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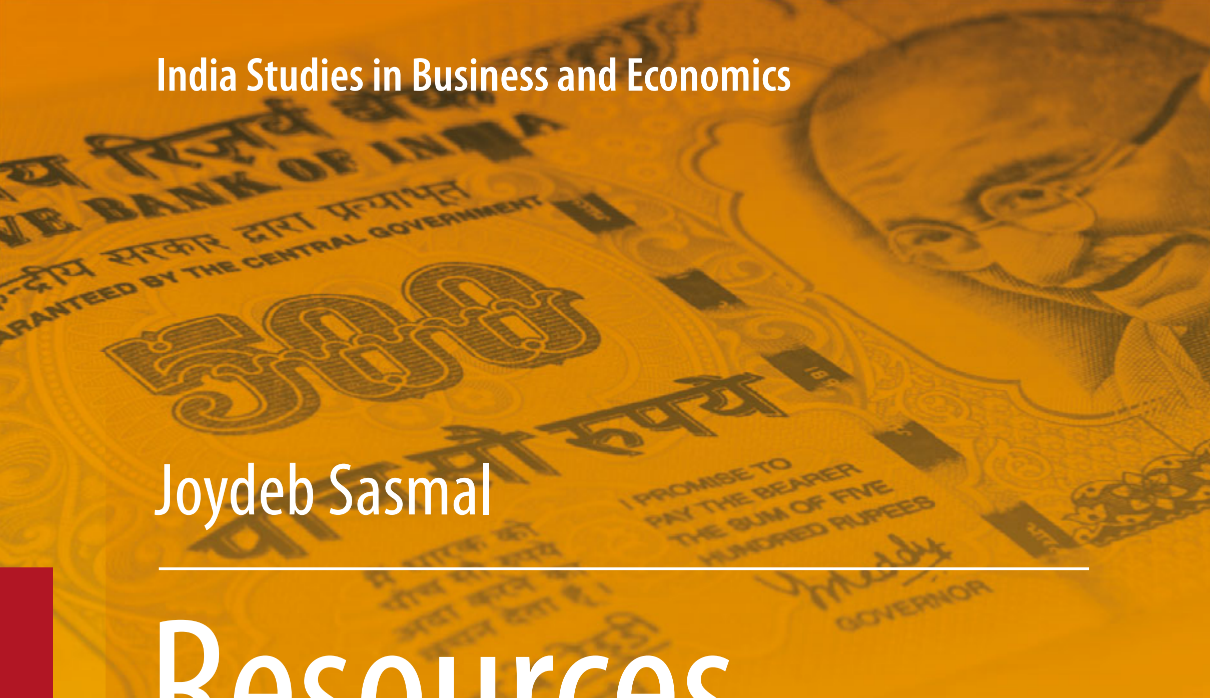

Joydeb Sasmal

Resources, Technology and Sustainability

An Analytical Perspective on Indian Agriculture

Springer

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An Analytical Perspective on Indian Agriculture

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This book is dedicated to
my mother Late Charubala Sasmal

and

my wife Bithika Sasmal

—Joydeb Sasmal

Foreword

Sustainable economic growth is one of the major concerns of our times. While growth is important not only from the point of view of increasing economic welfare in general but also from that of the very urgent task of ameliorating poverty and deprivation, it needs to be ensured that growth in the *current* period of time does not jeopardise *future* growth. The problem is that very often there is a trade-off between the two: the faster we grow now, the lower is the probability that the rate of growth will be sustained in the future. The reason behind this trade-off is the fundamental fact that economic growth entails—indeed, it is synonymous with—increase in the production of goods and services. The process of production uses natural resources. When the stocks of these resources seem to be large enough in relation to the current rate of their depletion, it does not occur to us that this may raise a serious sustainability issue. However, as the process of growth continues, there comes a stage where we are forced to pay attention to the matter.

The story of the expansion of the world output over the past two or three centuries largely conforms to this scenario. As is well-known, up to the late eighteenth century the world output was essentially stagnant (at least in per capita terms). It was only after the Industrial Revolution in the West that the growth rate picked up. Between 1820 and 1913 per capita world output grew at the average annual rate of 0.9 %. (Between 1700 and 1820 this rate was 0.1 %; it was virtually zero in the 100 years preceding 1700.) It is only over the past hundred years or so that this rate has significantly exceeded 1 %.

It is now generally recognised, however, that this positive growth performance has taken place at the cost of depletion of the natural resources of this planet and is likely to hit insurmountable constraints in the not-too-distant future. A major part of the problem is rightly identified with the ever-increasing use of energy, mainly in the process of industrial production but also in that of sustaining the pattern of consumption that the industrial society has engendered. Most of the natural resources which are currently used to produce energy (such as oil and coal) are exhaustible and cannot be replenished. So far as these are concerned, the only viable solution of the problem consists in finding alternative sources of energy. A lot of R and D efforts are, therefore, currently oriented towards this goal.

There also are vitally needed resources which may, in principle, be replenishable but the process of replenishment is costly. Water resources are the leading example of such resources. As is the case with the exhaustible resources problem, this is also a common problem of the world economy, afflicting advanced and developing economies equally. For the Indian economy, however, this problem has a special significance.

While water is an important input in all processes of material production, it is in agriculture that its importance is overriding. In the Indian economy agriculture occupies a position of special importance. While the share of agriculture in India's GDP is presently only around 13 %, about half of India's population is engaged in the agricultural sector. From the point of view of eradication of poverty, therefore, growth of the agricultural sector is of utmost importance. Moreover, in the economy as a whole the problem of slow growth in the rate of job creation has now become a major headache for the policy planners. Unless this rate can be raised above the rate of growth of the labour force, the problem of unemployment which is already quite severe can only get worse over time. This, however, can be done only by pushing up the growth rate of the economy in general and, particularly, that of the employment-intensive sectors such as manufacturing. For this, in turn, there must be adequate demand for the output (especially, manufacturing output) that is to be produced. In this context, again, agricultural growth becomes crucial since, as noted above, it accounts for the growth of income of about half of the country's population and it is income which is the source of demand.

As is well known, there was time in the 1960s when sluggish agricultural growth and a high rate of population growth combined to create a situation of acute food scarcity in India. The country had to import food grains from abroad on an emergency basis. The crisis spurned our policy planners into action. Much-needed investment was channelled into developing and implementing the technology of what later came to be called the Green Revolution.

In terms of growth of agricultural output Green Revolution was certainly a success story. For a long time since the 1970s India was a net exporter of agricultural goods. Gone were the days of emergency food imports.

Since the 1990s, however, some disturbing trends have been observed. The technology of the Green Revolution involved the use of a combination of adequate quantities of water, HYV seeds, fertilisers and pesticides. Continuous application of the technology created problems. It was groundwater which was used as the source of water supply. In those areas of the country where the Green Revolution was a runaway success in terms of production, the stock of groundwater is now nearly totally exhausted. Heavy doses of chemical fertilisers and pesticides have played havoc with the productivity of land. To make matters worse, investment (particularly, *public* investment) in agriculture has stagnated. As a result of all this, per capita agricultural output has stagnated too. In some recent years there have again been some food imports. Things have not yet gone out of hand. But the warning signals are unmistakable.

Few economists are more qualified than Prof. Joydeb Sasmal to discuss these and related problems relating to the agricultural economy of India. He has studied these matters in detail for the last three decades. He has now collected his major findings and weaved them into this book. The reader will find here a deep analysis of the issues connected with technological change, productivity, use of water resources, problems of land use, agricultural prices, food security and sustainability of agricultural growth. The analysis includes not only a rigorous statistical analysis of the facts and figures but also an analysis of optimal policies using the tools of optimal control theory. Altogether, this book is a major contribution to the study of the agricultural economy of India. Moreover, while the discussion is focused on India, the method of analysis employed will be of interest to those who wish to study these matters in the context of other developing economies. I recommend the book highly to the reader.

January 2016

Asis Kumar Banerjee
Former Vice-Chancellor
University of Calcutta

Preface

The book titled *Resources, Technology and Sustainability—An Analytical Perspective on Indian Agriculture* is the reflection of my research on agricultural economics for the last thirty years. Although I have research interest in diverse fields of economics, namely, economic growth, public economics, child labour, the major focus of my works has remained on natural resources, agriculture and sustainable growth. In the days of my student life in college and university in 1970s and 1980s, the low productivity, low capital investment and technological backwardness in agriculture were the subjects of major concern for farmers, agricultural sector and for the economy as a whole and this attracted me to be engaged in research on this field. The existing literature suggested that the productivity in traditional agriculture could not be increased without a technological breakthrough. At the beginning, I started my works with the objective of suggesting policies towards increasing productivity in agriculture. The frontline research in this field at that time published in renowned International Journals prompted me to undertake doctoral research on 'Adoption of Modern Technology in Agriculture'. I started my work in late 1980s in the Department of Economics, University of Calcutta, under the supervision of my respected teacher, Prof. Asis Kumar Banerjee. Professor Banerjee, one of the finest teacher in economics, with commendable grip over economic theory and quantitative economics, advised me to keep in mind that a good research must be based on sound theoretical framework and I was trained and guided accordingly. Many works were going on in the same line in the Indian context but hardly any of them had any theoretical backup. I got the necessary help and guidance from my supervisor to analyse the problems in a very rigorous and scientific manner. The seminal works of Gershon Feder, David Zilberman, Richard E. Just, Rulon D. Pope, Joseph Stiglitz, Avishay Braverman, Amit Bhaduri, T.N. Srinivasan, Zvi Griliches, V.W. Ruttan, T.W. Schultz, John Mellor, C.H. Hanumantha Rao, K.N. Raj, Derek Byerlee, Barbara Harriss and many others helped me to a great extent in this matter. In my doctoral thesis I was able to show that the adoption of a new technology is decision-making under uncertainty. Since the production under a new technology is uncertain, the adoption of the technology depends on the degree of risk and the risk preference of the farmers along with other factors. In the Indian context, the support measures of the government reduced the degree of risk and risk aversion of the farmers over time. So, many of the obstacles towards adoption of the new technology, known as high yielding variety (HYV) technology, were removed and the HYV technology was subsequently adopted on a wide scale. The adoption rate of the technology in small farms was found to be higher compared to the big farms. Irrigation, specially tube-well irrigation, played a vital role in the adoption of the new technology in Indian agriculture. The large-scale adoption of the HYV technology, extension of irrigation and use of chemical fertilisers resulted in remarkable increase in food grains production in India.

As a result of technological change and expansion of irrigation, Indian agriculture has achieved remarkable success in production. But at the same time it has caused huge stress on natural resources like land and water. Excessive depletion of ground water, soil degradation due to intensive cultivation and use of chemical inputs in increasing doses and loss of biodiversity are now posing a serious threat to sustainability of growth in the country. Now, issues like conservation of ground water, utilisation and proper management of surface water, soil health, crop diversification in favour of less water intensive crops, rain water harvest, efficient technology for irrigation, policy intervention for encouraging the use of resource friendly inputs, use of appropriate technology for resource conservation and sustainable growth have come into prominence. The focus of my research which was initially on technology adoption and productivity growth has now shifted towards conservation of resources and sustainable growth in agriculture policies. In fact, sustainable growth has now become a common agenda for research almost in all disciplines for the last three decades. By this time, Environmental and Resource Economics has become one of the prominent areas of research in Economics and in my post doctoral phase, I have joined this new line of research. The frontline research in this field published in Specialised Journals like *Journal of Environmental Economics and Management*, *Environment and Resource Economics*, *American Journal of Agricultural Economics, Oxford Economic Papers*, *Journal of Political Economy*, *Journal of Development Economics*, *Journal of Agricultural Economics*, *Quarterly Journal of International Agriculture* has enriched me to a great extent. Excellent works of the eminent scholars in this field provided the motivation to work on this field. During this phase, I have been immensely benefitted from my friend and renowned scholar, Prof. Sugata Marjit. Professor Marjit is a distinguished trade theorist but he has strong and deep insight in all branches of Economics. My long association and regular interaction with him has increased my interest in economic theory and improved my ability to deal with the problems in proper analytical structure. Since I got interested in growth oriented problems and resource use in dynamic perspective, the writings of Robert Solow, Joseph Stiglitz, Partha Dasgupta, K.G. Mäler, David Zilberman, Robert Barro, Kaushik Basu, Ronald Jones, Christopher Barrett, P.R. Agenor, J.A. Krautkraemer, Stephen Turnovsky provided the necessary skill and insights in formulating the research problems. One book that helped me a lot in pursuing my research in this field is 'Elements of Dynamic Optimisation' by AC Chiang (McGraw Hill Inc.), 1992.

The three major issues that I have addressed in my book are technological change, conservation of natural resources and sustainable growth in agriculture. Technological change has increased productivity. The growth in productivity has caused resource degradation putting a threat to the sustainability of growth. Again for resource conservation and sustainable growth, appropriate technology is needed. All these are very relevant and much discussed issues in agriculture. But what I have wanted to do is to analyse these problems in an integrated and very comprehensive manner. The whole analysis is based on sound theoretical framework. The question of sustainability has been addressed in a very broader perspective encompassing geography, soil and agro-climatic conditions, rainfall, cropping pattern and technological innovations. The use and management of natural resources have externality problems. So, market failure is there in resource use. Sometimes, market distortions are created by support measures of the government. Nevertheless, public intervention is needed to popularise the use of resource friendly inputs and production techniques and discourage the use of polluting inputs through taxes, subsidies and incentive payments. Sufficient public investment is necessary for the development of new scientific knowledge and innovations. Natural resources are undervalued by private agents. As a result, excess depletion of resources takes place causing threat to sustainability of growth. Here comes the role of the Social Planner who can make proper valuation of costs and benefits of resource use. All these issues have been addressed in this book using appropriate theoretical framework. The theoretical propositions have been empirically verified by time series econometric analyses. The optimal control theory has been extensively used to build up theoretical models to determine optimal use of resources in agricultural growth in dynamic perspective. The techniques of time series analysis as outlined in Walter Enders (2004), John Wiley & Sons, have been applied to the Indian data to derive empirical results. In some chapters I have used the theory of decision-making under uncertainty, the structure of general equilibrium model of Ronald Jones (1965) and the Specific Factor Trade Model of Jones and Marjit (2003) for analysing the problems. All the contemporary issues of agricultural growth like excess depletion of ground water, soil degradation, harvest of rain water, crop diversification, use of organic manure in cultivation, alternative uses of land, food security, the role of the government in resource management and scientific innovations and the importance of the frontiers of technology in future growth of agriculture have been analysed in proper context. I hope, the book will be helpful to readers at Graduation and Master's levels and to researchers. The book could not cover many aspects of agricultural growth. It has basically adopted a supply-side approach in explaining growth. Due to non-availability of data many econometric exercises could not be done. The author admits these deficiencies. The deficiencies may be corrected and the suggestions from the readers may be accommodated in further editions of the book.

The list of persons the author is indebted to in writing this book is very long. First of all, I would like to convey my deep regards and indebtedness to Prof. Asis

Kumar Banerjee who has taught me and trained me for analytical research and has been guiding me in my works for more than three decades. I have got a lot of encouragement, appreciation and valuable help in writing this book. He has been kind enough to write a Foreword for this book. I am very grateful to him. I owe a very special debt to Prof. Sugata Marjit for his encouragement, spontaneous help and valuable guidance at every moment of my academic career. I have learnt many things of my subject from his writings and my interactions and joint works with him. His innovative ideas and clarity in thought and ability to build up beautiful theoretical models have greatly influenced me. He has remained very cordial with me and provided valuable guidance at every stage of writing this book. Apart from being a great scholar, he is also a great human being.

A sizable portion of my unpublished PhD Thesis has been included in this book. Professor Dipankar Coondoo of Indian Statistical Institute, Calcutta and Prof. Debasish Mondal of Vidyasagar University were very generous to extend very valuable help in my PhD work. I am very grateful to both of them. I have been largely benefitted from the interactions with Prof. Rabindranath Bhattacharya, Prof. Manas Ranjan Gupta, Prof. Abhirup Sarkar, Prof. Sarmila Banerjee, Prof. Soumyen Sikdar, Prof. Partha Sen, Prof. Rajat Acharya, Prof. Kausik Gupta, Prof. Ajitava Raychauduri, Dr. Saibal Kar and Prof. Tarun Kabiraj on different problems of my research at different points of time. I am indebted to all of them.

I convey my sincere gratitude and thanks to my friend and co-author, Prof. Hans-Peter Weikard, Wageningen University, the Netherlands for his help and suggestions on my works. One of our joint papers has been included in this book in modified and extended form. I express my thanks and gratitude to Dr. Sayan Mukherjee for his valuable help in a chapter of this book. I take this opportunity to extend my thanks to my co-author Dr. Gorge Guillen, Universidad, Esan, Peru for his encouragement and help to my works.

My deepest regards to three great teachers—Prof. Rakhal Datta, Dr. Gopal Tribedi and Prof. G.K. Chadha. They are no more with us. But I gratefully acknowledge their help and love for me. Among my well-wishers I would like to thank and convey my gratitude to Prof. Sachinandan Sau, Dr. Biswajit Guha, Dr. D. N. Bhattacharya, Prof. Mamata Ray and Prof. Swapan Kumar Bhoumik.

I spent a long time in K.K. Das College under the University of Calcutta as a permanent teacher. I express my very sincere gratitude to Principal Sanjib Chandra Basu, my colleagues in the college and students for their encouragement and help in pursuing my research in the college. Presently I am in Vidyasagar University. Hon'ble Vice Chancellor of our University, Professor Ranjan Chakrabarti, is a great inspiration for me. He always encourages and provides all sorts of help for academic improvement. I respectfully acknowledge his cordial help and encouragement in writing this book. I also extend my gratitude to my colleagues and students in our Department in the University for their encouragement and cooperation in my academic pursuit.

I express my thanks to Oxford University Press for the permission of using two articles (one from *Oxford Economic Papers* and the other from *American Journal of Agricultural Economics*) partially in my book. I also like to extend my gratitude to

Sage Publication for giving permission to reproduce the modified version of my paper "Crop diversification for Conservation of Water Resource and Agricultural Growth: A Comparative Dynamic Analysis" originally published in *South Asian Journal of Macroeconomics and Public Finance*, Vol. 2, No. 2, Copyright © 2013 Sage Publications India, New Delhi, in my book.

I gratefully acknowledge that my two papers—one published in *Journal of Economics, Finance and Administrative Science* and the other in *Quarterly Journal of International Agriculture* jointly with Hans-Peter Weikard, have been partially used in modified and extended versions as theoretical backup for empirical exercises in my book. So, I convey my sincere thanks to the publishers of these two journals. I am deeply indebted to Springer for their interest in my book. I thankfully express my sincere gratitude to Sagarika Ghosh, Executive Editor, Springer, for her wholehearted cooperation and guidance at every stage in preparing the manuscript of this book.

Finally, I wish to thank my wife Bithika and sons—Ritwik and Koushik for their encouragement and help at every moment of preparing this book. Ritwik, being a student of economics, has provided me technical and academic help for this book. This book could not have been published unless Bithika took the full responsibility of my family leaving me free to be engaged in writing this book. I am really very indebted to her. Lastly, I should thank affectionate Sanat Datta (Jitu) for taking the trouble of typing the whole text of the book in software version.

January 2016 Joydeb Sasmal

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Contents

About the Author

Joydeb Sasmal is a professor of Economics at the Department of Economics with Rural Development, Vidyasagar University, Midnapore (W), West Bengal, India. He obtained his MA, MPhil and PhD degrees in Economics from the University of Calcutta. His research areas are natural resources, agriculture and sustainable growth, public economics, poverty and child labor and economic growth. He has published a number of papers in international and national journals and presented papers at conferences and seminars both in India and overseas. He did his PhD under the supervision of Professor Asis Kumar Banerjee, Former Vice Chancellor of the University of Calcutta. He has worked jointly with Sugata Marjit (CSSSC), Hans-Peter Weikard (The Netherlands), Jorge Guillen (Peru) and Ritwik Sasmal (Germany).

Chapter 1
An Overview of the Indian Agriculture

Abstract The introductory chapter of this book gives an overview of the Indian agriculture and describes how productivity in Indian agriculture has increased due to use of modern seeds, chemical inputs and extension of irrigation. It states that the growth in agricultural production has been achieved largely banking on ground water extraction. This has caused resource degradation in the country and it is now putting a threat to the sustainability of growth in the country. So, the conservation of natural resources has become very crucial for future growth. In the conservation of the resources, the recent developments of technology have significant role to play. In the scheme of the book, it has been mentioned that the issues like soil degradation, excess depletion of ground water, crop diversification, rain water harvest, major aspects of technological change and their impact on productivity and resource conservation, alternative uses of land and food security will be analysed in a very comprehensive and interrelated manner. The analysis will be based on sound theoretical frameworks and the theoretical prepositions will be empirically verified by econometric works based on Indian data.

1.1 Introduction

Agriculture plays an important role in the Indian economy even after six decades of planned development. The share of agriculture in the GDP of India (at 2004–05 prices) has declined to 13.9 % in 2012–13 from 40 % in 1970–71 although more than 50 % of the population of the country are dependent on agriculture for employment and livelihood. Nearly two-thirds of agricultural production in India are food crops and among the food crops rice and wheat are major items. Rice is the most water-intensive crop of the country. There has been substantial increase in agricultural production in the last four decades. The demand for food has been increasing at a high rate with population growth. To meet this growing demand, the domestic production of foodgrains in India has significantly increased. Total production of foodgrains in India was 108.42 million tonnes in 1970–71 and it has increased to 257.13 million tonnes in 2012–13. This remarkable increase in

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production can be attributed to productivity growth in the farming sector. Use of high-yielding variety (HYV) seeds, extension of irrigation and chemical fetilizers have significantly contributed to productivity growth. As a result of these measures the yield per hectare in foodgrains production has increased from 872 kg per hectare in 1970–71 to 2129 kg in 2012–13 (Source: Agricultural Statistics at a Glance 2014, Ministry of Agriculture, Government of India 2015a, b).

In 1950s and 1960s, the productivity in agriculture was very low. In 1960–61, the yield per hectare in foodgrains cultivation was only 710 kg and total production of foodgrains was 82.02 million tonnes. The productivity was low due to lack of irrigation, low capital investment and technological backwardness. The food shortage in the 1960s was so acute that it was compelling for the country to produce as much food as possible very quickly by any means. Accordingly, the new agricultural technology, known as HYV or Green Revolution technology was introduced in Indian agriculture in the mid-sixties. Up to mid-sixties, foodgrains production in India could be increased mainly by extensive cultivation but after that the net cropped area under foodgrains production has remained more or less fixed at 124 million hectares during the last forty years. The total production has increased over time as a result of intensive cultivation and higher productivity of land. As a result of technological break through India could turn into a net exporter country in foodgrains since early eighties. Irrigation is found to be the main driving force of productivity growth in India. The elasticity of foodgrains production with respect to irrigation has been found to be 1.18 (Sasmal 2014). That means, one percent increase in irrigation leads to 1.18 % increase in foodgrains production. The net irrigated area in the country has increased from 22.10 % of the total cultivated land in 1970–71 to 47 % in 2012–13 and in total irrigated land, the share well-irrigation has increased from 12.34 to 62 % during this period. In fact, extraction of ground water and expansion of tube-well irrigation has played a crucial role in the whole progress of agricultural growth in India. This has greatly facilitated the use of HYV seeds and chemical inputs for enhancing productivity of land. More than 61 % of the area under foodgrains production are now under HYV scheme. The use of chemical fertilizers per hectare has increased from 17.74 to 130 kg during this period (Source: Centre for Monitoring Indian Economy, (CMIE) 2010; Economic Survey 2014–15, Government of India). On the whole, India has achieved noticeable progress in foodgrains production as a result of technological change, development of infrastructure and extension services. The government took an important role in the diffusion of the new technology and productivity growth. The higher productivity in agriculture has resulted in reduction of rural poverty.

At the initial stage of the introduction of the new technology it was first introduced mainly in food crops like rice and wheat and in areas like Punjab, Haryana and Uttar Pradesh in 1960s. It has subsequently been spread in other parts of the country and extended to the cultivation of other crops. However, much crop-diversification has not taken place during this period. The growth rate of yield in the production of pulses, oilseeds, jowar, bajra and sugarcane could not show much improvement in the last four decades.

The adoption of a new technology involves risk and uncertainties. Although yield under modern technology is much higher than under traditional farming, there was lot of apprehension that the small and marginal farmers will not be able to adopt the new technology because the small farmers are more risk advise. But, it has been found that adoption rate of HYV technology among the small farmers is higher compared to the big farmers (Sasmal 1992). Feder (1980) and Harriss (1972) show that farm size will not be an obstacle to the adoption of a new technology under favourable conditions. In the Indian context, the government provided many facilities to agriculture through expansion of irrigation, extension services, supply of credit and subsidies on inputs for the diffusion of HYV technology. In a country like India where more than 80 % of land are cultivated and owned by small, marginal and medium farmers, the government has the responsibility to help them in various ways. But greater intensity of cultivation leads to land degradation if proper measures are not taken for soil treatment. Here again, the government measures are needed for resource management. The poor typically depend far more heavily on natural resources than the rich. They are found to be more interested in short run gain than preserving the resource for future use. There are other constraints also like lack of information, financial inability and lack of access to technical knowhow for maintaining soil fertility. If the land use crosses some threshold limit, there is possibility that the resource base will potentially collapse. So, both the farmers and the government need to be careful in this regard. In the process of technological change and productivity growth, the problem of water management is found to be more serious. On the whole, the problems of resource degradation are not confined to small farms only. The problems are general in nature in the country.

