
β_i and ν are coefficients of parameters to be estimated;
γ is the intercept term;
ε_{2i} is the random term.

The 2SLS model was estimated using the maximum likelihood method to identify the determinants of participation and cost of conservation.

Moreover, the presence of heteroskedasticity and multicollinearity were explored as these are common problems in the econometric analysis of cross-sectional data (Greene 2003: 215). Heteroskedasticity was accounted for

using robust estimation routines provided in the software package used. The severity of multicollinearity among explanatory variables was checked by using a Variance Inflation Factor (VIF) comparison (199: 328) and on the basis of which no serious multicollinearity problems was found. It is also important to explore the associations between dummy explanatory variables that were included in the model. This was checked by the computation of contingency coefficients for each pair of categorical variables. Once the variables to be included in the econometric model were decided, the treatment effect model was estimated using a two-stage least squares method using the LIMDEP econometric software. Description of variables considered for inclusion in the model is provided in Table 17.1 while summary statistics are provided in Table 17.2.

5 Results and discussion

5.1 Socio-economic characteristics of the sampled households

Labour availability is a major factor affecting participation in social and economic activities. Family size is a source of labour supply that determines participation of a household in forest coffee conservation. The average family size of sampled households was 6.68 and 6.72 for non-participants (NP) and participants (P) respectively. Yet, there was no significant difference between the NP and P groups in terms of mean family size. Economically active family members with the age of 15–64 years were 3.39 and 3.56 for participants and non-participants, respectively, while the dependency ratio for two groups was 1.17 and 1.07 in the same order. The education level of household head was defined as a categorical variable with about 50 per cent of the sampled households found to be illiterate. The remaining half of attended at least primary education. However, there was no statistically significant difference in literacy levels between the participants and non-participants.

Distance of conservation area from homestead of a farm household influences the participation in conservation of natural forest. The results show that participants live relatively closer to the conservation area as compared to the non-participants although the difference is not statistically significant.

Landholding of farm households is also one of the basic resources that affect decisions on agricultural production and conservation activities (Konyar and Osborn 1990). The average total landholding of non-participants in our sample was 2.73 ha which was slightly larger than that of the participants (2.08 ha) even though it is not statistical significant (see Table 17.3). Crop production is the primary farming activity of the respondents. Generally, cereals and coffee were the major crops grown followed by pulse, horticultural and other perennial crops like *khat*[4] and *enset* (false banana). About 30 per cent of the sampled households have forest or semi-forest coffee plots in the collaboratively conserved area while about 26 per cent of the total holding of the sampled households is under coffee production.

Table 17.1 Definition of the dependent and explanatory variables

Variable code	Description	Expected sign	
		Participation	Total cost
Total cost	Total cost of in situ conservation of *Coffea arabica* to household in ETB per household[a]		Total cost
Participation	Dummy with 1, if the household participates collaborative conservation; 0, otherwise.	Participation	
Family size	Family size in number	+	−
Age	Age of household head in years	−	+
Education	Dummy with 1, if the household attended formal education; 0, otherwise.	+	−
Native	Dummy with 1, if the household is native to the area; 0, otherwise	+	−
Oxen	Number of oxen owned	−	+
Livestock	Total livestock holding in TLU	−	+
Distance	Distance of conservation area from home stead of household in walking hours	−	−
Adjacent farm to forest	Dummy with 1, If the farmer have farm plot(s) in or adjacent to the conservation area; 0, otherwise.	+	−
Prior benefits	Benefits to the household as NTFPs before the natural forest was brought under conservation in ETB.	+	+
Forest coffee	Forest and semi-forest coffee plot owned in ha.	+	+
Crop land	Cropland holding of household in ha.	−	−
Perception	Dummy with 1, if the household perceives that conservation of *Coffea arabica* is beneficiary; 0, otherwise.	+	−
Inputs	Current forest product demand of household in the form of farm and other inputs from the conservation area per year in ETB.	−	+
Wildlife attack	Loss on households' property due to wildlife attack from conservation area in ETB.	−	+
Income	Total income of household in 2003/04 in ETB.	+	−
Ratio of conserved land	The ratio of land in the conservation area to the total land of the household in ha.	−	+

Notes: [a] Total cost includes the opportunity cost and transaction cost of in situ conservation.

Table 17.2 Summary statistics of explanatory variables

Variables	% of dummy with value of 1	Mean	SD
Family size		6.69	2.33
Age of household head		41.83	12.49
Oxen number		1.16	0.88
Livestock number		3.94	3.23
Distance (hrs)		0.41	0.52
Prior benefits (ETB)		1056	1200
Own forest coffee (ha)		0.29	0.76
Crop land (ha)		2.01	1.95
Inputs (ETB)		73.89	76.63
Wildlife attack (ETB)		404.57	340.46
Total income (ETB)		1371.61	1740.01
Ratio of conserved land		0.09	0.19
Education	50.5		
Being native	72.7		
Adjacent farm to forest	53.5		
Perception	79.8		
Participation	53.5		

Source: Own survey result, 2004.

Table 17.3 Socio-economic characteristics of sampled respondents

Characteristics	Participants	Non-participants	t-value	All case
Family size	6.68	6.72	−0.080	6.69
Dependency ratio	1.17	1.07	0.646	1.13
Distance (hrs)	0.36	0.46	−0.928	0.41
Fallow land (ha)	0.03	0.15	−2.752[a]	0.08
Cropland (ha)	2.08	2.73	−1.352	2.38
Oxen	0.9	1.4	−2.827[a]	1.2
Cattle	1.9	2.9	−2.032[b]	2.3
Small ruminant	0.2	0.2	0.229	0.2
Others[a]	0.2	0.3	−0.128	0.2
Total livestock	3.2	4.8	−2.230[b]	3.9
Education level	%	%	χ^2	
Illiterate	49.1	50.0	0.661	49.5
Primary	30.2	23.9		27.3
Secondary	20.8	26.1		23.2

Source: Own survey result, 2004.
Notes: a, b statistically significant at 1 per cent and 5 per cent probability levels, respectively.
[a] Include horses, donkeys, mules and chicken.

The average total livestock holding of participants and non-participants was 3.2 and 4.8 TLU, respectively. The difference is statistically significant and this could be due to the fact that most of the members of the forest user groups (participants) are highly dependent on the forest for their livelihood. About 23 per cent of the sample did not own oxen, while 5 per cent had no

livestock at all. The maximum number of oxen and total livestock unit per household was 4 and 17.4, respectively.

5.2 *Collaborative in situ conservation and its cost to local people*

Collaborative in situ conservation is a strategy to hand over the responsibility of conservation and sustainable use of natural resources to the local community through the establishment of forest user groups (Mburu 2004: 2). It turns the *de facto* open access state forest to regulated and controlled access. This scheme works by first establishing the forest user groups (FGUs) and by developing their management plan. Then, an agreement is signed with the local government based on the management plan for conservation and utilization of natural forest for five years. The agreement defines the roles and responsibilities of the forest user groups as well as that of the government. Accordingly, the user groups protect the forest from destruction and at a minimum preserve forest quality to the level it had been at the time of handover from the government. The local government provides technical support in terms of training and legal support to enforce rules and regulations. It also undertakes monitoring and evaluation activities in the process of implementation of the plan based on assessment of the status of each patch of forest during the establishment of FUGs.

In this strategy, members of the FGU are permitted to harvest forest products for house construction and farm inputs while non-members are not entitled to such use. Participants of the management strategy have regulated rights to harvest timber and non-timber forest products for household consumption on an individual basis. Income from forest coffee and other products harvested from the conserved area is distributed among members based on their level of participation in the production of these goods. The implementation of the plan is facilitated and coordinated by elected executive committees. Moreover, access to the natural forest is possible through permission from this committee. This reduces the benefits of participant households as compared to the open access case while non-participants lose the entire benefit that they used to receive from harvesting from conservation area prior to its designation.

On top of this, there are frequent meetings, and other obligations that participants are expected to undertake such as forest development and protection activities in order for them to continue to be members of the user group. These entail additional costs of conservation to the local household that can be categorized into three components: opportunity cost, transaction cost and cost due to wildlife attacks. Opportunity cost as forgone benefits from forest products was estimated at market price (Tietenberg 1992: 25). For those commodities that have no market price, proxy values were considered. Transaction cost was estimated as time, labour and money spent in conservation activities. The other cost component, wildlife attack is the value of livestock and crops damaged by wildlife estimated at local market price.

The opportunity cost of participating households was on average 580.43 ETB per year while it was 780.93 ETB per year for non-participants (see Table 17.4). The mean opportunity cost is not significantly different between the two groups. The sample participants incur a transaction cost of on average 185.78 ETB per year per household while non-participants incur only 0.65 ETB per year (spent mostly for conflict resolution). Participation involves transaction cost, which are significantly different between participants and non-participants (at the 1 per cent significance level). However, cost due to wildlife attack was 368.59 ETB per year for participants and about 445.68 ETB per year for non-participants, which was not statistically significant difference. This is perhaps due to variations in the extent of loss and value of households' property attacked by wildlife.

The total conservation cost of *Coffea arabica* in its natural habitat to the local people, under collaborative conservation strategy was, therefore, approximately 1135 ETB per year for participants while it was 1227 ETB per year for non-participants. Even though participation involves high transaction cost, the participants still bear lower overall cost of conservation. However, the mean cost difference between the two groups was not significant. This may imply ineffective implementation of the strategy, which means participants could not generate significant benefits from participation in the collaborative conservation schemes.

In addition, there are also social costs[5] with the collaborative in situ conservation strategy in the area, which were actually not included in the monetary value mentioned above. The participants in our focus group discussions noted that there was lack of clarity in the criteria as to how to exclude those who are not part of a particular forest user group. As a result there are some social as well as economic conflicts among members of the user groups and the non-users. This is basically between the *de facto* owner of some parts of the forest before the establishment of the forest user groups, and the new members or those considered as outsiders during the formation of the forest user groups. The new members did not have *de facto* owned plot(s) in the forest area while it was under state protection.

Table 17.4 Conservation costs of collaborative strategies at household level in ETB per year

Variables	P	NP	t-value
Opportunity cost	580.43	780.93	−1.237
Transaction cost	185.78	0.65	8.197[a]
Wildlife attack	368.59	445.68	−1.119
Total cost	1134.80	1227.26	−0.512

Source: Own survey result, 2004; a statistically significant at 1 per cent probability level.

5.3 Econometric analysis

Participation in collaborative conservation of natural forest with wild population of *Coffea arabica* is a combined effect of a number of socio-economic characteristics of the households and the linkage with the conservation area. The sign, magnitude and level of significance of the determinant estimators of participation and collaborative conservation costs of *Coffea arabica* in its natural habitat are given in Table 17.5.

The significant variables included in the treatment effect model are shown in Table 17.5. Number of oxen owned, having farm plots in or adjacent to the conservation area, benefit before conservation, and ratio of conserved land are found to have a significant impact on participation in collaborative conservation strategy. The cost of collaborative conservation is affected significantly by number of oxen, total livestock size, presence of farm plot in or adjacent to the conservation area, amount of forest and semi-forest coffee

Table 17.5 Determinants of participation and conservation costs functions

Variables	Participation decision		Cost function	
	Coefficient	t-value	Coefficient	t-value
Constant	−1.03979	−1.169	−1.75.398	−0.419
Family size	0.07428	1.005	28.919	0.802
Age	0.01245	0.806	−2.629	−0.325
Education	0.02253	0.110	66.761	0.741
Native	0.23717	0.609	–	–
Oxen	−0.79764	−2.159[b]	679.700	3.772[a]
Livestock	0.01699	0.197	−64.766	−1.648[c]
Distance to home stead	0.01852	0.063	31.804	0.257
Adjacent farm to forest	0.77218	2.188[b]	−311.695	−1.640[c]
Prior benefits (ETB)	0.00054	3.318[a]	–	–
Forest coffee (ha)	0.03052	0.756	42.055	2.448[a]
Crop land (ha)	−0.01922	−1.290	13.517	2.321[b]
Inputs (ETB)	0.00133	0.465	–	–
Perception	0.61267	1.556	–	–
Wildlife attack	−0.00047	−0.914	–	–
Income (ETB)	−0.00005	−0.373	−0.117	−2.018[b]
Ratio of conserved land	−3.08430	−2.072[b]	831.025	1.447
Predicted Participation	–	–	1046.063	3.567[a]
Log likelihood function	−47.97			
Restricted log likelihood	−68.37			
Chi-squared.	40.80[a]			
Adjusted −R[2]			0.3371	
F-value			5.15[a]	
Valid cases	99		99	
Correctly predicted observations	70.70			

Note: a, b, c statistically significant at 1 per cent, 5 per cent and 10 per cent probability levels, respectively.

owned by the household, cropland, income level, and the level of participation in the conservation activities.

The econometric model output shows that the number of oxen owned by the household has a negative and significant impact on participation. This is consistent with the result of Featherstone and Goodwin (1993: 76). The possible explanation is that households who have oxen may have a comparative advantage in crop cultivation and may not be willing to bear the transaction costs of collaborative conservation. As these households are not permitted to harvest forest products from the conservation area, the variable has a positive and significant impact on the cost of conservation. Livestock holding which is considered as a proxy variable for wealth status of households in the study area is also related negatively with costs of collaborative conservation strategy. Thus, households with more livestock holding are less likely to depend on natural forest as a means of livelihood which in turn implies that conservation would not be profitable for such households.

Having plot(s) adjacent to the conservation area was positively related to the level of participation while it has a negative relationship with the cost of conservation, which is significant at the 5 and 10 per cent probability level respectively. This implies that local households with land adjacent to the conservation area are more likely to participate in collaborative in situ conservation. Moreover, households with farm plot(s) out of the conservation area or at a distance incur lower cost of conservation. This implies that they are less dependent on the natural forest. On the other hand, benefits that the households used to harvest from the conservation area prior to the programme have a positive and significant relationship with participation in collaborative conservation. This implies that households who were dependent on the conservation area before the intervention tend to participate more in the collaborative conservation scheme.

In addition, the regression output reveals the existence of a positive relationship between costs of collaborative conservation and forest/semi-forest coffee holding of the household. This shows that households with more forest and semi-forest coffee holding are likely to incur higher costs in the conservation of natural forest with coffee. The possible explanation for this is that these households have forest and semi-forest coffee under *de facto* land holding in the conservation area, which they lost after the conservation intervention. Thus, the benefits they used to harvest from the conservation area decreased under this form of regulated access to the conserved area. This, in turn, increases the cost of conservation to these households. Cropland holding, which refers to access to lands that are out of the forest area, is also found to be related positively and significantly to the cost of collaborative in situ conservation. The possible explanation could be that households having more cropland may have a comparative advantage in crops production than in forest product extraction. As a result, they may not join the forest user groups that are established to conserve and use forest products. Yet this in turn entails that they are no longer permitted to collect forest products that

they used to harvest which may result in higher costs of the conservation strategy to households with more cropland.

Households with high income might have sources of income other than forest coffee. The income variable (total household income during the survey year) is found to have a negative relationship with the cost of conservation. It implies that households with better livelihood situations are less dependent on the natural forest with *Coffea arabica* such that conservation of natural forest results in lower cost to the households. The ratio of land under *de facto* ownership of household in the conservation area to the total land holding of the household has a negative and significant relationship with participation. This implies the existence of a significant number of households with *de facto* individual land holdings in collaborative conservation but which are not members of forest user groups. Yet, as hypothesized, the model output reveals that participation in collaborative conservation activities has a positive sign and strong relationship with conservation costs. This suggests that participation in collaborative conservation strategy results in considerable costs to the local people. It also implies that the benefits, which the participants are currently generating from the conservation area, are not sufficient to offset their costs.

6 Conclusion

An important conclusion stemming from the results of the descriptive analysis is the existence of significant differences in resource endowments and level of transaction costs incurred between participants and non-participants of collaborative in situ conservation. Moreover, the econometric analysis revealed that the number of oxen owned, having farm plots in or adjacent to the conservation area, benefits used to be earned before conservation, and ratio of conserved land have significant effect on participation of the households in collaborative conservation. In addition, variation in conservation costs of the collaborative strategy is significantly explained by the number of oxen owned and livestock holding, having farm plot in or adjacent to the conservation area, forest coffee, cropland, income, and participation in conservation.

The local people incur significant cost due to conservation of a given natural forest with *Coffea arabica*. This creates conflict between the local community and conservation intervention. A conservation strategy that minimizes the costs borne by households or compensating households may mitigate conflicts and improve sustainability of the conservation goals. Compensation issues may give rise to practical problems from equity, efficiency and ethical points of view. It is hardly possible to determine the level of appropriate compensation to each household and the recipients. So it would be preferable to go for a conservation approach that will minimize costs of conservation to the local communities and at the same time enable sustainable conservation of *Coffea arabica* biodiversity.

Collaborative conservation being implemented in the study area does not prohibit the forest user groups from accessing every part of the forest and provide the user rights to plant different fruit trees, manage them and so on, which may threaten biodiversity conservation of these targeted species. Therefore, conservation of *Coffea arabica* in natural forest may be achieved through a zoning scheme so that an outer buffer zone can be managed under a collaborative conservation strategy while stricter protection of the inner (core) zone could be adopted under the responsibility of the local communities. This strategy may enable the local community to share both the responsibilities to conserve biodiversity and benefit from these conservation efforts. Such an approach may also minimize the costs and increase the effectiveness of the strategy.

Notes

1 Biotic problems refer to biological factors associated with the production of coffee such as diseases, while abiotic problems include non-biological factors linked with coffee production such as erratic rainfall, drought etc. (Gole 2003: 1).
2 FARM Africa is one of the non-governmental organizations in Ethiopia that is involved in rural development and natural resource conservation activities.
3 Transaction costs include costs of enforcement, which is related to monitoring and evaluation and time spent in applying for establishment of forest users groups, negotiations, setting up and attending meetings, fulfilling obligation of the strategies, conflict resolution and so on.
4 *Catha edulis*, is stimulant perennial crop with chewable leaves.
5 Refers to its effect on social relationships among the community members. Any breakdown of social relation can lead to economic losses and erosion of social capital. This will create a problem in working together to take advantage of economies of scale and risk-pool behaviour (Ferraro 2001: 19).

References

Bekele, T. (2003) 'The potential of Bonga forest for certification', paper prepared for National Stockholders Workshop on Forest Certification, Organized by Institute of Biodiversity Conservation and Research (IBCR), FARM Africa and SOS Sahel, 25–26 August 20003, Addis Ababa, Ethiopia.

Brush, S.B. (2000) 'The issue of *in situ* conservation of crop genetic resources', in S. B. Brush (ed.) *Genes in the Field: On-farm Conservation of Crop Diversity*, Boca Raton, FL: IPGRI, IDRC, and Lewis Publishers.

Conrad, J.M. and Salas, G. (1993) 'Economic strategies for co-evolution: timber and butterflies in Mexico', *Land Economics* 69(4): 404–415.

EEA (The Ethiopian Economic Association) (2000) *Annual Report on the Ethiopian Economy*. Vol. 1. Addis Ababa, Ethiopia: EEA.

Ejigie, A. D. (2005) 'The economics of smallholder coffee farming risks and its influence on household use of forest in Southwestern Ethiopia', PhD thesis, University of Bonn, Germany.

FARM Africa (2002) 'Bonga Integrated Participatory Forest Management and Reproductive Health Project-Phase-II', Project document, Addis Ababa, Ethiopia.

Featherstone, A. M. and Goodwin, B. K. (1993) 'Factors influencing a farmer's decision in long-term conservation improvements', *Land Economics* 69(1): 67–81.

Ferraro, P.J. (2001) 'The local costs of establishing protected areas in low-income nations: Ranomafana Parks, Madagascar', Environmental Policy Working paper series No. 006, Department of Economics, Georgia State University.

Gittinger, J. P. (1982) *Economic Analysis of Agricultural Projects*, 2nd edn. London: The Johns Hopkins University Press.

Gole, W. T. (2003) *Vegetation of the Yayu Forest in SW Ethiopia: Impacts of Human Use and Implication for In Situ Conservation of Wild Coffea Arabica L. Populations*, *Ecology and Development Series*, No. 10, Göttingen: Cuvillier Verlag.

Greene, W. H. (2003) *Econometric Analysis*, 5th edn. Harlow: Pearson Education, Inc.

Gujarati, D. N. (1995) *Basic Econometrics*, 3rd edn. New York: McGraw-Hill. Inc.

Konyar, K. and Osborn, C.T. (1990) 'A national-level economic analysis of conservation reserve program participation: a discrete choice approach', *Journal of Agricultural Economics Research* 42(2): 5–12.

Kramer, R., Sharma, N. and Munasinghe, M. (1995) *Valuing Tropical Forest: Methodology and Case Study of Madagascar*. World Bank Environmental paper, No. 13, Washington, DC: The World Bank.

Maddala, G.S. (1983) *Limited Dependent and Qualitative Variables in Econometrics*. Cambridge: Cambridge University Press.

Mburu, J. (2004) 'Wildlife conservation and management in Kenya: towards a co-management approach', online available HTTP <http://www.feem.it/Feem/Pub/Publications/WPapers/default.hmt> (accessed January 2005).

Mburu, J., Birner, R. and Zeller, M. (2003) 'Relative importance and determinants of landowners' transaction costs in collaborative wildlife management in Kenya: an empirical analysis', *Ecological Economics* 45: 59–73.

Richards, M., Davies, J. and Yaron, G. (2003) *Stockholder Incentives in Participatory Forest Management: A Manual for Economic Analysis*, Overseas Development Institute, London: ITDG Publishing.

Sexena, S., Chandak, V., Ghosh, S.B., Sinha, R., Jain, N. and Gupta, A.K. (2004) *Cost of Conservation of Agrobiodiversity*. Online available HTTP: <http://iimad.er-net.in/publications/data2002-05-03anikGupta.pdf>. (accessed September 2004).

Smith, R.J. and Blundell, R.W. (1986) 'An exogeneity test for simultaneous equation tobit model with an application to labour supply', *Econometrica* 54 (3): 679–685.

Swanson, T. and Goeschl, T. (2000) 'Optimal genetic resource conservation: *in situ* and *ex-situ*' in S. B. Brush (ed.) *Genes in the Field: On-Farm Conservation of Crop Diversity*. Boca Raton, FL: IPGRI, IDRC, and Lewis Publishers.

Tedla, S. and Gebre, M. (1998) 'Biodiversity management in Ethiopia', in J. Mugabe and N. Clark (eds) *Managing Biodiversity: National Systems of Conservation and Innovation in Africa*. Kenya: ACTS Press.

Tietenberg, T. (1992) *Environment and Natural Resource Economics*, 3rd edn. New York: HarperCollins Publishers, Inc.

Zegeye, W. E. (2004) 'The economics of on farm conservation of crop diversity in Ethiopia: incentive, attribution preferences and opportunity costs of mantaining local varieties of crops'. PhD thesis. University of Bonn, Germany.

18 Agrobiodiversity in poor countries

Price premiums deemed to miss multifaceted targets?

Mitri Kitti, Jaakko Heikkilä and Anni Huhtala

1 Introduction

Many developed countries spend a considerable amount of money and other resources on bilateral and multilateral aid to developing countries. At the same time, many goods produced in the developing world have a potentially high commercial value, but the benefits of trade do not necessarily accrue to producer countries. On the contrary, many cash crops, such as coffee, may be produced by exploiting nature in a way that is unsustainable in the long run. Furthermore, most of the value added accrues to processors in the developed world.

It may be justified to question the rationality of having an aid mechanism that transfers money from the developed to the developing countries on one hand, and on the other hand, a trade mechanism that prevents developing countries from acquiring the full potential of their natural resources. Instead, it may be argued, the focus should be shifted to promoting 'fair' trade and reducing the distortions actively created in free markets. An example of such a challenge is monoculture in producing agricultural goods. Intensive monoculture, encouraged by high short-term returns from cash crops, could lead to dramatic yield losses in the long run due to decreased biodiversity and declining pollinator populations (Kevan and Phillips 2001: Nunes *et al.* 2003). A challenge for management is that it can be considered 'unfair' that the benefits of biodiversity conservation accrue to the local and global community at large, while the short-term costs are borne solely by the local community. That is why fair trade arguments are gaining ground. Yet, biodiversity conservation is rarely a major feature in international aid agreements to alleviate poverty (EU 2005).

By analyzing how much the producer would need to be compensated for undertaking sustainable coffee production, and comparing that to the existing price premiums for sustainable coffee, we can gain insight into whether sustainable production would be possible through fair trade. We investigate the role that price premiums can play in developing countries in preserving biodiversity when simultaneously aiming at eradication of poverty. We

incorporate ecological findings on the role of pollination services into an economic analysis of agro-forestry in coffee production.

Coffee makes an interesting case as it ranks as one of the five most valuable export commodities (US$7 billion in 2004) and coffee production employs about 25 million people worldwide (FAOSTAT 2007; Ricketts *et al.* 2004). Over 70 per cent of the world's coffee is produced by small-scale family farms. Most coffee producers live in poverty and manage agro-ecosystems in some of the world's most culturally and biologically diverse regions in Latin American, Asian, and African countries (Bacon 2005). Despite the increasing evidence that the abundance and diversity of bees can augment pollination and boost coffee yields in the long run (Roubik 2002; Klein *et al.* 2003a, 2003b, 2003c), shade trees on plantations and forest fragments nearby coffee farms are removed for the sake of greater short-term efficiency. Worldwide, the resulting loss of pollinator habitat is a considerable environmental problem (Kremen and Ricketts 2000). Moreover, international coffee prices fluctuate substantially due to, for instance, occasional overproduction (Lewin *et al.* 2004; Perfecto *et al.* 2005). This worsens the situation of impoverished farmers and may provoke the destruction of the remaining forest strips.

Pollinator deficits increase the costs of production, but more thorough cost-benefit analyses of pollination services in agriculture would be needed to analyze the economic impacts. In a study on alfalfa in Canada, the value of pollination to growers was estimated at 35 per cent of annual crop production. In Ontario, the cost of one hive of honey bees per hectare was about 1 per cent of production costs and the benefit, in terms of higher yields, was 700 per cent of the cost (Kevan and Phillips 2001). In addition, a few recent studies have paid attention to economic value of pollination services that materialize through agro-forestry benefits in coffee production systems, (e.g., Ricketts *et al.* 2004). Gobbi (2000) finds that investment in biodiversity-friendly certification criteria is financially viable for coffee farms, while Benítez *et al.* (2006), Ninan and Sathyaplan (2005), and Olschewski *et al.* (2006) note that the high opportunity costs of land managed by ecological principles, in terms of lost benefits of intensely cultivated coffee or alternative crops, precipitates biodiversity degradation. An overall conclusion from these studies is that policy measures such as trade-related standards, premiums, tax relief, or government institutions are necessary for adoption of biodiversity-friendly growing practices (see also Damodaran 2002; Bacon 2005; Perfecto *et al.* 2005).

We investigate the impact of price premiums as a policy instrument for reducing environmental degradation in the coffee production. Fair trade/eco-labelling is an example of a market-based conservation strategy where consumers pay a price premium for coffee which is produced on certified farms that are committed to preservation of biodiversity or fair working conditions (e.g. Perfecto *et al.* 2005; Swallow and Sedjo 2000; Sedjo and Swallow 2002). We study whether price premiums as a policy instrument work for both abolition of poverty and protection of biodiversity, or whether this leads to

conflicting outcomes when input use intensity or production cost structure of alternative technologies differ.

Our model explicitly accounts for the ecosystem services provided by pollinators. To gain insight into mechanisms that drive the land allocation processes, the choice between environmentally detrimental and sustainable farming technology is determined in our model by relative profits of the alternative technologies (cf. e.g. Bulte and Horan 2003). We analyse whether the management of landscapes for both agricultural production and conservation of wild biodiversity is possible as an alternative to conservation alone, which has turned out to be a costly option even in developed countries. In particular, we study what drives land use decisions when economic optimization is carried out by several small farmers or a sole owner. Obviously, these two farm structures lead to different outcomes. We investigate the possibility of multiple equilibria in adoption of technology: farmers specialize either in shade- or sun-grown coffee, or both farming practices coexist. We examine under what circumstances coexistence actually occurs.

We calibrate an empirical model to describe land use decisions at the level of a representative local community in Costa Rica. Commercial coffee production has been one of the most important factors in economic development of the country and still is a major source of employment in rural areas (Agne 2000). Moreover, deforestation has traditionally been an important environmental problem in the northern Latin American region. Our empirical analysis facilitates a characterization of the alternative equilibria in land use, and we can illustrate the magnitude of the ecological and economic impacts of price premiums as a policy measure.