The technological change and the resultant increase in agricultural production have put huge stress on the natural resources like water and land. The agricultural production in the country could be significantly increased largely banking on ground water extraction. However, the excessive depletion of ground water has caused a threat to sustainability of growth in agriculture (Rao 2002; Sidhu 2002; Sasmal 2012). The study of Bhullar and Sidhu (2006) shows that in Punjab where green revolution has been very successful, has been worst affected by excessive ground water depletion. The proportion of area in the state where water table is below the critical depth of 10 m has increased from 3 to 52 % during the period from 1973 to 2000. Ground Water Scenario 2009–10, Ministry of Water Resources, Government of India, reveals that in states like Punjab, Haryana and Rajasthan, the extraction of ground water has exceeded the naturally permissible limits. In these three states the extraction rates are 125, 109 and 145 % respectively of the available capacity. In other states like Tamil Nadu, Uttar Pradesh, Gujarat and Karnataka the rate of extraction is 70 % or more. Thus, ground water irrigation is going to be a limiting factor for future growth in agriculture in India. Sasmal (2012) shows that the rate of productivity growth in foodgrains productions has declined from mid-nineties and that is mainly due to decline in the growth rate of tube-well irrigation. On the other hand, the effect of HYV technology on agricultural productivity has almost exhausted. So, a new productivity-enhancing and resource-preserving technological progress is urgently needed in the country.

Intensive cultivation, continuous use of chemical inputs, short fallow period and lack of soil treatment measures are the causes of soil degradation. Salinization, nutrient depletion, loss of soil organic matters (SOM) have become very common in the developing countries. Tilman et al. (2002) report that since 1945, approximately 17 % of vegetated land has undergone soil degradation due to mismanagement and over use of the resource. After intensification of cultivation, the use of pesticides and other chemical inputs have killed many useful species of insects putting adverse impact on the natural process of regeneration of soil fertility. The chemical composition of soil and overall soil profile have changed and soil has become deficient in micronutrients. The use of organic manures could not increase to the required level. The crop rotation system has been replaced by mono-cropping in most of the cases. Sasmal (2003) finds in a field survey that productivity in HYV paddy cultivation has declined by 6–16.5 % over a period of 13 years despite 25–50 % increase of fertilizer use.

The concept of sustainable growth has become very important and popular in the last two-three decades. Sustainability is defined in many ways. One best known definition of sustainability has been provided by the “Brundtland Commission”, the World Commission on Environment and Development headed by the Prime Minister of Norway. According to this Commission, sustainability is defined as development that meets the needs of the present without compromising the ability of the future generations to meet their own needs (Kolstad 2000). Solow (1992) defines sustainability as making sure that the next generation is as well off as the current generation and ensuring that this continues for all time. In connection with this idea of sustainability, he suggests that man-made capital be used as substitute for natural resources.

Agriculture is a resource based activity. So, in relation to the above arguments, it can be said that for sustainable growth in agriculture, conservation of natural resources is very important. The use and conservation of natural resources have externality problems. So, the markets fail to provide optimal solution to these problems. There will be excessive use of resources and no initiatives or few initiatives will be taken at the individual level for conservation of resources. Dasgupta and Mäler (2009) draw our attention to the problem of under valuation of natural resources by private agents. Since proper valuation of natural resources is not done, the profit-maximising use of the resource by the private agents exceeds the level of sustainable use. In the conservation of resources, the marginal social benefit is greater than marginal private benefit. So, optimal level of conservation does not take place in most cases. So, here comes the role of the social planner and the government. In many cases, public investment and government intervention are necessary for conservation of natural resources.

Trade liberalization after the formation of World Trade Organisation (WTO) in 1995 and economic reforms in the country from 1990s, has added new dimensions to the problem of sustainable growth. Agriculture has been brought under the conditions of WTO agreements. The signatory countries of WTO are now required to reduce tariff rates on agricultural imports, curtail subsidies to agriculture and provide minimum access to the foreign goods in the domestic market. Gulati and Sharma (1994) have calculated the aggregate measure of support (AMS) to agriculture and shown that India's support level is below the permissible limit. So India does not need to curtail its support to agriculture on the condition of WTO. But net domestic capital formation in agriculture in the public sector of India has declined in the 1990s. The net capital formation at 2004–05 prices has declined from Rs. 6349 crore in 1994–95 to Rs. 3827 crore in 2000–01 although it has increased later from 2003–04 (Source: National Accounts Statistics, Ministry of Statistics and Programme implementation, Government of India 2011). The reduction in public expenditure has adversely affected agricultural growth in India.

Technological progress is necessary not only for enhancing productivity in agriculture, it is also necessary for conservation of natural resources. So, huge investment is required for new agricultural innovations and technological progress. In fact, biotechnology, irrigation technology, nanotechnology, remote sensing, geographic and information science (GIS) will play key role in future agricultural growth. Side by side with public sector investments, the Multi-National Corporations (MNCs) are making huge investment on agricultural research for developing new knowledge in the above fields. As per Intellectual Property Rights and Patent Rights of the WTO, new agricultural scientific knowledges are not always freely available to the farmers. So, the government will have to think how the cultivators can have access to the new knowledges of agriculture.

India is experiencing high rate of GDP growth after economic liberalization since 1990s. But growth has become very unbalanced and lopsided. While the service sector is growing at the annual rate of 10–12 %, agricultural growth rate is less than 2 % per annum. This has created a mismatch between demand and supply in the markets for food items. As a result, the country is passing through a phase of high food price inflation (Sasmal 2015). In this respect also, agriculture should be given greater attention.

At present, Indian agriculture is plagued with a number of problems ranging from technological stagnation and resource degradation to lack of public investment. Two important features of Indian agriculture are (i) small farm size and (ii) excess population pressure on land. In the absence of productive employment opportunities in the non-agricultural sector, the growing population are rather being forced to depend on agriculture for livelihood. As a result, agriculture is over-crowded and adverse 'land-man ratio' is creating additional problems for agricultural growth. Besides, in an era of economic liberalisation, the acquisition of land for the development of industries, Special Economic Zone (SEZ), housing and real estate has become a highly controversial issue and a matter of national debate. Land has become very important resource both for agriculture and non-agricultural sector. Land is necessary for industry and urbanisation. On the other hand, acquisition of land causes displacement of huge population from land and livelihood. The social cost of land acquisition is very high. So it is very difficult to resolve the trade-off. Whether land acquisition will hamper food security is another pertinent question.

1.2 Objectives and Scheme of the Book

The three main issues of this book are technological change, management of natural resources and sustainability of agricultural growth in the Indian context. These issues have been analysed rigorously in an interrelated manner using sound theoretical framework. The theoretical propositions have been supported by empirical evidences and econometric results. Agricultural innovations and technological advancements are necessary for both productivity growth and conservation of natural resources. So, the adoption of a new technology is important. The adoption of a new technology involves risk and uncertainty. Here, the theory of decision-making under uncertainty has been used to explain the behaviour of a farmer in respect of adoption of a new technology. On the basis of the theoretical results we have analysed the rate of adoption of HYV technology in Indian agriculture and its impact on productivity growth and resource use.

The intensification of cultivation and continuous use of chemical inputs have caused resource degradation side by side with increasing productivity in the farming sector. Since the use of HYV technology has increased productivity largely banking on ground water irrigation, we have theoretically demonstrated that excessive depletion of ground water may make agricultural growth unsustainable in the long run. The theoretical results have been verified by empirical results. Theoretical models have been constructed to show that crop-diversification in favour of less water-intensive crops and rain water harvesting can be helpful for conservation of water resource and sustainable agricultural growth. The techniques of optimal control theory and dynamic optimization and the framework of growth theory have been extensively used to develop the theoretical models. We have also used the techniques of comparative dynamic analysis to examine the effect of change of policy parameters on the optimal path of water stock.

Land degradation, soil fertility and soil health, measures for soil treatment are important issues for environment and agricultural growth. In this book we have addressed these issues and analysed the problems using sound theoretical framework. In addition to providing empirical evidences in support of theoretical arguments, simulation exercises have been done to verify the effect of government policy measures on soil fertility and agricultural growth. The supply of land is fixed in the country. With the growth of the non-agricultural sector, industry, housing and real estate and urbanisation have become strong contenders for land. The competing uses of land and its impact on food production has been examined in a two sector general equilibrium framework. The theoretical results indicate various possibilities with respect to land use and food security under different conditions. The food price inflation in an unbalanced growth of the economy, decline of public investment for agriculture and policy failure of the government in managing the food economy have been analysed in this book with the help of economic theory and using econometric results.

Finally, the frontiers of technology have been highlighted with the promise that biotechnology, irrigation technology, GIS and information technology and new innovations in agricultural science will take very crucial role in future growth of agriculture in the developing countries. The special feature of this book is that it has addressed the contemporary issues of agricultural growth in developing countries like India in a very comprehensive manner. The analyses of the issues are based on sound analytical framework and the hypotheses and theoretical propositions have been supported by the results of rigorous econometric exercises. For empirical verification of the theoretical arguments, Time Series econometric exercises and regression analysis have been done using data from the Indian context. The problems of resource conservation have been analysed in the framework of dynamic optimisation pointing out role of the optimising agent in resource use, given the constraints of optimal use of the natural resources.

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Chapter 2
Technological Change and Productivity Growth in Agriculture

Abstract This chapter has analysed various aspects of technological change in agriculture, identified the factors that determine the rate of adoption of a new technology and examined the impact of the new technology on productivity growth and resource use in the farming sector. The production functions have been estimated using the Generalised Stochastic Formulation of production functions to capture the input related risks in production. It has explained the effect of risk and uncertainty in production, farm size, risk preference, credit supply and education in the determination of the rate of adoption of a new technology in agriculture. Using the results of econometric analysis this chapter has shown that all the inputs do not increase risk in production. An input that increases mean output does not necessarily increase risk. The rate of adoption of high yielding variety technology is higher in small farms under some favourable conditions. The results show that as a result of technological change, the productivity has significantly increased in Indian agriculture. Irrigation, specially ground water irrigation, has played a crucial role in the technological change and productivity growth. At the same time, excessive depletion of ground water, intensive farming and use of chemical inputs have caused serious damage to natural resources.

2.1 Introduction

Agriculture has been playing an important role in the Indian economy since the time of independence. Although the share of agriculture in national income in India has declined to less than 15 % more than 50 % of the population of the country are still dependent on agriculture for employment and livelihood. Agricultural production is divided into two major components: foodgrains and non-foodgrains. The former accounts for approximately two-thirds of the total production. In the foodgrains category the major crops are paddy, wheat, maize, bajra, etc. Although agriculture

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plays a big role in the Indian economy, productivity in agriculture has remained very low compared to major food growing countries. The production of rice per hectare in India was 2000 kg in 1987, while it was 6190 kg in Japan and 5410 kg in China in the same year. For wheat, India's production per hectare in the same year was 2000 kg, whereas in France and China it was 5560 and 3030 kg respectively (Source: Tata Service Limited 1989). However, the scenario has changed over time and the productivity has increased in Indian agriculture in the last 30 years. The yield of rice and wheat per hectare has increased to 3721 and 3177 kg respectively in 2012. But despite growth the productivity in India is still much lower than the major countries. The productivity of rice in China and Japan has reached the figures of 6775 and 6739 kg respectively per hectare in 2012. The same is true for wheat and other major crops (Source: Agricultural Statistics at a Glance 2014, Government of India). Before the introduction of high yielding variety (HYV) technology in the mid-sixties India's foodgrains production was only 72.35 million tonnes in 1965–66 and it was not at all sufficient for the growing population of the country. From 1950 to 1965, the average rate of growth of agricultural production (all crops) in India was 3.02 % per annum while from 1965 to 1980, this average growth rate declined to 2.8 % per annum and it further declined to 0.8 % per annum during the period from 1980 to 1987 (Rao et al. 1988; World Development Report 1989).

Therefore, the growth rate of agricultural production in India was not only low but also it was declining over the years. Among the factors responsible for low productivity in Indian agriculture, technological backwardness is a major one. The uses of fertilizers, HYV seeds and other modern inputs are extremely low. Irrigation facilities are also very limited. The application of fertilizer per hectare of arable land in Japan, China, UK and USA was 427, 174, 378 and 91 kg respectively in 1987, whereas in India it was only 57 kg in the same year (Source: World Development Report 1989). Only 24 % of net cropped area under foodgrains in Inida was under irrigation in 1970–71 and in the same year the gross cropped area under foodgrains using the HYV technology was only 12.38 % (Source: Government of India 1991).

A technological breakthrough was a necessary condition for stepping up of agricultural production in India in 1960s and 1970s. The study of Hayami and Ruttan (1971) on productivity differences among countries shows that the differences in technical inputs and human capital do account for a very substantial share of agricultural productivity gaps among them. In their consideration, a common basis for achieving success in rapid growth in agricultural productivity is the capacity to generate an ecologically adapted and economically viable technology in each country. Schultz (1964) expresses the view that significant growth in productivity can not be brought about by reallocation of resources in a traditional agriculture. According to him, significant opportunities for growth would become available only through changes in technology. Mellor (1966) describes that the traditional agriculture is characterized by low capital investment and low productivity. A reallocation of resources through price changes may have some weak and temporary effects on production but a strong and long lasting effect will be forthcoming only in a situation of technological change. Lee (1971) on the basis of her study on Taiwanese agriculture, concludes that in the development of Taiwanese agriculture, technology played a crucial role. The postwar advances in technology in Taiwanese agriculture consisted of mainly extension of uses of fertilizers, pesticides, new crop varieties and new cultivation practices. Fan (1991) shows that in the development of Chinese agriculture in the last few years, technology had an important role.

Relative endowments of the two primary resources, land and labour are critical elements in determining a viable pattern of technological change in agriculture. Land constraint is much stronger in agricultural production than in any other sector of the economy. Agricultural growth can be viewed as a process of easing the constraints on production imposed by inelastic supplies of land and labour. So, generally two types of technologies are developed: (i) Biochemical technology and (ii) Mechanical technology. The former is land-augmenting in nature, while the latter is labour-saving in character. In a land scarce and labour abundant country like India, what was needed was to develop and adopt an appropriate biochemical technology. Mechanical technology involving tractors and power tillers, irrigation pumps and similar farming devices might be used only as a supplement to the former.

The acute food crisis of 1961–66 propelled the introduction of the HYV technology in Indian agriculture in the mid-sixties. It was a package programme consisting of HYV seeds, chemical fertilizers, pesticides, assured supply of water and a new agricultural practice. One important feature of this new technology is that the yield potential of the modern varieties is remarkably higher than that of the traditional varieties. The new technology was initially introduced mainly in the cultivation of rice and wheat. Since the new technology was risky, another important aspect of the new agricultural strategy was that, it was first introduced in less risky areas and among the farmers who were willing and capable of taking risk. It was expected that with the spread of knowledge of the new technology, uncertainties and risks would gradually decline and then it would spread in other parts of the country and be adopted by all other farmers.

The policy makers, planners, economists and researchers mostly supported the policy of such a technological change in Indian agriculture. However, some of them raised questions regarding the adaptability of the new technology to the given economic and institutional conditions of the Indian farmers and also with respect to the distribution of gains from the new technology. Rao (1968) suggested that along with institutional reforms, extension of irrigation and supply of credit to the farmers, due importance should be given to modernisation of agriculture for rapid growth in production. Minhas and Srinivasan (1968), while commenting on the official strategy for increasing agricultural production in India, remarked that the new agricultural strategy based on the introduction of new crop varieties and the use of chemical fertilizers, was in the right direction and necessary for the country. Krishna (1967), Narain (1977) recognized the role of price as an incentive for higher production but at the same time they suggested that the main emphasis should be given on technological change.

Dantwala (1986), strongly defended the policy of introducing the new technology in Indian agriculture. He remarked that the food-crisis in India in the mid-sixties was so acute and unprecedented that it was compelling for India to grow more food as quickly as possible by adopting the new technology, irrespective of where it was grown and by whom. It was however admitted that although the new technology is technically scale-neutral, in Indian socio-economic conditions, it has a class-bias in favour of large farmers. The Working Group of the Indian Council of Social Science Research analysed the alternative ways of agricultural growth in India and recommended the spread of the HYV technology in Indian agriculture, irrespective of whatever alternative is chosen.

The adoption of modern technology, particularly the land-augmenting biotechnology became more important in India in view of the fact that the demand for food and other agricultural products was increasing rapidly in India with population growth. But the scope for increasing agricultural production through extensive cultivation was almost exhausted by 1965. Gross area under foodgrains in India has remained more or less constant at 124 million hectares over the years (Source: Government of India 2001). In this backdrop, it was very difficult to increase the total production of the country without increasing the productivity per hectare. Again, productivity could be increased by adopting the HYV technology on a wider scale. Since the introduction of the HYV technology in the mid-sixties, the Government of India has been spending large sums of money on irrigation, extension services, rural electrification and subsidies on agricultural inputs like fertilizers and pesticides. Nevertheless the degree of adoption of the new technology by the farmers could not reach a significant level by 1980. In 1970–71, only 12.38 % of the gross area under foodgrains was under the HYV scheme and this proportion rose to 49 % in 1989–90 and it further increased to 61 % in 1997–98 (Source: Government of India 2000). The factors generally identified as the main constraints to the rapid adoption of a new technology in agriculture were lack of irrigation, lack of credit, small farm-size, lack of knowledge about the technology, lack of education, uncertainty in yield and aversion to risk of the farmers. This section investigates into the factors which really acted as constraints to the adoption of a productivity enhancing new technology in agriculture in countries like India.

2.2 Major Issues of Technological Change in Agriculture

2.2.1 The Adoption of a New Technology

A large volume of literature, both theoretical and empirical, is available to explain the rate and pattern of technological changes that are taking place in agriculture in the developing countries and to identify the factors causing such changes. The theoretical studies define the adoption variables rigorously, set precise relationships for estimation, suggest hypotheses and help interpreting the empirical results in a proper way. Feder et al. (1985) have made a comprehensive survey of the important studies on the adoption and diffusion of technological innovations in agriculture.

The survey provides an analytical framework for investigating the adoption behaviour of the farmers and suggests a quantitative definition of adoption of a new technology making a difference between individual (farm) level adoption and aggregate adoption. Final adoption by the individual farmer is defined as the degree of use of a new technology in the longrun when the farmer has full information about the new technology and its potential. Aggregate adoption is measured by the aggregate level of use of a specific new technology within a given geographical area or a given population. The 'diffusion of a technology' on the other hand is defined as the cumulative process of adoption of the technology measured in successive time periods.

There is a distinction between technologies that are divisible (such as HYVs, chemical fertilizers, etc.) and innovations that are not divisible (say, tractors, harvesters, etc.). The intensity of adoption for the former type of innovation can be measured at the individual level in a given period by the amount or share of farm area utilizing the technology or by the per hectare quantity of input used. Analogous measures may apply at the aggregate level for a region. For non-divisible innovations, the extent of adoption at the farm level in a given period is necessarily dichotomous (i.e. use/no-use) but in the aggregate, the measures become continuous.

The analytical framework for analyzing technological change in agriculture includes a model of farmer's decision making regarding the extent of use of a new technology. Generally, the farmer's decisions in this regard are assumed to be derived from the maximization of expected utility of income (or profit) subject to the constraints like land availability, supply of credit and so on. Profit is a function of the farmer's choices of crops and technology in each period. Given the discrete choice of a technology, income or profit is a continuous function of land allocation among crop varieties, the production functions of these crop varieties, the variable inputs and the prices of inputs and output. Given the discrete choice, land and input values, the perceived income of the farmer may be regarded as a random variable embodying both subjective and objective uncertainties. In this type of adoption model, generally, the production function can be assumed to be the only source of uncertainties. So, proper specification of uncertainties in production function is very important for analysis of technological change.

2.2.2 Uncertainty in Production

Agricultural production is uncertain by nature. This is due to uncertainties in rainfall, climatic conditions and other natural factors. But when a new technology is introduced, uncertainty in production generally arises due to lack of information and inefficient use of modern inputs. So, it is important to incorporate risk and uncertainty in production function properly. Just and Pope (1978, 1979) have developed a production function to accommodate properly the uncertainties in production. In their view, the popular econometric specification of the

Cobb-Douglas production function with log-linear disturbances can not properly reflect risk in production. It incorrectly imposes an a priori restriction on the production function that if the marginal contribution of an input to the mean output is positive, then a positive marginal effect on the variance of output is also imposed. Following Just and Pope (1978) the Cobb-Douglas form of the function with stochastic term is expressed as

$$Y = A\left(\prod_{i=1}^{n} x_i^{\alpha_i}\right)e^{\varepsilon}$$

where, Y is output, X_i is a factor input ($X_i > 0$), ε is a stochastic disturbance term with E(ε) = 0, V(ε) > 0 and A is a constant term. The marginal effect of input use on production variability is defined as $V(Y) = A^2\left(\Pi_{i=1}^{n} X_i^{2\alpha_i}\right)V(e^{\varepsilon})$. Just and Pope (1978) demonstrate that

$$\frac{\delta\, V(Y)}{\delta\, X_i} = \frac{2\alpha_i A^2}{X^i}\left(\prod_{i=1}^{n} X_i^{2\alpha_i}\right)V(e^{\varepsilon}) \ > \ 0, \quad \text{assuming}\, \alpha_i > 0.$$

Thus, an increase in input use always increases the variability of output if the marginal productivity of the input is positive. They have also pointed out that other functional forms like Transcendental, Translog, CES and Generalised Power Function have the same limitation when they are used with log-linear disturbances.

It needs to be noted that all inputs do not increase risk in production; on the contrary, there may be some inputs like irrigation, pesticide, equipments, etc., which are likely to reduce risk in production. Besides, the inputs which were risky at the early stage of their application may become risk-neutral subsequently. So, the production function must possess sufficient flexibility such that differential effects of an input on the mean and the variance of output are accommodated. Just and Pope (1978) have developed such a Generalised Stochastic Formulation (GSF) of the function which can be expressed as

$$Y = f(x) + h(x)\varepsilon, \quad E(\varepsilon) = 0,\ V(\varepsilon) = \sigma,$$

where Y is actual output, X is set of inputs, $f(x)$ is mean output, $h(x)$ is a term capturing the variability of output and is assumed to be positive and ε is a random term.

Here the production function has two components: (i) the Deterministic Component, $f(x)$ and (ii) the Stochastic Component, $h(x)$ ε. The former specifies the effects of inputs on the mean output and the latter specifies the effects of inputs on the variance of output. These two components are independent. Hence,

$$\frac{\delta\, V(Y)}{\delta\, x_i} = h_i(x) \ > \ = < 0.$$

Thus the authors have shown that the effect of an input on the variability of output may be positive, zero or negative. In a separate paper, Just and Pope (1979) have explained the estimation procedure of the production function, specifying it in the form

$$Y = f(X) + h^{\frac{1}{2}}(X)\varepsilon, \quad E(\varepsilon) = 0,\ V(\varepsilon) = 1;$$

where the mean output, $E(Y)$ is $f(x)$ and the variance of output, $V(Y)$ is $h(x)$. Here $\delta V(Y)/\delta x > \; = \; < 0$.

2.2.3 Uncertainties, Learning and Adoption of a New Technology

Most of the theoretical studies on the adoption behaviour of individual farmers use a static framework that relates the degree of adoption to factors affecting it. These studies investigate the properties of the solution to particular cases of the temporal optimization problem of the farmer. In these optimization problems, the farmer is to choose between two technologies: the traditional technology and a modern technology (such as HYVs and the inputs associated with them). Models dealing with such problems investigate how much land is allocated to modern technology and the amounts of modern inputs to be applied per unit of land under different circumstances. The uncertainties in production may be higher at the early stage of adoption of a new technology because the farmers do not have complete knowledge about the new technology at the initial stage. So the farmers may be more risk-averse about the technology. However, as time passes, learning takes place and the farmers are encouraged to adopt the technology on a larger scale.

Hiebert (1974) has used a stochastic production function and assumed risk aversion to examine the effects of uncertainty and imperfect information on fertilizer use and allocation of land to HYVs. In his approach farmers have different and incomplete information about the characteristics of new and improved inputs. So, there is the possibility of allocative errors and hence there are greater risks and uncertainties in production. Learning, here, has been interpreted to mean gaining more information about the technology. In Hiebert's formulation, the stock of information increases as the adoption process proceeds. This reduces risks and uncertainties in production and as a result the probability of adopting a new technology increases.

The likelihood of adopting a new technology also depend on the physical environment of cultivation. A more favourable environment such as better soil, water availability and efficient irrigation system increases the expected utility of net income from modern cultivation and thereby increases the probability of adopting the new technology. When irrigation is available both in the dry and rainy seasons, the probability of adoption is greater in the dry season compared to the rainy season. This is because mean yield is higher and variance of yield is lower in the dry season due to better agro-physical conditions.

2.2.4 Farm Size, Risk Aversion and the Adoption of a Modern Technology

There is a debate that the small farmers will be reluctant to adopt a new technology because the production under modern technology is uncertain and the small farmers are risk averse. In a model constructed by Feder (1980) it is assumed that production under the new technology is uncertain whereas yield of the traditional variety is certain. It is also assumed that there is risk aversion and that adoption of the new technology requires no fixed initial cost. In the model, if there is no credit constraint, fertilizer use per acre is independent of farm size. But the allocation of land to modern cultivation is affected by risk factors. The relationship between the share of land allocated to modern variety and farm size depends on the relationship between the relative risk aversion and income. It is demonstrated that if the adoption of modern technology involves some fixed cost, it is likely that the relationship between the proportion of land allocated to modern cultivation and farm size will be positive.

Feder and O'Mara (1981) have shown that a positive relationship between farm size and the share of modern farming can be explained by the existence of some fixed cost associated with the adoption of the new technology. As the new technology is perceived as more risky, it is argued that the small farmers will be less inclined to adopt the innovation as they are more risk averse. But the study considers risk aversion as a deterrent to innovation adoption by small farmers only to the extent that adoption entails fixed costs. In their reasoning fixed adoption costs do exist and such costs are not a characteristic of the HYV technology itself but are a result of information acquisition requirements, inefficient input distribution systems, etc. In their model the interaction between risk aversion and fixed costs can explain the differential and farm-size dependent pattern of technology adoption in both static and dynamic perspectives. In addition, there may exist a lower limit on the size of the adopting farm such that the farms smaller than this critical minimum will not be able to adopt the new technology due to higher adoption cost. The size of critical minimum may, however, decline over time if adoption cost declines due to learning and dissemination of information about the technology.

Just and Zilberman (1983) have developed a more generalized model to examine the relationship between the share of land allocated to modern variety and farm size. The model recognizes that production under both traditional and modern varieties are uncertain and assumes that production under the modern technology is more uncertain: It considers the fact that there may be some fixed cost of adoption of the new technology and land holding has some role in the risk-preference of the farmer. Given these specifications, the model shows that if the correlation of output under old and new technologies is low or negative and if the modern technology is sufficiently more risky than the traditional one, the larger farms will allocate more land in absolute terms but less land in proportionate terms to the new technology compared to the smaller farms when relative risk aversion is increasing and absolute risk aversion is decreasing with the farmer's income.

2.2.5 Adoption of Interrelated Technologies in Agriculture

The technologies may be interrelated or there may be some degree of complementarity among them. Feder (1982) has analysed the nature and extent of adoption of interrelated technologies in agriculture taking into account the complementarity among them, credit constraint and uncertainty in production. In his framework there are two types of modern technologies: one is scale-neutral (say HYVs) and the other is a lumpy one (say, tubewell) with a fixed capacity and a fixed installation cost. The farmers can use either of the two or both at the same time. The production is uncertain under both technologies. The yield under traditional system is however assumed to be riskless. The use of lumpy technology increases mean production and reduces the uncertainty of production under both traditional and modern crops.

The model of Feder indicates that while HYVs will be adopted by all farmers (in the absence of fixed adoption cost and credit constraint), there will be a critical farm size such that only the farms which are above this critical size will adopt the lumpy innovation for a given risk aversion. When HYVs are used combined with lumpy innovation, risk of HYVs declines. This encourages comparatively small farmers also to adopt lumpy innovation in association with HYVs. That means, the critical minimum size for the adoption of lumpy innovation declines. What proportion of land will be used for HYVs in association with the lumpy innovation depends on the nature and degree of complementarity between the two technologies (defined not only in terms of cross-yield effects but also in terms of cross-risk effects). This model further states that if there is a binding credit constraint, an element of substitutability between the technologies may be introduced. Then the adoption of one technology may retard the adoption of the other.

2.2.6 Education and Human Capital in the Adoption of a Risky Technology

In the adoption of a new technology education and human capital have some role. Schultz (1975) has explored that in a static traditional agriculture, experience is more valuable for the farm manager than education. But in a modernizing agriculture, education is important because it enhances the farmer's 'ability to deal with the disequilibria' arising out of the dynamics of innovation. Rahm and Huffman

(1984) have presented a model which examines the role of human capital in the adoption of reduced tillage practices in Iowa state. The results show that the human capital variables like education, health, extension services, etc., enhance the farmer's allocative skills and also the efficiency of the farmer in taking adoption-decisions.

Lin (1991) used the diffusion of F_1 hybrid rice as a case for examining the effects of education on the adoption of new technology in agriculture in China. He has presented a simple behavioural model where the adoption of a new technology is treated as a portfolio selection. In the model it is assumed that production under traditional farming is certain, whereas the yield under the new technology is uncertain. In Lin's study production process changes with the introduction of a new technology. But as the farmer's information is imperfect there is the possibility of allocative errors and hence the adoption of the new technology becomes risky. So, Lin's hypothesis is that as education enhances one's ability to receive, decode and understand information, the level of education has a positive impact on the adoption of a new technology. The empirical results based on micro level data confirm this hypothesis.

2.2.7 *Role of Price in the Adoption of a New Technology*

Hayami and Ruttan (1971), in their famous "induced innovation model", hypothesized that advances in both mechanical and biochemical technologies respond to changing relative prices of factors and to changes in the prices of factors relative to products. In their analytics, the technical change is guided along an efficient path by price signals in the market, provided that the prices efficiently reflect the changes in demand and supply of products and factors and there exists effective interaction among farmers, public research institutions and private agricultural supply firms. However, in practice, all these conditions are not always fulfilled.

Feder (1980) demonstrates that a decline in input price or an increase in output price does not necessarily lead to allocation of greater amount of land to modern cultivation or to application of greater amount of fertilizer per unit of land. Price will have a favourable effect on the use of a new technology only when the technology is not highly risky and adequate infrastructural facilities are available.

2.2.8 *Diffusion of a New Technology*

While the adoption of a new technology is defined as the amount of land or the share of land allocated to modern cultivation in a particular point of time, the diffusion of the technology is the cumulative process of adoption of the new technology in agriculture over time. It considers the problem of adoption at the aggregate level in a dynamic perspective. Griliches (1957) made a pioneering study of the factors responsible for the wide cross-section differences in the rates of use of hybrid seed corn in the USA. It is an econometric study where the logistic growth function has been fitted to the data. Three parameters of the function viz. origin, slope and ceiling have been estimated. The origin indicates the date of first adoption, the slope indicates the rate of adoption and the ceiling indicates the maximum cumulative percentage of adoption or long-run upper limit of adoption. The estimates have shown a S-shaped pattern of aggregate diffusion of the hybrid seed.

Griliches has remarked that it is not a single invention immediately adaptable everywhere. In contrast, the breeding of adaptable hybrids are to be done separately for each region. In the breeding process, some areas may be lagging behind the others. The results of the study indicate that the differences in the rates of adoption (slopes) and in the long run equilibrium uses of hybrid corn (ceilings) in different areas are explained, at least in part, by the differences in the profitability of the shift from the open pollinated to hybrid varieties in different parts of the country. The profitability of entry is again a function of market density, cost of innovation and cost of marketing. Jarvis (1981) has made a similar study on the diffusion of improved pastures in Uruguay. In his fitted logistic function both the rate of adoption and the maximum limit of adoption are positively related to the profitability of the technology.

Kislev and Shchori-Backrach (1973) have constructed a diffusion model to explain the process of an innovation cycle. They have considered comparative advantages, dynamic as well as static, to be crucial in determining the pattern of adoption of innovations. In the model it is assumed that the innovation is either a new product or a new method that appreciably affects the supply of an existing product. The industry is competitive and is composed of small firms. The model demonstrates that the producers with highest skills will be the early adopters of the innovation because they are more efficient in the acquisition of knowledge about the innovation. On the other hand, the less skilled firms will wait until sufficient experience is accumulated at the industry level. With the passage of time as output expands, knowledge about the new technology diffuses to the less skilled firms and the new technology is ultimately adopted. But with the joining of the less skilled firms in the rank of adopters, if the market supply increases substantially and prices fall the more skilled producers who have a higher opportunity cost for their labour and other resources may switch to a new product or a new method of production. Thus a new innovation takes place and hence, it is called an innovation cycle. Such a theory is well recognized in industrial sector and international trade. The present model shows that this theory is applicable to the agricultural sector also.

Feder and O'Mara (1982) have developed a model on 'information and innovation' using a Bayesian approach. They are of the view that learning and information accumulation play a major role in innovation diffusion. The hypothesis of the model is that the individual farmers revise their beliefs in a Bayesian fashion. It demonstrates that the Bayesian learning can generate a characteristic sigmoid-shaped adoption function for a dominant innovation.

2.2.9 Tenurial Arrangement and Technological Change in Agriculture

There is a large volume of literature which show that tenurial arrangement may have an important role in the decision-making with respect to the adoption of an innovation in agriculture. Bhaduri's theoretical model (1973) in the context of the production relations prevailing in Indian agriculture considers a semi-feudal agricultural system where the landlord exercises two modes of exploitations—usury and landownership. As the income of the tenant falls short of their consumption needs they are forced to take consumption loans from the landlord who charges high rate of interest on such loans. The landlord takes a share of the total crop as landowner. Another part of the crop is taken by him as interest and repayment of loan. As a result, the tenants are to take further loan for consumption. Thus, they are forced to be in perpetual indebtedness. Bhaduri's proposition is that in such a semi-feudal agricultural system, the landlord class will always resist the introduction of an improved technology which raises agricultural productivity. The reason is that if agricultural productivity increases, the tenant's income will rise and then their dependence on the landlord for consumption loan will decline. This will reduce the landlord's income from usury. So, Bhaduri concludes, the semi-feudal tenurial arrangement acts as a barrier to technological progress in agriculture.

Newbery (1975) has criticized Bhaduri's analysis with the argument that if the landlord has sufficient monopoly power to exploit the tenants and withhold innovations in agriculture, he ought to have sufficient power to extract the extra profit generated by the innovation. Srinivasan (1979) shows that Bhaduri's conclusion does not follow from his model. Using the same model he demonstrates that landlord's income will increase with the total output in all cases. So, the landlord will have an incentive in introducing an yield increasing innovation.

Bardhan and Rudra (1978) made an empirical survey on agrarian relations in eastern part of India which shows that Bhaduri's description of landlord-tenant relations has no empirical basis. Their evidences strongly suggest that incidence of usury as the main mode of exploitation is very rare. On the contrary, the landlords are, in general, found to take lot of interest in raising agricultural productivity by making productive investments and introducing new innovations. Using a theoretical model Braverman and Stiglitz (1986) show that the institutional structure of the agricultural sector in less developed countries may be an important determinant of whether a particular innovation is adopted or not. But what will actually happen depends on a number of conditions.

2.2.10 The Role of the Government

Feder and Slade (1985) have reviewed in a theoretical model the rationale of and scope for public sector involvement in the diffusion of a new technology in agriculture. They are of the view that the generation of an improved technology is not sufficient for agricultural growth. It is also necessary to diffuse the knowledge of the new technology among the farmers. Their model shows that in the initial stage, the farmers have limited information about the new technology. So, there will be a divergence between the true distribution and the perceived distribution of the net benefits from the technology and this may discourage the farmers to adopt it. In this situation they have suggested that the government could take an active role in the diffusion of knowledge of the new technology through extension services and other measures. The government intervention in the output and input markets through taxes and subsidies has been justified in the early stage of adoption. They suggest that government expenditure on infrastructure like irrigation and transportation and supply of credit from government sources may be also helpful for the diffusion of the new technology.

2.2.11 The Distribution of Gains from Technological Change

Bell (1972) demonstrates that the changes in the distribution of income after the introduction of new innovations in agriculture are only partly explained by the nature of innovations themselves. The factors which govern the rate and pattern of diffusion of the innovations and the consequent changes in income distribution are rooted substantially in the character of the prevailing socio-economic system. In a purely technical sense, the green revolution technology is scale neutral but the prevailing socio-economic conditions are such that they have some bias in favour of large farmers. The large farmers are in an advantageous position to adopt the new technology at an early stage and at a higher rate compared to the small farmers. So, the distribution of gains from technological change may not be equitable.

2.2.12 Evidences from Empirical Studies

The empirical study of Herdt (1987) on the use of modern technology in rice farming in Philippines reveals that the modern varieties have been almost universally adopted and farm size has no effect on the rate of adoption. Only in certain parts of the country the small farms lagged behind larger ones in fully adopting modern varieties but eventually caught up. The study also shows that technologies were adopted in Philippines as individual components, not as a package. Another finding of the study is that the biochemical technology has been, in general, more widely adopted by the farmers than the mechanical technology giving an indication that labour use per hectare has increased after the introduction of the HYV technology.

Antle and Crissman (1990) have analysed the growth of technical efficiency of the farmers over time under a situation of technological change in Philippines. According to them, the adoption of a new technology is a dynamic process and in this process, the efficiency of the farmers increases as learning takes place. At the early stage of adoption, the farmers may be less efficient because they do not have full knowledge about the new technology. But over time as learning takes place, the efficiency among the early adopters increases. The efficiency of the late adopters also increases if they have access to the information acquired by the early adopters. With increase in efficiency of the farmers the rate of adoption increases. The empirical results show that nitrogen fertilizer is not necessarily risk-increasing; on the contrary, it is risk-reducing under favourable conditions. This study also reveals that irrigation has improved technical efficiency in all cases and the modern varieties have benefitted relatively more from irrigation than the traditional varieties.

Byerlee and Polanco (1986) have tested a hypothesis that the farmers adopt improved technological components in a stepwise manner. In order to raise productivity in agriculture the researchers and extension-agents have developed technological package consisting of components such as crop varieties, fertilizers, planting method and weed control. The proponents of the package-approach argue that a package is needed to reap the positive interactions between several components. But Byerlee and Polanco have remarked that the farmer may not be in a situation to adopt a complete package due to capital scarcity, considerations of risk or supply constraints. So, they have proposed that the package may be disaggregated into clusters of one or two components and the farmers can rationally follow a process of stepwise adoption of the technological components in a sequential manner.

Perrin and Winkelman (1976) have summarized some of the important findings of the farm level studies on the adoption of new wheat and rice varieties in Kenya, Colombia, El Salvador, Mexico, Tunisia and India. The studies show that the differences in the adoption behaviour of the farmers are only partly explained by the differences in information, availability of inputs, market opportunities for the crop and risk aversion of the farmers. In most cases, little relationship is found to exist between farm size and adoption rate. The pattern of adoption among large and small farms is generally consistent with the proposition that small farms may lag behind larger ones in the early stage of adoption but soon they catch up. The most important finding of these studies is that the rate of adoption differs across farms and across areas due to differences in yield owing to differences in soil, climate, water availability and other biological factors. The result has the implication that agricultural technology is basically site-specific and hence, natural resources and environmental factors have important role in technological change.

Bera and Kelley (1990) have estimated the rate of diffusion of the high yielding varieties of rice in Bangladesh using logistic-type econometric models. The results show that the diffusion rate is not constant over time. The rate and level of adoption have been found to be influenced by flood damage, relative prices of competing crops like jute and traditional varieties of rice. One important result of the study is that the greater and more intensive is the damage to HYV (due to flood and other natural adverse conditions) the greater is the likelihood of farmers shifting from HYV to traditional varieties. The most important finding of this study is that the ceiling adoption level of HYV has nearly been reached in Bangladesh. So, unless new HYVs are developed with wider adaptability specially for drought and flood prone areas, little scope exists in Bangladesh for increasing production through increase of acreage under HYV of rice.

The study of Anderson and Hamal (1983) in the context of Nepal conclude that perception of risk and aversion to risk provide only a very partial explanation of the farmer's decision regarding the use of a new technology. The other factors like farmers' attitude towards bureaucrats, their access to factor markets, the procedures and preferences of implementing agencies are much more important in this regard.

Ruttan (1977) has drawn several important generalisations on the basis of a large number of empirical studies on the adoption of new technology in agriculture. Some of the generalisations are:

(i) the HYVs have been adopted at exceptionally rapid rates in those areas where they are technically and economically superior to local varieties.
(ii) neither farm size nor tenure has been a serious constraint to the adoption of new HYVs. The smaller farms and tenants might have lagged in the early phase of adoption but within a few years they have come to catch it up.
(iii) the use HYVs has intensified the use of labour in production.
(iv) Landowners have gained relatively more than the tenants.

It has been acknowledged that these are broad generalisations and there may be exceptions to these observations depending on differences in economic, socio-political and environmental factors.

2.2.13 The Indian Experience

Rao (1975) has made a comprehensive study of the magnitude and pattern of technological changes that have taken place in Indian agriculture since mid-sixties and of the factors influencing such changes. His study reveals that the rise in the prices of agricultural commodities and labour inputs relative to the prices of fertilizers, machineries and other equipments led to the adoption of both biochemical and mechanical technologies. This study shows that irrigation has positive impact on the use of HYVs. The profitability of HYVs is higher and uncertainty is lower in the Rabi-season (dry season) than in the Kharif Season (rainy season) and this is due to the fact that environmental factors are more suitable for HYVs in the Rabi-season. As regards the relationship between farm size and the use of biochemical inputs, Rao's argument is that although HYV seeds and fertilizers are scale-neutral in technical sense they are not resource-neutral. So, the adoption of biochemical technology will be more extensive among the large farmers than the small ones. The empirical findings of the study support this hypothesis.

Harriss (1972) made an empirical study on the adoption of HYV technology in India and identified the factors influencing the adoption process. He is of the view that irrigation itself is a primary innovation and it can be treated as a precondition for and stimulus to further innovation. Her analysis shows that as water-management is better in tubewell irrigation than in canal irrigation, the adoption rate of HYV is higher under the former than under the latter. The relationship between farm size and adoption rate is ambiguous in this study. Under certain conditions the small farmers have been found to be equally efficient in adopting the innovation. It has been also pointed out that given the costs and risks of the new technology the prevalent tenurial system may be a deterrent to innovations. The study reveals that the financial return from the new technology is the main motivation for adopting the new innovation. The prices of inputs and output appear to be very important in this regard. Another important finding of her study is that the acquisition of primary education has the greatest influence on fertilizer use. In the study of Harriss, the use of HYV seeds has intensified the use of labour. Hence, insufficient labour supply may turn out to be a constraint to the adoption of the HYV technology. The credit facilities, however, have not been able to create much incentives for using the innovations.

Muthiah (1971) has found that small and medium-size farms in India have adopted HYVs on a larger proportion of acreage than did the large farms. In respect of HYV adoption in wheat cultivation in India, it is also found that tenants are not only as innovative as landowners but also sometimes they use more fertilizers per hectare than do the owners of land. Bhalla (1979) shows in a study on Indian agriculture that lack of credit is a major constraint to the use of fertilizer. He concludes that access to credit might be responsible for the gain in income (and HYV area) made by the large farmers. A case study by Sidhu (1974) in Punjab shows that the new wheat-technology is neutral with respect to farm size. He finds that the new technology is neither labour-saving nor capital-saving in nature.

Bhalla and Chadha (1982), on the basis of their study in Punjab, have found that the advent of green revolution in Punjab has brought about an overall prosperity to its peasantry. As a result of the creation of an assured irrigation base and its fairly equitable distribution, all categories of cultivators have been able to record substantial increase in their output and income by adopting the new technology. The gains from the new technology is found to be distributed among the farmers more or less proportionately with their initial land holding positions. The study also reveals that the per hectare application of input resources of different farm-size groups is, in general, strikingly similar although some differences are noticed in paddy cultivation.

2.2.14 Summary

This section considers the major issues of technological change in agriculture in the developing countries like India. Here we have mainly considered the adoption of land-augmenting biotechnology in agriculture by the farmers. It makes a difference between adoption and diffusion of a new technology. The adoption is defined as the amount or share of land allocated to modern technology whereas diffusion of a new technology is described as the cumulative process of adoption of a new technology in an area over time. The productivity under modern cultivation is higher than the traditional variety. But production under modern variety is uncertain. So, risk and uncertainty and farmer's attitude to risk play important role in the adoption of a new technology in agriculture. The specification of risk in production function is important for explaining input related risk properly. The uncertainty in yield needs to be so incorporated in production function that an input does not necessarily become a risk-raising factor in production. Uncertainty in yield and risk of production may be a deterrent to the adoption of a modern technology in the initial stage. But as adoption process proceeds the farmers gathers more information and knowledge about the technology and as a result the probability of adopting a new technology increases. The government has important role in the diffusion of a new technology in agriculture through extension services, dissemination of knowledge and development of infrastructure. Equally, the spread of education and formation of human capital may be helpful for technological change in agriculture.

There is a debate that small farmers may not be able to adopt a new technology specially when the farmers are risk-averse and the adoption of the technology involves a fixed cost. But theoretical and empirical studies demonstrate that the adoption rate of the technology may be even higher in small farms under certain favourable conditions. Similarly tenancy farming is not always a constraint to technological change in agriculture.

Technically the HYV technology is scale-neutral in nature but economically, it may have some bias in favour of large farmers. So far as the distribution of gains from higher productivity of modern farming is concerned, all groups of farmers are found to be benefitted from higher productivity due to technological change although in some cases, the large farmers have gained more. While price is not found to have much influence on the diffusion of a technology, irrigation plays a key role in this regard in all cases. The geo-physical conditions also have significant impact on the adoption of a new technology in agriculture.

The new bio-technology popularly known as high yielding variety (HYV) technology puts huge stress on natural resources like land and water. This section highlights the major aspects of using HYV technology although there are other technologies which are interrelated and sometimes complementary in nature. For example, irrigation technology and technologies for water management and soil conservation are also very important in the present context. Irrigation is very important for productivity growth. The conservation of soil fertility and management of water resource are very important for sustainable growth. So, technology not only plays an important role in enhancing productivity but also help maintaining sustainable growth in agriculture through conservation of natural resources.

2.3 Modern Technology, Input Related Risk and Estimation of Production Functions

The adoption of a modern technology in agriculture depends on many factors among which risk and uncertainty in production and farmer's attitude towards risk are very important. Agricultural production is always uncertain. Natural and agro-climatic conditions create this uncertainty. This uncertainty may increase under a new technology. The new inputs of the modern technology like HYV seeds, chemical fertilizers and pesticides enhance agricultural productivity and at the same time, they may make production more uncertain and risky due to lack of adequate knowledge about the use of the inputs properly or some inherent properties and external effects of the inputs. So, risk becomes an important element in the decision-making with respect to the amount of land to be allocated to modern cultivation and the amounts of inputs to be used per unit of land. Naturally, it becomes important to examine the effects of the inputs not only on the mean output but also on the variability of output. The stochastic specifications of input-output relationship are examined in many ways. The most familiar and commonly used formulation for estimating production functions in such cases is the log-linear Cobb-Douglas (C-D) production function. But Just and Pope (1978) have demonstrated that the popular econometric specification of the C-D production function with log-linear disturbances incorrectly imposes a risk-increasing effect of an input on output. It puts a restriction that if an input has positive marginal effect on mean output, then a positive marginal effect on variance of output is also imposed. They further mention that the other functional forms like Transcendental, Translog, CES and the Generalised Power Function also will have the same limitation if they are used with log-linear disturbances.

But all inputs do not increase risk in production. On the contrary, there may be many inputs like irrigation, pesticide, equipments, etc., which generally reduce risk in production. Besides, the inputs which are risky at the early stage of their application may be subsequently risk-neutral or risk-reducing over time. So, the production function must possess sufficient flexibility such that differential effects of an input on the mean output and the variance of output are accommodated. Considering all these features in agricultural production Just and Pope (1978) have developed a Generalised Stochastic Formulation (GSF) of the production function which is expressed as

$$Y = f(X) + h(X)\varepsilon, \quad E(\varepsilon) = 0,\ V(\varepsilon) = \sigma$$

where Y is actual output, X is set of inputs, $f(X)$ is mean output, $h(X)$ is a term capturing the variability in output and is assumed to be positive and ε is a random term. Here, the production function has two components: (i) the Deterministic Component, $f(X)$ and (ii) the Stochastic Component, $h(X)\ \varepsilon$. The former specifies the effects of inputs on the mean output and the latter specifies the effects of inputs on the variance of output. These two components are independent. This formulation satisfies the postulate that

$$\frac{\partial V(Y)}{\partial X} > \, = \, < \quad 0 \,\text{where}\, V(Y) = E[Y - E(Y)]^2.$$

Most of the usual production functions like Cobb-Douglas, Translog, etc., can be used for the estimation of ‘f’ and ‘h’ and they will give consistent and efficient estimates. In a separate paper, Just and Pope (1979) have explained the estimation procedure of the production function, expressing the function in the following form:

$$Y = f(X) + h^{\frac{1}{2}}(X)\varepsilon, \quad E(\varepsilon) = 0, V(\varepsilon) = 1,$$

where the mean output $E(Y) = f(X)$ and the variance of output, $V(Y) = h(X)$ and $\frac{\partial V(Y)}{\partial X} > \, = \, < 0$.

Just and Pope (1979) have explained the estimation procedure of GSF in three steps and the technique of estimation has been used in this book to estimate the production functions empirically.

2.3.1 *The Estimation Procedure*

For the purpose of empirical estimation,[1] it is supposed that both ‘*f*’ and ‘*h*’ follow the standard Cobb-Douglas form, i.e.,

$$f(X) = \alpha_0 X_1^{\alpha_1} X_2^{\alpha_2} \cdots X_k^{\alpha_k}$$

and

$$h^{\frac{1}{2}}(X) = \beta_0 X_1^{\beta_1} X_2^{\beta_2} \cdots X_k^{\beta_k}$$

Now, the regression equation to be estimated is:

$$\begin{aligned} &Y_t = \alpha_0 X_{1t}^{\alpha_1} X_{2t}^{\alpha_2} \cdots X_{kt}^{\alpha_k} + h^{\frac{1}{2}}(X_{1t}, X_{2t} \cdots X_{kt}, \beta)\varepsilon_t \\ &t = 1, 2, \ldots T \end{aligned}$$

where ε_t is a spherical random disturbance term having $E(\varepsilon_t) = 0$, $E(\varepsilon_t\ \varepsilon'_t) = 0$, for $t \neq t'$ and $E\left(\varepsilon_t^2\right) = \sigma^2$ for $t = 1, 2, \ldots T$.