In Section 2 we discuss the background concepts of this paper. In Section 3 we discuss the basics of our theoretical model, and its application to a specific case is presented in Section 4. Conclusions are provided in Section 5.

2 Coffee trade, production, and pollination

In this section, we review the basic characteristics of coffee trade and production, and the relation of production to insect pollination. We also discuss the characteristics of the two production technologies analyzed in this study. The discussion concentrates on aspects that are relevant from the point of view of our analytic model and the empirical application.

2.1 Aid and coffee trade

Foreign aid is perhaps the most traditional means through which developed countries attempt to support the development of poorer countries. The sums involved are not insignificant: total aid peaked in 1991, when its value was US$69 billion (in 1995 prices). For a typical receiver country the aid amounted to about 7–8 per cent of the GNP (Svensson 2003). Foreign aid is undertaken for various reasons, ranging from moral responsibility for the

whole of our common globe (e.g. Opeskin 1996) to fighting terrorism by preventing the inequality that harbours it (e.g. Ministry for Foreign Affairs of Finland 2004) to more pragmatic reasons such as furthering one's own domestic interests (e.g. Diven 2001) or interests in the target areas. Multiple reasons for aid may explain, at least partially, why the relationships of aid with growth, poverty alleviation or development have not always been evident.

Furthermore, aid may be tied to the donor country's own exports. In early 1990s about 50 per cent of all bilateral aid was tied either totally or partially to exports. Although the percentage has fallen since, the phenomenon still exists (Wagner 2003). It is thus worth considering whether trade would be better for the developing countries than direct aid. Lord Farrer realized this point over a century ago:

> The true test of the value of Free Trade to England, or to any other country, is not whether she is progressing faster, or even doing a larger trade than another, but whether she is doing better herself with Free Trade than she would do without it; and whether, in her relation to other nations which are not Free Traders, she or they derive the greater benefit from their respective commercial systems.
>
> (Lord Farrer 1904)

There are various reasons for and against free trade, but perhaps the consensus is that given all other distortions in economies, trade without any regulations is not a sustainable solution. It may well be argued that neither is the present trade system, whose rules are made by developed countries in accordance to their own needs. Liberalization is usually urged where it suits rich countries best, but in areas where developed countries might actually benefit from trade, such as agricultural products and other raw materials, progress has been slow (Anderson *et al.* 2001). For instance, foreign aid to developing countries is currently at about US$79 billion a year (Erixon 2005). At the same, developed OECD countries spend about US$225 billion annually on agricultural subsidies for their own producers (OECD website 2007). It has been estimated that the trade barriers faced by developing countries cost them about US$100 billion annually, more than the amount they receive in aid (Anderson *et al.* 2001).

Organizations that promote alternative trade originate from the 1960s, and were first connected with movements of political solidarity. Soon, these aspirations combined with the idea of helping poorer countries through alternative trade. The slogan 'Trade not Aid' incorporated the idea that instead of giving millions, if not billions, of dollars in aid, why not pay a decent price for the products purchased from poorer countries and give producers in those countries an opportunity to take care of their own production environment? The products imported were mainly handicrafts, coffee and tea (Renard 2003).

Labels changed the course of fair trade in the late 1980s. Instead of searching for alternative distribution channels, labels made it possible to market fair trade products through the same channels that were used for marketing mainstream products. Coffee was the first product to receive this new treatment. The label of fair trade requires that the buyers agree to: purchase directly from the producers; pay a price that covers the production costs and a social premium; make an advance payment; and establish long-term contracts. Producers are required to participate in a democratic organization; allow workers to participate in trade unions and have decent wages, access to housing; follow health and safety standards; not use child labour; and implement programs to improve environmental sustainability (Renard 2003). Today, several labels exist in coffee production. In our analysis, we deal with an unspecified label that is related to the production of shade coffee as described below.

2.2 Coffee markets, production and pollination

Coffee is among the most exported foodstuffs. Developing countries export about 80 per cent of their production, consuming the remainder. The European Union and the United States are the largest importers, the share of EU being 45 per cent of all imports (Dicum and Luttinger 1999). Although the market share of fair trade and organic gourmet coffee is still small, demand for these products has been growing fast (Bacon 2005). Total demand for coffee has been fairly stable over the past years, but supply fluctuates substantially, primarily due to weather conditions. Variable weather is exacerbated by the fact that coffee takes about three years from planting to harvest, and thus the harvested area cannot be altered quickly in order to maintain a stable supply. In addition, coffee has a biannual production cycle, which further limits the possibility that production can adjust rapidly to demand (Agne 2000; Dicum and Luttinger 1999). As a result, the average price of coffee has fluctuated significantly.

Coffee production can be roughly divided into two main methods of production.[1] The traditional method (hereafter 'shade coffee') is to grow coffee in mixture with shade trees that may also produce other products of economic value, such as fruits or medicine. This method involves relatively fewer coffee plants per hectare, slower growth and lower yield per plant, and fewer commercial inputs. At the same time, it involves a longer life for the plant and affects biodiversity and soil quality positively.

The other method originated with techniques of intensive agriculture such as those of the Green Revolution, and involves growing coffee in the open air, without shade (hereafter 'sun coffee'). Coffee is grown on plantations as a monoculture, allowing for more coffee plants per hectare, more rapid growth and higher yields per plant. This approach has negative impacts on biodiversity and soil quality. The life-span of plants is shorter, and the producer relies on a single crop.

About two-thirds of world's crop species include cultivars that require

animal pollination and approximately one-third of food consumption in tropical countries originates from plants that are pollinated by insects (Kremen *et al.* 2002: Ricketts *et al.* 2004). Two main coffee variants are used in production. *Coffea canephora* var. *robusta* is grown mainly in West Africa and Southeast Asia and *Coffea arabica* is grown primarily in South and Central America, although this geographical division has begun to disintegrate (Dicum and Luttinger 1999).

In the case of the coffee plant, bees are an important pollinator. The highland coffee plant (*C. arabica*) is self-pollinating, but it has been shown that cross-pollination may increase the seed mass by 8 per cent and the fruit set[2] by 11.5 per cent, increasing yields by 20 per cent in sites far from the nearest forest. The lowland coffee plant (*C. canephora*) is sterile and predominantly wind-pollinated, but may produce a fruit set that is 16 per cent higher in plants that were pollinated by both wind and insects (as compared to only wind). In addition, cross-pollination is likely to lead to larger and more robust fruit, increasing both the quality and the quantity of the crop (Klein *et al.* 2003a, 2003b, 2003c; Ricketts *et al.* 2004; Roubik 2002).

It has recently been shown that it is both the diversity and the abundance of bees that are important for pollination. Hence, biological diversity provides greater and more predictable pollination services and increases the fruit set (and yield) of coffee plants. This impact may function in two ways. First, the complementary effects in a species-rich assemblage of pollinators better cover the spatial and temporal variability in flower resources. Second, diversity can lead to a greater probability that a species or a gene exists that provides the pollination service better or more efficiently than another species or gene (sampling effect) (Klein *et al.* 2003b). In conclusion, a more diverse pollinator community can be expected to produce higher levels of pollination services, with greater certainty, through complementary foraging behaviour, greater efficiency, broader tolerance of the climate and asynchronous population dynamics (Ricketts *et al.* 2004).

Bee diversity and abundance decrease with the distance to the nearest forest. As a result, the fruit set (and yield) of the open-pollinated coffee plant is inversely correlated with the forest distance. In order to maintain the pollination service that wild bee populations provide to coffee plants, the forest habitat of the bees needs to be conserved (Klein *et al.* 2003b, 2003c; Kremen *et al.* 2002; Ricketts *et al.* 2004; Steffan-Dewenter and Tscharntke 1999).

2.3 *Implications for modelling*

Given that sun coffee is intensively produced and generally hand-pollinated, the presence of pollinating insects nearby is of little relevance. In contrast, the pollination services of insects are important for the production of shade coffee. Therefore, in our model, the shade-coffee system includes a forest strip located at the edge of the production area which serves as a pollinator habitat. The decisive matter for pollination is the distance to the nearest forest,

rather than the shade trees themselves. This assumption represents conditions in the area of Costa Rica where the ecological parameters used in our empirical application were originally measured (Ricketts *et al.* 2004). Thus, whereas the per hectare yield of sun coffee is assumed constant, the yield of shade coffee depends on the distance to the nearest forest.

There are several other key assumptions in our empirical model. First, we do not account for price volatility. The justification for this assumption is that as long as both prices (sun and shade coffee) move together, results are not affected by price changes. Second, shade coffee attracts a price premium in the international market, generating a higher producer price. However, the benefit materializes only when production has been certified through a scheme. We assume an arbitrary certification scheme for shade coffee where any costs of certification are incorporated into the production costs. Third, production of shade coffee also involves a higher cost of per hectare, due to more labour.

Coffee production involves economic and environment dimensions, and both are important. For this reason, the two production technologies analyzed include different: (1) yield per hectare; (2) producer price per kilogram; (3) production costs per kilogram; (4) production costs per hectare; and (5) dependence on forests and pollination.

3 The model

In this section we describe in general terms the model that we use, the full details of which can be found in Kitti *et al.* (2006). We first describe the profit functions of sun-coffee and shade-coffee production technologies (indexed by 1 and 2, respectively). We then investigate two different farm structures: sole ownership and small-scale farms.

3.1 Yields and profits

The variable μ denotes the proportion of the area that is allocated to shade-coffee production. The proportion that is allocated for sun coffee is then $(1 - \mu)$. We assume that the yield of sun coffee depends only on the area which is allocated to its production. Hence, the effect of pollination on yield is assumed to be negligible, as discussed above. Yield is simply $(1 - \mu)Y_1 A$, where Y_1 is the yield per hectare and A is the size of the entire production area.

Coffee production costs are divided into costs that depend on yield, such as harvesting and transportation costs (c_1), and costs that depend on the production area, such as pest control and fertilization costs (e_1). In our empirical application, the area-dependent costs are further decomposed into labour costs and other costs. The profits of sun coffee production can then be expressed as $\pi_1(\mu) = (p_1 - c_1)(1 - \mu)Y_1 A - e_1(1 - \mu)A$, where p_1 is the per unit sun-coffee producer price.

The model for shade coffee is more complex because the yield depends on

the distance of the coffee plant to the border of the pollinator source, which is the forest strip surrounding the plantation. In practice, the forest patches could be distributed in a more complex manner, depending on the landscape. For instance, Olschewski *et al.* (2006) analyze the economic impacts of bee pollination by assuming that the cultivated region surrounds the forest. We assume that production includes the compulsory forest strip, located at the edges of the area cultivated in shade coffee. The forest strip has a fixed width, but the total size of the forest depends on the circumference (and thus size) of the area that is allocated to shade coffee. Hence, for any given area of shade-coffee production, the forest either covers the strip of given width or if the area is very small, the entire area.

Coffee plants form a continuous cover over the region in which they are grown; each point of the region produces some coffee. The relationship between the distance and the yield at any given point is given by the square-root relationship (Klein *et al.* 2003c) for the initial fruit set of a plant and the distance to forest. The final yield is proportional to the initial fruit set. We thus obtain an expression for yield as a function of forest distance, which we augment by the fact that the yield cannot fall below a certain minimum level Y_{min} no matter how far from the forest it is. For full derivation of the parameters, see Kitti *et al.* (2006).

The shape of the region in which shade coffee is produced is assumed to remain unchanged but its size may vary as the allocation of area to shade-coffee production changes. This assumption makes it possible to do all calculations in the original coordinates and to obtain the final yield by scaling the results by factor μ. In other words, we compute the yield as if the whole region were allocated to shade-coffee production and forest and then scale the resulting yield to the level that corresponds to the reduced area. Hence, in computing the total yield we avoid having to define the location of the shade-coffee region. The reduction and the crucial distances from the boundary of the region are illustrated in Figure 18.1. Note that in Figure 18.1, the white area on the right that is located between the forest strip (dotted region) and the dotted boundary line is allocated to sun coffee. In the shaded region, the yield is over Y_{min} and in the centre the yield is Y_{min}.

Once the level of yield has been determined, the total profit of shade coffee is obtained similarly to sun coffee. However, three remarks are warranted. First, we assume that the forest imposes no costs on the producers, and hence its area is subtracted when calculating the area-dependent production costs. Second, we assume that the forest strip produces no income for the farmer. Third, we have excluded the extra profits that might be associated with products of the shade trees, such as medicines, foods, construction materials and forage (Moguel and Toledo 1999). We are not aware of any economic analyses that have been conducted on the value of products from shade trees in coffee plantations. Note that we do not explicitly allow the farmers to allocate their land to forest but the forest area always depends on the area allocated to
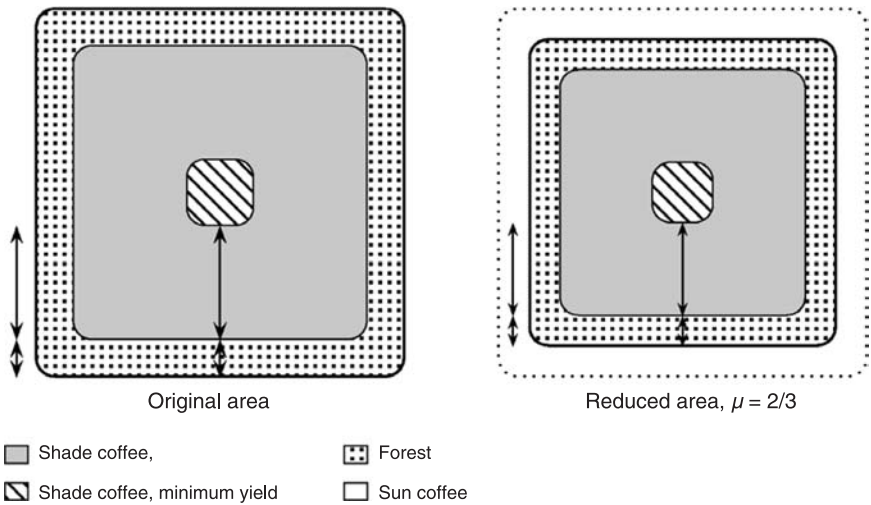
Figure 18.1 Reduction in shade coffee area.

shade coffee. If farmers wanted to have some forest, they would have to take the area of shade coffee that comes with it.

The main difference between the profit functions π_1 and π_2 is that the profit from sun coffee is linear in μ whereas the profit from shade coffee is nonlinear. Linearity of π_1 means that there are constant returns to scale in sun-coffee production. On the other hand, the non-linearity in π_2 is solely due to non-linear pollination effects and all the other factors that could cause non-linearities are omitted. In practice, there could be economies of scale in coffee production or other factors causing additional non-linearities. Nevertheless, when these effects are reasonably small or play the same role for both technologies, linearity of π_1 is a justifiable approximation.

3.2 Farm structures: sole owner and small-scale farms

We analyze two different farm structures: sole owner and small-scale farms. Under sole ownership there is a single decision-maker who chooses an optimal land allocation between sun coffee and shade coffee. The other farm structure involves a community of several small-scale farmers who choose between the two technologies. We do not consider where the small farms are actually located and assume that the shape of the cultivation region is independent of the actions of individual farmers. This makes it possible to formulate a static equilibrium model. We do not account for the process of decision-making, but instead describe its economic outcome.

In the case of the sole owner, the land allocation decision between shade and sun coffee is made by maximizing the joint profits of the two technologies (max $\pi_1(\mu) + \pi_2(\mu)$). The sole owner allocates the land to either of the two

technologies by satisfying the standard first-order optimality condition: marginal profit from the shade coffee is equal to the marginal profit from the sun coffee. Geometrically, this means that the optimum is at the point where π_2 has a tangential line with slope $A[(p_1 - c_1)Y_1 - e_1]$. This is illustrated in Figure 18.2 where the dotted line is the tangent of π_2 at the joint profits maximum (μ_0).

In the case of small-scale farms, we assume that there are a large number of small-scale farmers who decide between belonging to a community of sun- or shade-coffee farmers. Farmers make their decisions without any coordination. Because there are many farmers, the marginal contribution of each farmer to the profitability of the technology is negligible. The total profits from the technology are shared in proportion to farm sizes in the community. For a farmer whose land covers an area Δ of the community, the profits from production of sun coffee would be $\Delta = \pi_1(\mu)/[(1 - \mu)A]$ and from production of shade coffee, $\Delta = \pi_2(\mu)/(\mu A)$. This means that choices to allocate land between the two technologies depend on the profitability of the technology, measured as profits per hectare. Decisions based on profitability thus lead to outcomes that may differ from those based on marginal profits. Note that in this model an individual farmer must choose between the technologies and cannot allocate land to both. In practice, this means that the costs of having two production methods are prohibitively large for a small producer. An individual farmer faces a technology choice problem rather than a land allocation problem.

Since small-scale farmers choose their production technology on the basis of profitability, the equilibrium is obtained when the profits are equal. If one of the technologies is more profitable, at least some of the farmers would be willing to change. At the equilibrium, none of the farmers has an incentive to change the technology. This condition gives us the 'reference profit' line, illustrated in Figure 18.2. The line represents the opportunity cost of shade coffee production in the small-scale farm setting. In Figure 18.2 this line crosses the profit curve π_2 twice, which means that there are two equilibria.
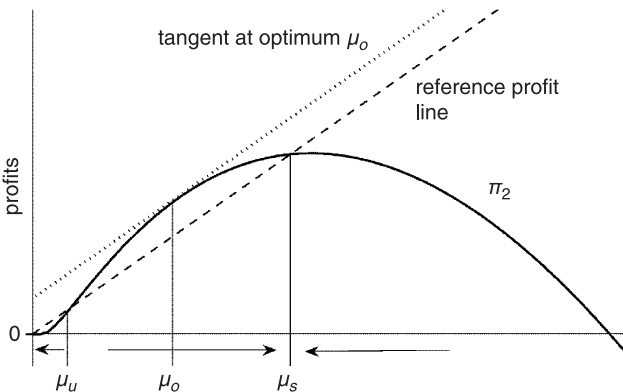
Figure 18.2 Profit from shade coffee, π_2, the optimality and equilibrium conditions.

3.3 General properties of the model

In the case of small-scale production, if there is an internal equilibrium (both sun- and shade-coffee production in the equilibrium), then the equilibrium profits are equal to the profits obtained when the whole area is allocated to sun coffee. This follows from the fact that shade coffee has the same profitability as sun coffee in equilibrium. Consequently, the total equilibrium profits are unaffected by the values of price p_2 and costs c_2 and e_2 as long as the equilibrium is internal.

Consider the properties of the profit function for shade coffee (π_2). For a small enough μ, the corresponding profit $\pi_2(\mu)$ is zero because the whole area is covered by the forest strip. Hence there is a threshold level for μ below which the entire region that is not in sun-coffee production is covered by the forest. Depending on the parameter values, the marginal profit is decreasing for a large enough μ. Decreasing marginal profits follow from the fact that the proportion of the area in which the yield is Y_{min} increases and the proportion of the area in which pollination is effective decreases. As μ increases, a larger proportion of the yield comes from the area which is far from the forest. However, when shade-coffee production is extremely profitable, it may happen that the marginal profit is increasing on the whole interval $(0,1)$ after the point in which π_2 becomes positive. An example of a profit function with diminishing marginal profits is illustrated in Figure 18.2.

In general, there are at most two equilibria for the small-scale farm setting. If the two equilibria are μ_u and μ_s as in Figure 18.2, then the profit function π_2 is above the reference profit line on the interval (μ_u, μ_s), which means that the profitability of shade coffee is greater than the profitability of sun coffee. Assuming that the many small-scale farmers allocate their land to the technology that is the most profitable, there is a tendency to move towards the equilibrium μ_s when starting from an allocation where μ belongs to the interval (μ_u, μ_s). For $\mu > \mu_s$, there is also a tendency to move towards μ_s because sun coffee is more profitable. Farmers shift from producing shade coffee to producing sun coffee, reducing μ. We can say that μ_s is a stable equilibrium. By similar reasoning, the equilibrium μ_u is unstable.

When keeping the other parameters at their initial levels and changing only one of them, the stable equilibrium allocation μ is increasing in p_2, c_1, and e_1, and decreasing in p_1, c_2, and e_2. In particular, parameters p_2, c_1, and e_1 (p_1, c_2, and e_2) have minimum (maximum) values above (below) which there is production of shade coffee in equilibrium. When one of the parameters p_2, c_1, or e_1 becomes large enough, there is only one internal solution at the equilibrium. This is because the stable equilibrium converges to $\mu=1$ as shade coffee becomes more profitable.

An example of a stable equilibrium as a function of p_2 is presented in Figure 18.3. Below a certain threshold (the first dotted vertical line), there are no internal equilibria and all area is allocated to sun coffee. Above the other threshold level (the second dotted vertical line), the stable equilibrium
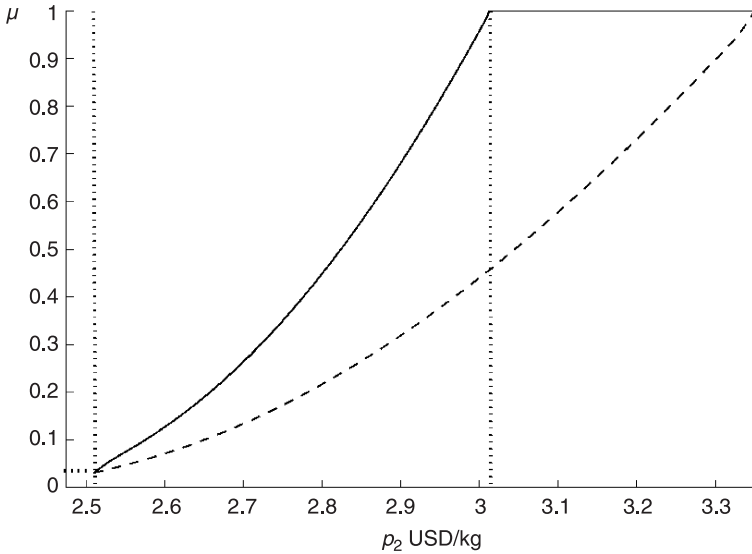
Figure 18.3 Equilibria and joint profits optimum (dashed line) as a function of p_2.

coincides with $\mu = 1$ and all area is allocated to shade coffee. Between these two lines, both technologies coexist. At the lower threshold level when shade coffee becomes profitable, the two equilibria and the joint profits maximum coincide, and there is a unique equilibrium.

The stable equilibrium is also dominant in the sense that the total profits $\pi_1 + \pi_2$ are higher in this equilibrium than in the other equilibrium. Assuming that the extreme allocations $\mu = 0$ and $\mu = 1$ are equilibria, we can compare the dominant equilibrium (small-scale farmers) with the joint profits maximum obtained under sole ownership. In Figure 18.2, the profit-maximizing point is where the line with slope $A[(p_1 - c_1)Y_1 - e_1]$ (the dotted line) is tangential to π_2. This point can never be above the dominant equilibrium. This means that there will always be more shade-coffee production in the equilibrium involving small-scale farmers than what would be optimal under sole ownership. This is a generic property of the model and follows from the fact that at the sole-owner maximum, shade coffee is more profitable than sun-coffee, although their marginal profits are the same. Small-scale farmers always have an incentive to shift from sun coffee production to shade coffee until the two technologies are equally profitable.

On basis of the analytical model we can conclude that if the internal equilibrium is unique and if π_2 crosses the reference profit line, $\mu = 1$ is the dominant equilibrium, whereas if π_2 is below the reference profit line $\mu = 0$ is the dominant equilibrium. If there are no internal equilibria, then shade-coffee production cannot be more profitable than sun-coffee production and $\mu = 0$ is the dominant equilibrium.

Since our model involves a rather complex yield function it is difficult to solve the equilibrium and joint-profits maximum analytically even when the shape of the cultivation region is simple. In the following section, we analyze the model numerically to obtain more insight into its properties. We will concentrate on the dominant equilibria for small-scale farmers.

4 Empirical application

Costa Rica produces *C. arabica*. The most important production area is Central Valley where sun coffee is the predominant production method. Shade coffee dominates in the surrounding areas of the valley (Agne 2000). Ricketts *et al.* (2004) have attempted to estimate the economic value of bee habitat conservation to the coffee producers in this region. Within a single large farm in Costa Rica, they estimated that the forest fragments provide pollination services worth US$60,000 annually. In order to provide some structure to our empirical application, we draw parameters for the production area, the forest area, and the yield and forest distance from this study. Certain ecological relationships have been taken from studies conducted elsewhere.

In our analysis, the total circular production area is 1,256 hectares (ha), which is the sum of 1,065 ha of coffee production and 191 ha of the most significant forest patches surrounding the region under coffee cultivation. We concentrate on bees as the providers of the pollination service, because they are important pollinators of both highland and lowland coffee. Important pollinators of coffee flowers in Costa Rica include the non-native, feral, African honeybees (*Apis mellifera*) and 10 native species of stingless bees (Kremen *et al.* 2002; Roubik 2002; Klein *et al.* 2003a; Ricketts *et al.* 2004).

Ricketts *et al.* (2004) point out that the shade trees in Costa Rica are fairly young and do not provide the cavities that are preferred for nesting sites by coffee-pollinating bees. For pollination services, it is thus the distance to the forest, rather than the shade trees themselves, that matter. A forest patch needs to be of a certain minimum size to allow suitable pollination to coffee (ibid.), and so we included the minimum width of the forest, such that it would act as a viable habitat even when the shade-coffee area is fairly small.

We assume that impact of pollination occurs only through increased fruit set, ignoring impacts on berry weight as well as other possible improvements in quality (see Olschewski *et al.* 2006). The purpose of the empirical application is to extract some stylized results from our model with parameter values that are as realistic as possible, rather than provide exact figures. Our main objectives are to assess: (1) whether coexistence of both production types is possible, given the model specification used; (2) to what extent the parameters used would need to be changed for a corner solution (of either sun or shade coffee); and (3) the impacts of price premiums on the environment and economic profitability.

All yield parameters are summarized in Table 18.1. The production cost data in the analysis are assumed to be in the same scale as the costs in Table 18.6 of Kilian *et al.* (2004). The price and cost parameters and their sources are presented in Table 18.2.

4.1 Equilibria

We compute numerically the dominant equilibrium (small-scale farming) and the joint-profits maximum (sole ownership) for our empirical data. Our base scenario corresponds to parameter values presented in Tables 18.1 and 18. For these values the dominant equilibrium is to allocate 90 per cent of the area to shade-coffee production. The joint-profits maximum that would maximize the total profits from the whole region is to allocate 41 per cent of the area to shade coffee. This means that when the farmers do not coordinate their decisions, they allocate a considerable amount of land in the more profitable technology that proves to be shade coffee, given our initial parameter values. The main characteristics of the dominant equilibrium (small-scale farming) and the joint-profits maximum (sole ownership) are summarized in Table 18.3.

Table 18.1 Yield parameters

Value	Parameter	Source
1,256 ha	The total production area including forest	Ricketts *et al.* (2004)
41 fa/ha*	Yield of sun coffee	Kilian *et al.* (2004)
12 fa/ha*	Minimum yield per hectare	Assumption
158 m	Forest strip width	Obtained by assuming a circular forest strip of 191 ha as in Ricketts *et al.* (2004)

Note: (*) fa = fanegas (255 kg fresh coffee or 46 kg of green coffee).

Table 18.2 Price and cost parameters

Symbol	Value (US$)	Parameter	Source
c_1	0.50/kg	Yield dependent costs in sun coffee production	Kilian *et al.* (2004), Ricketts *et al.* (2004)
c_2	0.50/kg	Yield dependent costs in shade coffee production	Kilian *et al.* (2004), Ricketts *et al.* (2004)
e_1	1,650/ha	Area dependent costs in sun coffee production	Kilian *et al.* (2004)
e_2	2,090/ha	Area dependent costs in shade coffee production	Agne (2000), Kilian *et al.* (2004)
p_1	1.39/kg	Producer price of sun coffee	Kilian *et al.* (2004)
p_2	2.98/kg	Producer price of shade coffee	Kilian *et al.* (2004)

Table 18.3 Characteristics of dominant equilibria and joint optima for base scenario

Technology	Scenario	μ	Profits (US$)	Profits (US$/ha)
shade coffee	equilibrium	0.90	32,200	28.5
sun coffee	equilibrium	0.10	3,600	28.5
shade coffee	optimum	0.41	88,000	169
sun coffee	optimum	0.59	21,000	28.5

The size of the forest strip is 181 ha in the dominant equilibrium and 120 ha in the joint-profits maximum. In the dominant equilibrium the profitability of the two technologies is the same whereas in the joint-profits maximum the profitability of shade coffee is much higher than that of sun coffee. The most striking difference is in the total profits which are about US$35,800 in the dominant equilibrium and US$109,000 in the joint-profits maximum. This is an interesting result. There seems to be a clear incentive for the small-scale farmers to coordinate their land allocation decisions to maximize their total economic benefits. Obviously, this would lead to a further decrease in land area allocated to shade coffee to 41 percent. This decrease is dramatic because, historically, farmers have cultivated only shade coffee. The dilemma for policy-makers is that maximizing joint profits would be an efficient way to increase economic benefits and alleviate poverty. However, there are most likely additional environmental benefits from having more shade-coffee production than would be provided by a profit-maximizing optimum.

There are many uncertainties related to the ecological data. Basic sensitivity analysis for selected key parameters provides the following observations. As the forest strip surrounding the shade-coffee region becomes wider, the equilibrium allocation as well as the joint-profits maximum of shade coffee decreases. The joint-profits maximum is less sensitive to the choice of the fixed width of the forest strip. The required width of forest strip clearly affects the attractiveness of shade coffee production. The effect of the yield of the sun coffee Y_1 suggests that if yields can be increased in sun coffee production, for instance, by 10 per cent, the price premium for shade coffee should increase by about 23 per cent. The sensitivity analysis also suggests that one should be careful not to draw definitive conclusions from the data regarding the absolute impacts of policies.

4.2. Price premiums and cost margins

The results in the base scenario were computed for a price premium of US$1.59/kg. In other words, the price of shade coffee is 115 per cent higher than that of sun coffee according to our price data. It is illustrative to compute a minimum price that would guarantee production of shade coffee. The threshold for the price p_2 below which there is no shade-coffee production in

the dominant equilibrium is about US\$2.51/kg, and so the price margin (p_2-p_1) should be at least US\$1.12/kg. This means that the price of shade coffee should be about 80 per cent higher than the price of sun coffee. The threshold for p_2 above which only shade coffee is grown in the dominant equilibrium is about US\$3.01/kg, and so the price margin (p_2-p_1) should be at least US\$1.62/kg. Actual premiums paid for sustainable coffee by the industry have been about US\$1.32/kg (Giovannucci 2001).

The upper and lower thresholds are illustrated as dotted vertical lines in Figure 18.3, where the equilibrium as well as the joint-profits maximum are illustrated as a function of p_2. Recall that the lower thresholds are the same for equilibria and the joint-profits maximum because when shade-coffee production becomes profitable, there is only one equilibrium and this equilibrium is also the joint-profit optimum. For our given initial prices and price premium in the base scenario, we can also obtain threshold levels for the cost c_2 and the cost margin c_2-c_1. The cost of shade coffee (c_2) should not increase above US\$0.97/kg. This implies that the cost margin should not exceed US\$0.47/kg while prices stay at their initial levels (Table 18.2).

Increases in shade-coffee production of 4.2 per cent and in forest area of 2.2 per cent would be achieved by increasing the price premium by about 0.8 per cent, or 1.3 US cents/kg. Table 18.4 summarizes the impact of price premium on the proportion of shade-coffee production μ, and forest area in the dominant equilibrium when the price premium is increased such that an additional USD 10/ha is delivered to the system.

Overall, our results suggest that premiums must be quite substantial to be able to encourage farmers to maintain their shade coffee production systems. Some studies indicate that certain consumer segments are willing to pay such premiums, but it is not likely to hold true for all consumers of coffee (CEC 2001; Loureiro and Lotade 2005).

5 Conclusions

Over-use of natural resources may be a direct consequence of poverty. The choice of farming practices typically involves a trade-off between short-term private benefits and a public good, biodiversity, or long-term sustainability in land use. By capturing the interaction between coffee yield and pollination

Table 18.4 Impacts when the price premium is increased so that an additional US\$10/ha is delivered to the production system

	New value	Change (%)
Value	US\$1.60/kg	+0.8
μ	0.94	+4.2
Forest area	185 ha	+2.2
Profits	US\$35,800	±0.0
Wage sum	US\$637,000	+0.8

services in an analytical bio-economic model, we investigated decline in bio-diversity related to two alternative production methods, sun- and shade-grown coffee.

We examined the pattern of technology choice at a representative local community level by calibrating an empirical model using data from Costa Rica. We found that maintaining environmentally sustainable farming practices requires over-allocation of land to shade-coffee production compared to what would be economically optimal. This results from inability to coordinate management decisions when several economic agents are involved.

We assumed that small-scale farmers choose between shade and sun coffee based on the profitability of each technology. This leads to a dominant equilibrium where the profitability of each technology is the same whereas in an economic optimum, marginal profits are equalized. In the dominant equilibrium, a smaller area of shade coffee would produce higher profits per hectare due to better pollination effect. Following Klein *et al.* (2003c) we assumed that the yield of a plant decreases as a function of distance to the forest surrounding the shade-coffee region. For a larger area of shade coffee, more plants are far away from the forest which serves as the source of pollinating bees. This explains why, in the dominant equilibrium, allocating less land to shade coffee would increase the total profits. It also explains why the opportunity costs of shade coffee production are high.

Furthermore, we analyzed price premiums and investigated whether it is possible to prevent loss of biodiversity simultaneously with alleviation of poverty. We recognize that maintaining environmentally sustainable farming practices requires a considerable allocation to this technology to guarantee its existence. That is why the opportunity costs of conservation may become very high. Furthermore, trade-offs between conservation of biodiversity and abolition of poverty should be taken into account when designing conservation policies. A policy instrument explicitly designed to promote economic (social) sustainability may turn out to conflict with goals of conserving biodiversity, and vice versa. Our results suggest that fetching price premiums high enough to promote the cultivation of shade coffee may pose a challenge. A policy recommendation would then be that addressing poverty in the first place could support also the conservation of biodiversity.

Acknowledgements

Notes

1 Our rough division into sun and shade coffee is a simplification of the actual production technologies. For instance, Moguel and Toledo (1999) divide coffee production systems in Mexico into five categories: (1) rustic; (2) traditional polyculture; (3) commercial polyculture; (4) shaded monoculture; and (5) unshaded monoculture. However, the two categories in our classification streamline the most essential economic and ecological differences of the alternative technologies for our purposes.

2 Fruit set is the number of fruits at harvest divided by the original number of flowers (Ricketts *et al.* 2004).

References

Agne, S. (2000) 'The impact of pesticide taxation on pesticide use and income in Costa Rica's coffee production', Special Issue Publication Series, No. 2. Universität Hannover. Available HTTP: <http://www.ifgb1.uni-hannover.de/ppp/ppps02.pdf> (accessed 20 September 2007).

Anderson, K., Dimaranan, B., Francois, J., Hertel, T., Hoekman, B. and Martin, W. (2001) 'The cost of rich (and poor) country protection to developing countries', Centre for International Economic Studies. Discussion Paper No. 0136, Adelaide University.

Bacon, C. (2005) 'Confronting the coffee crisis: can fair trade, organic, and specialty coffees reduce small-scale farmer vulnerability in northern Nicaragua?', *World Development* 33(3): 497–511.

Benítez, P.C., Kuosmanen, T., Olschewski, R. and van Kooten, G.C. (2006) 'Conservation payments under risk: a stochastic dominance approach', *American Journal of Agricultural Economics* 88: 1–15.

Bulte, E.H. and Horan, R.D. (2003) 'Habitat conservation, wildlife extraction and agricultural expansion', *Journal of Environmental Economics and Management* 45: 109–127.

CEC (Commission for Environmental Cooperation) (2001) 'Background on the potential market for sustainable coffee in North America', available HTTP: <http://www.cec.org/files/pdf/ECONOMY/background9eEN.PDF> (accessed 20 September 2007).

Damodaran, A. (2002) 'Conflict of trade-facilitating environmental regulations with biodiversity concerns: the case of coffee-farming units in India', *World Development* 30(7): 1123–1135.

Dicum, G. and Luttinger, N. (1999) *The Coffee Book: Anatomy of an Industry from Crop to the Last Drop*. New York: New Press.

Diven, P.J. (2001) 'The domestic determinants of US food aid policy', *Food Policy* 26: 455–474.

Erixon, F. (2005) 'Aid and development: will it work this time?' International Policy Network. Available HTTP: <http://www.policynetwork.net/uploaded/pdf/Aid_&_Development_final.pdf> (accessed 20 September 2007).

EU (2005) 'Countdown 2010. Project for a European conference on development cooperation', background document, EU.

FAOSTAT (2007) Available HTTP: <http://faostat.fao.org> (accessed 20 September 2007).

Giovannucci, D. (2001) 'Sustainable coffee survey of the North American specialty

coffee industry', SCAA and Commission for Environmental Cooperation, Long Beach, CA, and Montreal, Canada.

Gobbi, J. (2000) 'Is biodiversity-friendly coffee financially viable? An analysis of five different coffee production systems in western El Salvador', *Ecological Economics* 33: 267–281.

Kevan, P.G. and Phillips, T.M. (2001) 'The economic impacts of pollinator declines: an approach assessing the consequences', *Conservation Ecology* 5 (1). Available at: http://www.Consecol.org/vols/iss1/art8

Kilian, B., Pratt, L., Villalobos, A. and Jones, C. (2004) 'Can the private sector be competitive and contribute to development through sustainable agricultural business? A case study of coffee in Latin America', a paper presented at the 14th Annual World Food and Agribusiness Forum, Symposium and Case Conference. Montreux, Switzerland, 12–15 June.

Kitti, M., Heikkilä, J. and Huhtala, A. (2006) ' "Fair" policies for coffee trade – protecting people or biodiversity?' MTT Economic Research Discussion Paper 7/2006.

Klein, A.-M., Steffan-Dewenter, I. and Tscharntke, T. (2003a) 'Bee pollination and fruit set of *Coffea arabica* and *C. canephora* (Rubiaceae)', *American Journal of Botany* 90(1): 153–157.

Klein, A.-M., Steffan-Dewenter, I. and Tscharntke, T. (2003b) 'Fruit set of highland coffee increases with the diversity of pollinating bees', *Proceedings of the Royal Society London B* B 270: 955–961.

Klein, A.-M., Steffan-Dewenter, I. and Tscharntke, T. (2003c) 'Pollination of *Coffea canephora* in relation to local and regional agroforestry management', *Journal of Applied Ecology* 40: 837–845.

Kremen, C. and Ricketts, T.H. (2000) 'Global perspectives on pollination disruptions', *Conservation Biology* 14: 1226–1228.

Kremen, C., Williams, N.M. and Thorp, R.W. (2002) 'Crop pollination from native bees at risk from agricultural intensification', *Proceedings of the National Academy of Sciences* 99: 16812–16816.

Lewin, B., Giovannucci, D. and Varangis, P. (2004) 'Coffee markets: new paradigms in global supply and demand', Agriculture and Rural Development Discussion Paper 3, The World Bank, Washington, DC.

Lord Farrer (1904) *Free Trade Versus Fair Trade*, London: The Free Trade Union.

Loureiro, M.L. and Lotade, J. (2005) 'Do fair trade and eco-labels in coffee wake up the consumer conscience?', *Ecological Economics* 53: 129–138.

Ministry for Foreign Affairs of Finland (2004) 'Development policy', Government Resolution 5.2.2004.

Moguel, P. and Toledo, V.M. (1999) 'Biodiversity conservation in traditional coffee systems of Mexico', *Conservation Biology* 13(1): 11–21.

Ninan, K.N. and Sathyaplan, J. (2005) 'The economics of biodiversity conservation: a study of a coffee growing region in the Western Ghats of India', *Ecological Economics* 55: 61–72.

Nunes, P.A.L.D., van den Bergh, J.C.M. and Nijkamp, P. (2003) *The Ecological Economics of Biodiversity: Methods and Policy Applications*. Cheltenham: Edward Elgar.

OECD website. (2007) Available HTTP: <http://www.oecd.org/> (accessed 20 September 2007).

Olschewski, R., Tscharntke, T., Benítez, P. C., Schwarze, S. and Klein, A.-M. (2006)

'Economic evaluation of pollination services comparing coffee landscapes in Ecuador and Indonesia', *Ecology and Society* 11(1). Available at: http://www.ecologyandsociety.org/vol11/iss1/art7

Opeskin, B.R. (1996) 'The moral foundations of foreign aid', *World Development* 24(1): 21–44.

Perfecto, I., Vandermeer, J., Mas, A. and Pinto, L.S. (2005) 'Biodiversity, yield, and shade coffee certification', *Ecological Economics* 54: 435–446.

Raynolds, L., Murray, D. and Taylor, P.L. (2004) 'Fair trade coffee: building producer capacity via global networks', *Journal of International Development* 16: 1262–1271.

Renard, M.-C. (2003) 'Fair trade: quality, market and conventions', *Journal of Rural Studies* 19: 87–96.

Ricketts, T.H. (2004) 'Tropical forest fragments enhance pollinator activity in nearby coffee crops', *Conservation Biology* 18: 1262–1271.

Ricketts, T.H., Daily, G.C., Ehrlich, P.E. and Michener, C.D. (2004) 'Economic value of tropical forest to coffee production', *Proceedings of the National Academy of Sciences* 101(34): 12579–12582.

Roubik, D.W. (2002) 'The value of bees to the coffee harvest', *Nature* 417: 708.

Sedjo, R.A. and Swallow, S.K. (2002) 'Voluntary eco-labeling and the price premium', *Land Economics* 78: 272–284.

Steffan-Dewenter, I. and Tscharntke, T. (1999) 'Effects of habitat isolation on pollinator communities and seed set', *Oecologia* 121: 432–440.

Svensson, J. (2003) 'Why conditional aid does not work and what can be done about it?', *Journal of Development Economics* 70: 381–402.

Swallow, S.K. and Sedjo, R.A. (2000) 'Eco-labeling consequences in general equilibrium: a graphical assessment', *Land Economics* 76: 28–36.

TransFair USA (2005) 'Fair trade coffee facts and figures'. Department of Certification.

Wagner, D. (2003) 'Aid and trade – an empirical study', *Journal of the Japanese and International Economics* 17: 153–173.

19 Market participation and crop biodiversity in a developing economy

Bananas in Uganda

Svetlana Edmeades and Melinda Smale

1 Introduction

Over the past decade or so, detailed studies by applied economists have documented the fact that despite the pressures of agricultural industrialization, farmers persist in growing diverse crops and cultivars simultaneously—especially, but not exclusively, in developing economies (Brush *et al.*, 1992; Meng 1997; Van Dusen 2000; Birol 2004; Di Falco 2003; Gauchan 2004). Most of these studies confirm the expected negative association between the development of market infrastructure and crop biodiversity on individual farms, advanced earlier by anthropologists, ethnobotanists and conservationists. When more specific hypotheses about the relationship of input and output markets with crop biodiversity on farms have been tested, however, some ambiguities are apparent (Benin *et al.* 2004; Nagarajan *et al.*, 2005). One reason for ambiguity is the difficulty of establishing the causality of the relationship between crop biodiversity on farms and the participation of farmers in markets with cross-sectional data. Unfortunately, this causality is the crux of conservation policy for countries in the process of economic development. Is it because farmers are left out of markets that diversity is conserved? Can markets be used as a means of supporting on-farm diversity, and if so, in what way?

This chapter sheds some light on this issue by testing statistically the relationship between crop biodiversity on farms and at the farm-gate. Crop biodiversity on farms is a necessary condition for crop biodiversity at the farm-gate, where the harvest is sold. Generally, we consider that as markets develop, farmers will specialize in fewer crops and cultivars. Even when farmers are not fully commercialized, as in the context of semi-subsistence production, crop biodiversity at the point of sales may be lower than on farms because some farm households do not participate in markets or others sell fewer types than they grow. Consumers may demand less varied products, or consumer demand for differentiated products may not be well-articulated in market signals, which is a characteristic of markets in developing economies. Hence, the presence of crop biodiversity on farms does not guarantee diversity at farm-gate, suggesting that on farm diversity may not be sufficient for farm-gate diversity.

These relationships are a logical consequence of the organization of production on a household farm, as compared to the fully commercialized farm-firm of industrialized agriculture. On a household farm, the household's objective is to combine family labor and farm resources in order to maximize the utility from consumption of farm and non-farm goods, and leisure. When markets are missing or incomplete, the model of the household farm predicts that the demand for consumption goods will affect production choices. In that case, farmers cultivate diverse crops and cultivars in order to meet their subsistence needs and satisfy their preferences for consumption attributes. When markets function well, on the other hand, diversity on farms reflects the attribute preferences of off-farm consumers.

If on-farm diversity is a consequence of market development rather than market underdevelopment, we can surmise that a 'win–win' policy option is feasible for conservation. A 'win–win' option for conserving crop biodiversity would occur when market development is consistent with managing diverse crop genetic resources on farms, generating both private benefits and social benefits. Cash generation on farms can have important multiplier effects through other rural markets, creating private benefits. Management of heterogeneous crop cultivars can support genetic resistance to plant pests and diseases, and maintain rare alleles for future use by scientists and farmers. Both of these functions benefit society. The European Community has recognized such functions by supporting the concept of multi-functional agriculture.

In this chapter, we test the relationship between diversity on-farm and the involvement of farmers in banana markets using a two-stage econometric approach. Market participation is analyzed both in terms of: (1) the decision to participate in banana markets (as either a net seller or a net buyer of banana bunches); and (2) the composition of participation, measured by the number of banana cultivars sold at farm-gate (an indicator of intra-species richness). The model is applied to data from a survey of 540 households in the major banana-producing areas of Uganda.

2 Conceptual framework

The conceptual framework builds on the household model of on-farm adiversity (Van Dusen 2000) and related applications (Smale 2006). Two aspects of the conceptual framework are of particular importance in the analysis. First, in the non-separable case of the household model, because of market imperfections, optimal production choices on the farm are affected by the consumption preferences of the household (Singh *et al.*, 1986). Second, the conceptual framework draws from models that consider the attributes of goods in utility and production functions (Lancaster 1966; Ladd and Martin 1976; Ladd and Suvannunt 1976). The trait-based agricultural household model used here (Edmeades 2003) enables us to relate production choices

with market participation choices in the context of market imperfections that are so common in developing economies.

The agricultural household maximizes utility from the set of intrinsic quality attributes ($\mathbf{z^C}$) of the goods it consumes ($\mathbf{x}$), the consumption of an aggregate purchased good (g), and leisure (h), choosing the type and amount of goods it consumes and produces:, $u[\mathbf{x}(\mathbf{z}^c), g, h|\mathbf{\Omega}_{HH}, \mathbf{\Omega}_M]$, where $\mathbf{W}_{HH}$ captures the heterogeneity in household characteristics. The household is constrained by its production and budget limitations (full income constraint), as well as by market imperfections. The production technology is defined by variable inputs, including the agronomic traits of planting material ($\mathbf{z^P}$) and labor (l), used for the production of output (q) on a pre-allocated, fixed amount of land: $q(\mathbf{z^p}, l|\mathbf{\Omega}_F, \mathbf{\Omega}_M)$. The production technology is conditioned on the physical characteristics of the farm, denoted by $\mathbf{\Omega}_F$. The primary source of labor for crop production is typically the family (with total endowment of time for labor and leisure denoted by T). In rural communities in developing economies, planting material is often reproduced on-farm or obtained from farmer-to-farmer exchange, rather than through formal market mechanisms. Farmers' choices of cultivars are limited by the range of traits and attributes available to them locally. The number of distinct cultivars existing in the village, denoted by $\mathbf{V}$, represents the local stock (or endowment) of cultivar attributes. A sub-set of cultivars, $\mathbf{S} \in \mathbf{V}$, is supplied at farm-gate or exchanged at the market place. $\mathbf{S}$ represents the stock of cultivar attributes available at the village market. Although the bundles and levels of attributes provided by cultivars are fixed from the perspective of an individual household, the household can choose various sets of consumption and production attributes by changing the combination of cultivars and quantities of planting material grown. The set of planted and sold cultivars need not be the same across households. Hence, corner solutions are possible for specific cultivars.

Household preferences and production choices are conditioned on market characteristics ($\mathbf{\Omega}_M$). Market imperfections can affect both consumer and producer behavior within the framework of non-separable decision-making. Markets for agricultural outputs typically exist and are functional. However, households are often located far from markets and the bulkiness of banana bunches often makes it difficult for them to transport their harvest to market as individuals. Furthermore, premiums for quality differentials across cultivars (concerning the taste rather than observable characteristics) are seldom observed, which reduces the incentives for marketing a range of cultivars. This is depicted by the tradability constraint expressed as the difference between household output and consumption of goods, or marketed surplus: $ms = q - x \geq 0$. The constraint is binding for those households that remain autarkic with respect to output markets, consuming the goods they produce. The marketed surplus is positive for net selling households, as excess production is sold for cash.

Following Edmeades (2003) and recognizing that agricultural households make consumption and production decisions simultaneously, optimal

reduced form demands for planting material can be derived. The optimal demand for planting material (v) can be measured as either a count of stands (or trees) or an area share and it is expressed as: $v = v(\mathbf{z}^c, p, Y^*(\mathbf{z}^p, p, \mathbf{\Omega_F}, T, V, I)|\mathbf{\Omega_{HH}}, \mathbf{\Omega_M})$. Household full income Y^* is defined by production technology parameters (e.g. agronomic traits of planted cultivars, prices, farm characteristics), total endowments of time and stock of attributes, as well as exogenous sources of income, I. Aggregate goods are a numeraire commodity. Shadow values of family labor, planting material and non-traded cultivars are functions of prices, household, farm and market characteristics, and total endowments of inputs (T and V). Households are price takers in agricultural output markets.

To relate the reduced form to diversity on farm, scalar metrics were constructed over optimal demands for cultivars (Edmeades *et al.*, 2006):

$$\mathbf{d} = \mathbf{d}[v(\mathbf{z}^c, \mathbf{z}^p, p, T, V, I|\mathbf{\Omega_{HH}}, \mathbf{\Omega_F}, \mathbf{\Omega_M})] \tag{19.1}$$

Diversity at farm-gate is defined as a scalar metric constructed over the sub-set of cultivars sold at farm-gate or exchanged at the market:

$$\mathbf{d} = \mathbf{d}[s(\mathbf{z}^c, \mathbf{z}^p, p, T, V, I|\mathbf{\Omega_{HH}}, \mathbf{\Omega_F}, \mathbf{\Omega_M})] \text{ where } s \in v \tag{19.2}$$

Equations (19.1) and (19.2) are used in the econometric analysis of the association between on-farm and farm-gate diversity. Because farm-gate diversity is constructed over a sub-set of cultivars, a market participation decision is also included in the analysis and its relationship with diversity outcomes is examined.

3 Data

The data, collected in 2003, are drawn from a geo-referenced, multi-stage, random sample of banana-growing households in Uganda. The sample domain spans the major banana-producing areas in Eastern, Central, and Southwestern Uganda. The sample was stratified according to elevation, with a threshold of 1,200 meters above sea level. Prior biophysical information suggests that elevation is correlated with factors contributing to variation in productivity. A total of 27 primary sampling units were defined at the sub-county level and allocated proportionately with respect to elevation. One village was randomly selected per sub-county. A total of 20 households with access to land were selected randomly in each village. The total sample comprises 540 rural households in Uganda, of which 517 are identified as banana growers and are used in the analysis. Half of the households in the sample (51 per cent) participate in banana markets as sellers. A third of the households in the sample (197) are net sellers, 21 per cent are net buyers, and 13 per cent participate in banana markets as both sellers and buyers. More than a quarter of the households in the sample (28 per cent) remain autarkic with respect to banana markets.

4 Diversity of bananas on farms and at farm-gate

Uganda is a second center of diversity for bananas. A large number of distinct clones of the endemic cooking and beer bananas are grown in Uganda, as well as a number of unimproved, exotic types from Southeast Asia and a few recently developed hybrids. Farm families have multiple end-uses for bananas. These, and the biotic and abiotic pressures that affect bananas, influence the mixture and number of distinct banana cultivars grown. Households grow a large number of different banana cultivars simultaneously on their farms, with an average of seven and a maximum of 27 distinct cultivars. Endemic cooking bananas are the most widely grown use group in the sample—97 per cent of all households grow at least one cooking cultivar. The number of distinct cultivars per village ranges from 13 to 38, with an average of 23 (Edmeades *et al.*, 2006).

Bananas are produced for home consumption with excess production being sold for cash. Once harvested, banana bunches perish quickly, precluding storage. The point of sale is typically the farm-gate (literally on the household farm), with only a few farmers also selling at local markets. Bananas are sold in bunches. The bulky nature of banana bunches makes it difficult for farmers to transport them to local trading centers or urban markets. Typically, transportation costs (charged per bunch or per load) are borne by buyers (usually intermediaries or middlemen). Anecdotal evidence suggests that per unit costs of transportation, as well as fixed transactions costs, are similar across cultivars because banana bunches from different cultivars are sold at the same time and search, negotiating, and bargaining costs are borne concurrently.

The survey data confirm that the majority of the banana bunches sold (64 per cent) are from cultivars that are endemic to the region. Cooking cultivars dominate banana markets in terms of volume sold (in kg), followed by beer cultivars. Of all banana types sold, cooking cultivars represent 54 per cent. Beer cultivars were 26 per cent of marketed bananas during the year of the survey. Sweet cultivars represented 17 per cent, with the remaining 3 per cent made up of multi-use (hybrid) and roasting banana types. In the survey sample, bunches from 61 different cultivars were sold (11 of those are single observations, i.e. only one household sells this particular cultivar in the sample). Cooking banana bunches sold were comprised of 40 different cultivars, while the numbers of beer and sweet cultivars sold were 18 and 3, respectively.

Though several diversity indexes are defined in the literature and used in empirical analyses (Smale 2006), in this chapter the count index is used as a measure of diversity on farm and at farm-gate. The number of cultivars grown on farm and sold at farm-gate represents a diversity measure of richness. The focus on a single index is not restrictive but rather informative. The association between on-farm and farm-gate diversity can be extended using other indexes, with comparisons made across diversity measures. This, however, is beyond the scope of this chapter.

5 Econometric approach

The econometric approach enabled us to analyze market participation in terms of two aspects of decision-making: (1) the decision to participate in banana markets as either a net seller or a net buyer; and (2) the composition of participation, given by the number of cultivars sold at farm-gate. The simultaneity of the relationship between on-farm diversity and market participation was analyzed separately for buyers and sellers using a two-stage probit least squares (2SPLS) method (Maddala 1983). An instrumental variable method (2SLS) was then used to test the reciprocal causation in the relationship between on-farm diversity and farm-gate diversity.

In the presence of simultaneity, standard estimation methods result in biased and inconsistent estimates. A two-stage estimation approach provides the necessary corrections of the standard errors of estimates. Two-stage methods (such as 2SLS) are typically developed for use with continuous endogenous variables in each equation. Both on-farm and farm-gate diversity were defined as continuous variables. A different two-stage estimation procedure was used to account for market participation decisions, which were defined as dichotomous variables.

To illustrate the econometric approach, a two-equation model is defined:

$$y_1^* = a_1 y_2^* + \beta_1' x_1 + u_1 \text{ and } y_2^* = a_2 y_1^* + \beta_2' x_2 + u_2$$

where $a_1 \neq 0$ and $a_2 \neq 0$, i.e. the error terms are contemporaneously correlated. If both outcomes are observed, i.e. $y_1 = y_1^*$ and $y_2 = y_2^*$, then the usual simultaneous equations model applies. The 2SLS approach can be used to estimate the model, as both outcomes are continuous. If one outcome is observed, while the other is defined as a latent variable, $y_1 = y_1^*$ and $y_2 = y_2^*$ if $y_2^* > 0$ and $y_2 = 0$ otherwise, then the 2SPLS approach should be used to estimate the model (Keshk 2003).

6 Variables

Variables used in the analysis are summarized in Table 19.1. The expected effects for most explanatory variables are ambiguous and no *a priori* theoretical underpinning exists to support the direction of comparative static relationships because of the non-separable nature of the model.