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[1] The estimation procedure is based on the paper, Just and Pope (1979).

The parameters to be estimated are:

(i) $\alpha_0, \alpha_1, \alpha_2, \ldots \alpha_k$,
(ii) $\beta_0, \beta_1, \beta_2, \ldots \beta_k$.
and
(iii) σ, along with standard errors of the estimated coefficients.

To estimate the heteroscedastic non-linear regression equation, the following 3-step procedure may be used:

Step-I: The regression equation,

$$Y_t = \alpha_0 X_{1t}^{\alpha_1} X_{2t}^{\alpha_2} \cdots X_{kt}^{\alpha_k} + \varepsilon_t^*, t = 1, 2, \ldots T$$

is estimated by non-linear least-squares (assuming $E\left(\varepsilon_t^* \varepsilon_{t'}^*\right) = 0$ for $t \neq t'$).

Here, $\varepsilon_t^* = h^{\frac{1}{2}}(X_t, \beta)\varepsilon_t$. In other words, $\alpha_0, \alpha_1, \alpha_2, \ldots \alpha_k$ are estimated by minimizing $S_1^2 = \sum_{t=1}^{T} \left(Y_t - \alpha_0 X_{1t}^{\alpha_1} \cdots X_{kt}^{\alpha_k}\right)$ with respect to α's using some iterative procedure. The parameters $\alpha_0, \alpha_1, \alpha_2 \ldots \alpha_k$ may be estimated by the OLS method using the log-linear regression equation:

$$\log Y_t = \log \alpha_0 + \alpha_1 \log X_{1t} + \cdots + \alpha_k \log X_{kt}$$

and the OLS estimates of α's can be used as initial values in the iterative process.

Step-II: Suppose, the estimates obtained from Step-I (NLS) are $\hat{\alpha}_0, \hat{\alpha}_1, \ldots \hat{\alpha}_k$. Now one can compute the estimated value of $\hat{Y}_t = \hat{\alpha}_0 X_{1t}^{\hat{\alpha}_1} \cdots X_{kt}^{\hat{\alpha}_k}$. Let $e_t = Y_t - \hat{Y}_t$, $t = 1, 2, \ldots, T$ be the computed residuals. To have the estimates of β's the following regression is estimated by OLS:

$$\log|e_t| = \beta_0 + \beta_1 \log X_{1t} + \cdots + \beta_k \log X_{kt} + V_t$$

(logs are here natural logarithms) where V_t's are assumed to be spherical random disturbances.

Thus in Step-II, one obtains the OLS estimates $\hat{\beta}_0, \hat{\beta}_1, \ldots \hat{\beta}_k$ of the corresponding parameters. Here, actually, the estimates of the parameters β's are obtained by estimating the regression equation,

$$\varepsilon_t^* = h^{\frac{1}{2}}(X_t, \beta)\varepsilon_t, \text{ by log-linear OLS.}$$

Step-III: In Step-III, a weighted non-linear least-squares regression of Y_t on X_t with weights $h^{\frac{1}{2}}\left(X_t, \hat{\beta}\right)$ can attain asymptotic efficiency in estimates of α's. Using the estimates of β's, the dependent variable for the Step-III non-linear regression is constructed as

$$Y_t^* = Y_t \cdot h^{\frac{1}{2}}\left(X_t, \hat{\beta}\right) - \left(\hat{\beta}_0 + \hat{\beta}_1 \log X_{1t} + \cdots + \hat{\beta}_k \log X_{kt}\right)$$

for $t = 1, 2, \ldots T$ and the following regression equation is estimated:

$$Y_t^* = e\{(\alpha_0 - \beta_0) + (\alpha_1 - \beta_1)\log X_{1t} + \cdots + (\alpha_k - \beta_k)\log X_{kt}\} + W_t,$$

treating W_t to be a spherical random disturbance term. In other words, in Step-III, the estimates α_0, α_1, … α_k are obtained by minimizing the non-linear least squares

$$S_2^2 = \sum \left(Y_t^* - e^{\left\{\left(\alpha_0 - \hat{\beta}_0\right) + \left(\alpha_1 - \hat{\beta}_1\right)\log X_{1t} + \cdots + \left(\alpha_k - \hat{\beta}_k\right)\log X_{kt}\right\}}\right)^2$$

with respect to α_0, α_1, … α_k. These and the corresponding estimates of standard errors will be the final estimates.

2.3.2 *The Empirical Estimation of Production Functions*

Using the specification, $Y = f(X) + h^{\frac{1}{2}}(X)\varepsilon$ and following the procedure explained above, the production functions have been estimated for both traditional (Aman) and high yielding varieties (HYV) paddy to find out the effect of inputs on mean and variability of output. The results will indicate which inputs are increasing risk. While the production function for Aman paddy has been estimated for the rainy season only, the production functions for HYV paddy have been estimated for both the rainy and dry (Boro) seasons separately.[2] Again, the production functions for HYV paddy have been estimated separately for different irrigation systems in the dry season. The efficiency of irrigation under different systems of water supply is different. In the estimation of the production functions, four inputs have been included here and they are: X_1 is seed, X_2 is labour, X_3 is fertilizer and X_4 is pesticide. Y is output. The inputs and output have been considered in terms of per acre of land. Although irrigation is an important element in HYV paddy cultivation, the present study could not include it in the production function as an input. However, the impact of quality of irrigation on the mean and variance of output and also on the efficiency of inputs have been captured by estimating production functions under different modes of irrigation separately.[3]

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[2] Aman is traditional local variety paddy. The dry season is also called Boro season in many parts of India.

[3] In the empirical estimation of the production functions using the formulation of Just and Pope (1979), the OLS estimates of α's have been used as initial values in the iterative process.

2.3.3 Source of Data

The data used in this study are primary data collected by a field survey in Daspur Block-I of Midnapore district in West Bengal (an eastern state in India).[4] Farm level disaggregated data are very appropriate for estimating the production functions. So, farm level data were collected by a field survey. Daspur Block–I is predominantly an agriculture-based area. The total cultivated land in this Block is 13,000 ha, of which 10,020 ha are under irrigation. Irrigation is available from canals, tubewells (deep, mini deep and shallow), River water-lift schemes (RLI), boro-bandh, tanks etc. Most of the irrigation projects are in the public sector. Under boro-bandh irrigation, temporary reservoir is constructed on the river to store water and water overflows through canals to the fields in the dry season. Under RLI, water is lifted from river by diesel-run heavy pumps placed in a boat.

Out of the total 13,000 ha of cultivated land, 330 ha are high lands, 3200 ha are medium lands and the rest 6500 ha are low lands. The low lands in many cases are prone to flood and water-logging. The cropping intensity in this Block is very high and it is 169.47. The cropping intensity is defined as the ratio of gross cropped area and the net cropped area. High cropping intensity means that the practice of double or triple cropping is high.

The HYV technology has been in use in paddy cultivation in this Block since late sixties. The government has provided huge extension services for the diffusion of knowledge of the new technology among the farmers. The programmes adopted in this regard consisted of Trial Programmes, Demonstration Centres, Farmers Training Meetings, etc. The farmers in this Block are quite familiar with this new agricultural technology. In 1991–92, 5700 ha of land were under HYV paddy cultivation indicating that the rate of adoption of the HYV technology in the area was very high at that time.

Apart from irrigation and extension services, other facilities are also available in this Block. There are 21 Agricultural Cooperative Societies which provide improved seeds, agricultural inputs (like fertilizers) and financial credit to the farmers. The numbers of licensed dealers for supplying agricultural inputs to the farmers are as follows: fertilizers 172, pesticides 65, seeds 30. Other infrastructural facilities like transportation and rural electrification are also fairly good. All these factors helped the farmers to adopt the new technology. Most of the farmers in this Block are marginal farmers. The average cultivated land per farming household is 0.47 ha. Power tiller is used on a wide scale for cultivation of land in this Block. The farmers mainly use the hired services of power tillers against the payment of some rental charges. Another equipment which is also used on a large scale is irrigation pump, mainly run by electricity.

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[4] The survey was conducted in 1989–90 in connection with the author's doctoral research and it was financed by the University Grants Commission (India).

2.3.4 Methodology of Data Collection

The primary data were collected by a field survey using the method of multi-stage stratified random sampling. There are 157 villages in Daspur Block—I. Some of them were excluded from the list on the ground that either they were in highly flood-prone areas where normal agricultural activities are not possible or they were in remote areas where the collection of data is difficult. Out of the remaining villages 14 were selected in the first stage on the basis of random sampling. The lists of farmers along with their farm sizes of the selected 14 villages, were supplied by the Gram Panchayats.[5]

In the second stage, all the farmers in each of the randomly selected villages were classified into three categories: marginal, small and big. According to the local panchayat norms, the farmers having cultivated land up to 2.50 acres are marginal farmers, the farmers possessing cultivated land from 2.51 to 5.00 acres are small farmers and the farmers possessing cultivated land exceeding 5.00 acres are big farmers. Most of the farmers in each village have been found to be belonging to the category of marginal farmers. Some of them are possessing so little amounts of land that proper farming behaviour is not expected from them. So, in consultation with the villagers and local experts, the farmers possessing very small amount of land were excluded from the list. The number of farmers in each category for the 14 randomly selected villages taken together are as follows:

Marginal farmers	980
Small farmers	100
Big farmers	15
Total sample farmers	1095

Finally, 30 % farmers from each category in each of the randomly selected villages were selected as samples on the basis of random sampling. The sample size stood at 329. In the total sample the numbers of marginal, small and big farmers are 294, 30 and 5 respectively.

Cross-section farm level data on various aspects of paddy cultivation were collected from the sample farmers through a primary survey. An appropriate and well defined questionnaire was used for this purpose. Before the final survey was conducted, a 'Pilot-survey' had been done in the area. The 'various concepts' relating to the survey have been defined following standard literature and having consultations with the local experts. The data were collected for the year 1989–90 which was a normal year from the viewpoint of agricultural production. The variables for which data have been collected, are as follows:

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[5] These lists were prepared by the Gram Panchayats (local government) for planning purposes.

(i) *Farm size* total amount of cultivated land possessed by the farm family. It includes both irrigated as well as non-irrigated lands and it has been measured in acres.
(ii) *Area under irrigation* amount of land (measured in acres) under any form of irrigation. It has been recorded for the dry season and rainy season separately.
(iii) *Area under HYV* amount of land (measured in acres) used for the cultivation of high yielding varieties of paddy. It has also been recorded for the dry and rainy seasons separately.
(iv) *Amount of agricultural credit received by the farmer* agricultural credits are broadly classified into two categories—short term and long term. The former is taken for the purchase of variable inputs like fertilizers, pesticides, etc., whereas the latter is received for the purchase of fixed capitals like Power tiller, irrigation pump, setting up of shallow tube-wells etc. Data on both types of credits have been collected and they have been collected for the dry season and the rainy season separately. They have been measured in terms of Rupees.
(v) *Output of paddy per acre* it has been measured in terms of kilograms. The data on this variable have been collected for both traditional as well as high yielding varieties and they have been collected for the dry and rainy seasons separately.
(vi) *Input used per acre in paddy cultivation*

  (a) **Seed**—it has been measured in terms of value (in Rupees) where a higher value implies better quality of seed. As the physical amount of seed used per acre is more or less the same, it has been measured in terms of value to reflect the differences in quality.
  (b) **Labour**—It has been measured in terms of man-days of adult male workers.
  (c) **Fertilizer**—as heterogeneous types of fertilizers are used in cultivation, it has been measured in terms of value (in Rupees).
  (d) **Pesticides**—it has been also measured in terms of value (in Rupees).
  (e) **Use of Power tiller**—amount of land (measured in acres) prepared for cultivation by power tiller.
  (f) **Literacy rate**—the percentage of literate persons in the farming household. It has been taken as an 'index of education' of the farm family in this study.

2.3.5 Summary Statistics

The summary statistics in Table 2.1 are very revealing. The yield under HYV in the rainy season is higher than the traditional variety (Aman) but variance is also higher in the former. That means, under the new technology productivity is higher and at

Table 2.1 Mean values of different inputs used per acre of land for the cultivation of paddy, 1989–90 (at 1989–90 prices)

Crop variety and season	Seed (Rs.)	Labour (man-days)	Fertilizer (Rs.)	Pesticide (Rs.)
(1)	(2)	(3)	(4)	(5)
Aman in rainy season	84	62	106	Nil
HYV in rainy season	136	71	350	100
HYV in dry season	164	97	679	185

Source Calculated from primary survey data in Sasmal (1992)

Table 2.2 Mean and standard deviation of output of paddy, 1989–90

Crop varieties in different seasons and under different irrigation systems	Mean output per acre (kg)	Standard deviation of output
(1)	(2)	(3)
Aman in rainy season (all forms of irrigations taken together)[a]	987.44	180.40
HYV in rainy season (all forms of irrigations taken together)	1413.28	238.73
HYV in dry season (all forms of irrigations taken together)	1972.09	231.37
HYV in dry season (under bandh irrigation)	1762.38	244.93
HYV in dry season (under RLI)	1936.76	186.00
HYV in dry season (under tubewell irrigation)	2052.30	157.22

Source Calculated from primary survey data in Sasmal (1992)
[a] It includes production under non-irrigated land also

the same time uncertainty is also higher. Table 2.2. shows that mean output of HYV paddy in the dry season is highest and variance of output is lowest under tube-well irrigation. It is because of controlled system of water supply indicating highest efficiency of irrigation in this system. On the contrary, mean output is lowest and variability is almost highest in the rainy season when efficiency of water supply is very low. Among the three modes of irrigation bandh irrigation has the lowest efficiency in the dry season with lowest mean and highest variance of output. Water supply is uncontrolled in this system because water overflows to the fields from river.

2.3.6 *Estimation of Production Functions for HYV Paddy in the Dry and Rainy Seasons*

The estimates of the production function for HYV paddy in the dry and rainy seasons using the generalized stochastic formulation (GSF) have been presented in Table 2.3 (deterministic component) and Table 2.4 (stochastic component).

Table 2.3 Third-stage estimates of the deterministic component of the production function for HYV paddy in the rainy and dry seasons using GSF

Inputs		Coefficients of inputs in mean output		t-value of the coefficients	
		Rainy season	Dry season	Rainy season	Dry season
(1)		(2)	(3)	(4)	(5)
X_1	α_1 =	0.37 (0.13)	0.11 (0.07)	2.84[a]	1.57
X_2	α_2 =	0.79 (0.09)	0.83 (0.08)	8.77[a]	10.37[a]
X_3	α_3 =	0.17 (0.07)	0.41 (0.07)	2.42[a]	5.85[a]
X_4	α_4 =	0.52 (0.08)	0.48 (0.07)	6.50[a]	6.85[a]
Constant term	α_0 =	33.56 (7.71)	31.45 (4.54)	4.35[a]	7.06[a]
		$R^2 = 0.99$	$R^2 = 0.99$		
		n = 137	n = 263		

Similar results have been found in Sasmal (1993). The source of the results is Sasmal (1992)
Source Estimated from primary survey data in Sasmal (1992)
Figures in parentheses are standard errors
[a] significant at 5 % level

Table 2.4 Second-stage estimates of the stochastic component of the production function for HYV paddy in the rainy and dry seasons using GSF

Inputs		Coefficients of inputs in mean output		t-value of the coefficients	
		Rainy season	Dry season	Rainy season	Dry season
(1)		(2)	(3)	(4)	(5)
X_1	β_1 =	−1.18 (0.94)	−0.82 (0.56)	−1.25	−1.46
X_2	β_2 =	1.34 (0.72)	−1.15 (0.65)	1.86[a]	−1.76[a]
X_3	β_3 =	−0.54 (0.56)	−0.09 (0.56)	−0.96	−0.16
X_4	β_4 =	0.44 (0.62)	1.40 (0.59)	0.70	2.37[a]
Constant term	β_0 =	2.18 (1.56)	2.93 (1.15)	1.39	2.54[a]
		$R^2 = 0.05$	$R^2 = 0.03$		
		F = 1.68	F = 1.95		
		$n = 137$	$n = 263$		

Similar results have been found in Sasmal (1993). The source of the results is Sasmal (1992)
Source Estimated from Primary Survey data in Sasmal (1992)
Figures in parentheses are standard errors
[a] Significant at 5 % level

Table 2.3 shows the estimates of the magnitude and direction of the effects of inputs on the mean output of HYV paddy in the dry and rainy seasons. It shows that R^2 is very high implying that the variation in mean output is highly explained by the regression equation. The results also indicate that all the coefficients are positive and statistically significant. The most important factor in mean output is labour both in the dry and rainy seasons. Fertilizer and pesticide are the two most important ingredients of the HYV technology in paddy cultivation. They are found to have significant impact on mean output. Fertilizer becomes more effective in the dry season due to better irrigation and suitable agro-climatic conditions. Since HYV plants are more vulnerable to pests and disease in the rainy season pesticide is seen to have a greater role in mean output in the rainy season. Seed is another important component of the new technology. The amount of seed to be used per acre is more or less technically fixed. But the quality of seed differs and it is reflected in the cost of seed. In the present study, seed is represented in terms of cost, a higher cost implies better quality of seed. As the coefficient of seed is positive and statistically significant, it implies that better quality of seed leads to higher mean production.

Labour has appeared to be the most important factor in mean output. This result suggests that as the cultivation of HYV paddy is highly labour intensive (Harriss 1972; Ruttan 1977), proper cultivation is possible only when sufficient labour is employed particularly when the uses of labour-substituting machineries and equipments are limited.

Table 2.4 show the relative contributions of the sample inputs to the variability of output in the rainy and dry seasons. The very low R^2 indicates that the inputs do not explain the variability of output by any significant extent. The ‘goodness of fit’ of the regression equation to the observed data is also very weak. This may be due to the fact that there is inadequacy in the specification of the regression equation in the sense that many factors which may be really responsible for variability in output such as rainfall, nature of irrigation, weather conditions and physical environment have not been included in the regression equation.

Nevertheless, some factors have appeared to be significant in explaining the variability of output. Judging by the t-values, the coefficients of labour and pesticide are statistically significant. It is important to note that fertilizer has no risk-raising effect on production and it is consistent with the finding of Antle and Crissman (1990).[6] According to their explanation, in the short run the farmers may be inefficient in using the modern inputs like fertilizer. But over time as learning takes place, the farmer’s efficiency, both technical and allocative, will improve and as a result the input which was risky at the early stage, may be ultimately risk-neutral or risk-reducing. The HYV technology has been in use, in paddy cultivation in the present situation for quite a long period. So, it is very likely that the farmers have acquired sufficient knowledge about the use of the input by this time. The coefficient of seed in variability of output is statistically insignificant implying that quality of seed has failed to explain the uncertainty in production. It is interesting that labour is risk-reducing in the dry season and risk-raising in the rainy season. This result can be explained in the following way: The rainy season is the main cropping season of paddy in India and paddy being a labour intensive crop, the local demand for labour remains very high in the rainy season. This demand is further increased by the cultivation of HYV paddy. So, the farmer’s dependence on

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[6] Antle and Crissman (1990) have concluded that nitrogen fertilizer does not necessarily increase risk in production; on the contrary, it may reduce risk under favourable conditions. Their study is based on pooled time series and cross-section data in the context of Philippine agriculture.

‘hired labour’ increases and in that case, not only the uncertainty in timely availability of labour increases, but also, the possibility of unskilled labourers getting employed in large numbers increases. In effect, uncertainty in production may increase with increase in employment of hired labour.

Another interesting result is that the coefficient of fertilizer in mean output is much higher in the dry season than in the rainy season. The implication of this result is that the use of fertilizer becomes more effective in raising mean output in the dry season. This is possibly due to better physical and agro-climatic conditions and controlled supply of water. For the same reason, the relative importance of pesticide declines in the dry season compared to the rainy season. The coefficient of seed in mean output in the dry season is insignificant implying that the quality of seed does not matter so much in the dry season as it does in the rainy season. Another possible explanation of this result is that the farmers are using almost similar quality of seed in the dry season.[7] As the inter-farm variation in the quality of seed is low it fails to explain the variation in output per acre across farms. Although pesticide is risk neutral in the rainy season, surprisingly the coefficient of pesticide is positive and statistically significant in the dry season. Pesticide is generally supposed to reduce risk in production by controlling pests and disease. But here the effect is just reverse. It is a chemical input and it has some optimal doses of application. A favourable climatic condition may also be necessary for its effectiveness. Possibly the input could not be used properly in the dry season.

2.3.7 *Estimation of Production Functions for HYV Paddy Under Different Irrigation Systems in the Dry Season*

The three major irrigation systems in use in the area selected for this study are: bandh irrigation, river water-lift irrigation (RLI) and tube-well irrigation. Efficiency in water supply varies under these three systems (see Table 2.2). The most effective system is tube-well irrigation and RLI comes next in the rank of efficiency. Production functions for HYV paddy under these three systems in the dry season have been estimated separately. The estimates presented in Table 2.5 (deterministic components) and Table 2.6 (stochastic components) give idea about the efficiency of irrigation on output and input use.

Table 2.5 exhibits the input coefficients in mean output under different forms of irrigation. It shows that the coefficient of fertilizer is positive and significant under all the three systems of irrigation. It is also revealed that fertilizer becomes comparatively more effective under RLI and tube-well irrigation due to better water management. Pesticide has been found to have no significant impact on the mean output under RLI. The physical environment and the water management under this

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[7] Mean and standard deviation of seed in the dry season are Rs. 164 and 17 respectively, whereas they are Rs. 136 and 24 respectively in the rainy season.

Table 2.5 Third-stage estimates of the deterministic component of the production function for HYV paddy under different irrigation systems in the dry season using GSF

Inputs		Coefficients of inputs in mean output			t-value of the coefficients		
		Bandh irrigation	River lift irrigation	Tube-well irrigation	Bandh irrigation	River lift irrigation	Tube-well irrigation
(1)		(2)	(3)	(4)	(5)	(6)	(7)
X_1	$\alpha_1 =$	0.009 (0.108)	0.15 (0.11)	0.13 (0.14)	0.08	1.36	0.92
X_2	$\alpha_2 =$	1.356 (0.232)	1.14 (0.13)	0.63 (0.16)	5.84[a]	8.76[a]	3.94[a]
X_3	$\alpha_3 =$	0.319 (0.172)	0.43 (0.10)	0.44 (0.15)	1.85[a]	4.30[a]	2.93[a]
X_4	$\alpha_4 =$	0.328 (0.109)	0.13 (0.10)	0.29 (0.07)	3.00[a]	1.30	4.14[a]
Constant term	$\alpha_0 =$	21.240 (5.267)	32.01 (7.18)	63.79 (18.12)	4.03[a]	4.45[a]	3.52[a]
		$R^2 = 0.99$	$R^2 = 0.99$	$R^2 = 0.99$			
		n = 67	n = 68	n = 65			

Source Estimated from primary survey data in Sasmal (1992)
Figures in parentheses are standard errors
[a] Significant at 5 % level

Table 2.6 Second-stage estimates of the stochastic component of the production function for HYV paddy under different irrigation systems in the dry season using GSF

Inputs		Coefficients of inputs in the variability of output			t-value of the coefficients		
		Bandh irrigation	River lift irrigation	Tube-well irrigation	Bandh irrigation	River lift irrigation	Tube-well irrigation
(1)		(2)	(3)	(4)	(5)	(6)	(7)
X_1	$\beta_1 =$	−0.51 (1.62)	−1.78 (1.33)	−0.80 (1.28)	−0.21	−1.28	−0.62
X_2	$\beta_2 =$	−1.04 (3.15)	−2.39 (1.60)	3.08 (1.40)	−0.33	−1.49	2.20[a]
X_3	$\beta_3 =$	−0.31 (2.50)	0.32 (1.28)	−0.98 (1.36)	−0.12	0.25	−0.72
X_4	$\beta_4 =$	0.51 (1.66)	1.94 (1.38)	1.90 (0.67)	0.30	1.40	2.83[a]
Constant	$\beta_0 =$	4.36 (3.53)	4.93 (2.47)	4.15 (2.42)	1.23	1.99[a]	1.71[a]
		$R^2 = 0.02$	$R^2 = 0.05$	$R^2 = 0.26$			
		F = 0.28	F = 0.91	F = 5.36			
		n = 67	n = 68	n = 65			

Source Estimated from primary source data in Sasmal (1992)
Figures in parentheses are standard errors
[a] Significant at 5 % level

form of irrigation may be such that plants are less susceptible to pests and diseases. So, the application of pesticide becomes less important. It may be also true that this input could not be used properly in this case. In fact, pesticide will have significant contribution to mean output and it will have risk-reducing effect on output only when it is used properly and under favourable conditions. However, the coefficients of pesticide in mean output are positive and statistically significant under tube-well and bandh irrigations. The coefficient is higher under bandh irrigation indicating that the importance of pesticide is higher when water management is poor. For the same reason, the contribution of labour to mean output is highest under bandh irrigation.

Table 2.6 shows the coefficients of inputs in variability of output under different irrigation systems in the dry season. As before, R^2 is low under all the three systems. While F-statistics is insignificant under bandh and river water-lift irrigations, it is significant only under tube-well irrigation. It has been already discussed that there may be inadequacy in the specification of the regression equation in the sense that many factors which are really contributing to uncertainty in production, have not been included in the function. This inadequacy is likely to be more pronounced under bandh irrigation where water management is very poor. As a result, under this system all the input coefficients including the constant term of the function are found to be insignificant. Under RLI, water management is little better. But here also, the input coefficients are insignificant, although the constant term is significant and positive.