Individual characteristics are summarized for a representative household member who is identified as the person in charge of banana production and management decisions, in contrast to the usual emphasis on the household head. Gender captures preferences associated with growing and market participation behavior. Education and experience proxy for acquired human capital. The dependency ratio is measured as the number of economically dependent persons divided by total household size. Because of the importance of livestock to household consumption needs and cash requirements,

Table 19.1 Summary information of variables

Variable	Definition	Mean	St. D.
Count on farm	Number of cultivars grown on farms	7.14	3.61
Count at farm gate	Number of cultivars sold at farm-gate	1.42	2.40
Gender	Gender of household member in charge of banana production (1 = male)	0.62	0.49
Education	Years of schooling of household member in charge of banana production	5.21	4.02
Experience	Years of experience of household member in charge of banana production	10.21	10.62
Dependency ratio	The proportion of children and elderly members to household size	0.48	0.24
Exogenous income	Income received in previous year from sources other than farm production (in 10,000 Ugandan shillings)	90.88	282.60
Value of livestock	Value of livestock owned by the household (in 10,000 Ugandan shillings)	42.19	96.18
Farm area	Total farm area (in acres)	4.58	7.84
Banana share	Proportion of farm area allocated to banana production (intensity of banana production)	0.38	0.28
Age of plot	Number of years the household has grown bananas on the major banana plot	11.91	12.08
Stock of attributes	Number of distinct banana cultivars grown in the village	23.41	5.53
Southwest region	Household located in the Southwestern region of Uganda (= 1)	0.23	0.42
Eastern region	Household located in the Eastern region of Uganda (= 1)	0.30	0.46
Probability of BS	Probability of occurrence of Black Sigatoka disease on-farm	0.18	0.29
Probability of FW	Probability of occurrence of Fusarium wilt disease on-farm	0.20	0.28
Probability of WE	Probability of occurrence of weevils attack on-farm	0.39	0.33
Rainfall	Mean annual rainfall (in mm)	90.95	8.12
Sell bananas	Household sells bananas (= 1)	0.51	0.50
Buy bananas	Household purchases bananas (= 1)	0.34	0.47
Time to market	Time to nearest banana market (in hrs)	1.00	0.53
Average yield	Average expected bunch size per household (in kg)	12.36	5.49
Cooking quality	Importance of cooking quality: not important (= 1), indifferent (= 2), or very important (= 3)	2.56	0.68

the value of animals owned by the household is used as a proxy for wealth. Another indicator of wealth is exogenous income, which is measured as total income received in the previous year. Wealth is often associated positively with crop biodiversity in poorer economic contexts (Gauchan 2004; Benin *et al.* 2004).

The extent of area planted to bananas captures household-specific scale

effects, while the share devoted to bananas captures the intensity of banana production. The age of banana plantation is included to control for the time dimension of the diversity decision and the effects of past investments in the plantation stock. Long established plantations appear to be associated with greater on-farm diversity (Edmeades *et al.*, 2006). The total number of banana cultivars in the village proxies for the stock of planting material available to farmers for exchange through informal networks. Generally, a larger number of distinct cultivars in the village indicate a greater local supply that is readily available to households (Smale *et al.* 2001). However, the extent to which each farmer is willing to diversify could vary across farmers in a village, and some farmers may meet their end use needs with fewer cultivars than others.

Household location is included to capture regional differences in the provision of on-farm and farm-gate diversity. Regional differences are associated with biophysical characteristics of the production environment and the ethnic composition of the population, and hence with demand for cultivars. The frequencies of occurrence of the air-borne disease black Sigatoka and the soil-borne disease Fusarium wilt, as well as weevils, are major biotic pressures that are recognized and experienced by farmers. Since tolerance appears to vary by cultivar, disease pressures are expected to increase demand for a wider set of cultivars. Rainfall is also included as an agro-ecological characteristic that affects banana production and varies continuously.

Market participation may account for market failures encouraging farmers to grow some cultivars and not others. Though the predicted direction of the effect is ambiguous, some speculation is possible. Semi-subsistent households participating in banana markets as sellers often meet their consumption needs and sales requirements through their own production. They may grow a larger number of different cultivars, some allocated to their own consumption, and others set aside for market sales. By contrast, buyer participation is likely to reduce diversity on farms since it enables households to substitute on-farm production with market purchases. Households can then fulfill the range of their consumption needs through acquiring bunches at the market place rather than from their own banana plots.

The time taken to get to the nearest banana market is used as a transaction cost variable. The farther a household is from a market, the greater the incentive it has to maintain a wider range of distinct banana cultivars in order to satisfy consumption needs and the lower the incentive to participate in banana markets. This variable has been extensively used in previous studies of crop biodiversity on farms, with robust results. Most often the coefficient has a positive sign, supporting the notion that conservation is 'by default' and that inevitably, diversity will be eroded by the process of market development.

The average expected bunch size is also included as an indicator of yield. We calculated the variable as the mean of triangular distributions that were elicited from farmers for each cultivar, averaged at level of the household. The demand for cooking quality is defined at the level of the banana

production decision-maker. Attribute cards with illustrations were used to ensure visual recognition of cooking quality, and the respondent was asked to rate the attribute as not important (= 1), indifferent (= 2), or very important (= 3). The relative importance of attributes is believed to affect farm-gate diversity through trade-offs that farmers make when choosing the type and number of banana cultivars to consume and sell. The importance of attributes is believed to influence decisions about on-farm and farm-gate diversity.

7 Results

Table 19.2 presents the econometric results. In the first four columns, the direction of causality between on-farm diversity and market participation as either a net seller or a net buyer is examined. In the last two columns, the reciprocity of the relationship between on-farm and farm-gate diversity is tested. The Wu-Hausman F test and the Durbin-Wu-Hausman chi-square test confirm that on-farm diversity and farm-gate diversity are endogenous variables (*p*-values of 0.00002, 0.0063 and 0.0055, respectively). Instrumental variables were used to identify endogenous regressors in each equation. Biophysical characteristics (e.g. probability of occurrence of a disease or pest, rainfall), among other exogenous regressors, were used to identify on-farm diversity. Transaction cost variables (e.g. region and time to market) were used to identify farm-gate diversity. Statistical tests favored the hypotheses that instruments are both relevant and valid.[1]

There are four salient results that have bearing on our hypotheses. First, the decision of the household to participate in banana markets as a net seller or a net buyer does not influence the number of different cultivars the household chooses to grow. This finding is consistent with expectations about semi-subsistence agriculture. Farm production decisions for the staple crop appear to be driven by the consumption needs of the farm household rather than by consumer demand at the market. Second, the richness of banana cultivars grown on the farm influences the decision to participate in markets. Controlling for other factors such as transactions costs, greater on-farm diversity increases the likelihood that a household will sell banana bunches and reduces the probability that it will purchase banana bunches at local markets. Third, on-farm diversity has a significantly positive effect on farm-gate diversity. Semi-subsistence banana farmers do not specialize in sales, but sell the excess production from the diverse set of cultivars they grow. Again, this is consistent with expectations of farmer behavior in semi-subsistence agriculture. Fourth, greater farm-gate diversity bears no causal relationship with greater on-farm diversity.

In response to concerns regarding the causal direction of effects reported in empirical studies of on-farm diversity, this analysis provides some validation through applying a series of tests in simultaneous systems of equations. The relationship between market participation and on-farm diversity appears

Table 19.2 Regression results for on-farm diversity and market participation

Explanatory variable	Market participation				Composition of participation	
	Net sellers		Net buyers			
	Diversity on-farm	Sell	Diversity on-farm	Buy	Diversity on-farm	Diversity farm-gate
Diversity on farm (instrumented)		0.1240** (0.0459)		−0.1340** (0.0388)		0.5195** (0.0675)
Diversity at farm-gate (instrumented)					−0.8103 (0.5020)	
Sell (instrumented)	0.2963 (1.1691)					
Buy (instrumented)			−0.3094 (0.9243)			
Gender	−0.1376 (0.3899)	−0.0219 (0.1996)	−0.1548 (0.3092)	−0.0915 (0.1453)	0.0496 (0.3731)	0.1930 (0.2085)
Education	0.1172* (0.0611)	0.0148 (0.0252)	0.1219** (0.0386)	0.0089 (0.0187)	0.1682** (0.0536)	−0.0114 (0.0266)
Experience	−0.0139 (0.0570)		−0.0178 (0.0348)		−0.0812∧ (0.0463)	−0.0138 (0.0112)
Dependency ratio	0.0749 (1.1735)	−0.7028∧ (0.4078)	−0.0899 (0.5935)	0.0896 (0.2889)	−1.0315 (0.8217)	−0.9816** (0.3581)
Exogenous income	−0.0006 (0.0012)	−0.0008* (0.0004)	−0.0006 (0.0010)	0.0010** (0.0003)	−0.0014* (0.0007)	−0.0003 (0.0003)
Value of livestock	0.0052* (0.0020)		0.0052** (0.0015)		0.0053* (0.0024)	−0.0023* (0.0012)
Farm area	−0.0017 (0.0283)	0.0089 (0.0122)	−0.0008 (0.0202)	−0.0035 (0.0107)	0.0054 (0.0234)	
Banana share	−0.7216 (0.9850)	0.6031∧ (0.3585)	−0.6650 (0.6401)	−0.2985 (0.2691)	0.4910 (0.7397)	1.1691** (0.3930)
Age of plot	0.0700 (0.0606)		0.0676 (0.0526)		0.1542** (0.0471)	
Stock of attributes	0.2822** (0.0724)		0.2799** (0.0609)		0.4399** (0.0954)	
Southwest region	0.8764∧ (0.4945)		0.8389* (0.4019)			−0.7980* (0.3220)
Eastern region	−0.3224 (0.5113)		−0.4399 (0.6272)			0.2244 (0.2285)
Time to market		−0.3522∧ (0.1985)		0.4006** (0.1237)		−0.4167** (0.1394)
Average yield	0.0312 (0.0628)	0.0344* (0.0180)	0.0353 (0.0379)	−0.0218∧ (0.0128)	0.1343* (0.0596)	0.0824** (0.0172)
Cooking quality	0.1514 (0.6086)	−0.4680** (0.1400)	0.0735 (0.2703)	0.2496* (0.1069)	−0.2394 (0.2879)	−0.3003* (0.1271)
Probability of BS	0.6604 (0.7164)		0.6581 (0.5419)		0.6474 (0.6401)	
Probability of FW	0.9471 (0.7420)		0.9936∧ (0.5368)		1.2915* (0.6567)	
Probability of WE	−0.3020 (0.6597)		−0.1380 (0.5131)		−0.6775 (0.5816)	
Rainfall	−0.0706** (0.0263)		−0.0731** (0.0239)		−0.0897** (0.0306)	

Note: *,**,∧ indicate significance at the 1%, 5% and 10% level, respectively. The value of the Hansen J statistic led to failure to reject the null hypothesis. Rejection of the null hypothesis would have indicated either a misspecification of the second-stage regression or invalid instruments.

to be unidirectional rather than bidirectional. This is true for two aspects of market participation—the decision to buy or sell, and the number of banana bunch types sold. In other words, there is no reciprocity among the processes studied.

8 Conclusion

In the case of bananas in Uganda, for farmers to participate in markets and diversity to be observed at the farm-gate, farmers must grow diverse bananas. Therefore, diversity on-farm is a necessary condition for market involvement, both in terms of the decision to participate and the richness of cultivars sold. The lack of reciprocity in the relationship suggests, however, that on-farm diversity is not a sufficient condition for either market participation or farm-gate diversity. In other words, there is no guarantee that on-farm diversity will lead to market sales or diversity at the point of sale.

There are two important policy implications of these findings for *in situ* conservation and economic development. First, greater on-farm diversity can increase cash flows to households (i.e. private benefits) through market sales and diversification of products, without compromising efforts to conserve banana diversity *in situ*, on farms. Furthermore, greater market involvement with a more diverse set of crops and cultivars can generate a secondary diversification effect in related product markets. This has consequences for both producers (in terms of income) and consumers (in terms of satisfying preferences for product characteristics). To encourage this process, reducing transactions costs (costs of transport, search, and information) is typically recommended in order to stimulate market participation. However, high levels of diversity on farms may not be reflected in local markets. For local markets to drive diversity on farms as economies develop, other institutional factors must be addressed. For example, in Uganda, differential consumer preferences for cooking and beer cultivars would need to be expressed more clearly in price differentials. When differences in product quality are not visible to consumers, labeling systems would be necessary, and these have cost implications, particularly for developing economies.

Acknowledgements

Note

1 The null hypothesis that instruments are irrelevant is tested by excluding the instruments and comparing results with an F test. The null hypothesis was rejected

for each set of instruments at the 1 percent level of significance. Overidentification of all instruments was not rejected, implying that the overidentifying restrictions are valid; the p-value of the Jansen J statistic is 0.7008 and 0.2261, respectively, for both sets of instruments.

References

Benin, S., Smale, M., Pender, J. Gebremedhin, B. and Ehui, S. (2004) 'The economic determinants of cereal crop diversity on farms in the Ethiopian Highlands', *Agricultural Economics* 31: 197–208.

Birol, E. (2004) 'Valuing agricultural biodiversity on home gardens in Hungary: An application of stated and revealed preference methods', PhD thesis, University College London, University of London.

Brush, S., Taylor, E. and Bellon, M. (1992) 'Technology adoption and biological diversity in Andean potato agriculture', *Journal of Development Economics* 39: 365–387.

Di Falco, S. (2003) 'Crop genetic diversity, agroecosystem production and the stability of farm income', PhD dissertation, University of York.

Edmeades, S. (2003) 'Variety attributes and attribute trade-offs within the framework of agricultural household models: the case of bananas in Uganda', PhD dissertation, North Carolina State University.

Edmeades, S., Smale, M. and Karamura, D. (2006) 'Demand for cultivar attributes and the biodiversity of bananas on farms in Uganda', in M. Smale, (ed.) *Valuing Crop Biodiversity: On-farm Genetic Resources and Economic Change*. Wallingford: CABI Publishing, pp. 97–118.

Gauchan, D. (2004) 'Conserving crop genetic resources on-farm: the case of rice in Nepal', PhD dissertation, University of Birmingham.

Keshk, O. (2003) 'CDSIMEQ: A program to implement two-stage probit least squares', *The Stata Journal* 3(2): 157–167.

Ladd, G. and Martin, M. (1976) 'Prices and demands for input characteristics', *American Journal of Agricultural Economics* 58: 21–30.

Ladd, G. and Suvannunt, V. (1976) 'A model of consumer goods characteristics', *American Journal of Agricultural Economics* 58: 504–510.

Lancaster, K. (1966) 'A new approach to consumer theory', *The Journal of Political Economy* 74: 132–157.

Maddala, G. (1983) 'Limited-dependent and qualitative variables in econometrics', Econometric Society Monographs No. 3., Cambridge University Press.

Meng, E. (1997) 'Land allocation decisions and *in situ* conservation of crop genetic resources: the case of wheat landraces in Turkey', PhD dissertation, University of California at Davis.

Nagarajan, L., Smale, M. and Glewwe, P. (2005) 'Comparing farm and village-level determinants of millet diversity in marginal environments of India: the context of seed systems', EPTD Discussion paper No. 139, IFPRI, Washington, DC.

Singh, I., Squire, L. and Strauss, J. (1986) *Agricultural Household Models: Extensions, Applications and Policy*, Baltimore, MD: Johns Hopkins University Press.

Smale, M., Bellon, M. and Aguirre-Gomez, J. (2001) 'Maize diversity, variety attributes, and farmers' choices in southeastern Guanajuato, Mexico', *Economic Development and Cultural Change* 50: 201–225.

Smale, M. (ed.) (2006) '*Valuing Crop Biodiversity: On-farm Genetic Resources and Economic Change*', Wallingford: CABI Publishing.

Van Dusen, E. (2000) '*In situ* conservation of crop genetic resources in the Mexican *milpa* system', PhD dissertation, University of California at Davis.

20 The value of ecosystem services and agrobiodiversity in central Sulawesi

Klaus Glenk, Jan Barkmann and Rainer Marggraf

1 Introduction

The Convention on Biological Diversity (CBD) stresses the importance of protecting and using biodiversity in a sustainable manner. In particular, the CBD Ecosystem Approach summons the contracting parties to adopt economically and socially sound conservation strategies. The Central Sulawesi rainforests in Indonesia are part of the global Wallacea biodiversity 'hotspot' (Myers *et al.* 2000), and are among the world's most biologically valuable eco-regions (Olson and Dinerstein 1998). Due to their exceptional contribution to global biological diversity, the conservation of Central Sulawesi rainforests is an important case for an application of conservation strategies in line with the CBD Ecosystem Approach.

One of the obstacles to the design and implementation of economically sound conservation strategies is the lack of knowledge on the economic value of non-market benefits generated by tropical forest ecosystems and the agricultural land use systems that replace those systems (Balmford *et al.* 2002). This study contributes to filling this gap by making use of the *choice experiment* (CE) method. We estimate biodiversity benefits as perceived by inhabitants living in the dynamic agricultural landscape around Lore Lindu National Park (LLNP) in Central Sulawesi where most inhabitants are smallholder farmers (Schwarze 2004).

The quantification of non-market benefits of ecosystem services and agrobiodiversity obtained by local agrarian societies can provide useful information for the development of conservation policies in various ways:

- Conservation measures may have unwarranted socio-economic impacts on the local population that need to be considered carefully. Knowledge of local benefits associated with rainforest conservation and of conservation trade-offs with human development objectives can inform decisions on the design and structure of conservation measures or incentives (Steffen-Dewenter *et al.* 2007). These decisions require consideration of incentives across all scales and their interactions.
- Documenting the existence of local benefits for maintaining or

improving the provision of ecosystem services may convince regional or national governments to re-allocate their budget towards more financial support of conservation (cf. Pattanayak and Kramer 2001). This is particularly important if conservation schemes based on economic incentives are lacking.

- Knowledge of local benefits facilitates an assessment of the local acceptance of conservation measures. Such knowledge can underpin and support efforts to communicate and implement policy measures to the local population and local governments.

Birol and Rayn-Villalba (Chapter 14 in this volume) approach agrobiodiversity in terms of genetic diversity within crops. In this chapter, we employ a different notion of agrobiodiversity that refers mainly to aspects of biological diversity at the species or ecosystem level of the agricultural 'frontier' lands around LLNP. Rather than investigating preferences for different levels of biodiversity 'holistically' (cf. Christie *et al.* 2006), we assess stated preferences for concurrent changes in the provision of *several* different biodiversity-related ecosystem goods and services relevant to local farmers. From these data, implicit prices of biodiversity-related non-market benefits provided by a dynamically changing landscape comprised of arable land, agroforestry systems and forest are assessed. Furthermore, we analyse the influence of socio-economic, socio-demographic and attitudinal variables on choice behaviour in our farmer sample.

Developed in transport and marketing research, the CE technique has become increasingly popular in environmental valuation of non-market goods (Adamowicz *et al.* 1994; Bennett and Blamey 2001). Despite widespread applications of the CE in so-called industrialized countries, applications with respondents from so-called developing countries are comparably rare, particularly in rural areas.[1] For metropolitan areas, CEs are often applied to transport and sanitation issues (e.g. Abou-Ali and Carlsson 2004; Pham and Tran 2005; Alpizar and Carlsson 2003). Cook *et al.* (2007) used a choice experiment to elicit preferences for cholera and typhoid fever vaccines in Vietnam. Seenprachawong (2003) in Thailand and Othman *et al.* (2004) in Malaysia both applied a CE to obtain non-use values of coastal respectively mangrove wetland ecosystems. To our knowledge, this is the first study using a CE for the valuation of local non-market benefits of specific ecosystem goods and services obtained by a tropical rainforest.

A successful application of the choice experiment technique requires a careful adjustment of the survey instrument to suit the local cultural, institutional and natural environment. This is a particular challenge in rural areas of low-income countries. Apart from logistical constraints, respondents tend to have rather low levels of literacy. Consequently, there is an increased risk that the cognitive demand placed on respondents by the choice task is too high. To reduce this risk, we employed an array of efforts and adjustments to enable respondents to express their preferences meaningfully.

After describing central features of the research region (Section 2), a brief introduction into the choice experiment method (Section 3) is followed by an outline of study design issues (Section 4). Multinomial logit model results are reported and discussed in Section 5. Using the model parameter estimates, implicit prices (IPs) are calculated (Section 6). We show that an improved understanding of preferences can be achieved by including attribute inter-actions with socio-economic and/or attitude variables which, in turn, contribute to the development of rural conservation and development strategies (Section 7). The chapter ends with some concluding remarks.

2 The case study site around the Lore Lindu National Park

The research region is located in the humid tropics about one degree south of the equator. It comprises four main areas divided into seven administrative districts in the province of Central Sulawesi, Indonesia. In more than 115 villages, the case study area holds a population of about 130,000 on 7,220 km^2. Lore Lindu National Park is located at the centre of the study region. It covers some 2,200 km^2, and is one of the few large rainforest remnants on Sulawesi. A large number of species endemic to Sulawesi can be found in the National Park area including, e.g., the mammals anoa (*Bubalus sp.*) and babirussa (*Babyrousa babirussa*) as well as many endemic bird species includ-ing hornbills (*Rhyticeros cassidix, Penelopides exarhatus*) (Waltert *et al.* 2004).

The rainforest margin is usually composed of a succession from natural and semi-natural forest via increasingly intensified agroforestry systems to arable farm land. Along this gradient, the inhabitants extract timber and non-timber forest products such as rattan, cultivate cocoa or coffee as agroforestry cash crops, and grow wet rice (paddy) in the lowlands surround-ing LLNP. Cocoa and wetland rice together account for 57 per cent of the net crop income (Schwarze 2004). These different production systems are not only linked by the ecological processes within the rural Central Sulawesi landscape, but also by the mix of livelihood strategies employed by local farmers within a single household. For example, forest and agroforestry systems have an impact on water availability for the irrigation of wet rice downstream, and proximity to the forest influences biodiversity-dependent ecosystem services such as pollination and pest control.

3 The choice experiment method

In a CE, consumers state their preferences by (repeated) choices among differ-ent alternatives or goods following an experimental plan. The alternatives from which survey respondents make their choices is called a *choice set*. Rooted in Lancastarian consumer theory (Lancaster 1966, 1991), the goods are described in terms of objective characteristics (attributes) from which the consumer is assumed to derive utility. In environmental choice modelling, the

alternatives are often described as different development or policy options (Bennett and Adamowicz 2001). Another main pillar of choice modelling is random utility theory (RUT; e.g., McFadden 1973, Manski 1977). Utility is partitioned into a deterministic, systematic component or 'representative utility' and a random part of utility 'reflecting [the] unobserved individual idiosyncrasies of taste' (Louviere *et al.* 2001: 38):

$$U_{ij} = V_{ij}(X_{ij}, S_i) + \varepsilon_{ij} \ \forall j \in C_i \tag{20.1}$$

where U_{ij} is the utility an individual i is assumed to obtain from of alternative j in choice set C_i. V_{ij} is the deterministic part modelled as a function of the attributes of alternatives X_{ij} (a vector of attributes for alternative j as perceived by individual i), and of characteristics of the individual S_i. ε_{ij} is the random term. As the analyst is unable to measure ε_{ij}, it cannot be determined exactly why an individual chooses alternative j out of a set of competing options $C_i \ \forall \ j,k \in C_i$ and $i = 1,\dots I$. However, the systematic component V_{ij} allows probabilistic statements about the choices. This leads to Equation (20.2) (*Random Utility Model*; RUM). Assuming utility maximization, the probability that alternative j is chosen by individual i over any alternative k out of choice set C_i can be expressed as:

$$P(j \mid C_i) = P\ (U_{ij} > U_{ik}) = P\ [(V_{ij} + \varepsilon_{ij}) > (V_{ik} + \varepsilon_{ik})]\ \forall\ j, k \in\ C_i \text{ and } j \neq k \neq 0$$

$$= P\ [(V_{ij} - V_{ik}) > (\varepsilon_{ij} - \varepsilon_{ik})]\ \forall\ j, k \in\ C_i \text{ and } j \neq k \neq 0 \tag{20.2}$$

In order to estimate the probabilities of Equation (20.2), assumptions have to be made about the nature of the random error term. The majority of discrete choice models assumes that the random term is independently and identically distributed (IID), and related to the choice probability with a Type I extreme-value (Gumbel, Weibull, double-exponential) distribution with zero mean and a variance of μ^2. The IID assumption is associated with a behaviourally comparable assumption, the independence of irrelevant alternatives (IIA). The IIA assumption states that the ratio of probabilities of choosing alternative j over k out of choice set C_i remains unaffected of the presence or absence of any other alternative. All assumptions are given now for the conditional or multinomial logit model (MNL, McFadden 1973):

$$P(j|C_i) = \frac{\exp^{\mu V_{ji}}}{\displaystyle\sum_{k \in C_i} \exp^{\mu V_{ki}}} \tag{20.3}$$

where μ is the scale parameter usually set to 1 (constant error variances) and inversely proportional to the standard deviation of the error terms (Louviere *et al.* 2001: 163). V_{ij} is assumed to be linear and additive in parameters:

$$V_{ij} = aASC_j + \Sigma\beta_n f(X_n) \tag{20.4}$$

where X_n is the attribute level of attribute n of the jth alternative and β_n is the parameter value associated with attribute n. ASC_j is short for alternative specific constants that equal '1' for alternative j (otherwise: 0), and can be included for j-1 alternatives. If the alternatives are generic (unspecific, i.e. unlabelled), the ASCs are equal. Socio-economic variables can be interacted either with the ASCs and/or the attributes. ASCs take up systematic choice variations between the different options that cannot be explained by attributes or socio-economic variables (Bennett and Adamowicz 2001: 60). By maximum likelihood estimation, estimates for the coefficients associated with the attributes can be obtained.

As the parameters β_n in V_j are confounded with the scale parameter μ, the parameters are not separable. Thus, they cannot be interpreted in *absolute* terms. Consequently, the probabilities estimated using Equation (20.3) merely serve as an indication for the *relative* utility an individual obtains from choosing a particular alternative from a choice set. However, the scale parameters cancel out if marginal rates of substitution between any pair of attributes are estimated. If one of the attributes (characteristics) reflects 'cost', these trade-offs are called implicit prices (IPs). For any linear attribute n, they can be calculated by:

$$\text{Implicit price }(n) = -\left(\frac{\mu\beta_n}{\mu\beta_\$}\right) = -\left(\frac{\beta_n}{\beta_\$}\right) \tag{20.5}$$

where β_n is the coefficient of attribute n, and $\beta_\$$ is the coefficient of the 'cost' attribute. The implicit prices reflect the marginal willingness to pay (MWTP) for a marginal change in a single attribute on a *ceteris paribus* basis (Bennett and Adamowicz 2001).

4 The choice experiment design

The design of choice experiments includes decisions about: (1) the attributes of an alternative and the respective attribute levels; (2) the nature of the 'cost' attribute; (3) the situation in which the alternatives are presented to respondents ('framing'); (4) the definition of a potential base (reference) option; and (5) the experimental plan that allows for statistical estimation of attribute coefficients. In addition to design issues extensively discussed elsewhere (e.g., Bennett and Blamey 2001; Bateman *et al.* 2002), we had to overcome several specific challenges concerning 1–5 arising from the setting of our case study.

4.1 Attribute selection

From the universe of potential 'characteristics' of biodiversity and ecosystem services from which smallholder farmers around the Lore Lindu National

Park derive utility, which are to be selected? The decision on attribute selection was guided by: (1) the objectives of the analysts and the research question; (2) constraints imposed by respondents (subjective relevance, cognitive burden/task complexity); (3) the social context (e.g., problems concerning strategic behaviour); as well as (4) specific features of the bio-physical environment of the research area.

The selection of relevant attributes and attribute levels was based primarily on information gathered in semi-structured individual and 'peer-group' interviews in various villages of the research region conducted in 2003 and 2004. Following Blamey *et al.* (1997), we screened all attributes from a demand perspective. Furthermore, information and data obtained by experts and literature (e.g. Siebert 2002; Belsky and Siebert 2003, Keil 2004) were incorporated for further adjustment. The attributes and attribute levels are listed in Table 20.1, and are described below.

Jae and Delvecchio (2004) found that visual decision aids can improve making choices as they reduce task complexity and facilitate the mediation of information to low-literacy consumers. In pre-tests, we used five attributes including 'cost' in three choice scenarios including a status quo alternative. First presented orally only, the bulk of information on attributes caused fatigue and confusion among a number of respondents. Formal education of

Table 20.1 Attributes and levels

	Attribute	*Levels*	*Ecosystem service category*	*Value type (TEV)*
Rattan	availability of rattan (*Calamus spp.*) as expressed in distance from village	[*km*] 5, 10, 15, 20	provisioning service	Direct Use/ Option Value
Water	availability of irrigation water for wet rice cultivation as expressed in number of months with water scarcity	[*No of months*] 0, 1, 2, 3	regulating service	Indirect Use Value
Cocoa	preponderance of cocoa plantations differing along a shade tree gradient	[*% under shade*] 5, 35, 65, 95	regulating services	Indirect Use/ Option Value
Anoa	populations of different sizes of the endemic dwarf buffalo anoa (*Bubalus depressicornis/quarlesi*)	[*No. of animals*] 10, 180, 350, 520	cultural/pro-visioning service	Existence/ Direct Use Value
Cost	extra taxes or donation to village fund	[*1,000 IDR per year$*] 18, 36, 54, 72	–	–

Note: $ the amounts showing up on cards with a monthly payment scheme are 1/12 of the amounts shown in the table; 1 US$ ~ 8,500 IDR at the time of the survey.

53 per cent of the respondents did not transcend elementary school, indicating a rather low level of literacy. Thus, we evaluated photographs and paintings by a local artist as visual decision aids. Photographs often prompted respondents to discuss the specific location displayed, and how conditions in their village differed from conditions shown. In contrast, paintings developed in cooperation with local farmers achieved a degree of generalization that ensured that village-specific details became less important, while the key information could be highlighted. The paintings and their respective informational background were simultaneously presented to respondents during the explanation of the attributes. This way of presenting the context and attribute-specific information, raised interest and attention and increased understanding of the choice task. Detail sketches by the same artist reduced in size were also included in the choice cards.[2] Using these visual aids, further pre-tests suggested that respondents were able to cope with five attributes. For final refinement of the questionnaire, a pilot study was conducted in 2004 (*n = 96*).

Starting with the rattan attribute (Table 20.1), we provide background information on attribute design in the following paragraphs. Rattan (*Calamus spp.*) is the most important marketed forest product in the region. It serves as a major income source, particularly for the poorest, often landless residents (Schwarze 2004). If harvests fail, e.g. caused by droughts or flooding, rattan serves as an income alternative (Vedeld *et al.* 2004) also for *less poor* residents. Thus, rattan availability has an 'option' value component even for respondents who are usually not involved in rattan extraction. Previous research in the region (Zeller and Birner 2003) showed that the encounter distance from the forest edge to rattan harvesting locations increased from 4.4 km on average in 1990 to 14.5 km in 2001, indicating an overuse of rattan resources. Because market demand is likely to remain strong (Vantomme 2003), the decline of the commercially most valuable large-diameter and long canes in the Lore Lindu region is likely to continue (Siebert 2001, 2004). Siebert (2004: 429) reports that 'The declining availability of rattan cane was evident to collectors, who responded by . . . collecting in more distant areas, and shifting collection to less valuable rattan species.' From a conservation perspective, increased encounter distances mean that human disturbance extends deeper into the primary forest as the biggest share of rattan in the research region is collected inside LLNP. The rattan attribute was operationalized by the encounter distance to the nearest extracting location. We expect a negative sign indicating a utility gain for decreasing distance.

Good water availability is essential for the production of wetland rice, the region's main food crop. Reinforced by NGO narratives, anecdotal evidence prompts many locals to believe that deforestation on hillsides leads to water shortages in the valleys during the dry months of the year. Particularly, this appears to be the case when the water originates from small watersheds in combination with simple irrigation techniques (own data,[3] Burkard 2002). Keil (2004) showed that perceptions of the seasonal changes of precipitation

and water availability fit quite well with measured data. Thus, an ecosystem level attribute on the provision of irrigation water was created. Although negative impacts of land conversion at the hillsides on water availability were mentioned to respondents, the levels of the water availability attribute make no reference to forest cover. Instead, they were simply described as months with varying degrees of water shortage for irrigation purposes in an average year. We expected a negative sign of the water attribute coefficient related to a utility gain associated with improved availability of water for irrigation.

The operationalization of the rattan and the water attributes follow an explicit ecosystem service approach to environmental valuation with stated preference methods (Nunes and Bergh 2001; Barkmann *et al.* 2008). In this approach to the valuation of ecological regulating and provisioning functions, the description of attributes and attribute levels does not rest on the scientific description of the structural or functional characteristics of the investigated rural ecosystems. Instead, a level of description is chosen that relates to the benefits that respondents obtain from these structures and functions. For the valuation of agrobiodiversity in Central Sulawesi, we did not employ scientific descriptions of local biodiversity at the species or ecosystem level (biological status of rattan populations, percentage and distribution of forest cover) but the ecosystem services provided by these components of the region's biodiversity to local smallhold farmers.

Cocoa (*Theobroma sp.*) is the dominant cash crop in the Lore Lindu area. Increasingly, the production is intensified, resulting in monocultures with no or low levels of planted shade trees (e.g., *Gliricidia sepium*). Despite higher mean yields, intensification to sun-grown cocoa leads to higher agronomic and socioeconomic risks, e.g. soil degradation and negative impacts on local food security (Belsky and Siebert 2003). High shade cocoa farming can provide habitat for a wide range of native species contributing to biodiversity conservation, and maintains considerable levels of ecosystem functions (Siebert 2002; Steffan-Dewenter *et al.* 2007). Thus, this attribute reflects trade-offs between short-term economic goals and long-term biodiversity and resource conservation objectives. Attribute levels track a shade tree gradient (5, 35, 65, 95 per cent of shade) for preponderance of local cocoa plantations ranging from full-sun grown cocoa on one side to cocoa cultivated beneath primary or secondary forest vegetation on the other side. Due to an observed tendency for intensification and based on observations in the pilot study, we expected a negative sign for the cocoa coefficient although advantages such as improved pest control were pointed out to respondents.

The Sulawesi region is an important centre for species endemism, and the Lore Lindu National Park harbours many of Sulawesi's endemic mammals and birds (Whitten *et al.* 1987; Waltert *et al.* 2004). However, large recent forest clearings inside the National Park show that the forest frontier in the research region is by no means secured (Weber 2005). To find out how conservation objectives are supported by the local population, different population sizes of the endemic dwarf-buffalo anoa (*Bupalus depressicornis,*

B. quarlesi) were included as an attribute in the choice experiment. Population sizes in the research region are in decline (Zeller and Birner 2003; Burton *et al.* 2005). Burton *et al.* (2005) identified the Lore Lindu National Park as a focus area for conservation efforts of this animal. Individual prestudy interviews showed that anoa was the most widely known forest species. As a result of discussions with locals and experts,[4] the present population size was estimated as 350 individuals living in the forests of the Lore Lindu region. The anoa attribute may refer to different Total Economic Value categories. One is 'existence' value, i.e., the concern of respondents to protect individuals of a certain species 'although he or she has never seen one and is never likely to' (Pearce and Moran 1994: 12). Direct use value (hunting), bequest value (Burton *et al.* 2005), or even fear of being injured by the animal may also influence choices. With the exception of fear, all other considerations point to the hypothesis that anoa is perceived as an 'asset' resulting in a positive sign for the anoa attribute coefficient.

4.2 Framing

'The questionnaire must strive to establish the frame in respondents' minds which is appropriate to the circumstances of the . . . decision being made' (Bennett and Adamowicz 2001: 51). An appropriate context must be developed, in which the – hypothetical! – choice scenarios are presented to respondents. If the context is misleading or not credible, there is little incentive for respondents to take the choice task seriously.

   The five attributes of our study were framed as the outcome of alternative government development programmes on a village scale. Comprehensive regional or village development programmes addressing several different conservation and/or development issues are not unfamiliar to locals. One example is the 'Central Sulawesi Integrated Area and Development Program' (ANZDEC 1997). Before making choices, respondents were reminded emphatically of their budget constraints in order to reduce bias resulting from strategic behaviour or interviewer compliance.

4.3 The 'cost' attribute

It is suggestive to use *monetary* 'cost' terms, as money is the nearly universal medium of market exchange. However, it may be useful in so-called developing countries and semi-subsistence economies to employ other forms of payment. For example, rice quantities or corn meals were used in CV and CE studies in Madagascar and Kenya (Shyamsundar and Kramer 1996; Cerda *et al.* 2007), and Mekonnen (2000) offered payment in cash *or kind* for management of community woodland in rural Ethiopia (CV). Although rice is a staple food in the study region, it also has several disadvantages as the unit of the 'cost' attribute. People may value a specific quantity of rice differently due to the following reasons: (1) varying breeds of rice are planted and sold with

differing prices; (2) there is a disparity between respondents owning rice fields, respondents working in rice fields as seasonal farm hands, and respondents not engaged in rice cultivation at all. This – in addition to fluctuating market prices – results in a wide range of uncertainties for an ex post translation of rice quantities into monetary units. Another alternative payment method, especially addressing the poorer parts of the population, could be 'wage labour' (compare to Adamowicz *et al.* 1997a). However, it seems to be (1) morally questionable to 'let the poor work'; and (2) hard to find a specific and appropriate purpose for the work. In contrast, exploratory studies showed that all people are familiar with monetary issues even in remote parts of our project area. Thus, we felt legitimized in designing a monetary 'cost' attribute.

Our prestudies indicated clearly that several of the poorer respondents would not be able to pay the higher amounts demanded by some CE alternatives (see Table 20.1). Therefore, the interpretation of our stated preference values needs to recognize constraints by respondents' *ability* to pay in addition to their *willingness* to pay (Whittington 1998). As the wealth status of the inhabitants differs to a large extent, it proved to be a challenging task to derive an appropriate price range for the cost attribute.[5] According to Whittington (1998), the highest price should be rejected by 90–95 per cent of the respondents in close-ended CVM studies. Initially, the levels were derived following this rule of thumb by using different 'prices' in pre-tests based on initial information obtained by a payment-ladder approach (Bateman *et al.* 2002: 138f). Offering the highest price to the poor could embarrass them, and could make 'the interviewers look insensitive and/or uninformed' (Whittington 1998: 8). Hence, the range of 'price' levels was cut at the high end, accepting an underestimation of WTP by ignoring the higher WTP of a low percentage of rather well-off people. WTP values are calculated as the amount paid per year.

The 'cost' attribute was double split-sampled. One half of respondents were confronted with a rise in 'house- and land' tax (*Pajak Bumi Bangunan*), the other half with a donation to a village fund (*Iuran dana pembangunan desa*) affecting every household of the case study region. Both payment vehicles are familiar and widely accepted within the region. The second split sample involved monthly versus yearly payments. Results of this split-sample experiments will be reported elsewhere.

4.4 Experimental design and the status quo

Out of the *4⁵* possible combinations of attribute levels, an orthogonal fraction of 16 was selected by experimental design techniques (Louviere *et al.* 2001) using SPSS 12.0. These were combined into choice sets that consisted of two (generic) alternatives A and B and a status-quo option each presented on a choice card. The resulting sets of the main-effects design were blocked into four versions, so that each respondent faced four choices. All attributes

entered the analysis as continuous attributes using actual values (see Table 20.1). Half of the respondents received choice sets with an reverted attribute order on the choice cards (for an analysis, see Glenk 2007).

Inclusion of a status quo option allows the estimation of economic welfare measures (Louviere *et al.* 2001). The status quo or 'do-nothing' option is the reference from which the scenarios offered by the researcher to the respondents differ. Its specification is important because it affects the utility of the other options relative to the status quo. Furthermore, the specification influences if outcomes are viewed as gains or losses (Blamey *et al.* 1997: 14). With an exception for 'anoa' and 'cost', respondents of our study were directly asked which attribute levels they perceived as most similar to the present situation. By this means, respondents created their 'individual' status quo or 'self-explicated' alternative (Blamey *et al.* 2001: 137). We did so for the following reasons:

1   The individual status quo addresses local heterogeneities in environmental and socio-demographic conditions better than a constant base reference enabling economic valuation based on a valid status quo in the first place.
2   Involving respondents in the preparation of the choice experiment, and customising the status quo reduced some 'disbelief' about the hypothetical nature of the choice task and the survey. A constant, and thus often locally wrong, status quo would have resulted in very critical discussions and cast doubt on the study.
3   Prior to the choice task, the respondents had to intensively engage with the present situation regarding the attributes. As a result, it is likely that respondents were more confident about their choices as they became more familiar with the attributes.

Economic choices are *inter alia* related to respondent perceptions (McFadden 2001). However, if respondent perceptions diverge from actual (objective) measures, there are implications for welfare measures calculated as impacts of objectively defined changes (Adamowicz *et al.* 1997b). Several lines of evidence suggest that perceived and actual status quo do not differ substantially in our study. For example, we observed much lower variations of the self-explicated status quo within villages than between villages (data not shown). Also, perceived scores for local water availability had been documented to reflect measured precipitation data well (Keil 2004). Still, we cannot exclude the possibility of divergence. A certain divergence is unavoidable because the offered attribute level will often either over- or under-state the actual situation due to the coarse resolution of the attribute level range.

A dominant choice set was included prior to the actual choice experiment to test for rationality (Bradley 1988; Bradley and Daly 1994; Hanley *et al.* 2000; Johnson and Mathews 2001), and serve as a 'warm-up' task. The dominant choice set was constructed by assigning unattractive – identical –

attribute levels to options A and B except for price. The – almost always[6] – dominant option in the choice set was the relatively more attractive status quo. Two additional choice sets not derived from the main effects design were included for further model testing to be reported elsewhere.

4.5 Socio-demographic characteristics (SDC)

Additional data collected included information about the choice task, e.g. difficulty, confusion, and data on several socio-demographic and attitudinal individual characteristics (e.g., age, education). We included some socio-demographic variables as interactions with the ASC to better understand the choice pattern of respondents as far as it systematically differentiates between the generic alternatives A and B on the one hand, and the status quo (Table 20.2).

The dummy KL for respondents from Kulawi and Lore areas was created because forest degradation on hillsides is far less visible here than in the Sigi Biromaru and Palolo areas. Hence, the threat imposed by environmental degradation is less obvious in Kulawi or Lore. In contrast, Sigi Biromaru and Palolo respondents may display a higher propensity to associate *unobserved attributes* with the offered development programme as they hope for an end to environmental degradation at large. The inclusion of such unobserved attributes in choices would discourage choosing the status quo. Therefore, we expect the interaction of dummy KL with the non-status quo ASC to have a negative coefficient indicating a higher probability of choosing the status quo if people live in the less degraded Kulawi and Lore areas.

The influence of respondent comprehension of the choice task (UNDS) was evaluated by the interviewers immediately after the CE using a five-point scale. UNDS was also interacted with the ASC. The status quo option may be used as an 'easy way out' due to task difficulties (Kontoleon and Yabe 2004). We expect that the likelihood of choosing the status quo increases for decreasing scores of understanding, providing indication that this strategy was used.

Table 20.2 Variables interacted with ASC

Variable	Description	Mean	Std. Dev.
KL	Dummy variable showing whether respondent is from Lore or Kulawi districts	0.52	0.50
UNDS	5-point scale for overall understanding of the choice task as perceived by the interviewer[§]	3.14	0.85
PRISEC	Indicator for perceived discretionary income: share of total household income spend on primary needs rather than spent on secondary needs)[§§]	1.96	0.69
YOUNG	Dummy variable for age of respondent ≤ 35 years	0.29	0.45
OLD	Dummy variable for age of respondent ≥ 55 years	0.27	0.45

Note: [§] 1: 'not at all'; 5: 'very well'; [§§]1: 1/4 up to ½; 3: 3/4 to everything.

We used a perceptual measure of discretionary income modified from Green and Tunstall (1992) as a proxy for disposable income (PRISEC). We expect a negative coefficient of the ASC*PRISEC interaction. Respondents who feel less able to spend on secondary rather than primary needs are more likely to choose the status quo option which is not associated with additional payments. This may be an expression of more severe budget constraints of poorer households. Dummies for different age groups (YOUNG, OLD) were included without having prior expectations of their influence on choosing the status quo option.

4.6 Data collection

In order to aggregate the (perceived) economic values of the sample population to the research region for the investigated ecosystem services, a stratified village sampling frame with 12 villages was adopted. The strata for the sample were ethnicity, vicinity to the Lore Lindu National Park, and village population density. Households were randomly selected within each village (for sampling frame details see Zeller *et al.* 2002). The CE survey was administered to 301 households (December 2004–March 2005). Face-to-face interviews were conducted by six well-trained local enumerators. To minimize interviewer effects, enumerators were randomly assigned to households.

5 Model results and discussion

All 301 households completed the choice task, and 235 made choices which at least once included either option A or B. Some 66 respondents (22 per cent) chose the status quo in all four choices; 53 respondents did so as they perceived the present situation to be the relatively best option. This was the case either because of a good 'individual' status quo or because they could not afford the payment required in some choices. The remaining 13 respondents always chose the status quo because of 'protest', payment aversion, or because the choice task clearly exceeded their cognitive capability. These respondents were classified as 'essentially not responding to the CE task' (Adamowicz *et al.* 1998: 68) resulting in 288 responses for further analysis. Some 261 respondents (91 per cent) chose an option from the dominant choice set that was classified as rational. Therefore, we assume that most respondents understood the choice task sufficiently. Model results are listed in Table 20.3.

For the base model (see Table 20.3), it is assumed that each attribute reflects an individual's utility in a linear fashion. Overall, the base model was highly significant ($p < 0.001$). Except for the anoa attribute, which is significant at the 5 per cent level, all other choice set attributes are significant at the 1 per cent level or better. A positive sign shows that *more* of an attribute results in a higher probability of an alternative being chosen, while a negative parameter signifies that *more* of an attribute has a negative effect on the odds

Table 20.3 MNL model results

Variable	Base model		Model 1		Model 2	
Rattan availability	−0.0354	***	−0.0404	***	−0.0408	***
	(−4.619)		(−5.179)		(−5.127)	
Water for irrigation of paddy rice	−0.88	***	−0.8943	***	−0.8885	***
	(−18.734)		(−18.772)		(−18.277)	
Cocoa Shade (linear)	−0.0105	***	0.0126	*	0.0126	*
	(−6.620)		(2.067)		(2.047)	
Cocoa Shade^2 (quadratic)			−0.0247	***	−0.0249	***
			(−3.913)		(−3.890)	
Anoa Population Size	0.0009	**	0.0009	**	0.0009	**
	(2.856)		(2.688)		(2.655)	
Cost (Tax rise/village fund donation)	−0.0262	***	−0.0254	***	−0.0256	***
	(−9.420)		(−9.146)		(−9.162)	
ASC (non-*status quo* choice)	0.3481	*	0.4892	***	2.1967	***
	(2.553)		(3.486)		(5.660)	
ASC*KL					−0.4039	**
					(−2.854)	
ASC*UNDS					−0.2842	***
					(−3.377)	
ASC*PRISEC					−0.2320	*
					(−2.240)	
ASC*YOUNG					−0.2851	
					(−1.651)	
ASC*OLD					−0.2731	
					(−1.575)	
Log-likelihood	−865.0992		−857.3425		−843.0408	
Number of observations	1152		1152		1152	
Adjusted ρ^2 (Pseudo-R^2)§	0.2583		0.2646		0.2753	

Notes: ***: significant at $p < 0.001$; **: significant at $p < 0.01$; *: significant at $p < 0.05$; t-statistics in parentheses.
§ Pseudo-R^2 as compared to constant-only model.
Source: Own calculations.

of an alternative being chosen. 'Water' and 'rattan' have – as expected – negative signs. The 'anoa' attribute is positive and significant, indicating that people do care for the maintenance of viable populations of this animal. For the 'cocoa' attribute, the coefficient is negative and significant, denoting a negative effect of more shade.

Indicating a threshold for shade-related intensification, a quadratic term for cocoa is negative and significant (Table 20.3, Model 1). Utility peaks at a level of shading of approximately 28 per cent. We find a significant improvement of model fit using the quadratic specification as compared to the base model (Likelihood Ratio test: 15.51, one degree of freedom) as well as for additionally including interactions with socio-demographic characteristics in Model 2 (LR test: 28.60, 5 d.f.).

All interactions with SDCs are significant at the 5 per cent level or better except for the dummies for age groups. The model fit of all models was

assessed by the value of adjusted ρ^2 (Pseudo-R^2) conservatively compared to the *constants only* model. Pseudo-R^2 was 0.258 for the base model, and increases for model 1 (0.265) and model 2 (0.275). These pseudo-R^2 values can be compared to values of R^2 as in OLS regression models, where values of ρ^2 of 0.3 correspond to R^2 values of about 0.6 (Hensher *et al.* 2005), representing a decent model fit. In the following, we use Model 2 to calculate implicit prices.

All models exhibit a positive and significant value for the ASC. This suggests that there is no particular propensity to choose the status quo option relative to the alternatives as often reported (e.g., Adamowicz *et al*. 1998). Respondents receive, on average and everything else held constant, more utility from departing from the present situation than from keeping it. This could be due to a number of reasons such as inclusion of unobserved attributes associated with a governmental programme, or perceived task compliance. According to the high rate of status quo choices among all choices (53 per cent) it is unlikely, however, that respondents felt collectively 'forced' to choose among the non-status quo alternatives as a consequence of compliance with any the assumed interviewer or research intentions.

The interactions of the ASC with individual characteristics can shed some light on potential reasons and their heterogeneous distribution among the sample population. The coefficient of ASC*KL is negative as expected. Accordingly, the likelihood to move away from the status quo decreases if the respondent is from the environmentally less degraded Kulawi or Lore districts. Surprisingly, higher understanding of the choice task as judged by the interviewers increases the likelihood of choosing the status quo relative to the alternatives. This finding supports the assumption that respondents did not have a tendency to use the status quo as an 'easy way out' in case of difficulties associated with the choice task. Alternatively, respondents who display higher understanding scores may make less use of unobserved ('positive') attributes subjectively *ascribed* to the non-status quo options.

The fewer respondents reported to be able to spend on secondary rather than primary needs, the more likely they were to choose the status quo. We interpret this as an expression of the limited ability to pay of poorer households. Neither young nor old age has a significant impact on choosing the status quo.

Using equation (20.5) and Model 2, implicit prices were calculated for the attributes (Table 20.4). Confidence intervals were derived using a Krinsky and Robb (1986) procedure with 1,000 random draws. High implicit prices suggest those attributes to policy-makers whose protection or improvement may warrant more resources (Colombo *et al.* 2005: 89). However, care must be taken when comparing the implicit prices as the units of attributes differ. MWTP to avoid one month of water scarcity for irrigation is about 34,800 IDR (~ US$ 4.1) per year, 100 more individuals of anoa are worth about 3,400 IDR (~ US$ 0.4) per year. MWTP for a 1 per cent change of shading in the cocoa attribute is slightly lower (395 IDR) if calculated without a quadratic

Table 20.4 Implicit prices in IDR/year (US$)

		Rattan	Water	Cocoa[§]	Anoa
Median		−1,598	−34,803	−481	34
		(−0.19)	(−4.1)	(−0.06)	(0.004)
	Lower bound	2,356	−45,502	−666	10
		(−0.28)	(−5.35)	(−0.08)	(0.001)
95%					
	Upper bound	−946	−28,453	−339	61
		(−0.11)	(−3.36)	(−0.04)	(0.007)

Note: [§] calculated as mean slope between 5% and 95%;
Source: Own calculations.

term. This is due to the dramatic decrease in utility for very high shade levels because of the quadratic relationship. A similar effect of using a quadratic term was found by Adamowicz *et al.* (1998).

As indicated in Section 4.1, choices regarding the anoa attribute may be motivated by both beneficial and problematic aspects concerning this species. Some 51 per cent of the respondents stated with respect to an open question to obtain benefits mostly related to the protection of a species which is 'special' (*khas*) to Sulawesi. This indicates a preponderance of existence and bequest value motives. Only about 14 per cent name benefits from the direct use of anoa (meat, horns, skin, etc.). On the other hand, not all respondents may have reported benefits obtained from (illegal) hunting activities. About one-third (32 per cent) of respondents could not mention any positive aspects, while 53 per cent reported potential or actual problems related to anoa. Problems were mainly associated with the perception of anoa as a 'wild and ferocious' animal (cf. Whitten *et al.* 1987). Anoas would 'chase after people' and would 'like to make use of their horns when meeting people'. A few respondents added the important detail 'if disturbed' to these statements.

On average, respondents showed preferences for a greater size of the anoa population as documented by the positive coefficients in all models reported in Table 20.3. Due to the mixed perception on anoa, the three models presented above are insufficient to exclude the possibility that some respondents actually preferred lower anoa numbers. In order to assess the existence and degree of such a 'reversed' preference relation, we included two interaction variables with the anoa attribute in the utility function (Table 20.5). The two variables were designed to capture: (1) the *general* attitude towards anoa; and (2) respondents' knowledge of the threat of extinction (see Figure 20.1). The means and standard deviations are 3.05 (0.94) for *ANOHAPPY* and 2.99 (1.4) for *ANOSURV* (5-point Likert scale).

The sign of the coefficient for the anoa attribute (significant at the 5 per cent level) is negative. The coefficients of the two interactions included are both positive and significant (*ANOHAPPY*: P = 0.03; *ANOSURV*: 0.002). The more positive people felt about anoa, and the more likely they thought

Table 20.5 MNL model: anoa attribute interactions

Variable	Coefficient	
Anoa Population Size	−0.0034	*
	(−2.578)	
Anoa * *ANOHAPPY*	0.0007	*
	(2.166)	
Anoa * *ANOSURV*	0.0007	**
	(3.033)	
Rattan availability	−0.0401	***
	(−5.121)	
Water for irrigation of paddy rice	−0.9066	***
	(−18.826)	
Cocoa Shade (linear)	0.013	*
	(2.134)	
Cocoa Shade^2 (quadratic)	−0.0252	***
	(−3.974)	
Cost (Tax rise/village fund donation)	−0.0255	***
	(−9.155)	
ASC (non-status quo choice)	0.4868	***
	(3.456)	
Log-likelihood	−850.654	
Number of observations	1152	
Adjusted ρ^2 (Pseudo-R^2)§	0.27	

Notes: ***: significant at $p < 0.001$; **: significant at $p < 0.01$; *: significant at $p < 0.05$; t-statistics in parentheses.
§ Pseudo-R^2 as compared to constant-only model.
Source: Own calculations.

that a population of 10 remaining individuals would become extinct, the higher the utility they obtained from maintaining larger population sizes in the Lore Lindu area. Using the scores of individual respondents for the two interaction variables, about one-fifth (19 per cent) of the respondents would actually prefer *smaller* population sizes of anoa.

6 Conclusion

A choice experiment on the valuation of four biodiversity-related ecosystem services used by farmers at agricultural frontier lands was successfully conducted on one of Indonesia's outer islands in the global biodiversity 'hotspot' Wallacea. Our respondents, mostly farmers or at least partially working as farm hands – understood the choice task sufficiently; statistical diagnostics indicate very reasonable model performance. The careful adjustment of the design of the CE interview to a rural setting in a so-called developing country contributed essentially to this result. Our adjustment included the use of visualizations, the strategy to adjust the status quo to the perceptions of the individual respondents, and an ecosystem services approach focusing

(1) General Attitude (*ANOHAPPY*):

Which of these pictures is suited best to describe your feeling when you think of anoa?

(1)   *Score*   (5)

(2) Knowledge of threat of extinction (*ANOSURV*):

Let's suppose that there are 10 individuals of *anoa* remaining in the whole Lore Lindu Region. Do you think that anoa will…

　　　　　… *definitely survive*　　　　　　　*(1)*
　　　　　… *probably survive*
　　　　　… *maybe survive, maybe not*　　　*Score*
　　　　　… *probably become extinct*
　　　　　… *definitely become extinct*　　　*(5)*
　　　　　　　　　　　　　　　　　　　　…in the region?

Figure 20.1 Survey questions of the two variables interacted with anoa.

explicitly on the real-world benefits of functional changes in biological diversity at the species and ecosystem level (Barkmann *et al.* 2008).

Statistically significant attribute coefficients allowed for the calculation of implicit prices for an improved provision of several biodiversity-related eco-system services ('water', 'rattan', 'anoa'). The magnitude of the calculated MWTP is quite substantial considering the living conditions and the low cash income of the inhabitants of the Lore Lindu region. Respondents indicated a willingness to contribute actively to the maintenance of their natural resource base. Even for maintaining viable population sizes of the local endemic dwarf buffalo anoa, residents had, on average, small MWTP although direct or indirect use benefits are likely to be very low.