F-statistic is significant only under tube-well irrigation. This is explained by the fact that the external factors which are likely to have significant impact on the variability of output viz., waterlogging, attacks of pests and disease, uncertainty in water supply, etc. are less prominent in this system of irrigation. So, the specification of the function improves and the explanation of the uncertainty in production by the inputs slightly improves. It needs to be noted that labour is a risk-reducing factor in HYV cultivation in the dry season when all modes of irrigation are taken together (see Table 2.4). But if labour is considered for tube-well irrigation only, it becomes a risk-raising factor. Explanations have been provided for the results in Table 2.4. So far as the effect of labour on the variability of output under tube-well irrigation is concerned it may be mentioned that the areas served by tube-well irrigation are nearer to the town in the present study. Here, employment opportunities are high throughout the year and there is scarcity in labour supply. The supply of labour is also influenced by the labour organisations and the political parties. So, the supply of labour becomes more uncertain and this factor contributes to uncertainty in production.

2.3.8 *Estimation of Production Function for Aman (Traditional) Paddy in the Rainy Season*

The estimates of the production function for Aman paddy in the rainy season using the GSF have been presented in Table 2.7. The input set of this production function excludes pesticide because, the use of pesticide under the traditional variety is very rare. Table 2.7 shows that the coefficients of all the three inputs, seed, labour and fertilizer in mean output are positive and statistically significant. The most important factors are seed and labour. It is also revealed that the contributions of labour and seed to mean output are greater under traditional variety than those under high yielding varieties in the rainy season (see Table 2.3). Fertilizer is not an essential input for Aman paddy. But if it is used, it will have a mean-raising effect on production. However, the effect is smaller as compared to that under high yielding varieties.

Table 2.7 also shows the coefficients of inputs in the variability of output of Aman paddy. The very low R^2 indicates that as before the inputs considered here fail to explain the variability of output by any considerable extent. The 'goodness of fit' of the regression equation to the observed data is also very poor. All the factor coefficients including the constant term of the function are found to be insignificant. That means, the variability in output is explained by the factors other than the inputs considered here.

Table 2.7 The estimates of production function for Aman paddy in the rainy season

Inputs		Third-stage estimates of the deterministic component			Second-stage estimates of the stochastic component	
		Coefficients of inputs in mean output	t-values of the coefficients		Coefficients of inputs in mean output	t-values of the coefficients
(1)		(2)	(3)		(4)	(5)
X_1	$\alpha_1 =$	1.25 (0.15)	8.33[a]	$\beta_1 =$	−0.59 (0.72)	−0.81
X_2	$\alpha_2 =$	1.25 (0.10)	12.50[a]	$\beta_2 =$	0.80 (0.68)	1.17
X_3	$\alpha_3 =$	0.14 (0.02)	7.00[a]	$\beta_3 =$	0.19 (0.20)	0.95
Constant term	$\alpha_0 =$	6.94 (0.98)	7.03[a]	$\beta_0 =$	0.79 (0.99)	0.82
		$R^2 = 0.99$			$R^2 = 0.012$	
		n = 223			F = 0.92	
					n = 223	

Source Estimated from primary survey data in Sasmal (1992)
Figures in parentheses are standard errors
[a] Significant at 5 % level

2.3.9 Summary

In this sub-section we have estimated production functions for Aman (Traditional) paddy and HYV paddy using the generalized stochastic formulation (GSF) of production function developed by Just and Pope (1978, 1979). The GSF shows the differential effects of the inputs on the mean and variability of output. In GSF, an input which has positive marginal effect on mean output, does not necessarily have positive marginal effect on the variability of output. The functions have been estimated using farm level primary data. The results show that fertilizer and labour have significant positive impact on mean output under all irrigation systems both in the dry and rainy seasons. Fertilizer is more effective in raising productivity in the dry season and under tube-well irrigation. This is because of greater efficiency in water supply in tube-well irrigation and better agro-climatic conditions in the dry season. Among the three modes of irrigation, tube-well, bandh and river-lift, the most efficient system is tube-well irrigation. The other inputs like seed and pesticide are not found to have much impact on the mean and variability of output. The inputs have failed to explain the variability of output in these estimations. This is because there may be inadequacy in the specification of the regression equation in the sense that the factors which are really responsible for variability of output have not been included in the production function. Since mean output is higher and uncertainty in production is lower under tube-well irrigation, this mode of irrigation has been largely utilized for HYV cultivation.

2.4 Uncertainty in Production, Risk Preference and Adoption of a New Technology in Agriculture—A Theoretical Framework

The theoretical framework of adoption of a new technology in agriculture under production uncertainty in this section is based on the work of Feder (1980).[8] Following Feder it is assumed that two distinct technologies are available to a farmer: traditional technology and modern technology. The modern technology can be the high yielding variety (HYV) technology. It is also assumed that output from both technologies are homogeneous. Traditional technology requires no specialized inputs and yields a given net return per acre with certainty. In other words, there is no uncertainty with regard to the yield per acre under the traditional variety. But the production under modern technology requires some modern inputs, namely, improved seed, chemical fertilizers and pesticides. For simplicity, it is assumed that only chemical fertilizer is required for production under modern cultivation and the yield per acre under modern technology is uncertain. But the yield potential of the

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[8] This section of the book largely draws from Feder (1980).

modern variety is significantly superior to that of the traditional variety. The production under modern technology is subject to both subjective and objective uncertainties. As the modern varieties are more susceptible to pests and weather conditions, there are objective uncertainties. The subjective uncertainties originate from the farmer's incomplete knowledge regarding the cultivation practice and production function parameters. So, the cultivation of modern varieties is risky.

A general specification of the production function exhibiting such uncertainties has been developed by Just and Pope (1978), the details of which have been explained in the previous section. The function can be written as

$$q = f(z) + \varepsilon g(z) \tag{2.1}$$

where,

q actual output per acre.
f mean output per acre.
z fertilizer used per acre.
g a term related to output variability and is assumed to be positive.
ε a random variable, $E(\varepsilon) = 0$.

The production function possesses the following properties:

(a) $f' = \frac{df}{dz} > 0$
(b) $f'' < 0$
(c) $g' = \frac{dg}{dz} > 0$
(d) $f(0) > 0$
(e) $g(0) > 0$

This formulation of the production function is flexible enough to allow situations where some inputs (like pesticides and irrigation) have opposite effects on mean and variance of output. The familiar Cobb-Douglas production function with log linear disturbances, can not accommodate such flexibility. It wrongly imposes a risk-increasing effect of such inputs on output. Other common stochastic production functions like Transcendental, Translog, CES, etc. also appear inadequate in this respect when they are used with log linear disturbances.

Given the above specifications of the production function, the analytical framework can be characterized by the following assumptions:

(i) The farmer is an owner cultivator.
(ii) The farmer has a fixed amount of land denoted by $\overline{L}$.
(iii) The farmer operates in a situation of perfect competition, i.e., perfect competition prevails both in product market and input market.
(iv) There is no credit constraint.
(v) There is no constraint on the supply of labour and the availability of other inputs.

(vi) The farmer is familiar with the new technology. That means, he knows that such a technology is available and he has the necessary knowledge of using it.

(vii) The farmer's objective is to maximize the expected utility of income.

Now, the income of the farmer is defined as

$$\pi = \left\{P \cdot L[f(z) + \varepsilon g(z)] + R\left(\overline{L} - L\right) - c \cdot z \cdot L\right\} \tag{2.2}$$

where

P is price of output.
L is amount of land allocated to modern cultivation.
R is value of net return per acre under traditional variety.
c is price of fertilizer per unit.
The utility function of the farmer is

$$U = U(\pi), U' > 0, \text{ and } U'' < 0.$$

The utility function is strictly concave implying that the farmer is risk averse. $\left(-\frac{U''}{U'}\right)$ is the measure of absolute risk aversion and $\left(-\frac{U''}{U'}\right) \cdot \pi$ is relative risk aversion (Arrow 1971; Pratt 1964).

$\frac{d\left(-\frac{U''}{U'}\right)}{d\,\pi} < = > 0$, implies decreasing, constant and increasing absolute risk aversion.

Here non-increasing risk aversion is assumed.

Now, the problem of the farmer is to choose the optimal values of L and z, so as to maximize the expected utility of income,

$$EU(\pi) = EU\left\{P \cdot L[f(z) + \varepsilon g(z)] + R\left(\overline{L} - L\right) - cZL\right\} \tag{2.3}$$

It is a static optimization problem. The first order conditions for maximization of Eq. (2.3) are:

$$\frac{\partial EU}{\partial L} = E\{U'[P(f(z) + \varepsilon g(z)) - R - cZ]\} = 0. \tag{2.4}$$

$$\frac{\partial\, EU}{\partial\, z} = E\{U'[P(f'(z) + \varepsilon g'(z)) - c]\}L = 0. \tag{2.5}$$

The second order conditions can be satisfied if (i) $U'' < 0$ (which is a specification about U) and (ii) $f'' < -g''[\,E(U'\varepsilon)/EU']$. By Lemma 1 of Feder (1977), $[EU'\varepsilon/EU'] < 0$. So, given the specifications of f'' and g'', $g'' \geq 0$ is a sufficient condition for ensuring second-order conditions, although $g'' < 0$ can also be accommodated. In other words, the maximum solution can be obtained if the marginal mean productivity decreases faster than the marginal contribution to the risk component (g).

Now, the optimum values of z and L (denoted by z^* and L^* respectively) can be obtained from the Eqs. (2.4) and (2.5) and are expected to depend on P, c, R, ε and $\overline{L}$ and also on the parameters of $f(z)$, and $g(z)$ and utility function $U(.)$. According to Feder (1980) the optimal level of z is independent of the degree of risk-aversion, the degree of variability of ε and the farm size ($\overline{L}$).

The main objective of this exercise is to see how the optimal level of land-allocation to modern cultivation is affected by different factors and parameters namely, risk aversion, farm size and credit constraint.

2.4.1 The Optimal Allocation of Land and Risk-Aversion

The area allocated to modern variety may be affected by the degree of risk aversion of the farmer and to study the impact of risk-aversion, we may assume a specific form of utility function as in Feder (1980):

$$U(\pi) = \frac{\pi^{1-\gamma}}{(1-\gamma)}; \quad 1 > \gamma > 0 \tag{2.6}$$

where γ is the Arrow (1971), Pratt (1964) measure of relative risk-aversion. The larger is γ, more risk-averse is the farmer.

Now, it can be shown that optimal allocation of land to modern cultivation declines with higher degree of risk-aversion.

Given the Eq. (2.6),

$$EU = E\left\{\frac{\pi^{1-\gamma}}{(1-\gamma)}\right\}$$

$$\frac{\partial EU}{\partial L} = E(\pi^{-\gamma} \cdot A) = 0,$$

or,

$$E(U'A) = 0, \tag{2.7}$$

where $U' = \pi^{-\gamma}$
and $A = P\{f(z) + \varepsilon g(z)\} - R - cz$

Now, totally differentiating the Eq. (2.7) w.r.t. γ and L^*, one gets

$$E\{-\pi^{-\gamma}\log \pi A\}d\gamma + E\{-\gamma\pi^{-\gamma-1}A^2\}dL^* = 0.$$

or

$$\begin{aligned}\frac{dL*}{d\gamma} &= \frac{E(\pi^{-\gamma}\log \pi A)}{E(-\gamma\ \pi^{-\gamma-1}A^2)}\\ &= \frac{E(U'\log \pi A)}{E(U''A^2)}, \quad \text{where } U'' = -\gamma\pi^{-\gamma-1}\end{aligned}$$

Again,

$$\log U = (1-\gamma)\log \pi - \log(1-\gamma)$$

So,

$$\frac{dL^*}{d\gamma} = \frac{E(U'\log \pi A)}{E(U''A^2)}$$

or,

$$\frac{dL^*}{d\gamma} = \frac{E\ (U'\ \log\ UA)}{E\ \{\,(1-\gamma)\ U''A^2\}} + \frac{\log\ (1-\gamma)}{(1-\gamma)} \cdot \frac{E\ (U'A)}{E\ (U''\ A^2)}$$

or,

$$\frac{dL^*}{d\gamma} = \frac{E(U'\log UA)}{E\{(1-\gamma)U''A^2\}} \tag{2.8}$$

because,

$$\frac{\log(1-\gamma)}{1-\gamma}\cdot\frac{E(U'A)}{E(U''A^2)} = 0, \quad \text{as} \quad E(U'A) = 0$$

from Eq. (2.4).

The denominator of Eq. (2.8) is obviously negative while the numerator is positive. So, $\frac{dL^*}{d\gamma} < 0$. Then it follows, if the degree of risk-aversion rises, the optimal allocation of land to modern cultivation declines. The farmers are mostly risk-averse and risk-aversion may increase for various reasons and in that case the adoption of a new technology will decline.

2.4.2 The Relation Between Farm Size and Adoption of a New Technology

Now, the effect of farm size on the allocation of land to modern cultivation can be examined. Feder (1980) has shown that optimum level of fertilizer (z*) per acre is independent of the farm size. So, totally differentiating only the Eq. (2.4) w.r.t. $L*$ and $\overline{L}$ one gets

$$E\left[U''\{P(f(z)+\varepsilon g(z))-R-cz\}^2\right]dL^* + E[U''\{P(f(z)+\varepsilon g(z))-R-cz\}R]d\overline{L} = 0$$

or,

$$E\left[U''B^2\right]dL^* + E[U''BR]d\overline{L} = 0$$

where

$$B = \{P(f(z)+\varepsilon g(z))-R-cz\},$$

or,

$$\frac{dL^*}{d\overline{L}} = \frac{E(U''BR)}{-E(U''B^2)} \tag{2.9}$$

If absolute risk-aversion decreases with income (a plausible assumption), $E(U''BR) > 0$, and by the assumption of risk-aversion, $E(U''B^2) < 0$ (Feder and O'Mara 1981). So,

$$\frac{dL^*}{d\overline{L}} > 0$$

Therefore, if the farmer is a risk-averter and the absolute risk-aversion decreases with income, the large farmer will allocate a greater amount of land to modern cultivation.

Thus, a positive relationship between the amount of land allocated to modern cultivation and farm size is obtained under certain conditions. A more interesting problem is to examine the relationship between farm size and the proportion of land allocated to modern cultivation. This will be a true measure of rate of adoption of a new technology.

Let 'l' be the proportion of land allocated to modern cultivation, i.e.,

$$l = \frac{L}{\overline{L}}. \quad \text{Then,}$$

$$\frac{dl^*}{d\overline{L}} = \frac{d\left(\frac{L^*}{\overline{L}}\right)}{d\overline{L}} = \frac{\overline{L}\cdot\frac{dL^*}{d\overline{L}} - L^*}{\overline{L}^2}$$

or,

$$\frac{d\,l^*}{d\,\overline{L}} = \frac{\overline{L}\cdot E(U''\,BR) + L^*\,E(U''\,B^2)}{-\overline{L}^2 E(U''\,B^2)}$$

or,

$$\frac{d\,l^*}{d\,\overline{L}} = \frac{E\left(U''\,B\,R\,\overline{L} + U''\,B^2\,L^*\right)}{-\overline{L}^2\,E\,(U''\,B^2)}$$

or,

$$\frac{d\,l^*}{d\,\overline{L}} = \frac{E\left[U''\,B\left\{R\,\overline{L} + B\,L^*\right\}\right]}{-\overline{L}^2\,E\,(U''\,B^2)}$$

or,

$$\frac{d\,l^*}{d\,\overline{L}} = \frac{E\,(U''\,B\,\pi)}{-\overline{L}^2\,E\,(U''\,B^2)} \tag{2.10}$$

The denominator of Eq. (2.10) is positive by assumption of risk-aversion. But the numerator $E(U''\,B\,\pi) < \; = \; > 0$, depending on whether relative risk-aversion is increasing, constant or decreasing in income (π). So,

(a) If the relative-risk aversion increases with π,
$\frac{d\,l^*}{d\,\overline{L}} < 0$, i.e., the large farmer will allocate a smaller proportion of land to modern cultivation.
(b) if the relative risk-aversion decreases with π,
$\frac{d\,l^*}{d\,\overline{L}} > 0$, i.e., the large farmer will allocate a larger proportion of land to modern cultivation.
(c) if the relative risk-aversion remains constant,
$\frac{d\,l^*}{d\,\overline{L}} = 0$, i.e., the proportion of land allocated to modern cultivation will be independent of farm size.

So, relative risk-aversion becomes an important determinant of the relationship between farm size and rate of adoption of a new technology in agriculture. Whether relative risk-aversion will decrease with income or not again depends on a number of factors like, availability of irrigation, bank credit, labour supply and government support measures.

2.4.3 Extension of the Result

It has so far been assumed that there is no fixed cost in the adoption of a modern technology. Now, let us suppose that there is some fixed adoption cost (say, on irrigation pump, tractor or the cost of acquisition of information regarding the new technology) and it is denoted by ‘F’. Then the expected income of the farmer becomes

$$\pi = \left[P \cdot L\{f(z) + \varepsilon g(z)\} + R\left(\overline{L} - L\right) - c \cdot z \cdot L - F\right] \tag{2.11}$$

Then, the Eq. (2.10) becomes

$$\frac{d\,l^*}{d\overline{L}} = \frac{E\{U'' B(\pi + F)\}}{-E\{U'' B^2\}\overline{L}^2} \tag{2.12}$$

Here, also, the denominator is positive. Now, if the relative risk-aversion is approximately constant, $E(U'' B\,\pi)$ is zero. But the other term $E(U'' B\,F)$ will be positive and then $\frac{d\,l^*}{d\overline{L}} > 0$

Therefore, if the adoption of a new technology involves some fixed cost and relative risk-aversion is more or less constant, the large farmers will allocate a larger proportion of land to modern cultivation.

The use of fertilizer per unit of land is also an indicator of technological change in agriculture. Feder (1980) shows that a reduction in the cost of fertilizer leads to an increase in the optimal use of fertilizer per acre (z*), i.e., $\frac{d\,z^*}{d\,c} < 0$. He also shows that fertilizer use per acre will increase with an increase in output price i.e., $\frac{d\,z^*}{d\,p} > 0$ provided the elasticity of risk-response to fertilizer is lower than the elasticity of mean output-response to fertilizer.

2.4.4 The Credit Constraint and the Optimal Allocation of Land to Modern Cultivation

The modern cultivation requires cash outlay for the purchase of inputs like seed, chemical fertilizer, pesticides, etc. and the fund is provided from farmer’s own savings and credit received from different sources, both institutional and non-institutional. It has so far been assumed that there is no credit constraint in the sense that total cash available to the farmer is equal to the total cost of inputs.

If there is credit constraint, the non-availability of sufficient credit may become a constraint to the adoption of the new technology. Now let us assume that there is effective credit constraint in the sense that total cash expenditure can not exceed farmer’s cash availability. Following Feder (1980), it can be expressed as

$$K = c \cdot z \cdot L \tag{2.13}$$

Where K = total cash available to the farmer (consisting of both farmer's own resource and credit received).

It is further assumed that both own resource and access to credit are proportional to the size of farm and it is expressed as

$$K = k \cdot \overline{L} \tag{2.14}$$

where k is the ratio of proportionality between availability of cash and farm size i.e., $k = \frac{K}{\overline{L}}$ and k is fixed.

Now, from Eqs. (2.13) and (2.14)

$$L = \frac{k\overline{L}}{cZ} \tag{2.15}$$

From the differentiation of Eq. (2.15) w.r.t. 'k', we get

$$\frac{dL}{dk} = \left[\frac{\overline{L}}{cz}\right]\left[1 - \frac{dz}{dk} \cdot \frac{k}{z}\right] \tag{2.16}$$

where, $\frac{dz}{dk} \cdot \frac{k}{z}$ is the elasticity of fertilizer use w.r.t. k.

Now if $\left(\frac{dz}{dk} \cdot \frac{k}{z}\right) < 1$,

$\left(\frac{dL}{dk}\right)$ becomes positive implying that if k rises, the cash availability to the farmer will increase and this will lead to greater allocation of land to modern cultivation. Therefore, if there is effective credit constraint, an increase in credit supply will encourage greater allocation of land to modern cultivation.

2.4.5 An Extension

In Eq. (2.16), it has been stated that total cash available to the farmer is just equal to the total variable cost ($c\,z\,L$). Let us now assume that cash is required for fixed cost also and it is denoted by F. It is justified on the ground that the adoption of the new technology may involve some cost for setting up of irrigation pump, purchase of power tiller etc. Then, the credit constraint becomes

$$K = czL + F \tag{2.17}$$

Now, combining the Eqs. (2.14) and (2.17), we get

$$L = \left(\frac{k\overline{L}}{cz}\right) - \left(\frac{F}{cz}\right) \tag{2.18}$$

Now, the differentiation of Eq. (2.18) w.r.t. k gives

$$\frac{dL}{dk} = \frac{\overline{L}}{cz}\left[1 - \frac{dz}{dk} \cdot \frac{k}{z}\right] + \left[\frac{F \cdot c \cdot \frac{dz}{dk}}{c^2 z^2}\right] \tag{2.19}$$

$\left(\frac{\overline{L}}{cz}\right) \left[1 - \frac{dz}{dk} \cdot \frac{k}{z}\right]$ is positive from the Eq. (2.16). Feder (1980) has shown that if absolute risk-aversion is non-increasing and relative risk-aversion is non-decreasing (which are plausible assumptions) $\left(\frac{dz}{dk}\right)$ will be positive. Then $\left(\frac{F \cdot c \cdot \frac{dz}{dk}}{c^2 z^2}\right)$ will be positive. As a result, $\left(\frac{dL}{dk}\right)$ in Eq. (2.19) will not only be positive but also, its value will be larger than that in Eq. (2.16). The implication of the result is that the availability of credit will be more important in the adoption of a new technology when it involves some fixed cost.

2.4.6 Irrigation and Adoption of a New Technology in Agriculture

Making extension in Feder (1980) and using the structure of Mondal and Sasmal (2010) we can examine the effect of irrigation on technology adoption in agriculture. In the rainy season the HYV cultivation is possible without irrigation although the mean output may be lower and output may be subject to greater variability. If we insert irrigation into the production function as an efficiency factor it will enhance the mean output and reduce the variability of output. In the dry season irrigation is essential but the efficiency of irrigation may differ depending on the mode of irrigation. After incorporating irrigation we get the production function as

$$q = (1 + mI)f(z) + \varepsilon(1 - nI)g(z) \tag{2.20}$$

where I is some index of irrigation and $0 \leq I < 1$. 'I' increases mean output at the rate m and reduces risk in production at the rate n. It may be assumed that highest efficiency in irrigation is generally not achieved. So I is less than 1.

Now, the objective function of the farmer is to maximize

$$EU(\pi) = EU\left\{P \cdot L[(1 + mI)f(z) + \varepsilon \cdot (1 - nI)g(z)] + R\left(\overline{L} - L\right) - czL - vIL\right\} \tag{2.21}$$

where v is cost of irrigation per unit.

The first order conditions for the maximization of Eq. (2.21) are:

$$E[U'[P\{(1+mI)f(z)+\varepsilon(1-nI)g(z)\}-R-cz-vI]]=0 \tag{2.22}$$

$$E[U'[PL\{(1+mI)f'(z)+\varepsilon(1-nI)g'(z)\}-cL]]=0 \tag{2.23}$$

The second order conditions are also satisfied. Now, the optimum values of Z and L (i.e., Z^* and L^*) are obtained from the Eqs. (2.22) and (2.23).

Let us now examine the effect of change in the quality of irrigation on optimal values on Z and L. By using lemma 4 (Feder 1977), we get

$$P(1+mI)f'(z)g(z)-cg(z)-P(1+mI)f(z)g'(z)+Rg'(z)+czg'(z)+vIg'(z)=0. \tag{2.24}$$

Now, totally differentiating (2.24) w.r.t. z and I one gets

$$(P\cdot m\cdot f'g-P\cdot m\cdot fg'+vg')dI+\left\{\begin{array}{r} P(1+mI)f'(z)g'(z)+P(1+mI)f''(z)g(z) \\ -c\cdot g'(z)-P(1+mI)f(z)g''(z)-P(1+mI) \\ f'(z)g'(z)+Rg''(z)+c\cdot z\cdot g''(z)+c\cdot g'(z) \\ +vIg''(z) \end{array}\right\}dz=0 \tag{2.25}$$

The Eq. (2.25) gives

$$\frac{dz}{dI}=\frac{P\cdot m(f'g-g'f)+vg'}{P(1+mI)f''(z)g(z)+g''(z)(R+cz-P(1+mI)f(z)+vI)} \tag{2.26}$$

In Eq. (2.26), the numerator is positive (Feder 1980) and in the denominator, $P(1+mI)f''(z)g(z)$ is negative but $g''(z)(R+cz-P(1+mI)f(z)+vI)$ is indeterminate. So, $\left(\frac{dZ}{dI}\right)$ is also indeterminate. Therefore, the impact of irrigation on fertilizer use is not clear.