In the fast-growing sector of cocoa agroforestry, on the other hand, respondents indicated an unexpectedly clear preference for fewer shade trees in local cocoa plantations. Thus, biodiversity conservation measures aiming at more sustainable ways of cocoa cultivation (measured here by a shade tree gradient) are unlikely to be successful without offering economic incentives for cocoa farmers. Compared to the annual revenues from more intensive agroforestry of several hundred US$/yr/ha, the disutility stemming from shading alone itself appears rather low (< 4 US$/yr/ha per 40–50 per cent shade reduction). Thus, the introduction of a certification scheme for high-shading 'biodiversity-friendly' cocoa production may realistically achieve a price premium per hectare that suffices to offset high-shade disadvantages (Steffan-Dewenter *et al.* 2007).

Using the anoa attribute as an example, we showed the importance of looking beyond mean effects by using interactions of attitudinal variables with attributes. On average, respondents had preferences for greater sizes of the anoa population. In an interaction model, preferences for different sizes of the anoa population were found to be a function of a general attitude towards this species, and of knowledge of the threat of its extinction. As a result of an analysis of the two interaction terms, we predict that nearly one fifth of the local population does actually not prefer larger but smaller anoa populations. Additionally, 14 per cent of respondents mentioned hunting-related benefits when asked what advantages anoas have. Respondents in these groups are not necessarily hunters of anoa. Still, there is reason to assume that people with a negative general attitude and/or limited knowledge regarding the threat of extinction are more likely to actively or passively support hunting activities. Results from population models reported by Manansang *et al.* (1996) indicate that anoa populations may only be able to survive a hunting rate of 2–3 per cent each year. Our results suggest that the threat of extinction may persist in spite of 'mean' preferences for anoa conservation.

Educational efforts – addressing both adults and children – may help to alter people's attitude and their knowledge of anoa, which were shown to influence preferences. Creating knowledge and awareness can therefore contribute to the conservation of this endemic species. Environmental education may take some time to make an impact. In the meantime, immediately effective conservation measures are needed. This is in line with Burton *et al.* (2005: 40), who conclude that 'law enforcement should be combined with an environmental education campaign that stresses that the anoas are unique to Sulawesi and in danger of being lost forever.'

In sum, we documented the applicability of carefully conducted choice experiments for the valuation of selected biodiversity and functional ecosystem service benefits in a rural area of a low-income country. Our MWTP estimates can be used to facilitate the design of economically informed and socio-economically sensitive conservation strategies in the Lore Lindu area. In particular, the estimated non-market benefits may be incorporated into a cost-benefit analysis of conservation strategies that stop deforestation and further intensification of cocoa agroforestry systems. But also for directly applicable conservation strategies such as a certification scheme for the 'biodiversity-friendly' production of cocoa under a canopy of shade trees, interesting results could be obtained.

Notes

1 On applications of CVM in so-called developing countries, see, e.g., Whittington (2002).
2 See such material at http://ufgb989.uni-forst.gwdg.de/DPS/pdf/SDP16b.pdf.
3 For example in the village of Sintuwu, one of the streams providing water for irrigation dried up after significant forest loss; in another village the water declined to such an extent that irrigation is hardly possible any more.

4 The authors would like to thank TNC Palu and Muhammad Yasin Paada from UNTAD.
5 While a few households live in concrete houses, have access to satellite television and sometimes even own a car, others share a wooden hut without electricity.
6 The level included for cocoa was 95 per cent shade in options A and B, while the payment was less in option A. For respondents focusing on the advantages of high shade cocoa agroforestry, their self-explicated status quo may not have been dominant. Choices from respondents choosing option A who explained that they did so because they, in fact, preferred very high shade were still counted as 'rational'. Respondents choosing A or B for other reasons were not counted as 'rational', and given a brief repetition of the explanation of the choice task before continuing with the analysed part of the CE.

References

Abou-Ali, H. and Carlsson, F. (2004) '*Evaluating the Welfare Effects of Improved Water Quality Using the Choice Experiment Method*', Working Papers in Economics No. 131, Department of Economics, Gothenburg University.

Adamowicz, W., Boxall, P., Williams, M. and Louviere, J. (1998) 'Stated preferences approaches to measuring passive use values', *American Journal of Agricultural Economics* 80: 64–75.

Adamowicz, W., Louviere, J. and Williams, M. (1994) 'Combining stated and revealed preference methods for valuing environmental amenities', *Journal of Environmental Economics and Management* 26: 271–292.

Adamowicz, W., Luckert, M. and Veeman, M. (1997a) 'Issues in using valuation techniques cross-culturally: three cases in Zimbabwe using contingent valuation, observed behaviour and derived demand techniques', *Commonwealth Forestry Review* 76(3): 194–197.

Adamowicz, W., Swait, J., Boxall, P., Louviere, J. and Williams, M. (1997b), 'Perceptions versus objective measures of environmental quality in combined revealed and stated preference models of environmental valuation', *Journal of Environmental Economics and Management* 32: 65–84.

Akiyama, T. and Nishio, A. (1996) '*Indonesia's cocoa boom: hands-off policy encourages smallholder dynamism*', Policy Research Working Paper 1580. The World Bank, Washington, DC.

Alpizar, F. and Carlsson, F. (2003) 'Policy implications and analysis of the determinants of travel mode choice: an application of choice experiments to metropolitan Costa Rica', *Environment and Development Economics* 8: 603–619.

ANZDEC (1997) *Central Sulawesi Integrated Area Development and Conservation Project*. TA NO 2518 – INO. Draft Final Report – Annex (Working Papers). Indonesia.

Balmford, A., Bruner, A., Cooper, P., Constanza, R., Faber, S., Green, R., Jenkins, M. *et al*. (2002) 'Economic reasons for conserving wild nature', *Science* 297: 950–53.

Barkmann, J., Glenk, K., Handi, H., Sundawati, L., Witte, J.-P. and Marggraf, R. (2007) 'Assessing economic preferences for biological diversity and ecosystem services at the Central Sulawesi rainforest margin – a choice experiment approach', in T. Tscharntke, C. Leuschner, E. Guhardja and M. Zeller (eds) *The Stability of Tropical Rainforest Margins: Linking Ecological, Economic and Social Constraints of Land Use and Conservation*. New York: Springer.

Barkmann, J., Glenk, K., Keil, A., de Vries, K., Leemhuis, C., Dietrich, N., Gerold, G.

and Marggraf, R. (2008) 'Confronting unfamiliarity with ecosystem functions: the case for an ecosystem service approach to environmental valuation with stated preference methods', *Ecological Economics* 65(1): 48–62.

Bateman, I.J., Carson, R.T., Day, B. Hanemann, M., Hanley, N., Hett, Jones-Lee, M. *et al.* (2002) *Economic Valuation with Stated Preference Techniques: A Manual*. Cheltenham: Edward Elgar.

Belsky, J. and Siebert, F. (2003) 'Cultivating cocoa: implications of sun-grown cocoa on local food security and environmental sustainability'. *Agriculture and Human Values* 20: 277–285.

Bennett, J. and Adamowicz, W. (2001) 'Some fundamentals of environmental choice modelling', in J. Bennett and R. Blamey (eds). *The Choice Modelling Approach to Environmental Valuation*. Cheltenham: Edward Elgar.

Bennett, J. and Blamey, R. (eds) (2001) *The Choice Modelling Approach to Environmental Valuation*. Cheltenham: Edward Elgar.

Blamey, R., Louviere, J. and Bennett J. (2001), 'Choice set design', in J. Bennett and R. Blamey (eds) *The Choice Modelling Approach to Environmental Valuation*. Cheltenham: Edward Elgar.

Blamey, R., Rolfe, J., Bennett, J. and Morrison, M. (1997) *Environmental Choice Modelling: Issues and Qualitative Insights*. Research Report No. 4. Canberra, Australia: School of Economics and Management, The University of New South Wales.

Bradley, M. (1988) 'Realism and adaptation in designing hypothetical travel choice concepts', *Journal of Transport Economics and Policy* 22: 121–137.

Bradley, M. and Daly, A. (1994) 'Use of the logit scaling approach to test for rank-order and fatigue effects in stated preference data'. *Transportation* 21: 167–184.

Burkard, G. (2002) '*Natural Resource Management in Central Sulawesi: Past Experience and Future Prospects*', STORMA Discussion Paper Series No 8. Bogor, Indonesia: Universities of Göttingen and Kassel, Germany and the Institut Pertanian Bogor and Universitas Tadulako, Indonesia.

Burton, J., Hedges, S. and Mustari, A. (2005) 'The taxonomic status, distribution and conservation of the lowland anoa Bubalus depressicornis and mountain anoa *Bubalus quarlesi*'. *Mammal Review* 35(1): 25–50.

Carson, R., Flores, N. and Mitchell, R. (1999) 'The theory and measurement of passive use value', in I. Bateman and K. Willis (eds). *Valuing Environmental Preferences*. Oxford: Oxford University Press.

Cerda, C., Diafas, J., Barkmann, J., Mburu, J. and Marggraf, R. (2007) 'WTP or WTA, or both? Experiences from two choice experiments for early planning stages', in J. Meyerhoff, N. Lienhoop and P. Elsasser (eds) *Stated Preference Methods for Economic Valuation: Applications from Germany and Austria*. Marburg: Metropolis.

Christie, M., Hanley, N., Warren, J., Hyde, T., Murphy, K. and Wright, R. (2004) 'A valuation of biodiversity in the UK using choice experiments and contingent valuation', paper presented at Kings College, Cambridge: 6th International BIOECON conference on 'Economics and the Analysis of Biology and Biodiversity'.

Christie, M., Hanley, N., Warren, J. and Wright, R. (2006) 'Valuing the diversity of biodiversity', *Ecological Economics* 58(2): 304–317.

Colombo, S., Calatrava-Requena, J. and Hanley, N. (2005) 'Designing policy for reducing the off-farm effects of soil erosion using choice experiments', *Journal of Agricultural Economics* 56(1): 81–95.

Cook, J., Whittington, D., Canh, D.G., Johnson, F.R. and Nyamete, A. (2007) 'Reliability of stated preferences for cholera and typhoid vaccines with time to think in Hue, Vietnam', *Economic Inquiry* 45(1): 100–114.

Glenk, K. (2007) 'A split-sample experiment to test for effects of attribute order in choice experiments', in J. Meyerhoff, N. Lienhoop and P. Elsasser (eds.) *Stated Preference Methods for Economic Valuation: Applications from Germany and Austria*. Marburg: Metropolis.

Green, C. and Tunstall, S. (1992) 'The recreational and amenity value of river corridors', in P. Boon, P. Calow and G. Petts (eds). *River Conservation and Management*. Chichester: John Wiley & Sons, Ltd.

Hanley, N., Wright, R. and Koop, G. (2000) 'Modelling recreation demand using choice experiments: climbing in Scotland', *Environmental and Resources Economics* 22: 449–466.

Hensher, D., Rose, J. and Greene, W. (2005) *Applied Choice Analysis: A Primer*. Cambridge: Cambridge University Press.

Jae, H. and Delvecchio, D. (2004) 'Decision-making by low-literacy consumers in the presence of point-of-purchse information', *The Journal of Consumer Affairs* 38(2): 342–354.

Johnson, F. and Matthews, K. (2001) 'Sources and effects of utility-theoretic inconsistencies in stated-preference surveys'. *American Journal of Agricultural Economics* 83(5): 1328–1333.

Keil, A. (2004) '*The socio-economic impact of ENSO-related drought on farm households in Central Sulawesi, Indonesia*', PhD thesis, Institute of Rural Development, Georg-August-Universität Göttingen.

Kontoleon, A. and Yabe, M. (2004) 'Assessing the impacts of alternative "opt-out" formats in choice experiment studies', *Journal of Agricultural Policy Research* 5: 1–32.

Krinsky, I. and Robb, A. (1986) 'On approximating the statistical properties of elasticities', *Review of Economics and Statistics* 68: 715–719.

Lancaster, K. (1966) 'A new approach to consumer theory', *Journal of Political Economy* 74: 132–157.

Lancaster, K. (1991) *Modern Consumer Theory*. Brookfield, VT: Edward Elgar.

Louviere, J., Hensher, D. and Swait, J. (2001) *Stated Choice Methods – Analysis and Application*. Cambridge: Cambridge University Press.

Manansang, J., Hedges, S., Siswomartono, D., Miller, P.S. and Seal, U.S. (1996) *Population and Habitat Viability Assessment Workshop for the Anoa* (Bubalus depressicornis *and* Bubalus quarlesi). Apple Valley, MN: Conservation Breeding Specialist Group (SSC/IUCN).

Manski, C. (1977) 'The structure of random utility models', *Theory and Decision* 8: 229–254.

McFadden, D. (1973) 'Conditional logit analysis of qualitative choice behavior', in P. Zarembka (ed.) *Frontiers in Econometrics*. New York: Academic Press.

McFadden, D. (2001) 'Economic choices', *The American Economic Review* 91(3): 351–378.

Mekonnen, A. (2000) 'Valuation of community forestry in Ethopia: a contingent valuation study of rural households', *Environment and Development Economics* 5: 289–308.

Myers, N., Russel, A., Mittermeier, R., Mittermeier, C., da Fonseca, G. and Kent, J. (2000) 'Biodiversity hotspots for conservation priorities', *Nature* 403: 853–858.

Nunes, P. and v.d. Bergh J. (2001) 'Economic valuation of biodiversity: sense or nonsense?', *Ecological Economics* 39(2): 203–222.

Pattanayak, S.K. and Kramer, A.A. (2001) 'Worth of watersheds: a producer surplus approach for valuing drought mitigation in Eastern Indonesia', *Environment and Development Economics*. 6(1): 123–146.

Olson, D.M. and Dinerstein, E. (1998) 'The Global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions', *Conservation Biology* 12(3): 502–515.

Othman, J., Bennett, J., and Blamey, R. (2004) 'Environmental values and resource management options: a choice modelling experience', *Environment and Development Economics* 9(6): 803–824.

Pham, K. and Tran, V. (2005) *Household Demand for Improved Water Services in Ho Chi Minh City: A Comparison of Contingent Valuation and Choice Modeling Estimates*. EEPSEA Research Report Series No. 2005-RR3, Economy and Environment Program for Southeast Asia, Singapore.

Pearce, D. and Moran, D. (1994) *The Economic Value of Biodiversity*. IUCN – The World Conservation Union. London: Earthscan Publications.

Schwarze, S. (2004) '*Determinants of income generating activities of rural households; a quantitive study in the vicinity of the Lore-Lindu National Park in Central Sulawesi/Indonesia*'. PhD thesis, Institute of Rural Development, Georg-August-Universität Göttingen.

Seenprachawong, U. (2003) '*An Economic Valuation of Coastal Ecosystems in Phang Nga Bay, Thailand*'. EEPSEA Research Report Series No. 2003-RR5, Economy and Environment Program for Southeast Asia, Singapore.

Shyamsundar, P. and Kramer, R. (1996) 'Tropical forest protection: an empirical analysis of the costs borne by local people', *Journal of Environmental Economics and Management* 31: 129–144.

Siebert, S. (2001) 'Sustainable harvesting of wild rattan: viable concept or ecological oxymoron?' *Unasylva* 52: 36–45.

Siebert, S. (2002) 'From shade to sun-grown perennial crops in Sulawesi, Indonesia: implications for biodiversity conservation and soil fertility', *Biodiversity and Conservation* 11: 1889–1902.

Siebert, S. (2004) 'Demographic effects of rattan cane collecting and implications for sustainable harvesting', *Conservation Biology* 18(2): 424–431.

Steffan-Dewenter, I., Kessler, M., Barkmann, J., Bos, M., Buchori, D., Erasmi, S., Faust, H. *et al.* (2007) 'Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification', *Proceedings of the National Academy of Sciences* 104: 4973–4978.

Vantomme, P. (2003) 'Growing imbalance between supply and demand for rattan?', *Journal of Bamboo and Rattan* 2(4): 407–415.

Vedeld, P, Angelsen, A., Sjaastad, E. and Berg, G. (2004) 'Counting on the environment: Forest incomes and the rural poor'. Environment Department Papers No. 98. The World Bank, Washington, DC.

Waltert, M., Mardiastuti, A. and Mühlenberg. M. (2004) 'Effects of land use on bird species richness in Sulawesi, Indonesia', *Conservation Biology* 18(5): 1339–1346.

Weber, R. (2005) '*Kulturlandschaftswandel während des 20. Jh. in Zentralsulawesi – eine historisch-geographische Analyse der Lore-Lindu-Bergregenwaldregion*', PhD thesis, Institute of Geography, Georg-August-Universität Göttingen.

Whitten, A., Henderson, G. and Mustafa, M. (1987) *The Ecology of Sulawesi*. Yogyakarta, Indonesia: Gadjah Mada University Press.

Whittington, D. (1998) 'Administering contingent valuation surveys in developing countries', *World Development* 26(1): 21–30.

Whittington, D. (2002) 'Improving the performance of contingent valuation studies in developing countries', *Environmental and Resource Economics* 22(1–2): 323–367.

Zeller, M. and Birner, R. (2003) '*Teilprojekt A3. Der Einfluss von Märkten und Politik-maßnahmen auf die Ressourcennutzung*'. Sonderforschungsbereich 552 'Stability of Rainforest Margins in Indonesia' der Deutschen Forschungsgemeinschaft, Ergebnisbericht über die 1. Förderungsphase 2000/2–2003/1. Georg-August-Universität Göttingen and University of Kassel.

Zeller, M., Schwarze, S. and van Rheenen, T. (2002) *Statistical Sampling Frame and Methods Used for the Selection of Villages and Households in the Scope of the Research Programme on Stability of Rainforest Margins in Indonesia (STORMA)*. STORMA Discussion Paper Series No 1. Bogor, Indonesia: Georg-August-Universität Göttingen and University of Kassel, Germany, and the Institut Pertanian Bogor and Universitas Tadulako, Indonesia.

21 Farmers' participation in agri-environmental programs and impact on farm performance

An empirical analysis applied to Swedish agriculture

Karin Larsén

1 Introduction

The main objectives of agri-environmental programs are to reduce the threat to the environment associated with agriculture and to conserve nature and cultivated landscapes. Agri-environmental subsidies paid to Swedish farmers in 2003 amounted to 2,211 million SEK, corresponding to 25 percent of all direct payments to Swedish farms (Statistics Sweden 2004). The three largest programs, which together constitute approximately 80 percent of all agri-environmental payments to Swedish farmers, are compensatory payments for measures related to conservation of grazing lands, management of open landscapes and organic production methods.

A farmer's required compensation for participating in an agri-environmental program is likely to be determined by factors that determine the cost of participation but may also be affected by non-economic factors such as attitudes and awareness. The costs associated with participation include both loss of income from agricultural production (because some program practices imply lower anticipated yields as they, for example, preclude the use of certain inputs) and costs associated with implementing and maintaining program practices (such as the cost of maintaining grazing lands or constructing wetlands). The variable costs are probably known only by the farmer, whereas the fixed costs are more easy to observe by policy-makers.

A farmer who decides to participate in an agri-environmental payment program also has to make a decision about the extent of participation, i.e. how many acres would be devoted to the program and how many would be retained for conventional production. On the simplifying assumption that a farmer maximizes his profit margin and is risk-neutral, he/she will choose to participate in an agri-environmental program only if the profit equates to or is greater than otherwise and the acreage devoted to the program will be decided where the subsidy level equals the marginal value of land in conventional production (opportunity cost of land).[1] Thus, factors that determine the opportunity cost of land may well explain the decision to participate and the extent of participation in agri-environmental programs.

One of the main objectives from the social planner's perspective is to achieve cost-effectiveness of the program, i.e. to achieve the objective of the program at the lowest possible cost for society. In practice, payment programs are always constrained by a budget. Cost-effectiveness subject to a budget constraint requires that the farmer receive his/her minimum required compensation for participation in the program. Another consideration in the optimal policy design is whether the fixed costs are known to the social planner. Anthon *et al.* (2007) discussed the impact of fixed costs and budget constraints on optimal contract design.

Hence, knowledge of the factors that determine farmer participation in an agri-environmental payment program for different groups of producers is thus very useful from a policy point of view. Ultimately, the objective is to obtain an estimate of the farmer's "minimum required compensation" for the provision of an environmental service.

There is a vast amount of literature that analyses farmers' participation in agri-environmental programs. Two recent examples are Damianos and Giannakopoulos (2002) who analysed farmers' participation and level of participation in agri-environmental schemes and Greece and Boisvert and Chang (2005) who examined farmers' participation in the Conservation Reserve Program (in the US) and impact on farm productivity and efficiency.

The objective of the present study was to analyse the determinants of participation, its extent (in terms of land area) and impact on farm performance of participating in agri-environmental programs. By examining the effects of the subsidy program, its efficiency could be evaluated. Ultimately, the goal is to analyse the farmer's minimum required compensation for program participation. The method to be used when analysing the impact of program participation is, however, not obvious and some complications associated with these types of analyses, in the context of agri-environmental program participation, are discussed. The outline of the chapter is as follows. First, the agri-environmental programs in Sweden are described. Thereafter, the empirical models are presented followed by a description of the data used in the empirical application. Finally, the results are presented and discussed.

2 Agri-environmental programs in Sweden

The agri-environmental program in the CAP (Common Agricultural Policy) that applies to all member countries of the European Union (including Sweden) and is co-financed by EU and each member country, aims to reduce the environmental risk associated with agriculture and to preserve nature and cultivated landscapes (European Commission 2005). Swedish farms can receive compensatory payments for between nine and eleven different agri-environmental measures (depending on, for example, where the farm is geographically located), of which the three largest are compensatory payments for preservation of grazing lands, open landscapes and organic production. Agri-environmental programs in Sweden can be divided into two main

groups: programs related to: (1) arable land management and (2) pasture land management. The programs related to arable land management compensate farms for agri-environmental measures undertaken on arable land, including input reduction measures, organic farming, conversion of arable land to grazing land and hayfields and preservation of natural or cultural elements on, or in connection with, arable land. The second type of program compensates farmers for conserving of grazing land and hay fields on pasture land. The arable land management programs are further split into programs whereby the farmer is compensated for agricultural production on arable land while following the program regulations (for example, organic farming and input reduction measures), programs that compensate maintenance of arable that is not used in crop production (for example, open landscapes) and compensation for natural and cultural elements on, or in connection with arable land.

The Swedish agri-environmental payment programs were revised in 2000. Under the revised program regime, the duration of commitments is 5 years in schemes that started both before and after year 2000 (an exception is the 20-year commitment for wetlands). Therefore, some of the payments in the old program were still being distributed after 2000 and it was possible to obtain payments from both programs simultaneously. The compensations are uniform for some programs and differentiated for others (by region or crops/animals). For example, payment for organic production depends on which crop and/or form of livestock is produced, whereas payment for grazing land and hayfields is uniform. The payment for open landscape is differentiated
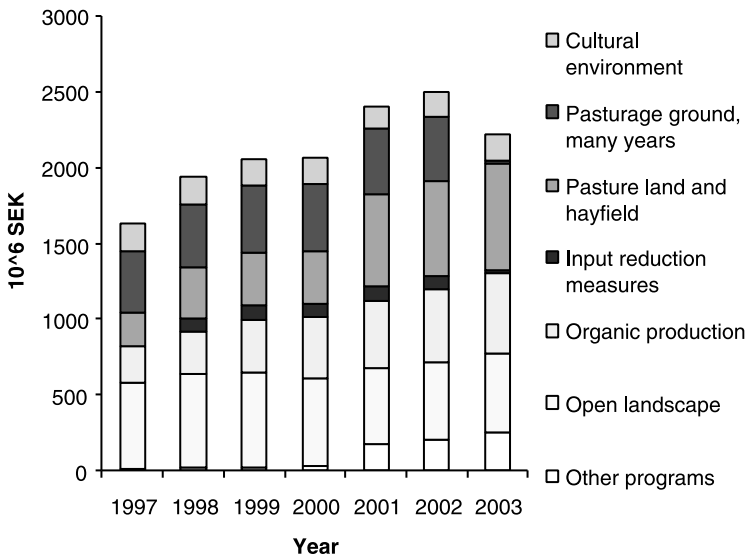
Figure 21.1 Payments for agri-environmental measures for the period 1997–2003, divided by program.

Source: Statistics Sweden, own construction

for five production regions and additional requirements to qualify for payments are imposed for some of the regions. Figure 21.1 shows the size of total agri-environmental payments to Swedish farms during the time period 1997–2003.

3 Empirical analysis

The empirical analysis is divided in two parts. First, factors that influence the farmer's decision to participate in an agri-environmental program are analyzed. Participation decisions are often analyzed using a binary choice model such as the logit or probit. However, because the farmer makes two choices—to participate or not in the agri-environmental subsidy program and the extent of participation (given participation)—both the participation decision and the level of participation may be of interest to analyse. A so-called "hurdle" or "threshold-crossing" model, originally suggested by Cragg (1971), can be used for this purpose. These types of models involve an analysis both of the participation decision and the level of participation.

In the second part of the analysis, the effect on farm performance of participating in the agri-environmental program on farm performance is analysed. Return on Assets (ROA) is used as a measure of farm performance (profitability). In order to obtain an unbiased assessment of program participation on farm performance, potential endogeneity of the participation choices is taken into account by using instrumental variables. The empirical analysis is therefore conducted in the following two steps:

1 Determinants of the farmer's participation in the agri-environmental subsidy program as well as determinants of the extent (acreage) of participation are analyzed.
2 The effect of participation on farm performance (profitability) is analyzed.

3.1 Determinants of participation and level of participation

Farmer i's decision to participate in agri-environmental program m is described by the following equation, where I_{im}^* is an underlying latent variable:

$$I_{im}^* = a_m{}' Z_{im} + e_{im} \tag{21.1}$$

where

$I_{im} = 1$ if $e_{im} > -Z_{im}a_m$ $i = 1, \ldots, N$;
(farm i is a participant in program m)

0 otherwise (farm i is a non-participant of program m)

Given that a farm participates in the agri-environmental program *m*, its production of agri-environmental services is analysed by estimating equation (21.2).

$$LP_{Eim}^* = \beta_m' X_{im} + u_{im} \tag{21.2}$$

where

$LP_{Eim} = LP_{Eim}^*$ if $u_{im} > -Z_{im}\beta_m$ $i = 1, \ldots, N$; (if farm *i* is a participant)

0 otherwise   (if non-participant)

As argued earlier, the participation choice will be determined by factors that affect the farm's cost of participation (opportunity cost of land). Thus, the explanatory variables (the vectors Z_{it} and X_{it}) include variables that explain the productivity/profitability of a farm. The explanatory variables are discussed in greater detail in the next section.

The model described above is a so-called double-hurdle model and estimation of this model was originally discussed by Cragg (1971). The log-likelihood function of the model can be found in Jones (1989). This log-likelihood function can however be decomposed if restrictions on the joint distribution of the error terms, *u* and *e*, are imposed. If *u* and *e* are independent, the model reduces to the so-called "Cragg model". If it is assumed that the participation decision dominates the consumption decision, so-called "first hurdle dominance", the log-likelihood function reduces to Heckman's generalized Tobit (the sample selection model). In this case, the decision to be a non-participant is considered as a separate discrete choice rather than a standard corner solution. When independence and dominance can be assumed simultaneously ("Complete dominance"), the model reduces to a Probit part and an OLS part (Jones, 1989).

3.2 *Effect of program participation on farm performance*

In the second part of the empirical analysis, the impact of program participation on farm performance is analyzed. A desirable objective of this type of analysis is to obtain an estimate of the farmer's "minimum required compensation" for the provision of an agri-environmental service (preferably also for different groups of farms in order to analyse whether payments should be differentiated or not). Since the choice of method for this type of analysis is not obvious, we will begin by reviewing potential methods. Two groups of methods when the participation choice is treated as binary are the following:

1   Comparison performance measures among participants and non-participants. This can be done by, for example, using a switching regression framework where determinants of farm performance are analyzed

for the two groups separately and estimates of counterfactual perform-
ance measures can be obtained. Potential endogeneity of the participa-
tion choice can be accounted for by including error correction terms (the
inverse Mill's ratio) as an explanatory variable (see, for example,
Heckman 1979 and Lee 1978).[2][3] Alternatively, determinants of farm
performance can be analysed for the whole sample simultaneously while
including a dummy variable to indicate participation (IV-estimation can
be employed to correct for potential endogeneity of the participation
dummy). A review of these types of methods is given in Maddala (1983).

2   Calculation of compensation required by the farmer based on option
value theory (see, for example, Kuminoff and Wossink 2005). An
appealing feature of this approach is that an estimate of the required
compensation that includes a risk premium can be obtained.