Now, totally differentiating the Eq. (2.24) w.r.t. L, z and I, we get

$$E\{U''B^2\}dL+E\{U''B\cdot S\cdot L+U'S\}dz+E\left\{\begin{array}{l} U''B[P\{mf(z)-g(z)\}L-vL] \\ +U'[P\{mf(z)-\varepsilon g(z)\}-v] \end{array}\right\}dI=0 \tag{2.27}$$

where

$$B=[P\{(1+mI)f(z)+(1-nI)\varepsilon g(z)\}-R-cz-vI]$$

$$S=P\{(1+mI)f'(z)+\varepsilon\cdot(1-nI)g'(z)\}-cL$$

Now, dividing Eq. (2.27) by $E(U''B^2)dI$ we get

$$\frac{dL}{dI} + \frac{E\{U''BSL + U'S\}}{E\{U''B^2\}} \cdot \frac{dz}{dI} + \frac{\{E\{U''B[\{P \cdot m \cdot f(z) - \varepsilon g(z)\}L - vL] + U'[P\{m \cdot f(z) - \varepsilon g(z)\} - v]\}\}}{E\{U''B^2\}} = 0$$

or,

$$\frac{dL}{dI} = \frac{-E\{U''BTL + U'T\}}{E\{U''B^2\}} - \frac{E\{U''BSL + U'S\}}{E\{U''B^2\}} \cdot \frac{dz}{dI} \tag{2.28}$$

where $T = P\{m \cdot f(z) - \varepsilon g(z)\} - v$

In Eq. (2.28) $\frac{E\{U''BTL + U'T\}}{E\{U''B^2\}} < 0$,

and $\frac{E\{U''BSL + U'S\}}{E\{U''B^2\}} < 0$ by Lemma 2, (Feder 1977) and (Feder and O'Mara 1981).

Now, as $\left(\frac{dz}{dI}\right)$ is indeterminate, $\left(\frac{dL}{dI}\right)$ is also indeterminate.

However, if $\left(\frac{dz}{dI}\right)$ is positive, $\left(\frac{dL}{dI}\right)$ will also be positive.

In Eq. (2.26) $\{P \cdot m(f' \cdot g - g'f) + vg'\}$ is positive (Feder 1980). In the denominator of Eq. (2.26) $\{P(1 + mI)f''(z)g(z)\}$ is negative (by specification about 'f'), and $\{R + cz - P((1 + mI)f(z) + vI)\}$ is negative (by superiority of the new technology over the traditional one). Now, if g'' is sufficiently negative, and f'' is slightly negative the denominator of Eq. (2.26) will be positive. Then both $\left(\frac{dz}{dI}\right)$ and $\left(\frac{dL}{dI}\right)$ will be positive.

Therefore, a sufficiency condition for $\left(\frac{dz}{dI}\right)$ and $\left(\frac{dL}{dI}\right)$ to be positive is that irrigation must be sufficiently risk-reducing (so that g'' is sufficiently negative) and mean productivity-raising (so that f'' is negative but magnitude is very small).

Let us now consider the impact of irrigation on the proportion of land allocated to modern cultivation (l) where $l = \frac{L}{\overline{L}}$.

Now,

$$\frac{dl}{dI} = \frac{d\left(L/\overline{L}\right)}{dI} = \frac{\overline{L} \cdot \frac{dL}{dI}}{\overline{L}^2} = \frac{1}{\overline{L}} \cdot \frac{dL}{dI}$$

Here, also, the sign of $\left(\frac{dl}{dI}\right)$ is indeterminate as $\left(\frac{dL}{dI}\right)$ is indeterminate. But under the same sufficiency conditions $\left(\frac{dl}{dI}\right)$ will be positive.

Therefore, the effect of irrigation on the allocation of land to HYV is not unambiguous. However, irrigation will lead to higher allocation of land to HYV only when it is sufficiently risk-reducing and mean productivity-raising when production is uncertain and the farmer is risk-averse.

2.4.7 Adoption of High-Yielding Variety (HYV) Technology—The Indian Experience

The HYV technology was adopted in India in 1960s and 1970s to have quick and substantial increase in foodgrains production.[9] At the initial stage this new technology was adopted in selected parts of India like Punjab, Haryana, Western Uttar Pradesh and subsequently it was extended to other parts of the country. This technology has been adopted mainly in foodcrops like paddy, wheat, maize, sorghum, etc. Many factors like farm size, irrigation, availability of credit, education in the farming household, knowledge about the new technology are found to influence the farmer's decision regarding the adoption of the new technology. In this section, we will consider the use of HYV technology in paddy cultivation. The theoretical framework of the previous section has explained the conditions under which the above factors affect the farmer's decision in this regard.

The degree of adoption of the HYV technology in paddy cultivation has been defined in the following two ways:

(a) amount of land allocated to HYV(L), and
(b) proportion of land allocated to HYV (l).

where $l = \frac{L}{\overline{L}}$ and $\overline{L}$ is total cultivated land of the farmer (i.e., farm size) and L is amount of land allocated to modern variety. The proportion of land allocated to HYV denoted by 'l' is a better measure of the rate of adoption of a new technology. So, this study explains the 'proportion of land allocated to HYV' with the help of a number of explanatory variables.

Here, we have used farm level primary data to explain the adoption rate of HYV technology in paddy cultivation. The following regression equation has been estimated using cross-section primary data at the farm level.

$$l = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + u \tag{2.29}$$

where,

l	the proportion of land allocated to HYV (the dependent variable),
X_1	farm size,
X_2	the proportion of land under irrigation,
X_3	short term credit received by the farmer
X_4	literacy rate in the farm-family (an index of education).

X_1, X_2, X_3 and X_4 are the explanatory variables and α_1, α_2, α_3 and α_4 are the regression coefficients of X_1, X_2, X_3 and X_4 respectively.[10] α_0 is the constant term of

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[9] A similar study has been done in Sasmal (1998).

[10] In the cross section farm level data the prices of inputs and output are same for all farmers. So, prices could not be included in the regression as explanatory variables.

the function. u is the random term with $E(u) = 0$. The parameters of regression Eq. (2.29) are estimated by the OLS method. The source and the methodology of collecting data have been discussed in Sect. 2.3. The regression Eq. (2.29) has been estimated for HYV paddy for the dry season and the rainy season separately.

2.4.8 Explanations for the Adoption of High-Yielding Variety Technology in the Dry Season

The estimates of the regression Eq. (2.29) for the dry season have been presented in Table 2.8.[11] The very high R^2 implies that the proportion of land allocated to HYV in the dry season is well explained by the chosen explanatory variables. The F-Statistic is also statistically significant indicting that 'goodness of fit' of the regression equation to the observed data is high.

The results in Table 2.8 show that the regression coefficients of X_1, X_2 and X_3 are statistically significant at 5 % level. That means, farm size, proportion of land under irrigation and supply of credit to the farmer are significant factors in the determination of the proportion of land to be allocated to HYV technology in the dry season. The regression coefficient of education is found to be insignificant. The constant term is significant and positive. These results can be explained in the following way:

(a) The regression coefficient of farm size is statistically significant and it is negative in sign. This means that the relationship between the 'proportion of land allocated to HYV' and farm size is inverse. The implication of this result is that small farmers allocate a higher proportion of land to HYV compared to large farmers. This result is very important and it contradicts the view that small farm size is a serious constraint to the adoption of a new technology in agriculture. The theoretical justification of this result is that if relative risk aversion increases with farm size, the relationship between the 'proportion of land allocated to HYV' and farm size will be negative, if there is no fixed adoption cost (Feder 1980). Now, the question why does relative risk aversion increase with farm size? It also needs to be seen whether there is any fixed cost in the adoption of this new technology in the present case. The following are the relevant explanations:

(i) This study finds that the adoption of HYV technology, by and large, involves no fixed cost in the present case. Generally, the acquisition of knowledge about the new technology, the setting up of irrigation pump, the purchase of equipments like tractor/power tiller, threshing machine, etc., involve some fixed cost. In the present case, the government has played an important role in

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[11] It is observed that there is no significant multicollinearity among the explanatory variables of regression Eq. (2.1) both in the dry and the rainy seasons.

Table 2.8 Regression results showing the relationship between the 'proportion of land allocated to HYV' and the explanatory variables in the dry season

Explanatory variables		Coefficients of the variables	t-value of the coefficients
(1)		(2)	(3)
X_1	$\alpha_1 =$	−2.045 (1.088)	-1.88^a
X_2	$\alpha_2 =$	0.603 (0.039)	15.32^a
X_3	$\alpha_3 =$	0.002 (0.001)	2.05^a
X_4	$\alpha_4 =$	0.004 (0.044)	0.09
Constant term	$\alpha_0 =$	14.385 (4.780)	3.01^a
	$R^2 = 0.52$, $F = 55.56$, $n = 262$		

Figures in parentheses are standard errors

Source Sasmal (1992)

[a] Significant at 5 % level

the diffusion of knowledge about the technology through extension services. As a result, the farmers have been able to gather knowledge free of cost. The services of threshing machine, spray machine and power tiller are easily available on hire against payment of rental charges in the particular area of study. In fact, a market has developed in the area to provide such services. So, the farmers, particularly the small farmers, do not require to purchase these equipments of their own. The most important item which may involve some fixed cost in the process of adoption is the setting up of irrigation pump, because without irrigation, HYV paddy cultivation is not possible, particularly in the dry season. But the government has set up huge irrigation network in the public sector in the present situation. So, most of the farmers do not have to bear any fixed cost for irrigation. Thus, the fixed cost of adoption of the HYV technology in the present study is either zero or it is borne by the government.

(ii) Apart from providing irrigation and extension services, the government also plays an important role in supplying credit to the farmers through banks and cooperative societies. In addition, there are arrangements for supplying agricultural inputs like fertilizers, seeds and pesticides to the farmers through authorized dealers at subsidized rates. As a result of these facilities, the risk and uncertainty in production and the risk aversion of the farmers specially of the small farmers decline sufficiently.

(iii) Given the above facilities, the small farmers get some additional advantages from family labour over their larger counterparts as HYV paddy is highly labour-intensive.[12]

The survey report informs that the degree of farm mechanization is very limited in the area of the study. So, the farmer's dependence on hired labour increases with increase in farm size. As a result, the uncertainty in timely

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[12] The estimation of production functions for HYV paddy in Sect. 2.3 shows that HYV paddy is highly labour intensive. Similar result is also obtained by the studies of Ruttan (1977), Harriss (1972).

availability of labour increases. At the same time, the possibility of less skilled labourers getting employed in large numbers also increases. All these lead to additional risk in production for large farmers. Moreover, as the demand for hired labour increases, the wage rate rises. This, in turn, increases the wage bill paid to the workers. In effect, the large farmers decide to use HYV technology at a lower rate to avoid the risk of financial loss in the event of crop failure. Thus the large farmers are placed in a position of comparative disadvantage vis-a-vs the small farmers who depend mainly on family labour for cultivation. As a result of the above reasons, the relative risk aversion increases with increase in farm size.

Therefore, the absence of fixed cost for adoption of the new technology, the government involvement in irrigation, credit, etc., the greater intensity of labour use in HYV paddy cultivation and the limited mechanization explain an inverse relationship between the rate of adoption of the HYV technology and farm size. The result has the implication that the non-availability of labour may become a constraint to the extensive use of the technology in large farms. Another important observation of this study is that the provisions of irrigation, credit supply and extension services in the public sector enable the farmers, particularly the small farmers, to adopt the HYV technology at a larger scale. The role of the government in the diffusion of a new technology in agriculture has been explained by Feder and Slade (1985). They have argued that in the initial stage of adoption, the farmers have limited knowledge about the new technology. So, there may be a divergence between the true distribution and the perceived distribution of the net benefits from the new technology and this divergence may act as a deterring factor to adoption of the technology. Therefore, government should take an active role in the diffusion of knowledge through extension services. They also recommend government involvement in irrigation and credit supply for rapid adoption of a new technology. Moreover, in less developed countries like India, information about a new agricultural technology and provision for irrigation are considered as public goods. Public sector investment in the dissemination of information and development of irrigation is also justified on the ground of strong positive externalities. As regards the government involvement in supply of credit one has to consider the typically imperfect nature of rural credit markets in less developed countries. The market imperfection can not ensure desirable amounts of credit to the farmers. So, in a less developed country like India, the role of the government is very important for technological change and productivity growth in agriculture.

(b) The coefficient of irrigation has been found to be positive and statistically significant in Table 2.8. It means that the proportion of land under irrigation has significant impact on the proportion of land to be allocated to HYV in the dry season. As the coefficient is positive, it implies that the percentage of land under HYV will increase if the percentage of land under irrigation increases. Irrigation has appeared to be the most important factor in determining the proportion of land to be allocated to HYV in the dry season. First of all, cultivation of paddy is not possible in the dry season without irrigation.

However, it may be pointed out that an extension of irrigation does not necessarily lead to greater allocation of land to HYV. The proportion of land under HYV will increase only when the irrigation is sufficiently risk-reducing and mean productivity-raising. The irrigation systems are more effective in the dry compared to the rainy season. Besides, the physical environment and the agro-climatic conditions in the dry season are more appropriate for the cultivation of HYV paddy. In the present study, it is found that the mean output of HYV paddy is sufficiently higher and the variance of output is significantly lower in the dry season than those in the rainy season. So, it is very natural that the impact of irrigation on the rate of adoption of HYV technology will be significant and positive in the dry season.

(c) The regression coefficient of the supply of credit has been found to be positive and statistically significant. It suggests that the supply of credit to the farmers from institutional sources is helpful for allocating more land to modern cultivation. That means, effective credit constraint is there in the dry season. The study here considers the effect of short term credit only. The cultivation of HYV paddy involves a big amount of financial investment. But most of the farmers in India are poor, and they are in need of credit. Under such circumstances, if sufficient credit is made available from institutional sources, the farmers will be encouraged to devote greater amount of land to modern cultivation. This explanation is consistent with the theoretical result of Feder (1980) which suggests that in the presence of an effective credit constraint, an increase in credit supply will lead to greater allocation of land to modern cultivation. However, it may be noted that the mere expansion of credit supply will not be helpful for adoption of a new technology unless the supporting facilities like irrigation, proper knowledge about the technology, regular supply of inputs are available. In addition and more importantly, the soil and climatic conditions will have to be suitable for HYV cultivation.

(d) The coefficient of education has been found to be insignificant in determining the proportion of land to be allocated to HYV cultivation in the dry season. This result is not very unusual. The studies of Harriss (1972), Rahm and Huffman (1984), Lin (1991) show that education increases the degree of adoption of a new technology by enhancing the farmer's efficiency. Schultz (1975) also expresses the view that in a modernizing agriculture, education is more important than experience. But in a static traditional agriculture, experience is more valuable than education. Kalirajan and Shand (1985) are of the view that in cases where the new technology is well adapted to local conditions, experience and receptivity to advise may be more important than education.

Therefore, at the early stage of adoption of a new technology when the farmers do not have much knowledge about the technology, education is very important. But after the introduction of the technology, when the farmers are quite familiar with it and the technology itself gets adapted to the local conditions, education may be less important in the process of adoption. In the present case, the HYV technology has been in use in the area for a period of more than two decades. Endowed with such a long experience, the farmers are very likely to have acquired sufficient knowledge about the technology and this has been confirmed also in the survey report of the study. At this stage, one may not find much impact of education on the rate of adoption of the HYV technology in a cross section study. But depending on this result, one should not conclude that education has no role in the degree of adoption of a new technology in agriculture.

2.4.9 *Explanations for Adoption of High-Yielding Variety in Paddy Cultivation in the Rainy Season*

The estimates of the regression Eq. (2.29) for the rainy season have been presented in Table 2.9. The results show that R^2 is not very high, but the F-statistic is significant. The equation fits well to the observed data although the variation in the adoption rate is not significantly explained by the explanatory variables. The results reveal that only the coefficient of farm size is significant and it is negative in sign as in the dry season. But the coefficients of X_2, X_3 and X_4 are insignificant. That means, irrigation, supply of credit and education have no significant effect on the proportion of land to be allocated to HYV cultivation in the rainy season. The constant term is found to be significant and positive. These results are explained in the following way:

The reasons behind the inverse relationship between the proportion of land allocated to HYV and farm size in the rainy season are same as those of the dry season. Here again, the absence of fixed cost for adoption of a new technology, the government involvement in irrigation, credit, etc., more intensive use of labour in HYV paddy cultivation and limited mechanization explain such a relationship.

The most striking result for the rainy season is that the proportion of land under irrigation has no significant impact on the proportion of land allocated to HYV. In

Table 2.9 Regression results showing the relationship between the 'proportion of land allocated to HYV' and the explanatory variables in the rainy season

Explanatory variables		Coefficients of the variables	t-value of the coefficients
(1)		(2)	(3)
X_1	$\alpha_1 =$	−10.660 (2.295)	-4.65^a
X_2	$\alpha_2 =$	0.018 (0.067)	0.28
X_3	$\alpha_3 =$	0.001 (0.003)	0.41
X_4	$\alpha_4 =$	0.115 (0.118)	0.98
Constant term	$\alpha_0 =$	55.490 (9.710)	5.71^a
	$R^2 = 0.15$, $F = 4.66$, $n = 136$		

Figures in parentheses are standard errors

[a]Significant at 5 % level

Source Sasmal (1992)

explaining this result it may be pointed out that the cultivation of HYV paddy in the rainy season is highly risky and less profitable (already explained in Sect. 2.3). This is mainly because the physical environment and the agro-climatic conditions of the rainy season are, in general, not suitable for HYV paddy cultivation. The problems of excess rainfall, waterlogging, abrupt change in weather condition etc., are very common. The plants are also more vulnerable to pests and disease in the rainy season. Under such conditions, HYV paddy is less adaptable and cultivation is risky. In addition, the irrigation systems are also not very effective in the rainy season, because they are mostly designed for dry season. Given these constraints, irrigation fails to make significant impact on the rate of adoption of the HYV technology in the rainy season. This result is consistent with our theoretical argument that irrigation leads to greater allocation of land to modern variety only if the irrigation is sufficiently risk-reducing and mean-output-raising.

The impact of short term credit on the degree of adoption of the HYV technology is insignificant in the rainy season. It has already been explained that if there is an effective credit constraint, an increase in credit supply will lead to greater allocation of land to modern cultivation. But mere expansion of credit may not be effective in raising the degree of adoption, unless the supporting facilities like effective irrigation system, etc. are available and agro-climatic conditions are suitable for HYV cultivation. But these conditions are not fulfilled in the rainy season. It has been already explained that the HYV paddy is risky and less adaptable in the rainy season due to adverse physical and agro-climatic conditions. So, credit supply has no role in the adoption of the new technology in the rainy season. As in the dry season, in the rainy season also, education has been found to have no significant impact on the degree of adoption of the HYV technology. The explanation is the same as before.

2.4.10 Irrigation and the Adoption of HYV Technology at the National Level—A Time Series Analysis

The HYV technology has been adopted in India on a large scale mainly in foodgrains production. The percentage of area under HYV cultivation in foodgrains production has increased from 15 % in 1970–71 to 61 % in 1997–98. The use of chemical fertilizer, an important component of HYV technology, has increased from 17.74 kg per hectare in 1970–71 to 115.25 kg in 2007–08 (Source: Economic Survey, Government of India, various issues). The extension of irrigation, particularly tube-well irrigation, has played a significant role in this technological change. The percentage of net irrigated area in the country has increased from 22.17 to 44.2 % during this period. In this sub-section, the relationship between irrigation and the use of HYV technology in foodgrains cultivation has been empirically verified by time series analysis. The variables considered here are percentage of area under HYV cultivation (PERCENT_HYV), net cropped area under irrigation

(N_IRRI_A), area under tube-well irrigation (T_WELL_IRRI_A) and fertilizer (Fert). The sources of data are Economic Survey, Government of India (several issues), Centre for Monitoring Indian Economy (CMIE) (2002 2010). The period of analysis ranges from 1970–71 to 2007–08. The time series analysis has been done using methods outlined in Enders (2004).

2.4.11 Methodology of Analysis

To check stationarity of the series of the variables Augmented Dickey-Fuller (ADF) Unit Root Test has been done. Engle-Granger Cointegration Test has been done to examine whether the series are cointegrated or not. After cointegration, Granger Causality Test and OLS Regression have been done to examine the direction and magnitude of the relationship among the variables over time. The results show that there is meaningful and significant relationship between irrigation, HYV cultivation and fertilizer use. The results of ADF Unit Root Test in Table 2.10 show that the series PERCENT_HYV, N_IRRI_A, T_WELL_IRRI_A and Fert are stationary at first difference.

In Engle-Granger Cointegration Test in Table 2.11, it is found that the series PERCENT_HYV and N_IRRI_A are Cointegrated i.e., PERCENT_HYV and N_IRRI_A are C (1, 1). That means, there is meaningful relationship between the two variables. The pair-wise Granger Causality Test of Table 2.12 suggests that there is bi-directional causality between them. If the variables are cointegrated the OLS regression coefficients give efficient estimates. The results in Table 2.13 show that R^2 is very high. The high value of F-Statistic shows overall significance of the regression. The coefficient of N_IRRI_A is positive and statistically highly significant. That means, expansion of area under irrigation significantly explains the adoption of HYV technology in foodgrains production in India over time.

One interesting feature of expansion of irrigation is that the area under irrigation has increased mainly due to increase of tube-well irrigation. The share of tube-well irrigation in net irrigated land increased from 12 to 42 % in the last four decades. On the other hand, area under canal irrigation has remained more or less constant and irrigation from tanks has declined (Centre for Monitoring Indian Economy, CMIE 2010).

The results of Engle-Granger Cointegration Test of Table 2.14 show that T_WELL_A and N_IRRI_A are cointegrated at first difference i.e. C (1, 1). That means, there is meaningful relationship between them. The series are stationary at first difference (see Table 2.10). The OLS regression of N_IRRI_A on T_WELL_A shows that the increase of net irrigated area is explained positively and significantly by the expansion of area under tube-well irrigation. The result has the implication that it is the expansion of tube-well irrigation that has significantly helped the adoption of HYV technology in India in foodgrains production on a wide scale (Table 2.15).

Table 2.10 Augmented Dickey_Fuller unit root test of the series of variables

	t-statistic	Prob*
Null hypothesis: D (PERCENT_HYV) has a unit root[a]		
Time period: 1970–1996		
ADF test statistic	−6.0529	0.000
Test critical values		
1 % level	−3.7378	
5 % level	−2.9918	
10 % level	−2.6355	
Null hypothesis: D (N_IRRI_A) has a unit root		
Time period: 1970–1996		
ADF test statistic	−10.0632	0.000
Test critical values		
1 % level	−3.6267	
5 % level	−2.9458	
10 % level	−2.6115	
Null hypothesis: D (T_WELL_IRRI_A) has a unit root		
Time period: 1970–1996		
ADF test statistic	−7.0314	0.000
Test critical values		
1 % level	−3.6267	
5 % level	−2.9458	
10 % level	−2.6115	
Null hypothesis: D (Fert) has a unit root		
Time period: 1970–2007		
ADF test statistic	−5.5357	0.000
Test critical values		
1 % level	−3.6267	
5 % level	−2.9458	
10 % level	−2.6115	

*Mackinnon (1996) one sided p-values

[a] We have been able to collect appropriate data on HYV cultivation in foodgrains production from Economic Survey, Government of India, upto 1996–97. The data available from other sources after this period are not very consistent

Table 2.11 Engle-Granger cointegration test between PERCENT_HYV and N_IRRI_A

Series: PERCENT_HYV N_IRRI_A				
Time Period: 1970–1996				
Null hypothesis: series are not cointegrated				
Dependent	tau-statistic	Prob*	Z-statistic	Prob*
PERCENT_HYV	−4.8238	0.003	−24.1363	0.003
N_IRRI_A	−4.9230	0.002	−25.6596	0.001

*Mackinnon (1996) p-values

Table 2.12 Pair-wise Granger causality test between PERCENT_HYV and N_IRRI_A

Period: 1970–1996		
Lag: 2		
Null hypothesis	F-statistic	Prob
N_IRRI_A does not Granger cause PERCENT_HYV	2.9085	0.077
PERCENT_HYV does not Granger cause N_IRRI_A	3.3187	0.056

Table 2.13 OLS regression of PERCENT_HYV on N_IRRI_A

Dependent variable: PERCENT_HYV			
Observation: 27			
Variable	Coefficient	t-statistic	Prob.
N_IRRI_A	0.0017	16.7194[a]	0.000
C	−34.3681	−7.5985	0.000
$R^2 = 0.91$			
Adjusted $R^2 = 0.91$			
F-statistic = 279.53			

[a]Significant at 1 % level

Table 2.14 Engle-Granger cointegration test between T_WELL_IRRI_A and N_IRRI_A

Series: T_WELL_IRRI_A N_IRRI_A				
Null hypothesis: series are not cointegrated				
Dependent	tau-statistic	Prob*	Z-statistic	Prob*
T_WELL_IRRI_A	−3.9217	0.0198	−22.3673	0.012
N_IRRI_A	−4.1277	0.0122	−23.6541	0.008

Table 2.15 OLS regression of N_IRRI_A on T_WELL_IRR_A

Dependent variable: N_IRRI_A				
Variable	Coefficient	t-statistic	Prob.	R^2
T_WELL_IRRI_A	1.4112	24.6528[a]	0.000	0.94
Constant	26080.77	28.4747[a]	0.000	

[a]Significant at 1 % level

The use of chemical fertilizer (Fert) is an important part of HYV technology and technological change in agriculture. In the last four decades there has been nearly seven-fold increase of fertilizer use per hectare in the country. The expansion of irrigation and use of HYV seeds are significantly responsible for the increase of fertilizer use. The results in Table 2.16 shows that N_IRRI_A and Fert are cointegrated at first difference i.e. C (1, 1). So, there is meaningful long-run relationship between them. The OLS regression in Table 2.17 shows that fertilizer use is positively and significantly affected by irrigation. So, it can be concluded that expansion of tube-well irrigation has not only increased the area under irrigation but also significantly helped the adoption of HYV technology and fertilizer use (Table 2.18).