It should be noted that the methods used to evaluate the effect of program
participation on farm performance that treats participation decision as bin-
ary may not be appropriate for the following reasons: (1) farmers receive
compensation for several different types of agri-environmental measures and
the nature of these can differ substantially (see previous); (2) the extent of
participation (acreage) in a given agri-environmental programs differs
substantially between participants (see Table 21.3 on pp. 402–403).

In this study, the impact of participation on farm performance will is
analysed by estimating model (20.3) where the coefficient of the participation
dummy (*D*), *y*, is a measure of the average impact of participation on farm
performance.

$$FarmPerformance = \alpha + \beta X + yD + \varepsilon \qquad (20.3)$$

Where *FarmPerfomance* is measured by ROA (Return on Assets, i.e. the net
returns over total farm assets, *D* is a dummy indicator for participating in
agri-environmental program (*D = 1* if the farmer is a participant in at least one
agri-environmental program and *0* otherwise) and *X* is a vector of other
explanatory variables such as farm/farmer characteristics.

The dependent variable, Return on Assets (ROA), is calculated as

ROA = (Total revenues—Total costs—Depreciation) /
(Total farm assets)

There are a few things one should note when using ROA as a measure of farm
performance. For example, the value of land and buildings is generally lower
in northern Sweden, which will reduce the value of Total farm assets and
hence increase the value of ROA. However, ROA should still be an accurate
measure of the net return on invested capital. It may also be more accurate to
subtract the value of the family's labour, as this is not included as a cost (this
was not done here, however).

A second matter to note is the potential endogeneity of the participation dummy variable. It is reasonable to expect that farms that perform better when they participate in an agri-environmental program will be more likely to participate. In that case, the dummy variable for farm performance may be endogenous. If the potential endogeneity of the participation dummy is not taken into account, the parameter estimate of the participation dummy may be biased. Potential endogeneity for the participation dummy may be considered by using a two-stage least squares estimation (2SLS).

4 Data

The data used in the empirical application consist of FADN variables for Swedish farms for the period 1998–1999 complemented by information about the farm's participation and extent of participation (measured in acres) in agri-environmental programs. Information about the farmers' participation in agri-environmental programs was provided by the Swedish Board of Agriculture. FADN (Farm Accountant Data Network) consists of accountancy data from a sample of agricultural holdings that are representative with respect to region, economic size and type of farming. In Sweden, the FADN variables are available for about 1000 farms each year and about 100 of the farms are replaced each year. The total number of farms that participated in the FADN 1998–1999 is 1,926. Some 1,482 of the farms (77 percent) participate in at least one agri-environmental program.

Table 21.1 Summary statistics (N = 1926)

Variable	Unit	Mean	SD
Value of total output	Thousand SEK[†]	816.3	973.2
ROA		−0.059	0.17
Land	Hectares	94.1	109.8
Animal units (excl pigs)	Number	54	80
Farmer's age	Years	49.0	10.0
Rented land	Share	0.41	0.38
Hired labour	Share	0.070	0.17
Biological yield capacity	kg/hectare	4057	578
Managerial ability	Share	0.46	0.20
Production region*	Share		
Area 1—Nö		0.15	
Area 2—Nn		0.14	
Area 3—Ssk		0.15	
Area 4—Ss		0.15	
Area 5—Gns		0.26	
Area 6—Gsk		0.04	
Area 7—Gmb		0.06	
Area 8—Gss		0.05	

Notes: [†] SEK = Swedish Krone, 1999 monetary values, ROA = Return on assets.
* The production regions used are those used in Agriwise (2005) and are shown in figure 21.2.

1		Nö Norrland övre
2		Nn Norrland nedre
3		Ssk Svealands skogsbygder
4		Ss Svealands släubygder
5		Gns Götalands norra släubygder
6		Gsk Götalands skogsbygder
7		Gmb Götalands mellanbygder
8		Gss Götalands södra släubygder
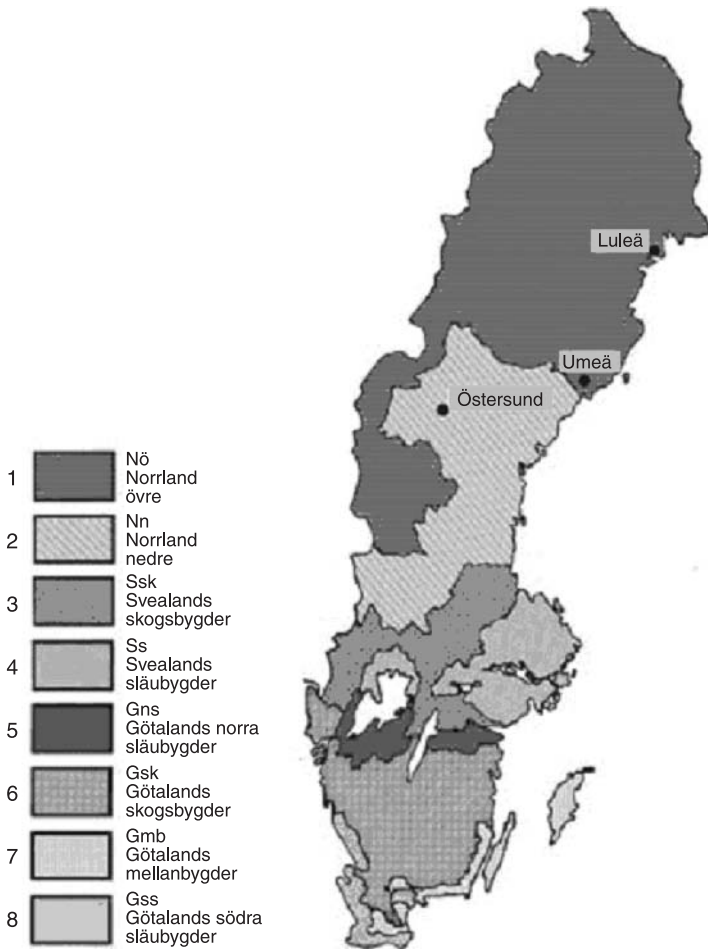
Figure 21.2 Production regions in Sweden.
Source: Agriwise (2005).

In Table 21.1, summary statistics for value of total output, ROA, land, and farm/farmer characteristics are presented. "Value of total output" consists of total revenues from crop and livestock production. ROA is a measure of profitability and is calculated as described in the previous section. Farm characteristics include farmer's age, share of rented land and hired labour, biological yield capacity, managerial ability, dummy indicators for production regions (Sweden is divided into eight production regions, see Figure 21.2) and number of animal units (excluding pigs). Biological yield capacity is a measure of the land's productivity in a given region. The expected yield of barley is used as a proxy for biological yield capacity (as barley is the only crop that is grown in all parts in Sweden). A measure of the farmer's technical

Table 21.2 Summary statistics of subsidy paid to farmers in the sample and acreage for which subsidies are received (for some programs)

Agri-environmental program	Share of farms that participate in the program	Average for participants in agri-environmental program (Standard deviation)	
		Acreage	(Payment received)/ (total revenues)
Open landscape	0.44	36.2 (31.0)	0.06 (0.07)
Organic production	0.17	39.8 (59.5)	0.09 (0.1)
Conservation of pastureland	0.27	18.5 (29.6)	0.05 (0.08)

efficiency in conventional production (calculated using Data Envelopment Analysis) is used a proxy for managerial ability (a fully efficient farm has an efficiency score equal to 1).[4]

In Table 21.2, the average environmental subsidy paid to the farms in the sample as well as the average acreage for which subsidy is received are presented (along with standard deviations) for the three largest programs. For all three programs, there are large variations in the extent of participation (acreage devoted to the programs) as well as the compensatory payment's share of total farm income.

5 Results

The results of the estimation of the participation and level equations, for participation in any agri-environmental program and for each of the three largest programs separately, are presented in Table 21.4 (pages 402–3). The double-hurdle model was estimated assuming "first hurdle dominance" which implies that the farmer's decision to participate in an agri-environmental program is considered as a discrete choice and not as a marginal adjustment (Jones 1989). It should be noted that the parameter estimates cannot be interpreted as marginal effects on the participation and level decisions in these types of models. However, the sign of the parameters should be the same as the marginal effects.

For all programs, size of the farm (acreage) has a positive and statistically significant impact on the probability of being a program participant. Moreover, the extent of participation increases as the size of the farm increases. Biological yield capacity has a negative and statistically significant impact on the probability to being a participant in the Open landscape program as well as the level of participation in the same program. The results also suggest that geographical localization often has a statistically significant impact on the probability of being a participant in an agri-environmental program. How-

ever, given that the farmer is a participant, localization does not influence the extent of participation (except for Open landscapes). In most cases, farmer's age has no significant impact on the decision to participate or the level of participation. Farms with a large number of animal units (excluding pigs) are more likely to participate in agri-environmental programs.

The parameter estimates and standard deviations of the estimation of the farm performance equation (Equation 21.3) are reported in Table 21.3. The model was estimated with OLS and 2SLS (as the participation dummy is likely to be endogenous). The first column reports the results for the OLS-estimation. The parameter of the participation dummy is 0.024 and statistically significant at the 1 percent-level, suggesting that participation in agri-environmental programs increases the profitability of the average farm by 2.4 percent. The model was then estimated with 2SLS. The number of grazing animal units and acreage of pasture ground are instrumental variables as many of the programs (directly or indirectly) require that there are grazing animals on the farm. A test for the validity of the instruments could not reject that they are valid instruments.[5] In this case, the magnitude of the participation dummy variable was greater, 0.085, and significant at the 1 percent-level, suggesting that participation in agri-environmental programs increases the profitability of the average farm by 8.5 percent. Thus, the results of the OLS and the 2SLS-regressions suggest that the impact from participation on ROA is 2.4 percent and 8.5 percent respectively and statistically significant at the 1 percent-level.

Table 21.3 Estimation results of farm performance equation

	Dependent variable: ROA	
	OLS-estimates (Standard error)	2SLS-estimates (Standard error)
Constant	−0.15***	−0.23***
	(0.028)	(0.038)
Participation dummy	0.024***	0.085***
	(0.007)	(0.037)
Land	0.0082	0.00036***
	(0.0080)	(0.000038)
Share hired labor	−0.26***	−0.26***
	(0.022)	(0.022)
Share rented land	0.0082***	0.0074
	(0.0080)	(0.0082)
Farmer's age	−0.00083	−0.00075**
	(0.00030)	(0.00031)
Biological yield capacity	−0.0000013***	0.0000068
	(0.0000053)	(0.0000057)
Managerial ability	0.38***	0.39***
	(0.015)	(0.016)
R-square	0.30	0.27

Note: ***,**,* indicate statistical significance at 1. 5 and 10% respectively.

Table 21.4 Determinants of participation and level equations (standard error within parenthesis)

Variable	Any agri-environmental program		Conservation of grazing land		Organic production.		Open landscapes	
	Part. Equation	Level Equation	Part. Equation	Level Equation	Part. Equation	Level Equation	Part. Equation	Level Equation
Constant	1.43*** (0.37)	20 (23)	-2.2*** (0.34)	36* (18)	-0.86*** (0.33)	-283 (199)	2.56*** (-0.0015)	35*** (10)
Land	0.0010* (0.00056)	0.43*** (0.028)	0.0030*** (0.00052)	0.063*** (0.011)	0.0010** (0.00043)	0.25*** (0.09)	-0.0015*** (0.00045)	0.012 (0.019)
Share of hired labour	-0.66*** (0.25)	0.27 (0.18)	-0.24 (0.24)	-28*** (6.8)	0.39 (0.24)	6.0 (69)	-1.44*** (0.28)	-49*** (15)
Share of rented land	0.00064 (0.094)	9.5 (6.8)	-0.033 (0.092)	7.1** (3.1)	0.12 (0.098)	21 (25)	0.076 (0.099)	12*** (3.4)
Farmer's age	-0.00083 (0.0034)	-0.11 (0.25)	0.0057 (0.0034)*	-0.32** (0.12)	-0.00053 (0.0037)	-0.26 (0.81)	-0.00098 (0.0035)	-0.16 (0.12)
Biological yield capacity	-0.00015* (0.000078)	-0.0099* (0.0051)	0.000066 (0.000070)	-0.00015 (0.0026)	-0.0000058 (0.000070)	0.0045 (0.014)	-0.00044*** (0.000077)	-0.0088*** (0.0030)
Region								
P1—Nö	-0.88*** (0.22)	-67*** (16)	0.061 (0.21)	17** (8.7)	-1.09*** (0.21)	-180 (124)	-2.24*** (0.22)	-88*** (20)
P2—Nn	-0.40* (0.22)	-37*** (13)	0.85*** (0.20)	11 (9.0)	-0.56*** (0.18)	-94 (70)	-1.09*** (0.19)	-35*** (9.0)
P3—Ssk	-0.53** (0.21)	-42*** (13)	0.64*** (0.20)	10 (8.7)	-0.35** (0.17)	-55 (52)	-1.98*** (0.20)	-66*** (17)
P4—Ss	-0.65** (0.21)	-47*** (14)	0.59*** (0.20)	1.9 (8.6)	-0.40** (0.18)	-53 (55)	-1.68*** (0.20)	-41*** (14)
P5—Gns	-0.18 (0.20)	-7.2 (12)	0.46** (0.18)	5.4 (8.1)	-0.47*** (0.16)	-78 (60)	-0.20 (0.18)	-3.7 (4.7)

P6—Gsk	−0.31	−9.0	0.46**	1.5	−0.44**	−62	−0.40*	−6.5
	(0.25)	(16)	(0.23)	(9.6)	(0.22)	(67)	(0.23)	(6.7)
P7—Gmb	−0.035	0.77	0.48*	0.83	0.46***	68	0.19	2.7
	(0.25)	(14)	(0.21)	(9.1)	(0.18)	(57)	(0.23)	(5.4)
Animal units	0.010***	0.79***	0.0049***	0.019	0.0028***	0.55**	0.0062**	0.38***
	(0.00085)	(0.055)	(0.00053)	(0.020)	(0.00050)	(2.0)	(0.00059)*	(0.044)
Log L	−853	−8200	−963	−2398	−783	−1710	−805	−3746
Restricted Log L	−1040	−9060	−1126	−2514	−887	−1832	−1321	−4119

Notes: ***, **, * indicate statistical significance at 1, 5 and 10% respectively.

6 Conclusion

In this study, farmers' participation in agri-environmental programs and the effect of program participation on farm performance (measured by profitability) was analyzed.

The estimation results of the participation equations suggest that the farm's geographical location often has a significant impact on participation choice, but not always on the extent of participation. Not surprisingly, larger farms (in terms of acreage) are more likely to be included in the programs, as well as farms with numerous animal units (excluding pigs). In the second part of the analysis, the effect of participation on farm performance (profitability) was analyzed. OLS and 2SLS estimations both suggested that the average impact of participation on farm performance (ROA) is positive (2.4–8.5 percent) and statistical significant at the 1 percent-level. Thus, the results suggest that farmers' compensation for participating in the programs is, on average, higher than their loss of income from conventional production. An important question for policy-makers is thus whether this "overcompensation" is acceptable or not.

Although this study provides some information about the effectiveness of the current agri-environmental program in Sweden, the results do not allow us to make concrete suggestions concerning the design of an optimal payment program. In order to do this, further research is needed. A desirable objective from a policy point of view would be to calculate the "minimum required compensation" for the various agri-environmental measures and for categories of farms. There are, however, a couple of factors that makes this task complicated: (1) there are usually several widely differing types of agri-environmental programs (the impact on farm performance from participation in a specific program is therefore difficult to ascertain); (2) as shown in this study, the extent of participation (in terms of land area) varies widely among participants; and (3) profit, revenue and costs functions are often difficult to estimate when there is lack of variation in the price data.

One avenue for further research could be to evaluate methods to determine the effects of participation in specific programs, thereby facilitating more concrete suggestions for e.g. optimal payments for designated programs and whether or not these should be differentiated.

Notes

1 There are studies that suggest that some agri-evironmental measures, such as organic production, are considered riskier than conventional production (see; for example, Kuminoff and Wossink, 2005). If this is the case, the farmers required compensation will also include a risk premium.
2 There are reasons to believe that a farmer's decision to participate in an agri-environmental program is not random. Assuming that farmers act as profit maximizers, a farmer with high productivity in conventional farming would require a higher compensation than a farmer with low productivity in conventional farming (since the opportunity cost of land is higher for the more productive farmer).

3 A related approach is the so-called propensity score, originally suggested by Rosenbaum and Rubin (1983). The idea of propensity scores is to match participants and non-participants who have the same or similar predicted probabilities, in order to obtain an unbiased estimate of the treatment effect.
4 One output (total value of production) and four inputs (land, capital, labor and other) were used when deriving the efficiency scores.
5 The coefficients of these variables were significant at the 5 percent-level when used as regressors in the participation choice equation.

References

Anthon, S., Bogetoft, P. and Jellesmark Thorsen, B. (2007) "Socially optimal procurement with tight budgeting and rationing". *Journal of Public Economics* 91: 1625–1642.

Boisvert, R.N. and Chang, H-H. (2005) "Explaining participation in conservation reserve program and its effects on farm productivity and efficiency", paper presented at the 2005 Annual Meeting of the American Agricultural Economics Association, Providence, Rhode Island, July 24–27.

Cragg, J.G. (1971) "Some statistical models for limited dependent variables with application to the demand for durable goods", *Econometrica* 39(5): 829–844.

Damianos, D. and Giannakopoulos, N. (2002) "Farmers' participation in agri-environmental schemes in Greece" *British Food Journal* 104: 3–5.

European Commission (2005) "Agri-environment Measures—Overview on General Principles, Types of Measures, and Application". Directorate General for Agriculture and Rural Development, March.

Heckman, J. (1979) "Sample selection bias as a specification error", *Econometrica* 47: 153–162.

Jones, A.M. (1989) "A Double-Hurdle Model of Cigarette Consumption", *Journal of Applied Econometrics* 4: 23–39.

Kuminoff, N.V. and Wossink, A. (2005) "Valuing the option to convert from conventional to organic farming", paper presented at the 2005 Annual Meeting of the American Agricultural Economics Association, Providence, Rhode Island, July 24–27.

Lee, L.F. (1978) "Unionism and wage rates: a simultaneous equations model with quantitative and limited dependent variables", *International Economic Review* 19 (2): 415–433.

Maddala, G.S (1983) *Limited-Dependent and Qualitative Variables in Econometrics*. Cambridge: Cambridge University Press.

Rosenbaum, P.R. and Rubin, D.B. (1983). "The central role of propensity score in observational studies for casual effects", *Biometrica* 70: 41–55.

Statistics Sweden (2004) *Statistical Yearbook of Sweden 2004*, vol. 90. Stockholm: Statistics Sweden.

22 Over-compensation payments for agro-biodiversity conservation

Cornelia Ohl, Martin Drechsler, Karin Johst and Franz Wätzold

1 Introduction

In former times, agricultural production in Europe led to a great variety of land-use systems which provided a broad habitat and species diversity. However, over the past 50 years many habitats have been destroyed by intensive fertiliser and pesticide use, irrigation and drainage to achieve homogeneous water levels best suited for production as well as the destruction of natural and man-made landscape structures such as wet sinks, hedges and stone walls. Agricultural intensification is now considered a main cause of farmland biodiversity losses. Additionally, land abandonment in areas with small and extensive farming systems is a growing problem as in such areas low-intensity farming such as livestock rearing and traditional cultivation methods have created semi-natural habitats that support a wide range of species. In order to reverse the trend of intensification and land abandonment, the EU developed 'agri-environmental schemes' which were set up all over the EU following Regulation 2078/92.

Agri-environmental schemes are now based on Regulation 1257/99, and all over Europe a few billion Euros are spent on such schemes each year (European Commission 2005). Schemes as in Europe where farmers and other land-users[1] are paid to carry out conservation measures on a voluntary basis exist all over the world; for the USA, see e.g. Claasen and Horan (2000) and Defenders of Wildlife (2002); for developing countries, Landell-Mills and Porras (2002); for OECD countries OECD (2003); and for a general overview, Clough (2000). Although our research is motivated by challenges of agri-environmental payment design in Europe this analysis might be relevant for their design as well.

In Europe, Regulation 1257/99 gives some general guidelines for payment design while leaving it largely up to the individual Member States how to distribute a given conservation budget to the farmers. This provides a challenge for ecological and economic reasons:

Ecological research emphasises the need to design agri-environmental schemes in a way that habitat heterogeneity is generated locally (e.g. Benton *et al.* 2003). Habitat heterogeneity is important to conserve a variety

of species in a region and it is suitable to cope with scientific uncertainty regarding the effects of conservation measures on species. In addition, some species need spatio-temporally differentiated conservation measures due to time-dependent habitat quality. So, how to create habitat heterogeneity? On the one hand, it may be created by the same measure which is carried out at different times and places. For example, the conservation of the white stork (*Ciconia ciconia*) requires a spatio-temporally differentiated mosaic of freshly mowed meadows (Johst *et al.* 2002). On the other hand, habitat heterogeneity may also be created by completely different measures. For example, the mowing of a meadow at a certain pre-specified date to protect meadow birds and the reduction of cattle on a meadow for nutrient input reduction to create habitats for endangered plants that require nutrient poor soil (Weiss 1999).

Economic research argues that conservation policies should be cost-effective (e.g., Ando *et al.* 1998; Wätzold and Drechsler 2005). Here, we refer to cost-effectiveness as the ability of an instrument to achieve the ecological goal with the lowest possible budget.[2] The level of cost-effectiveness that can be achieved depends, *inter alia*, on the ability to reduce the producer surplus obtained by farmers. Producer surplus is the part of the payment that exceeds the minimum compensation needed to provide sufficient incentives to a farmer to participate in a programme. Profit-maximising farmers are usually expected to participate in an agri-environmental programme if complying with the programme does not worsen their actual income situation (as given by performing their business as usual). With a producer surplus the farmers are even better off than in the business as usual enhancing the probability of participation in the programme. However, the higher the producer surplus (over-compensation) is, the larger the budget is allocated for pure transfers which could otherwise be used for conservation purposes. Producer surpluses thus improve farmers' income situation but usually not the state of the environment and are consequently not allowed under current EU regulations.

Taking both ecological and economic considerations into account, the critical question is: How to design agri-environmental schemes that generate habitat heterogeneity in a cost-effective manner?

One option to generate a diverse agricultural landscape allowing the conservation of heterogeneous habitats is the design of a specific programme for each required habitat type (e.g. if habitat heterogeneity requires different mowing regimes in an area, then a programme should be set up for each mowing type, cf. Johst *et al.* 2002). However, as Ohl *et al.* (2008) suggest, depending on farmers' cost functions it may not be possible to differentiate payments in a way that farmers participate in *all* programmes that are necessary to generate the desired habitat heterogeneity. The reason is that payments associated with one particular programme (e.g. mowing meadows not before the middle of June to conserve meadow breeding birds like the whinchat in Germany) may be so low that farmers end up participating in alternative (better rewarded) programmes (that may e.g. be associated with the conservation of protected butterfly species like the Large Blue which in

Germany requires omitting the second cut in July to conserve it). Increasing payments for the programme with hitherto no participation may have exactly the effect that all farmers now wish to participate in this programme leaving the other programmes with no participation.

However, Ohl *et al.* (2006) identified types of cost functions for which any desired level of habitat heterogeneity can be generated through appropriately differentiated payments. One example is where the cost functions of different land users do not intersect with each other. In these cases farmers are expected to carry out agri-environmental conservation measures in a way that the aggregated opportunity costs are minimised. However, do payment schemes that can be conducive for a heterogeneous agricultural landscape avoid the problem of generating excessive producer surpluses? The aim of this chapter is to demonstrate that over-compensation to farmers with the lowest opportunity costs may still be required to stimulate the conservation of the target level of habitat heterogeneity in agricultural landscapes.

The chapter is structured as follows. The next section explains in more detail why agro-biodiversity at the landscape level (associated with the concept of habitat heterogeneity) is beneficial for conservation from an ecological point of view. Section 3 presents a theoretical model and determines the minimum required compensation payment to land users as well as the extent of producer surpluses associated with the most cost-effective payment scheme. The final section summarises the results and discusses the policy implications from the analysis.

2 The need for habitat heterogeneity in agro-biodiversity conservation

One of the primary goals of agro-biodiversity conservation is to protect all endangered species in a given agricultural landscape up to whole ecosystems (Benton *et al.* 2003; Drechsler *et al.* 2007). As species usually differ in their demands on habitat types or require different habitats for their survival, a heterogeneous landscape (habitat mosaic) seems to be an adequate measure to supply each species with its specific requirements in time and/or space to survive (e.g. Benton *et al.* 2003; Johst *et al.* 2006). For example, a variety of animal species need grassland habitat for reproduction but they need it at different times (e.g., in Germany, some bird species need it for breeding at the end of May whereas some butterfly species need it for egg deposition in July). High reproductive success and survival of multiple species therefore require a grassland mosaic consisting of areas mowed at different dates. Besides the multi-species conservation aim there are additional reasons calling for a spatiotemporal habitat mosaic.

A first reason is uncertainty (Ludwig *et al.* 2001). Knowledge about the effects of a particular conservation measure on a particular species is often insufficient. Moreover, the impact of a conservation measure can vary from landscape to landscape, e.g., through climatic or soil differences (Johst *et al.*

2006). Therefore, information from the field or by means of experiments is often context-dependent and highly variable. Establishing a heterogeneous landscape with a sufficient diversity of habitat types is seen as an adequate measure to meet the shortcomings of insufficient or uncertain knowledge regarding species' requirements. In other words, habitat diversity increases the chance of randomly covering those habitat types which support the species of interest.

A second reason is that habitat suitability is sometimes not permanent but transient, such as in the case of growing grass after cutting a meadow or succession sequences in plant or forest communities (e.g., Johst *et al.* 2001; Johst and Huth 2005). Consequently, habitat suitability depends on the point in time at which conservation measures or farming activities, e.g., mowing, are carried out. Species can cope with such transience and the resulting landscape dynamics by specific traits like high mobility (Johst *et al.* 2002; Keymer *et al.* 2000), or they can be adapted to different successional stages of the vegetation. In any case, the landscape must be sufficiently heterogeneous in the form of a shifting mosaic in habitat quality.

In summary, at least four reasons associated with agro-biodiversity conservation require the establishment of spatio-temporally heterogeneous habitats in agricultural landscapes (habitat mosaics): (1) the need for multi-species conservation; (2) multiple resource use of species; (3) the existence of uncertainties in species' habitat requirements; and (4) a possible transience of habitat quality.

3 The model

In this section we build upon the model developed by Ohl *et al.* (2006, 2008) and theoretically address the question of what is the minimum required compensation payment allocated to land users in order to generate the socially desired habitat heterogeneity.

It is assumed that land users maximise their individual profits and in line with most agri-environmental programmes in Europe, that land users cannot be arbitrarily excluded from measures already taken up by other land users. Without loss of generality, in order to simplify the analysis, we begin with the case of three land users ($N = 3$). This is then followed by the consideration of $N > 3$ land users.

3.1 The case of three land-users

We consider three land users numbered $i = 1, 2, 3$ each of which may manage their land in the usual manner (denoted as land use strategy $t = 0$) or in one of two conservation-friendly ways ($t = a$ or $t = b$). For generality, each land user can also represent a group of land users with similar costs for switching their land use from $t = 0$ to $t = a$ or $t = b$, respectively. Each land user is assumed to manage a certain land area. The objective of the social planner (conservation

manager) is to ensure that only one of the three activities ($t = 0, a, b$) is carried out by exactly one land user, i.e., in one of the three area compartments.