Table 2.16 Engle-Granger cointegration test between N_IRRI_A and Fert

Null hypothesis: series are not cointegrated				
Time period: 1970–2007				
Dependent	tau-statistic	Prob*	Z-statistic	Prob*
Fert	−4.2787	0.0084	−25.0848	0.005
N_IRRI_A	−4.5700	0.0040	−26.4428	0.003

Table 2.17 OLS regression of Fert on N_IRRI_A

Dependent variable: Fert			
Variable	Coefficient	t-statistic	Prob.
N_IRRI_A	0.0030	25.0027	0.000
Constant	−86.2349	−14.6017	0.000
$R^2 = 0.94$			
F statistic = 625.13			
Sample size = 38			

Table 2.18 Cropped area and production of foodgrains and some major crops in India

	1970–71	1990–91	2000–01	2012–13
Gross cropped area under foodgrains (million hectares)	124.32	127.84	121.05	120.78
Total production of foodgrains (million tonnes)	108.42	176.39	196.81	257.13
Gross cropped area under rice (million hectares)	37.76	42.69	44.71	42.75
Total production of rice (million tonnes)	43.07	74.29	84.98	105.24
Gross cropped area under wheat (million hectares)	19.14	24.17	25.73	30.00
Total production of wheat (million tonnes)	23.83	55.14	69.68	93.51
Gross cropped area under pulses (million hectares)	22.02	24.66	20.35	23.26
Total production of pulses (million tonnes)	11.82	14.26	11.08	18.34
Gross cropped area under oilseeds (million hectares)	16.64	24.15	22.77	26.48
Total production of oilseeds (million tonnes)	9.63	18.61	18.44	30.94

Source Agricultural statistics at a Glance 2014, Government of India, Ministry of Agriculture, Oxford University Press 2015a

2.4.12 Summary

Following Feder (1980) it has been theoretically explained how the optimal share of land allocated to modern cultivation and the amount of fertilizer to be used per unit of land are determined under production uncertainty. The degree of risk and risk preference of the farmers play important role in the decision of adoption of a new technology. The adoption rate of the new technology may be higher in small farms under certain favourable conditions. The degree of risk and effective credit constraint may act as obstacles to technological change in agriculture. Irrigation is important for reducing uncertainty in production and increasing mean output. However, irrigation will lead to higher adoption of a modern technology only when irrigation is sufficiently risk-reducing and mean output-raising.

The empirical study based on farm level primary data in paddy cultivation, the use of HYV technology is explained significantly by irrigation, credit supply and farm size. Irrigation plays the most important role in this regard. The relationship between adoption rate of HYV technology and farm size is found to be negative implying that small farmers use the new technology at a higher rate compared to the big farmers. At the aggregate level, irrigation specially tube-well irrigation has played a crucial role in the spread of HYV technology and use of fertilizer in India.

2.5 Technological Change and Productivity Growth in Indian Agriculture

The Indian agriculture has undergone significant technological changes in the last four decades leading to remarkable growth in productivity in the cultivation of major crops. The technological change can be conceived as a package programme consisting of use of modern variety seeds, chemical fertilizers, pesticides and expansion of irrigation, specially tube-well irrigation. The HYV technology was first introduced in foodgrains production and subsequently it has been extended to other crops. The net cropped area in India has remained more or less fixed at 1,40,267 thousand hectares in the last 40 years although the gross cropped area has increased from 1,65,791 thousand hectares in 1970–71 to 1,95,835 thousand hectares in 2007–08 due to intensive farming. The gross cropped area under foodgrains has remained unchanged around 124 million hectares during this period. But the production of foodgrains has increased from 108.42 million tonnes in 1970–71 to 257.13 million tonnes in 2012–13 (Source: Centre for Monitoring Indian Economy 2002, 2010). That means, the production of foodgrains has been more than doubled and this remarkable increase in production can be largely attributed to productivity growth. The yield per hectare in foodgrains production has increased from 872 kg in 1970–71 to 2128 kg in 2012–13 (See Table 2.19). It is also revealed in Table 2.19 that the two major foodcrops rice and wheat have achieved noticeable growth in productivity in India in the last four decades. However, pulses and sugarcane could not show much progress in productivity. The increase in yield in cotton is found to be very high although the productivity in the cultivation of oilseeds has remained moderate in the same period. On the whole, the productivity of all crops has increased over the years. But the productivity growth in the cultivation of foodgrains specially in rice and wheat is found to be very impressive.

Table 2.19 Yield of major crops per hectare in India (kilogram per hectare)

Crop	Year		
	1970–71	1990–91	2012–13
Foodgrains	872	1380	2128
Rice	1132	1740	2462
Wheat	1307	2281	3117
Pulses	524	578	789
Oilseeds	579	771	1168
Sugarcane	48	65	70
Cotton[a] (Bales of 170 kgs per hectare)	106	225	486

Source Economic Survey, Government of India (2015b)

[a]Yield is measured in terms of Bales per hectare

Let us now see how various components of technological change have contributed to this productivity growth. The use of HYV seeds has played an important role in the present context. Table 2.20 shows that the gross area under foodgrains brought under HYV scheme has increased from 18.70 million hectares in 1970–71 to 76 million hectares in 1997–98. That means, nearly 62 % of the gross cultivated area under food-grains are using HYV seeds and other related inputs. In the cultivation of rice and wheat in particular, the use of HYV seeds is very high (see Table 2.21). The major food-producing states like Uttar Pradesh, Punjab, Haryana, Andhra Pradesh, Madhya Pradesh, West Bengal have largely adopted the modern variety of seeds in foodgrains cultivation (See Table 2.22).

The HYV technology is closely associated with irrigation and fertilizer use. Table 2.23 shows that net irrigated area in the country has increased from 31,103 thousand hectares in 1970–71 to 62,286 thousand hectares in 2007–08 which is 44.22 % of the net cropped area of the country. The area under irrigation in India has increased largely banking on tube-well irrigation. The share of tube-well irrigation in the total irrigated land of India has increased from 14.34 to 41.91 % in the last four decades (See Table 2.23). The three-fold increase of tube-well irrigation has greatly facilitated HYV cultivation and fertilizer use. The use of HYV seeds and fertilizer combined with irrigation have resulted in significant growth of productivity in the farming sector. Table 2.24 shows that total fertilizer consumption has increased from 2657 thousand tonnes in 1970–71 to 25,536 thousand tonnes in 2007–08 with the result that fertilizer use per hectare has increased from 17.74 to 130 kg during this period. The significant increase of nitrogen fertilizer over the years is also an indicator of technological change in Indian agriculture.

Table 2.20 Gross area under HYV scheme in foodgrains production of India (million hectares)

1970–71	1980–81	1990–91	1997–98[a]
18.70	43.10	65.00	76.00

Source Economic survey, Government of India, several issues

[a]After 1997–98, systematic and consistent data on HYV cultivation are not available

Table 2.21 Crop-wise increase of area under HYV scheme in foodgrains production of India (million hectares)

Year	Rice	Wheat	Jowar	Bajra	Maize
1970–71	5.59	6.68	0.80	2.05	0.46
1989–90	26.16	20.29	6.87	5.59	2.26

Source Indian Agriculture in Brief, 24th edition, Ministry of Agriculture, Government of India (1992)

Table 2.22 State-wise area of using HYV seeds in major food crops of India in 1990–91 (lac hectares)

States	Rice	Wheat	Bajra
Andhra Pradesh	36.51	–	–
Bihar	16.43	15.00	–
Madhya Pradesh	27.50	20.00	–
Punjab	18.24	32.40	–
Haryana	–	18.30	–
Orissa	26.00	–	–
Maharashtra	–	–	37.59
Uttar Pradesh	48.61	82.00	–
West Bengal	34.43	–	–
Tamil Nadu	17.80	–	–

Source Indian Agriculture in Brief, 24th edition, Ministry of Agriculture, Government of India (1992)

Table 2.23 Increase of net irrigated area in Indian Agriculture over time (000 ha)

	1970–71	1990–91	2000–01	2007–08
Net irrigated area	31,103 (22.17)[a]	48,023 (33.61)[a]	55,133 (39.00)[a]	62,286 (44.22)[a]
Area under tube-well irrigation	4461 (14.34)[b]	14,257 (29.68)[b]	22,569 (40.93)[b]	26,105 (41.91)[b]

Source Centre for Monitoring Indian Economy, CMIE (1998, 2010)

[a] Figures in parentheses are percentage shares of irrigated area in total cultivated land

[b] Figures in parentheses are percentage shares of tube-well irrigation in total irrigated land

2.5.1 Technological Change and Productivity Growth—A Time Series Analysis

The technological change has taken place mainly in foodgrains production and like in other developing countries foodgrains production is the major farming sector of India. So, we are interested in the yield of foodgrains production (Yield) in the present study. We have explained the growth in Yield by fertilizer use (FERT) and

Table 2.24 Use of chemical fertilizers in Indian agriculture over time (000 tonnes)

	1970–71	1990–91	2000–01	2007–08
Total consumption of fertilizers	2657	12,546	16,631	25,536
Total consumption of nitrogen (N)	1798	7997	10,862	16,820
Total consumption of phosphate (P)	558	3221	4212	6653
Total consumption of potassium (K)	201	1328	1557	2061
Consumption of fertilizers per hectare (kg)	17.74	67.55	89.73	130

Source Agricultural statistics at a Glance 2014, Ministry of Agriculture, Government of India, Oxford University Press 2015a

expansion of net irrigated area (N_IRRI_A) using time series techniques as outlined in Enders (2004). The series of Yield, FERT and N_IRRI_A are stationary at first difference in Augmented Dickey-Fuller Unit Root Test (see Tables 2.25 and 2.29). The results in Table 2.26 show that the series of Yield and FERT are cointegrated of the same order in Engle-Granger Cointegration Test i.e. the series are CI(1, 1). Since the variables are cointegrated, there is meaningful long-run relationship between them and the OLS regression gives efficient estimates of their relationship. Here, the results of OLS regression of Yield on FERT in Table 2.28, show that the coefficient of FERT is positive and statistically significant at 1 % level. That means, yield in foodgrains production is significantly explained by fertilizer use. Moreover, we find a Granger causality between the two variables. There is two-way causality. FERT Granger causes Yield and the other way round (See Table 2.27). The economic interpretation is that fertilizer use enhances

Table 2.25 Augmented Dickey-Fuller unit root test on D (Yield) and D (FERT)

	t-statistic	Prob*
Null hypothesis: D (Yield) has a unit root		
Period: 1970–2012		
Augmented Dickey-Fuller test statistic	−6.7263	0.000
Test critical values		
1 % level	−3.6009	
5 % level	−2.9350	
10 % level	−2.6058	
Null hypothesis: D (FERT) has a unit root		
Period: 1970–2012		
Augmented Dickey-Fuller test statistic	−5.2616	0.000
Test critical values		
1 % level	−3.6155	
5 % level	−2.9411	
10 % level	−2.6090	

*Mackinnon (1996) p-values

Table 2.26 Engle-Granger cointegration test

Series: Yield FERT				
Period: 1970–2012				
No. of observation: 42				
Null hypothesis: series are not cointegrated				
Dependent	tau-statistics	Prob	z-statistic	Prob*
YIELD	−3.7441	0.028	−16.042*	0.079
FERT	−4.1493	0.010	−17.023*	0.061

*Mackinnon (1996) p-values

Table 2.27 Pair-wise Granger causality test between yield and FERT

Null hypothesis			
		F-statistic	Prob*
FERT does not	Granger cause yield	8.209	0.001
Yield does not	Granger cause FERT	6.055	0.005

*Mackinnon (1996) p-values

Table 2.28 OLS regression of yield on FERT

Dependent variable: yield			
No. of observations: 42			
Variable	Coefficient	t-statistic	Prob
FERT	9.7907	32.104[a]	0.000
C	719.1439	31.235[a]	0.000

$R^2 = 0.96$

F-statistic = 1030.72

[a] Significant at 1 % level

Table 2.29 Augmented Dickey-Fuller unit root test On D (Yield) and D (N_IRRI_A)

	t-statistic	Prob*
Null hypothesis: D (Yield) has a unit root		
Period: 1970–2007		
Augmented Dickey-Fuller test statistic	−6.7233	0.000
Test critical values		
1 % level	−3.6009	
5 % level	−2.9350	
10 % level	−2.6058	
Null Hypothesis: D (N_IRRI_A) has a unit root		
Period: 1970–2007		
Augmented Dickey-Fuller test statistic	−10.0632	0.000
Test critical values		
1 % level	−3.6267	
5 % level	−2.9458	
10 % level	−2.0115	

*Mackinnon (1996) p-values

productivity of land and at the same time, higher productivity encourages more use of fertilizer per hectare.

The Engle-Granger Cointegration Test in Table 2.30 shows that the series of Yield and N_IRRI_A are cointegrated of the same order i.e. the variables are CI (1, 1). Therefore, there is meaningful long-run relationship between 'net area under irrigation' and yield in foodgrains production. Since the variables are cointegrated the estimates of OLS regression between them will be efficient. The results in Table 2.32 show that irrigation has strong positive impact on yield in foodgrains cultivation. In Engle-Granger Causality Test, it is found that N_IRRI_A Granger causes Yield (see Table 2.31). In fact, irrigation has been found to be the main driving force in productivity growth.

Using the same data set and taking log of the variables we have estimated the elasticity of Yield with respect to FERT, N_IRRI_A and HYV following the equation:

$$\log Y = \alpha_0 + \alpha_i \log X_i, \quad i = 1, 2, 3$$

Table 2.30 Engle-Granger cointegration test

Series: yield N_IRRI_A

Period: 1970–2007

Null hypothesis: series are not cointegrated

Dependent	tau-statistic	Prob*	z-statistic	Prob*
YIELD	−4.7291	0.002	−28.0433	0.001
N_IRRI-A	−4.9838	0.001	−29.5895	0.001

*Mackinnon (1996) p-values

Table 2.31 Fair-wise Granger causality test between N_IRRI_A and yield

Null hypothesis	F-statistic	Prob*
N_IRRI_A does not Granger cause yield	2.8616	0.072
Yield does not Granger cause N_IRRI_A	2.1754	0.130

Table 2.32 OLS regression of yield on N_IRRI_A

Dependent variable: yield

No. of observations: 37

Variable	Coefficient	t-statistic	Prob
N_IRRI_A	0.0329	26.3054[a]	0.000
C	−237.8337	−3.9889[a]	0.000

R^2 = 0.95, F-Statistic = 691.97

[a] Significant at 1 % level

where Y = Yield, X_1 = FERT, X_2 = N_IRRI_A, X_3 = HYV. α_1 = elasticity of Yield w.r.t. FERT, α_2 = elasticity of Yield w.r.t. N_IRRI_A, and α_3 = elasticity of Yield w.r.t. HYV. The estimated results are as follows:

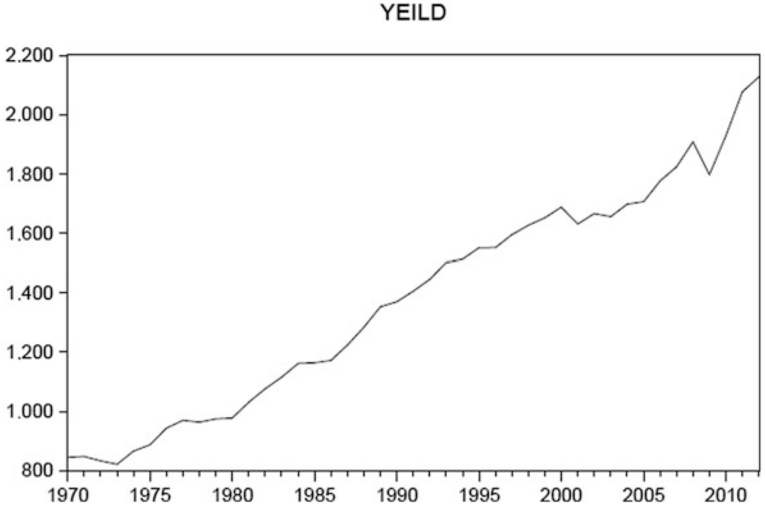

Fig. 2.1 Yield of foodgrains production in India over the period from 1970–71 to 2012 (kilogram per hectare)

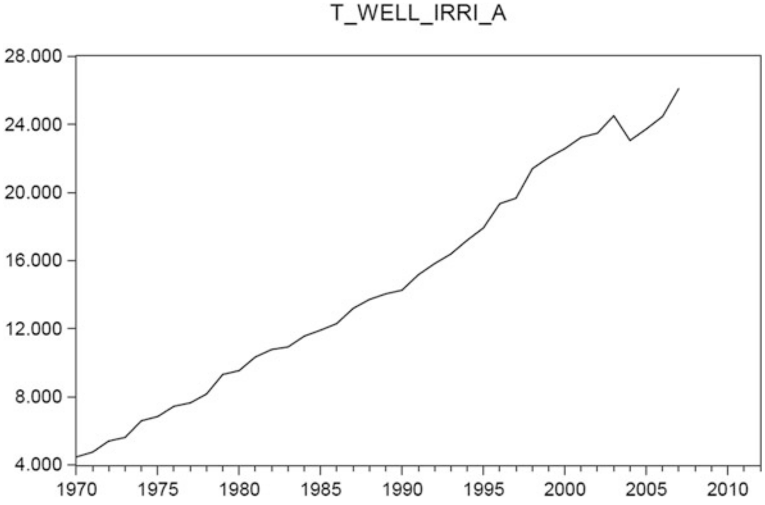

Fig. 2.2 Net irrigated area in India (000 ha) over the years

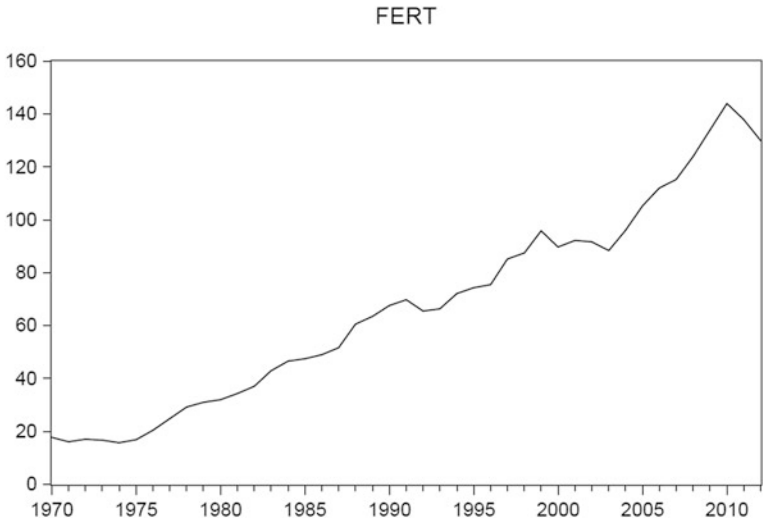

Fig. 2.3 Consumption of chemical fertilizer in Indian agriculture (kilogram per hectare)

$$\alpha_1 = 0.41 \, \alpha_2 = 1.18 \, \alpha_3 = 0.53$$

$\alpha_1 = 0.41$, $\alpha_2 = 1.18$, $\alpha_3 = 0.53$

It is important to note that elasticity of yield with respect to irrigation is highest and it is 1.18. The implication is that if area of irrigation is increased by 100 %, the yield will increase by 118 % (Figs. 2.1, 2.2 and 2.3).

2.5.2 *Summary*

The technological change in Indian agriculture is characterised by significant expansion of irrigation and use of HYV seed and chemical fertilizer on a large scale. As a result of technological change, productivity in agriculture, specially in foodgrains production, has significantly increased. Irrigation, specially tube-well irrigation has been found to be the most important factor in productivity growth.

2.6 Technological Change, Productivity Growth and Resource Degradation

The use of modern technology has enhanced productivity of land significantly through intensive cultivation and application of HYV seeds and chemical inputs like fertilizer and pesticides. The greater intensity of cultivation and the requirement of controlled supply of water in modern cultivation have put excessive stress on natural resources like land and water. Headley (1972) explains clearly that there are a number of environmental problems which are related to the pressure for the productivity growth and the resulting adoption of industrial products and techniques. The technical externalities and under valuation of resources make excessive use of the natural resources. He elaborates the problem by saying that intensive cultivation has been criticized for its contribution to sedimentation problems as well as the alteration of landscape through removal of natural vegetation. Similarly, chemical pesticide use has been seriously attacked for the discharge of toxic chemicals into the environment. Fertilizer use on the other hand has been suspected as a possible source of nitrates in streams and underground water supplies. Side by side with the challenge of providing adequate food and maintaining the income of the farmers, there is now an additional challenge of finding and maintaining the right relationship between agriculture and the natural environment. It has been noted that agriculture is not using the least cost bundle of resources. The inputs such as fertilizers are underpriced because the costs of pollution are not accounted for at the time of their use.

No doubt, the adoption of HYV technology has resulted in remarkable increase in productivity growth in Indian agriculture. But excess depletion of ground water, use of chemical inputs in increasing doses and intensive cultivation have weakened the resource base of the country putting a question mark before the sustainability of growth in agriculture. The total area of degraded land in India is nearly 90 lakh hectares which accounts for 20 % of total cultivated land. The states with large areas of degraded land are Madhya Pradesh (1663 thousand hectares), Rajasthan (879 thousand hectares), Karnataka (779 thousand hectares), Maharashtra (767 thousand hectares), Andhra Pradesh (607 thousand hectares), Gujarat (550 thousand hectares) and West Bengal (526 thousand hectares). In Haryana which is one of the most successful states in India in HYV cultivation, the share of degraded land in total operated area is 34 % against the national average of 20 % (Source: Compendium of Environment Statistics, India 2011). Apart from greater intensity of cultivation, the use of chemical inputs like fertilizers and pesticides is one of the

Table 2.33 Consumption of pesticides in major states of India in 2007–08

States	Total quantity (in metric tonnes)	Use per hectare (kg)
Andhra Pradesh	1381	0.12
Bihar	951	0.13
Gujarat	2650	0.28
Haryana	4288	1.21
Punjab	5760	1.35
Rajasthan	3333	0.21
Tamil Nadu	2317	0.43
Uttar Pradesh	8968	0.53
West Bengal	4100	0.75
All India	43,860	0.31

Source Compendium of Environment Statistics, India (2011)
Ministry of Statistics and Programme Implementation
Government of India

major causes of soil degradation. The use of fertilizers per hectare in agriculturally important states of India are as follows: 216 kg in Punjab, 189 kg in Haryana, 197 kg in Andhra Pradesh, 185 kg in Tamil Nadu and 150 kg in Uttar Pradesh. The national average is 115 kg per hectare (Source: Centre for Monitoring Indian Economy, CMIE 2010). The consumption of pesticides in major states of India is given below in Table 2.33.

The large quantities of use of fertilizers and pesticides not only pollutes food and water but also causes degradation of soil and biodiversity.

The tube-well irrigation has played a very crucial role in the technological change and productivity growth in Indian agriculture. The share of well-irrigation in net irrigated area of the country has increased from 12 % in 1970–71 to 60 % in 2007–08. But excessive extraction of ground water has not only caused a threat to future growth in agriculture but also resulted in contamination and salinization of water and soil. In agriculturally successful states like Punjab and Haryana, the extraction of ground water has crossed the permissible limits. The depletion of ground water is 45 % and 9 % higher in Punjab and Haryana respectively than the permissible limits. In Rajasthan, excess depletion is 25 %. In states like Uttar Pradesh, Tamil Nadu, Karnataka and Gujarat, the extraction of water is more than 70 % of the full potential of ground water irrigation. For the country as a whole, 58 % of the potential of ground water irrigation has been utilized by this time. The remaining 42 % can be utilized for future production and that is mainly in eastern part of India. If water level in the aquifer declines below 10–20 m from the ground level, it becomes difficult or impossible to extract ground water for irrigation. The percentage of wells showing 10–20 m water depth below ground level is very high in states like Punjab (39 %), Haryana (30 %), Rajasthan (29 %), Gujarat (28 %) and Madhya Pradesh (22 %) (Source: Government of India 2009). This is the outcome of excessive dependence on tube-well irrigation. Since India's agricultural growth is largely dependent on ground water irrigation and expansion of surface water irrigation is very limited, the scarcity of water supply has become a serious constraint to future growth. It needs special mention that in Punjab, a state of India, which is known as foodbed of India and where the green revolution technology has been most successfully implemented, the extraction of ground water has crossed the sustainable limit and the use of fertilizer and pesticide is the highest per hectare in the country. The Steering Committee of the Planning Commission observes that the use of nitrogen in excessive doses is adversely affecting the soil profile having its negative impact on land productivity (Bhullar and Sidhu 2006).