Any land user i carrying out activity t realises a certain profit level $\pi_i(t)$. Without loss of generality we scale these profits such that $\pi_i (t = 0) = 0$ ($i = 1, 2, 3$). It is also assumed that the costs of each of the three possible activities are different. Another assumption involves the idea that without any policy intervention the profit π_i ($i = 1,2,3$) is maximised when the activity $t = 0$ is chosen. That is, the entire landscape would be managed with activity $t = 0$ as this would be the most profitable one. If a land user switches to an alternative land use a or b, this leads to positive opportunity costs (foregone profits) as given by:

$$C_i (t) = -\pi_i (t) \tag{22.1}$$

for all land users for $t = a, b$. The next idea is to introduce habitat hetero-geneity through compensation payments p_t ($t = a, b$). For a land user who switches from $t = 0$ to another activity, the profit becomes:

$$\pi_i (t) = p_t - C_i (t) \qquad (i = 1,2,3; t = a, b). \tag{22.2}$$

By our definition, habitat heterogeneity means that one land user x (with $x \in \{1,2,3\}$) carries out activity 0, another one (named y with $y \in \{1,2,3\}$ and $y \neq x$) carries out activity a and the third one (z with $z \in \{1,2,3\}$ and $y \neq z \neq x$) carries out activity b. To achieve such an allocation, the profit of land user x (y) (z) must be maximised by carrying out activity 0 (a) (b), i.e. if

$$\pi_x (0) > \max \{\pi_x (a), \pi_x (b)\}$$
$$\pi_y (a) > \max \{\pi_y (0), \pi_y (b)\} \tag{22.3}$$
$$\pi_z (b) > \max \{\pi_z (0), \pi_z (a)\}$$

Payment schemes (p_a, p_b) that are able to induce habitat heterogeneity thus need to fulfil Equation (22.3) for exactly one combination (x, y, z) with $x, y, z \in \{1,2,3\}$ and $x \neq y \neq z \neq x$. Ohl *et al.* (2008) argue that Equation (22.3) is fulfilled if and only if

(a) $C_y (a) < p_a < C_x (a)$

(b) $C_z (b) < p_b < C_x (b)$

(c) $p_b < p^{(u)} \equiv p_a + C_y (b) - C_y (a)$ $\qquad$ (22.4)

(d) $p_b > p^{(l)} \equiv p_a + C_z (b) - C_z (a)$

If payments are chosen according to Equation (22.4) farmers y and z take the desired measures a and b, respectively, and farmer x stays in the business
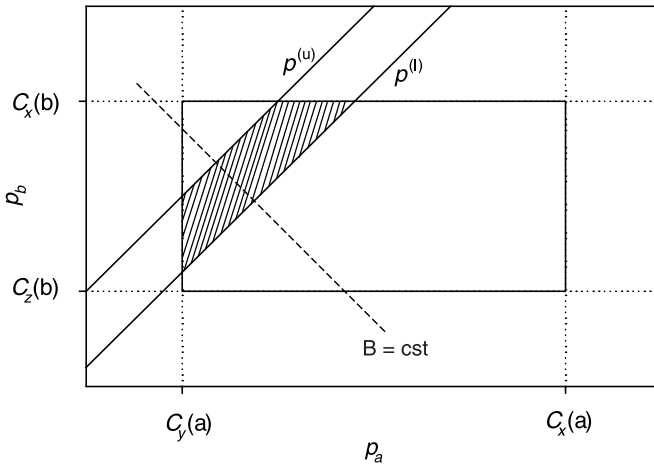
Figure 22.1 Payment schemes (p_a, p_b) that induce habitat heterogeneity; dotted line represents a budget line B = const.

as usual. Plotting p_a and p_b in 2-dimensional space (Figure 22.1), such payment schemes (in the following we call them feasible payment schemes) are represented by points (p_a, p_b) that are located within the intersection of a rectangle and a strip. The rectangle has left and right borders of $C_y(a)$ and $C_x(a)$ (Equation 22.4a) and upper and lower borders of $C_x(b)$ and $C_z(b)$ (Equation 22.4b). The strip that has an upper boundary of $p^{(u)}$ (Equation 22.4c) and a lower boundary of $p^{(l)}$ (Equation 22.4d).

For feasible payment schemes to exist, the intersection of rectangle and strip must be non-empty, i.e. the lower bound of the strip must lie below the upper right corner of the rectangle: $p^{(l)}$ ($p_a = C_y(a)$) < $C_x(b)$ and the upper bound of the strip must lie above the lower right corner of the rectangle: $p^{(l)}$ ($p_a = C_x(a)$) > $C_z(b)$. Evaluation of these equations delivers a necessary and sufficient condition for the existence of feasible payment schemes (p_a, p_b) that induce habitat heterogeneity: there must exist an allocation strategy[3] of land users (x, y, z) to the three activities t (t ∈ {0, a, b} such that

$$C_y(a) + C_z(b) < \min[C_x(a) + C_y(b), C_y(a) + C_x(b), C_x(a) + C_z(b), C_z(a) + C_x(b), C_z(a) + C_y(b)] \tag{22.5}$$

or in a more compact form:

$$C_y(a) + C_z(b) < \min_{\substack{i,j \in \{1,2,3\} \\ i \neq j \\ (i,j) \neq (y,z)}} \{C_i(a) + C_j(b)\}. \tag{22.5'}$$

Noting that $C_x(0) = C_y(0) = C_z(0) = 0$, Equation (22.5) considers all six possible allocation strategies (x, y, z) of land users to the three activities

t ($t \in \{0, a, b\}$) and calculates the sum of their costs, $C_x(0) + C_y(a) + C_z(b)$. If and only if there exists a unique cost minimum regarding these six sums a payment scheme that induces the desired habitat heterogeneity exists.

As laid out by Ohl *et al.* (2008) there can be no more than one allocation strategy (x, y, z) that fulfils Equation (22.5). The cost of the allocation strategy is given by the sum of individual opportunity cost for conservation: $C_y(a) + C_z(b)$. This aggregated cost is independent of the choice of the payments p_a and p_b. Consequently individual profit maximisation ensures that each land user gains most if s/he seeks to minimise her/his cost given the payment for the conservation activity $t \neq 0$.

With this set up in mind, one can also focus on the criterion of budget-efficiency. Budget-efficiency implies that the sum of the payments, $B = p_a + p_b$, is minimised. Figure 22.1 illustrates that budget lines are lines with slope minus one (dashed line). A budget increase is represented by a shift of the budget line towards the upper right, away from the lower left corner ($C_y(a)$, $C_z(b)$) of the rectangle. A budget decline is represented by a shift towards the lower left corner. The budget-efficient payment scheme (p_a, p_b) is thus obtained by shifting the budget line as close as possible to the lower left corner of the rectangle while keeping it within the shaded intersection of feasible payment schemes:

$$B \rightarrow B_{\min} = \min[p_a + p_b] \tag{22.6}$$

subject to condition (3).

There are three different cases with feasible payment schemes that can be distinguished. They are associated with: (i.a) the lower bound of the strip lies *above* the lower left corner of the rectangle (the case shown in Figure 22.1); (i.b) the upper bound of the strip lies *below* the lower left corner of the rectangle; and (i.c) the lower left corner of the rectangle lies *within* the strip.

Case (i.a): The lower bound of the strip lies above the lower left corner of the rectangle, i.e.

$$C_z(b) < p^{(l)}(p_a = C_y(a)) = C_y(a) + C_z(b) - C_z(a) \Leftrightarrow C_y(a) - C_z(a) \equiv \varepsilon_b > 0, \tag{22.7}$$

Equation (22.7) tells that land user z can carry out activity a at lower costs than land user y. Here the minimum required budget is associated with the point where the lower bound of the strip (Equation 22.5) intersects the left border of the rectangle:

$$p_a *\overset{\downarrow}{=} C_y(a)$$
$$p_b *\overset{\downarrow}{=} p^{(l)}(p_a *) = C_z(b) + \varepsilon_b \tag{22.8}$$

Note that on the boundaries of the shapes in Figure 22.1 the land users are

indifferent between different activities. A clear preference for the desired allocation is obtained only inside the intersection, so the payments p_a^* and p_b^* must marginally exceed $C_y(a)$ and $C_z(b) + \varepsilon_b$, which is indicated by the symbol $\overset{\downarrow}{=}$ (in mathematics used to express "approached from above").

The budget has the magnitude

$$B_{min} \overset{\downarrow}{=} p_a^* + p_b^* = C_y(a) + C_z(b) + \varepsilon_b. \tag{22.9}$$

Case (i.b): The upper bound of the strip lies below the lower left corner of the rectangle, i.e.

$$C_z(b) > p^{(u)}(p_a = C_y(a)) = C_y(a) + C_y(b) - C_y(a) = C_y(b) \Leftrightarrow C_z(b) - C_y(b) \equiv \varepsilon_a > 0, \tag{22.10}$$

Equation (22.10) tells that land user y can carry out activity b at lower costs than land user z. In this case the minimum required budget is achieved at the point where the upper bound of the strip (Equation 22.5) intersects the lower border of the rectangle:

$$p_b^* \overset{\downarrow}{=} C_z(b)$$

$$C_z(b) \overset{\downarrow}{=} p^{(u)}(p_a^*) = p_a^* + C_y(b) - C_y(a) \Leftrightarrow p_a^* \overset{\downarrow}{=} C_y(a) + \varepsilon_a \tag{22.11}$$

The budget has magnitude:

$$B_{min} \overset{\downarrow}{=} p_a^* + p_b^* = C_y(a) + C_z(b) + \varepsilon_a. \tag{22.12}$$

Case (i.c): the lower left corner of the rectangle lies within the strip, i.e.,

$$C_y(a) < C_z(a) \wedge C_z(b) < C_y(b), \tag{22.13}$$

Equation (22.13) reflects that land user y can carry out activity a at lower costs than land user z while the opposite is true for activity b. In such a setting the minimum required budget is given by the lower left corner of the rectangle:

$$p_a^* \overset{\downarrow}{=} C_y(a) \tag{22.14}$$

$$p_b^* \overset{\downarrow}{=} C_z(b)$$

and it is associated with the following level:

$$B_{min} \overset{\downarrow}{=} p_a^* + p_b^* = C_y(a) + C_z(b). \tag{22.15}$$

The general interpretation of the three cases is as follows:

Case (i.a): The difference $\varepsilon_b = C_y(a) - C_z(a)$ introduced in Equation (7) is positive. This means that the cost $C_y(a)$ of land user y for activity $t = a$ is

higher than the cost $C_z(a)$ of land user z for the same activity $t = a$. As we know from Equation (22.8), the compensation payment p_a^* is just above the opportunity costs of land user y: $p_a^* \overset{!}{=} C_y(a)$. If land user z was treated in an analogous manner and offered a payment $p_b^* \overset{!}{=} C_z(b)$ that just covers her opportunity cost, her profit would also be just above zero. So, in principle, the land user would be willing to carry out activity b. However, land user z would be even better off by taking activity a (thus, joining land user y), because then her profit would change by $C_y(a) - C_z(a)$ which is positive by the above definition of the present case (i.a). To make sure that land user z stays with activity $t = b$ the compensation payment for this activity must cover the opportunity cost $C_z(b)$ plus the incentive component ε_b. Land user z thus receives a producer surplus $p_b^* - C_z(a) \overset{!}{=} \varepsilon_b$, (Equation 22.8). Consequently, the budget has to cover the opportunity costs $C_y(a) + C_z(b)$ plus the incentive component ε_b, as shown by Equation (22.9).

Case (i.b): The difference $\varepsilon_a = C_z(b) - C_y(b)$ introduced by Equation (22.10) is positive, implying that the cost $C_z(b)$ of land user z for activity $t = b$ is higher than the cost $C_y(b)$ of land user y for the same activity $t = b$. Conversely to case (i.a), the total profit of land user z is (just above) zero while that of land user y is just above ε_a (Equation 22.11). Analogously to case (i.a) the incentive component ε_a has to be paid to land user y (on top of the opportunity cost $C_y(a)$) for not joining land user z and performing with activity $t = b$. Land user z would be compensated only for the opportunity cost $C_z(b)$. Hence, the budget has to cover the costs $C_y(a) + C_z(b)$ plus the incentive component ε_a.

Case (i.c): Neither case (i.a) nor case (i.b) is observed.[4] The total profits of both land users are just above zero, i.e. $p_a \overset{!}{=} C_y(a)$ and $p_b \overset{!}{=} C_z(b)$. In this case there are no incentives for similar choices. That is, no additional incentives to separate land users have to be set in the design of the payment scheme, i.e., the incentive components ε_a and ε_b equal zero. Thus the budget has to cover no more than the aggregated opportunity cost $C_y(a) + C_z(b)$.

We can thus conclude that only in case (i.c) the minimum required compensation can be achieved without over-compensation to the land users, i.e., no producer surplus is paid to the land users (the incentive components ε_a and ε_b equal zero). However, in the cases (i.a) and (i.b), land users take up all required activities only if additional incentives (ε_b in case i.a and ε_a in case i.b) are paid on top of the opportunity cost ($C_z(b)$ in case i.a and $C_y(a)$ in case i.b). The source of this kind of over-compensation is the possibility for land users to participate in different conservation programmes. If land users follow their privately optimal strategy (individual profit maximisation) they would choose the most profitable option. If one activity is the most profitable for both of them the incentive components turn out to be positive ($\varepsilon_a, \varepsilon_b > 0$). To ensure that each activity is taken up and habitat heterogeneity is achieved may thus require additional payments to self-select and separate the different land users. This would be similar to a design that aims at achieving an incentive-compatible payment strategy.

3.2 The case of N > 3 land-users

Now we can turn to the problem of allocating $N > 3$ land users to three different activities. We can assume that n_a and n_b land users would be associated with land use activity a, and b respectively; the remaining $n_0 = N = n_a - n_b$ land users would carry out activity 0. In an analogous manner to the $N=3$ case, payment schemes (p_a, p_b) that achieve this objective exist if and only if a unique cost-minimising allocation of the N farmers into the three different activities exists, i.e:

$$C_{tot} = \sum_{i \in I_a} C_i(a) + \sum_{i \in I_b} C_i(b) < \min_{\substack{(I_a' \neq I_a) \wedge (I_b' \neq I_b), \\ |I_a'|=|I_a|, |I_b'|=|I_b|}} \left\{ \sum_{i \in I_a'} C_i(a) + \sum_{i \in I_b'} C_i(b) \right\}, \qquad (22.16)$$

where I_0, I_a and I_b are index sets containing the indices of the land users performing activities 0, a and b, respectively, and $|I_0| = n_0$, $|I_a| = n_a$ and $|I_b| = n_b$ the desired sizes of the sets. Equation (22.16) is the analogon to Equation (22.5′). Similar to the $N = 3$ case the feasible payment schemes (p_a, p_b) lie within a non-empty intersection of a rectangle and a strip (Figure 22.2).

The boundaries of the rectangle are given by Equation (22.17):

$$\overline{C}_a(a) = \max_{i \in I_a} C_i(a), \quad \underline{C}_0(a) = \min_{i \in I_0} C_i(a), \quad \underline{C}_0(b) = \min_{i \in I_0} C_i(b), \quad \overline{C}_b(b)$$
$$= \max_{i \in I_b} C_i(b) \qquad (22.17)$$

and the strip upper and lower bounds

$$p^{(u)} = p_a + \underline{C}_a(b,a) \text{ and}$$
$$p^{(l)} = p_a + \overline{C}_b(b,a) \qquad (22.18)$$
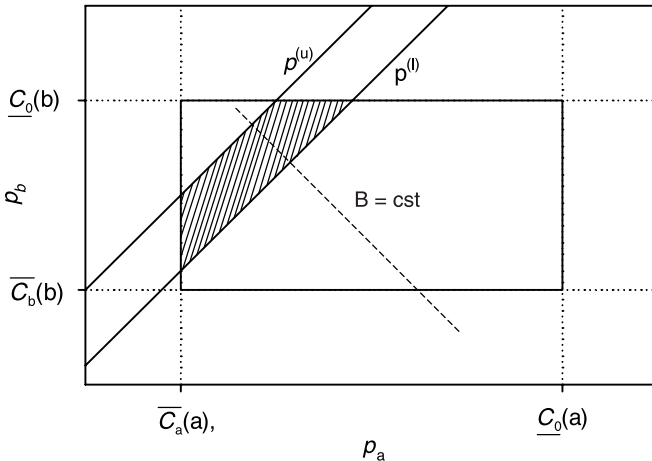
Figure 22.2 Payment schemes (p_a, p_b) that induce habitat heterogeneity in the $N > 3$ land users case; dashed line represents a budgert line B = const..

with

$$\underline{C}_a(b,a) = \min_{i \in I_a} [C_i(b) - C_i(a)], \quad \overline{C}_b(b,a) = \max_{i \in I_b} [C_i(b) - C_i(a)]. \tag{22.19}$$

Similar to the case of $N = 3$ land users, the budget (cost-) efficient payment is obtained by shifting the budget line as close as possible to the lower left corner $(\overline{C}_a(a), \overline{C}_b(b))$ of the rectangle:

$$B \to B_{\min} = \min [p_a + p_b], \tag{22.20}$$

subject to keeping the line within the shaded intersection defined by Equations (22.17)–(22.19).

Once again there are three different cases with feasible payment schemes to distinguish: (ii.a) the lower bound of the strip lies *above* the lower left corner of the rectangle (the case shown in Figure 22.2), (ii.b) The upper bound of the strip lies *below* the lower left corner of the rectangle; and (ii.c) the lower left corner of the rectangle lies *within* the strip.

Case (ii.a): The lower bound of the strip lies above the lower left corner of the rectangle, i.e.

$$\overline{C}_b(b) < p^{(l)} (p_a = \overline{C}_a(a)) = \overline{C}_a(a) + \overline{C}_b(b, a)$$
$$\Leftrightarrow \varepsilon_b \equiv \overline{C}_a(a) + \overline{C}_b(b, a) - \overline{C}_b(b) > 0 \tag{22.21}$$

Here the minimum required budget is achieved at the point where the lower bound of the strip (Equation 22.18) intersects the left border of the rectangle:

$$p^a * \overset{\downarrow}{=} \overline{C}_a(a)$$
$$p_b * \overset{\downarrow}{=} p^{(l)} (p_a *) = \overline{C}_a(a) + \overline{C}_b(b, a) = \overline{C}_b(b) + \varepsilon_b \tag{22.22}$$

The budget has the magnitude

$$B_{\min} \overset{\downarrow}{=} p_a * + p_b * = \overline{C}_a(a) + \overline{C}_b(b) + \varepsilon_b \tag{22.23}$$

Case (ii.b): The upper bound of the strip lies below the lower left corner of the rectangle, i.e.

$$\overline{C}_b(b) > p^{(u)} (p_a = \overline{C}_a(a)) = \overline{C}_a(a) + \underline{C}_a(b, a)$$
$$\Leftrightarrow \varepsilon_a \equiv \overline{C}_b(b) - \overline{C}_a(a) - \underline{C}_a(b, a) > 0 \tag{22.24}$$

In this case the minimum required budget is achieved at the point where the upper bound of the strip (Equation 22.18) intersects the lower border of the rectangle:

$$p_b * \overset{\downarrow}{=} \overline{C}_b (b)$$

$$\overline{C}_b (b) \overset{\downarrow}{=} p^{(u)} (p_a *) = p_a * + \underline{C}_a (b, a) \Leftrightarrow p_a * \overset{\downarrow}{=} \overline{C}_a (a) + \varepsilon_a \tag{22.25}$$

The budget level is

$$B_{\min} \overset{\downarrow}{=} \overline{C}_a (a) + \overline{C}_b (b) + \varepsilon_a \tag{22.26}$$

Case (ii.c): the lower left corner of the rectangle lies within the strip, i.e.,

$$\overline{C}_a (a) + \underline{C}_a (b, a) < \overline{C}_b (b) < \overline{C}_a (a) + \overline{C}_b (b, a) \tag{22.27}$$

Here the minimum feasible budget is given by lower left corner of the rectangle;

$$p_a * \overset{\downarrow}{=} \overline{C}_a (a)$$

$$p_b * \overset{\downarrow}{=} \overline{C}_b (b) \tag{22.28}$$

and its level amounts to

$$B_{\min} \overset{\downarrow}{=} \overline{C}_a (a) + \overline{C}_b (b) \tag{22.29}$$

The general interpretation of the three cases is analogous to the $N = 3$ case: In case (ii.a) an incentive component $\varepsilon_b > 0$ has to be paid to the land users allocated to activity b for not performing with activity $t = a$. The budget has to cover the costs $(\overline{C}_a(a) + (\overline{C}_b(b)$ plus the incentive component ε_b. In case (ii.b) an incentive component $\varepsilon_a > 0$ has to be paid to the land users allocated to activity $t = a$ for not performing with activity $t = b$. The budget has to cover the costs $(\overline{C}_a(a) + (\overline{C}_b(b)$ plus the incentive component ε_a. In case (ii.c) no incentives beyond the maximum actual opportunity costs $(\overline{C}_a(a)$ and $(\overline{C}_b(b)$ have to be paid.

4 Conclusion

Habitat heterogeneity is necessary for biodiversity conservation in agricultural landscapes due to the objective of multi-species conservation, multiple resource use of species, the existence of uncertainties in species habitat requirements and a possible transience of habitat quality. Given the policy framework of voluntary agri-environmental schemes, such as those being used in Europe, one possible option to generate habitat heterogeneity is the differentiation of schemes such that for each habitat type a specific programme is designed where farmers receive a payment if they carry out the respective measures. However, giving land users the possibility to choose among different programmes offers opportunities for strategic behaviour. Such a behaviour may create need for over-compensation of land users even

in a setting where policy-makers are fully informed regarding the (opportunity) costs of land users taking part in the set of different conservation programmes. Assuming profit-maximising behaviour of land users, they would choose the programme which is associated with the largest increase in their individual profits. This may lead to a situation where farmers want to join some measures but not others and thus the socially desired habitat heterogeneity for the sake of agro-biodiversity conservation would not emerge. In this case, in order to assure that a sufficient number of land users participate in each of the programmes, an extra incentive component (to self-select and separate the farmers) on top of the compensation for opportunity costs has to be paid. This leads to producer surpluses of land users (cf. Figures 22.1 and 22.2).

The type and degree of over-compensation critically depend on the profit functions of the land users. In this chapter we have shown that over-compensation is avoided if not only the *total cost* for all measures is minimised (which was introduced as the necessary condition for achieving an allocation (*x, y, z*) that introduces habitat heterogeneity at all), but if in addition the cost for *each individual* measure is minimised [eq. 22.13]: the cost of measure t = a is minimised with land user y $[C_y(a)<C_z(a)]$ and the cost of measure t = b is minimised with land user z $[C_z(b)<C_z(a)]$; i.e. each land user takes the conservation measure which poses him/her the lowest opportunity cost so that in the end all measures in the set of programmes are taken and total opportunity costs (the sum of all conservation costs) are at minimum. Future research should therefore concentrate on analysing the factors (program design) pushing such a setting. Such research might be especially important for agro-biodiversity conservation in developing countries where budgets are even more binding than in developed economies.

Notwithstanding this, situations which require over-compensation of land users may not be avoidable. Therefore, an additional recommendation is to analyse the behavioural motivation of the land users, especially whether their choice behaviour is driven by profit maximisation only or if conservation concerns also motivate their behaviour. In fact, if land users have a preference for nature conservation, they might be willing to agree on a split of measures such that each of the measures is taken even if this split is not optimal from the profit maximising point of view. In this context, the ecological goal may be reached even if land users do not obtain a producer surplus and also even if they get less than their opportunity cost of conservation. However, in reality a sufficient number of such land users may not easily be found.

The findings by Larsen chapter 21 in this volume show that under the most important conservation programmes in Sweden over-compensation takes place. Our model reveals that the extent of over-compensation may be asymmetrically distributed among the land users; some of them may need to be compensated for their individual opportunity costs only, while others would need to be offered an additional payment on top of the opportunity cost. This may lead to problems of fairness in the distribution of payments for

conservation across different types of land users. Such problems may in particular be important in poorer parts of the world. If some land users are able to improve their individual income situation by receiving pure transfers (over-compensation) for conservation-friendly land use measures while other land users can hardly make a living conflicts among the local land users and resistance against programmes of biodiversity conservation may rise. This calls for future research in taking into account not only efficiency issues but also fairness considerations.

Notes

1 In this chapter the terms 'land users' and 'farmers' are used interchangeably. However it should be noted that in order to generate habitat heterogeneity land users need not necessarily be farmers. For instance, depending on the measures to be taken land users may also be foresters or hunters.
2 This may also be referred to as budget efficiency. See Wätzold and Schwerdtner (2005) for a more detailed discussion on cost-effectiveness.
3 An allocation strategy (x, y, z) with $x = 1$, $y = 2$ and $z = 3$ for example means [cf. equ. (22.3)] that land user 1 performs with $t = 0$, land user 2 with $t = a$ and land user 3 with $t = b$.
4 Note that case (i.a) excludes case (i.b) and vice versa, so all three cases are mutually exclusive.

References

Ando, A., Camm, J., Polaskym, S. and Solow, A. (1998) 'Species distributions, land values, and efficient conservation' *Science* 279: 2126–2128.

Benton, T.G., Vickery, J.A. and Wilson, J.D. (2003) 'Farmland biodiversity: is habitat heterogeneity the key?' *Trends in Ecology and Evolution* 18(4): 182–188.

Claasen, R., and Horan, R. D. (2000) 'Environmental payments to farmers: issues of program design', *Agricultural Outlook* June–July: 15–18.

Clough, P. (2000) 'Encouraging private biodiversity: Incentives for biodiversity conservation on private land', Treasury Working Paper 00/25, Wellington, New Zealand. http://www.treasury.govt.nz/workingpapers/2000/00–25.asp.

Defenders of Wildlife (2002) *Conservation in America: State Government Incentive for Habitat Conservation*. Washington, DC: Defenders of Wildlife.

Drechsler, M., Wätzold, F, Johst, K., Bergmann, H. and Settele, J. (2007) 'A model-based approach for designing cost-effective compensation payments for conservation of endangered species in real landscapes', *Biological Conservation* 140: 174–186.

European Commission (2005) Agri-environment Measures: Overview on General Principles, Types of Measures, and Application. Study of the European Commission Directorate General for Agriculture and Rural Development, Unit G-4 – Evaluation of Measures applied to Agriculture, March 2005. Available at: http://europa.eu.int/comm/agriculture/publi/reports/agrienv/rep_en.pdf; (22. October 2005).

Johst, K., Brandl, R. and Eber, S. (2002) 'Metapopulation persistence in dynamic landscapes: the role of dispersal distance', *Oikos* 98: 263–270.

Johst, K., Brandl, R. and Pfeifer, R. (2001) 'Foraging in a patchy and dynamic

landscape: human land use and the white stork', *Ecological Applications* 11: 60–69.

Johst, K., Drechsler, M., Thomas, J. and Settele, J. (2006) 'Influence of mowing on the persistence of two endangered large blue butterfly species', *Journal of Applied Ecology* 43: 333–342.

Johst, K. and Huth, A. (2005), 'Testing the intermediate disturbance hypothesis: When will there be two peaks of diversity?', *Diversity and Distribution* 11: 111–120.

Johst, K., Drechsler, M. & Wätzold, F. (2002), 'An ecological-economic modelling procedure to design compensation payments for the efficient spatio-temporal allocation of species protection measures', *Ecological Economics* 41: 37–49.

Keymer, J. E., Marquet, P. A., Velasco-Hernandez, J. X. and Levin, S. A. (2000) 'Extinction thresholds and metapopulation persistence in dynamic landscapes', *The American Naturalist* 156: 478–494.

Landell-Mills, N., and Porras, I. (2002) *Silver Bullets or Fools' Gold? A Global Review of Markets for Forest Environmental services and Their Impact on the Poor*. London: International Institute for Environment and Development (IIED).

Ludwig, D., Mangel, M. and Haddad, B. (2001) 'Ecology, conservation, and public policy', *Annual Review of Ecology and Systematics* 32: 481–517.

OECD (2003) 'Agri-environmental policy measures: Overview of developments'. Paris: OECD. (*http://www.oecd.org/dataoecd/25/46/18987100.pdf*, 11. October 2007).

Ohl, C., Drechsler, M., Johst, K. and Wätzold, F. (2006) 'Managing land use and land cover change in the biodiversity context with regard to efficiency, equality and ecological accuracy', UFZ-Discussion Paper, Department of Economics, Helmholtz Centre for Environmental Research, No. 3.

Ohl, C. *et al.* (2008) 'Compensation payments for Habitat Heterogeneity: Existence, efficiency, and fairness considerations', *Ecological Economics*, doi: 10.1016/j.ecolecon.2008.04.011.

Wätzold, F. and Drechsler M. (2005) 'Spatially uniform versus spatially heterogeneous compensation payments for biodiversity-enhancing land-use measures', *Environmental and Resource Economics* 31: 73–93.

Wätzold, F. &. Schwerdtner, K. (2005) 'Why be wasteful when preserving a valuable resource? A review article on the cost-effectiveness of European conservation policy', *Biological Conservation* 123: 327–338.

Weiss, Stuart B. (1999) 'Cars, cows, and checkerspot butterflies: nitrogen deposition and management of nutrient-poor grasslands for a Threatened species', *Conservation Biology* 13(6): 1476–1486.

Index