According to the World Development Report (2008), the green revolution in Asia has significantly increased cereal production in the continent after 1970. India also has achieved remarkable success in foodgrains production in the last four decades. However, the intensification of farming has brought environmental problems in various ways. The on-site and off-site effects of intensive agriculture have caused soil degradation in the forms of salinization, nutrient depletion, loss of soil organic matters (SOM), agrochemical pollution and loss of local biodiversity. Tilman et al. (2002) estimate that since 1945, approximately 17 % of vegetated land has undergone human induced soil degradation and loss of productivity often through poor fertilizer and water management, soil erosion and shortened fallow periods. The study also notes that continuous cropping and inadequate replenishment of nutrients have caused soil organic matter levels to decline. Land is the most important ingredient of agricultural production and the level of soil fertility depends on the rate of depletion, natural regeneration and artificial replenishment. The depletion rate is determined by intensity and technique of farming. Regeneration, on the other hand, depends on a number of factors like crop rotation, fallow system, application of organic fertilizers etc. (Krautkraemer 1994; Barrett 1991; Sasmal and Weikard 2013).

Sustainability has become an increasingly important issue and there are many definitions of sustainability. Perhaps the most widely acceptable definition of sustainable development is that of the Brundtland Commission that ‘sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (Kolstad 2000). Sustainability requires nondecreasing utility over time or preservation of the opportunity sets available to the future (Krautkraemer and Batina 1999). In optimal growth models using non-renewable resources, capital accumulation and technological progress are engines of economic growth while finite endowments of natural and environmental resources act as drag on economic growth. In such models non-negative growth is feasible if there is enough technological progress, sufficient elasticity of substitution between natural resource inputs and reproducible capital and there are renewable resources that can substitute for the non-renewable resources (Dasgupta and Heal 1974; Solow 1974; Stiglitz 1974; Krautkraemer and Batina 1999). In case of agricultural production where growth depends largely on renewable resources like land and water, the conservation of such resources is very important for sustainability of growth. Rosegrant and Sombilla (1997) have given projection of future global food supply and demand with possible resource limitations including land and land degradation, energy and fertilizer, water availability and global climate change. Although global per capita arable land has been decreasing steadily due to urbanisation and other factors, it is not going to pose a serious threat to future global food production. But land degradation can be devastating in some localities, specially in fragile environments. However, on the global basis, the yield impact of land degradation will be very small relative to crop yield growth from technological change and increased quantity and efficiency of input use. According to their projection, water scarcity is going to be the most serious threat to attainment of projected yield growth in agriculture. Global water withdrawals will increase by 35 % by 2020 and particularly serious pressure on water resources will occur in developing countries where water withdrawals are projected to rise by 43 % in 2020.

The farmers specially in the developing countries, are generally not much serious about maintaining soil health and adopting measures for replenishment of soil nutrients. Lynch and Lovell (2003) have identified the factors that affect the landowner’s decision to participate in agricultural land preservation programmes. In this study, the factors like farm size, growing crops, distance to the nearest city, percentage of income from farming, available information etc. are found to be important in this respect. Since conservation of soil generates ecological services and protects the biodiversity, the policy intervention of the government is required to increase positive externalities of soil conservation and ensure sustainable growth in agriculture (Sasmal and Weikard 2013). In case of conservation of water resource also the government has a big role to play. Dasgupta and Mäler (2009) draw attention to the externality problems associated with the use of natural resources. They also point out the problem of under valuation of natural resources by private agents. Apart from these aspects, the government projects for conservation of natural resources are of public good nature. So, the market will not bring the optimal solution to the problems of resource degradation. Here, government intervention and public investment are very important. The conservation of resources are very important for future production in agriculture. Equally important is the technological change in various fields for productivity growth and resource conservation. Here again, the public policies have crucial role to play.

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Chapter 3
Use of Water Resource and Sustainability of Growth in Agriculture

Abstract This chapter has analysed the importance of water conservation for sustainability of agricultural growth. The elasticity of agricultural production with respect to irrigation is very high and India has achieved significant growth in foodgrains production largely banking on ground water extraction. Using theoretical models and empirical results of time series analysis, this chapter has shown that excess depletion of ground water may make agricultural growth unsustainable in the long run. The effectiveness of price control through taxes and subsidies and crop diversification in favour of less water intensive crops as policy instruments for water conservation have been examined using theoretical models of comparative dynamic analysis and results of the test of cointegration in time series analysis. Mixed results have been obtained in these respects and regional factors like soil characteristics, geographical and agro-climatic conditions and cropping pattern have been found to be important in some cases. A theoretical model has been constructed to demonstrate that optimal public investment by the social planner for harvesting rain water can ensure sustainable balanced growth in agriculture.

3.1 Introduction

Agriculture in India has achieved remarkable success in the last 40 years. The HYV technology, irrigation, use of modern inputs have significantly contributed to this growth. Extension of irrigation, specially tube-well irrigation, has played a pivotal role in the whole process of agricultural growth. The extension of irrigation has greatly facilitated the use of HYV seeds and chemical fertilizers leading to higher productivity in the farming sector. But excess depletion of ground water has caused huge damage to the resource base and it is putting a question mark before the sustainability of growth. Rosegrant and Sombilla (1997) warned that the shortage of water supply would be the major threat to future growth in foodgrains production. Sasmal (2014) shows that the rate of extraction of ground water in most of the states of India is very high and in some states it has crossed the permissible limits.

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This chapter analyses how excess depletion of ground water makes agricultural growth unsustainable in the long run. It shows that the declining rate of growth in yield in foodgrains production has been associated with the declining rate of ground water extraction. So, emphasis has been given on the conservation of water resource and utilization of surface water. Regulatory price measures, crop-diversification in favour of less water intensive crops and rain water harvest have been suggested as alternative policy measures for water management and agricultural growth (Shah et al. 1995; Rao 2002; Goetz 1997; Sasmal 2011, 2014).

This chapter has been devoted to the analysis of ground water conservation following the policy of price control and crop diversification using the framework of comparative dynamic analysis. We have also developed a theoretical model of agricultural growth in this section to demonstrate how investment for rain water harvest can ensure sustainable growth in agriculture. The importance of government intervention and the role of the social planner in resource management and agricultural growth have been highlighted using theoretical models and econometric results.

3.2 Excess Depletion of Ground Water and Supply of Water as a Limiting Factor to Future Growth

3.2.1 Introduction

Agriculture in the less developed countries has achieved remarkable growth specially in foodgrains production in the last few decades. India also has experienced high rate of growth in agricultural production during this period. The index of yield of major crops (base: 1981–82 = 100) has increased to 242.19 in 2012–13. The gross area under cultivation of foodgrains in India has remained more or less constant at 124 million ha for the last four decades. But the yield per hectare has increased from 872 kg in 1970–71 to 2128 kg in 2012–13 (Economic Survey, Government of India 2008–09 and 2014–15). This growth in productivity can be largely attributed to irrigation, high yielding variety (HYV) seed and fertilizer use. In most of the cases these three factors are closely related and they have jointly made significant contribution to productivity growth. Schultz (1964) expressed the view that significant growth in productivity could not be brought about by reallocation of resources in a traditional agriculture. According to him, significant opportunities for growth would become available only through changes in technology. Mellor (1966) is also of the similar view. He observes that the traditional agriculture is characterized by low capital investment and low productivity. A strong and long-lasting effect on productivity will be forthcoming only in a situation of technological change. So, technological change is a necessary condition for growth in a backward agriculture. Accordingly, the modern technology known as HYV technology was adopted in Indian agriculture in the mid-60s. It was a package programme of HYV seeds, chemical fertilizers, pesticides, assured supply of water and a new agricultural practice. The requirement of controlled and assured supply of water of the new technology necessitated the expansion of tube-well irrigation and in fact, the spectacular growth in agricultural productivity in the country could be achieved largely banking on ground water extraction. The extension of irrigation facilitated the use of HYV seeds and chemical fertilizers (Sasmal 2012). In effect, the production of foodgrains in India has increased from 108.4 million tonnes in 1970–71 to 257.10 million tonnes in 2012–13.

The input subsidy, minimum support price (MSP), extension works of the government and higher productivity of modern technology have encouraged large scale adoption of the HYV seeds in the cultivation of paddy and wheat, fertilizer use and investment on tube-well irrigation. The geo-physical condition of the country has also permitted the expansion of tube-well irrigation in most of the cases. The share of irrigated land in net sown area has increased from 22.17 % in 1970–71 to 44.22 % in 2007–08. The share of tube-well irrigation in net irrigated area has increased from 14.34 to 41.91 % during this period. Irrigation has played a crucial role in productivity growth and tube-well irrigation has largely contributed to the expansion of irrigation in the country (Source: Centre for Monitoring Indian Economy 2010).

However, the country is experiencing deceleration in growth in foodgrains production since 1990s. Not only the share of agriculture in GDP has declined from 40 % in 1970–71 to 14 % in 2012–13 but also there is trend of decline in the annual growth rate of yield in the last 20 years. The annual average growth rate of yield in foodgrains production was 2.77 % during the period from 1970–71 to 1995–96. It came down to 0.83 % for the period from 1995–96 to 2005–06. However very recently, the growth rate has improved to some extent. There may be various reasons behind the declining trend. The shortage of water supply is considered to be a major cause of this declining trend in productivity although the other factors like soil degradation, technological stagnation, credit constraint, problems of agricultural marketing, lack of infrastructure are also there. But the point is that irrigation, specially tube-well irrigation is going to be the most important limiting factor for future growth.

Rosegrant and Sombilla (1997) have pointed out that the major threat that may come in the way of future foodgrains production will be the shortage of water supply. Sasmal (2006, 2009) explained how over-exploitation of ground water has weakened the resource base of the country and is putting a threat to the sustainability of growth. The area under canal irrigation has remained more or less constant over a period of 40 years. The tank irrigation on the other hand, has declined at the rate of 1.8 % per year during this period. Although the percentage share of tube-well irrigation in the net irrigated area has remarkably increased, the annual growth rate of tube-well irrigation has declined from late 1990s. The implication is very clear. The potential of tube-well irrigation is going to be exhausted. In this context, Sasmal (2010, 2011) argues for development of infrastructure to harvest rain water for sustaining growth in agriculture. The technological progress for enhancing the productivity of water, better surface water management and crop-diversification in favour of less water-intensive crops are also being suggested to ensure sustainability of growth (Sasmal 2013a, b, 2014).

3.2.2 Extraction of Ground Water and Agricultural Growth

3.2.2.1 The Model

Let us consider an agricultural system where production is based on tube-well irrigation. The production function is:

$$Q = F(W, Z) \tag{3.1}$$

where Q is output, W is extraction of ground water, and Z is some variable input, say, chemical fertilizer. The function has the following specifications:

$$Q_W > 0, Q_{WW} < 0, Q_Z > 0 \text{ and } Q_{ZZ} < 0.$$

There are two sources of water supply—(i) Ground Water and (ii) Surface Water. The quantity of surface water available and utilized for cultivation is fixed due to given infrastructure and natural conditions. So the extraction of ground water is the source of increase in water supply for agricultural growth and it affects the water stock in the aquifer. The dynamics of the stock is:

$$\dot{S} = -W + R$$

where R is natural recharge to the aquifer and it is constant depending on average rainfall and geophysical conditions.

For simplicity, we assume that utilization of surface water is free of cost. But the extraction of ground water involves cost and the cost per unit is denoted by τ. The cost function is:

$$\tau = \tau(W, S) \tag{3.2}$$

where $\tau_W > 0, \tau_{WW} > 0, \tau_S < 0, \tau_{SS} < 0.$

The utility function of the farmer is: $U = U(C)$, where $U'(C)\rangle 0, U''(C)\langle 0.$

The income of the farmer is

$$\pi = P \cdot Q - \tau W - vZ$$

where P is the price of output and v is the price of the variable input and these are given. It is assumed that the whole income is spent on consumption i.e., $\pi = C$. The extraction of ground water and use of chemical inputs have externality problems and they involve some environmental costs. However, the private individuals disregard such costs.

In a decentralized framework, the objective of the private individual is to increase income from agricultural production so that utility from consumption can be increased. So, following Sasmal (2012) the objective of the individual farmer can be defined as:

$$
\begin{aligned}
& Max \int_{0}^{T} \pi\, e^{-\rho t} \cdot dt \\
& \lim T \to \infty \\
\text{s.t. } & \dot{S} = -W + R \\
& S(0) = S_0, S(T) \geq \overline{S}
\end{aligned}
\tag{3.3}
$$

So is the initial stock of ground water and $\overline{S}$ is the minimum stock of water that must be maintained at the end of the planning period. It is a dynamic optimization problem over infinite time horizon which can be solved by using the maximum principle of optimal control theory (Chiang 1992). Here, ρ is the rate of discount of future income.

The current value Hamiltonian is:

$$H = PQ - \tau \cdot W - vZ + \lambda(-W + R) \tag{3.4}$$

Here, W, Z are control variables, S is state variable and λ is costate variable. λ is the current value shadow price of ground water stock. The first order necessary conditions for maximization of H are:

$$\frac{\partial H}{\partial W} = P \cdot Q_W - \tau - \tau_W \cdot W - \lambda = 0 \tag{3.5}$$

$$\frac{\partial H}{\partial Z} = P \cdot Q_Z - v = 0 \tag{3.6}$$

$$-\frac{\partial H}{\partial S} = \dot{\lambda} = \rho\lambda + W \cdot \tau_S \tag{3.7}$$

$$-\frac{\partial H}{\partial \lambda} = \dot{S} = -W + R \tag{3.8}$$

The transversality conditions:

$$
\begin{aligned}
& \lambda(T) \geq 0, \lambda(T)S(T) = 0 \\
& \lim \mathrm{T} \to \infty
\end{aligned}
$$

The second order conditions are satisfied by strict concavity of H in W, Z and S jointly (see Appendix 1). The Eqs. (3.5) and (3.6) determine the optimal values of W and Z at each point of time and they are determined in terms of state, and costate variables and set of parameters as

$$\hat{W} = \hat{W}(S, \lambda, S_0, P, v, \rho)$$
$$\hat{Z} = \hat{Z}(S, \lambda, S_0, P, v, \rho)$$

The condition (3.5) suggests that the marginal benefit of water extraction should be equal to the cost of water extraction plus the cost of not preserving the water resource for future use. On the other hand, in condition (3.6) the marginal benefit of using fertilizer is just equal to the price of fertilizer per unit. Equation (3.7) shows the rate of change of shadow price of ground water over time. Equation (3.8) traces out the dynamics of ground water stock over time.

Now the optimal solution to this dynamic optimization problem can be described by the following two differential equations:

$$\dot{\lambda} = \rho\lambda + W \cdot \tau_S \tag{3.9}$$

$$\dot{S} = -W + R \tag{3.10}$$

In a decentralized system where the private agents disregard environmental and external costs of water depletion and sometimes the government subsidizes the extraction of water, it is very likely that there will be over exploitation of water. That means, $W > R$ and

$$\dot{S} = -W + R \langle 0$$

Now following Jones (2002) this may be expressed as

$\dot{S} = -E$ and $\frac{E(t)}{S(t)} = -\gamma$ (assuming that a constant fraction of the existing stock is depleted for irrigation at each point of time). γ is the ratio of the extraction and stock of the resource.

Now, we have, $\dot{S} = -\gamma S(t)$

The solution to this differential equation gives the path of water stock as

$$S(t) = S_0 e^{-\gamma t} \tag{3.11}$$

where γ will be the rate decline of water stock. The Eq. (3.11) indicates that there will be exponential decay of the water stock in the aquifer. Referring to the Eq. (3.11), it needs to be mentioned here that the stock of the resource will decline at an exponential rate in case of exhaustible resource. But ground water is a renewable resource. So, the stock may not decline at the exponential rate. However, the stock of water will definitely decline over time. Now as water stock declines, $W(t)$ will also decline. Since utilization of surface water remains unchanged in the present model, a lower rate of water extraction will lead to decline in the growth rate of agricultural production (Fig. 3.1).

In balanced growth all the variables grow at the same rate and it requires that the production function exhibits constant returns to scale (CRS). To demonstrate

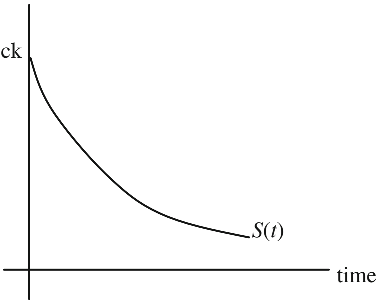

Fig. 3.1 The stock of ground water over time

declining growth rate in agriculture in a balanced growth path, we consider the production function in Cobb-Douglas form with CRS as:

$$Q = AW^{\alpha}Z^{1-\alpha} \tag{3.12}$$

Taking log and derivative of (3.12) with respect to time we get

$g_Q = g_A + \alpha g_W + (1 - \alpha)g_Z$ where g_Q is growth rate of output, g_A is exogenous growth rate of efficiency in production, g_W is growth of depletion of ground water and g_Z is growth rate of fertilizer use:

We assume that there is no technological progress. So, $g_A = 0$. Now,

$$g_Q = \alpha g_W + (1 - \alpha)g_z \tag{3.13}$$

Here, g_Q depends on the growth rates of W and Z given the production elasticity α. So, in a balanced growth path if g_W declines g_Q will also decline.

In the extreme situation if $g_W < 0$ and $\alpha > (1 - \alpha)$ g_Q may even be negative. Thus scarcity of water supply will become a limiting factor for future growth and excess depletion of water may make agricultural growth unsustainable in the long-run.

3.2.2.2 Empirical Evidences

Table 3.1 shows that area under tank irrigation has gradually declined over time in the last four decades. The area under canal irrigation has remained more or less constant during this period. But tube-well irrigation has increased both in terms of absolute area and percentage share of irrigated land. In fact, tube-well irrigation has largely contributed to the overall expansion of irrigation in the country.

3.2.2.3 Time Series Analysis

Time series analyses have been done on the relationship between tube-well irrigation, fertilizer use and yield in foodgrains production following the methods outlined in Enders (2004) and using Indian data from 1970–71 to 2007–08. Here we have

Table 3.1 Sources of irrigation in India in net cropped area (000 ha)

Type of irrigation	1970–71	1990–91	2000–01	2007–08	2012–13
Canal	12,838	17,453	15,965	16,531	15,628
Tank	4112	2944	2455	1965	1748
Tube-well	4461 (14.34 %)	14,257	22,569	26,105 (41.91 %)	30,497 (46 %)
All wells	11,887 (38.22 %)	24,694	33,829	37,787 (60.67 %)	41,261 (62 %)

Figures in parentheses are percentage shares in net irrigated area

Source Centre for Monitoring Indian Economy (1998, 2010) and Ministry of Agriculture, Government of India (2015a, b, c)

examined the long run relationship between tube-well irrigation (TW_IRRI) and yield per hectare in foodgrains production (yield), between Yield and Fertilizer use per hectare (FERT) and also between TW_IRRI and FERT. The data have been taken from Economic Survey, Government of India (several issues) and Centre for Monitoring Indian Economy (CMIE) (1998 and 2010). The empirical results establish that the declining growth rates of tube-well irrigation and fertilizer use are responsible for declining growth rate in yield. In Augmented Dickey-Fuller (ADF) Unit Root test the variables are non-stationary at level but stationary at first difference. In Engle-Granger test, they are found to be cointegrated of the same order signifying that there is meaningful long run relationship between ground water irrigation, fertilizer use and productivity growth. The results show that as the growth rate of ground water extraction declines, the growth rate of yield also declines. That means, shortage of water supply is acting as a constraint to further growth (Figs. 3.2, 3.3 and 3.4).

The results in Table 3.2 show that Yield and TW_IRRI are cointegrated of the same order i.e. CI (1,1). So, there is a meaningful relationship between them in the long run. Since the variables are cointegrated, OLS estimates on their relationship are efficient (Ender 2004). The results of OLS Regression in Table 3.3 show that the variation in yield in foodgrains production is significantly explained by tube-well irrigation. The coefficient of TW_IRRI is positive and statistically significant at 1 % level. Both R^2 and F-statistic are high implying that overall significance of the regression is very high.

In Table 3.4 the variables Yield and FERT are cointegrated of the same order in Engle-Granger Cointegration Test. Since the variables are cointegrated, the OLS regression between them will give efficient estimates. In Table 3.5 it is found that the coefficient of FERT is positive and statistically significant at 1 % level. That means, fertilizer significantly explains the increase in yield in foodgrains production.

According to the results of Table 3.6, irrigation (N_IRRI_A) and fertilizer use (FERT) are cointegrated. That means, there is a meaningful long run relationship between them. Tube-well irrigation has significantly contributed to the expansion of irrigation in the country. Therefore, tube-well irrigation directly and through its

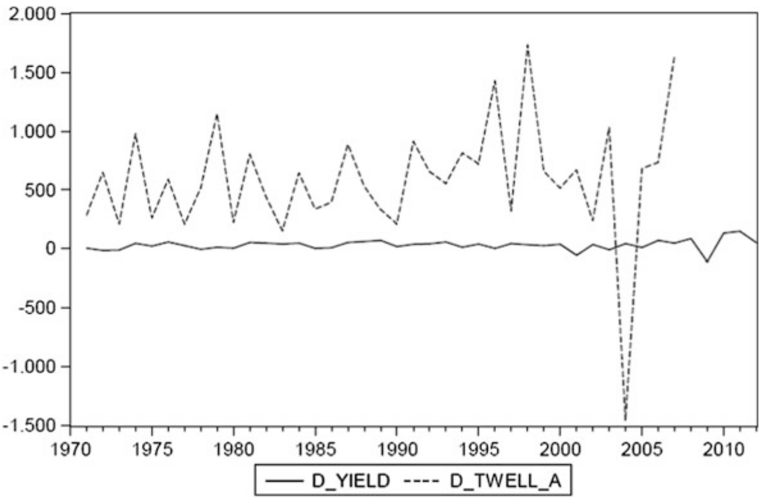

Fig. 3.2 Stationary series of Yield and TW_IRRI at first difference

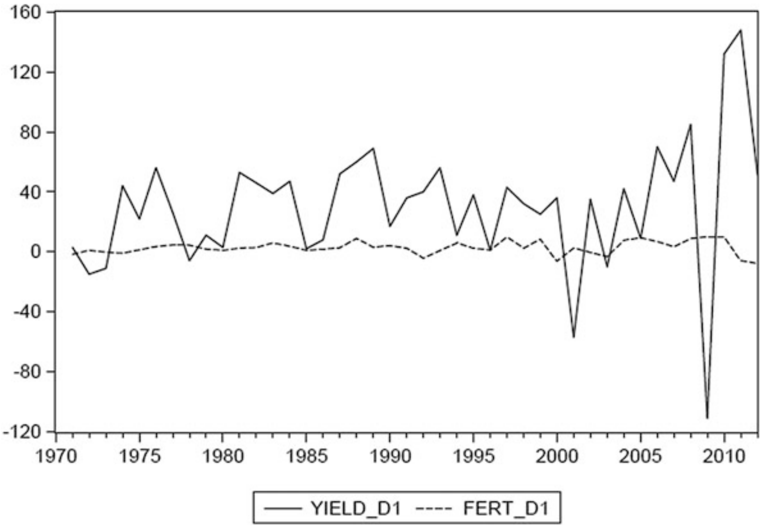

Fig. 3.3 Stationary series of Yield and FERT at first difference

effect on expansion of irrigation and fertilizer use has largely contributed to the growth of yield in foodgrains production.

It is evident from Table 3.7 that the annual average growth rate of area under tube-well irrigation has declined from 5.16 % in the period 1970–1995 to 3.65 % in the period from 1995 to 2005. This has been associated with the decline in the growth rate of fertilizer use from 7.23 to 2.28 % during this period. These have

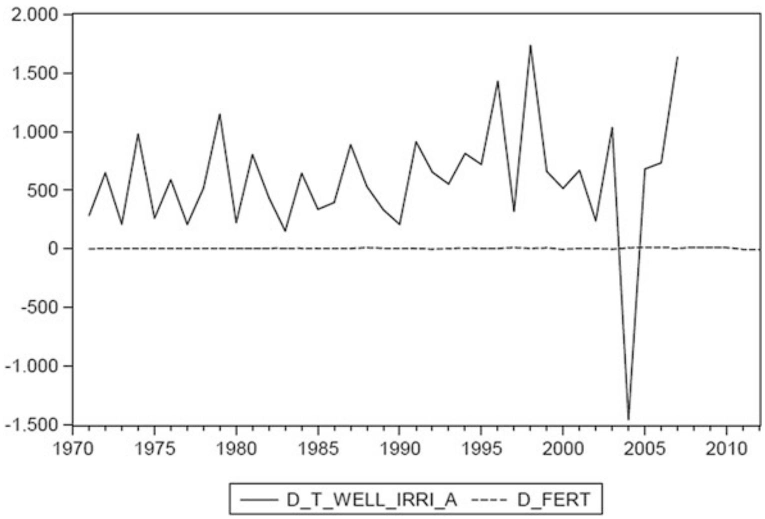

Fig. 3.4 Stationary series of TW_IRRI and FERT at first difference

Table 3.2 Relationship between yield in foodgrains production (Yield) and Tube-well irrigation (TW_IRRI)

Engle—Granger cointegration test				
Series: Yield TW_IRRI				
Sample: 1970–2007				
Observations: 38				
Null Hypothesis: Series are not cointegrated				
Dependent	tau-statistic	Prob*	Z-statistic	Prob*
Yield	−2.2931	0.3924	−91.7059	0.001
TW_IRRI	−2.2785	0.3992	−348.3130	0.001

*Mackinnon (1996), p-values

Table 3.3 OLS regression of yield of foodgrains (Yield) on Tube-well irrigation (TW_IRRI)

Dependent variable: Yield			
Sample: 1970–2007			
Observations: 38			
Variable	Coefficient	t-statistic	Prob*
TW_IRRI	0.0483	34.4090*	0.0000
Constant	593.6705	26.4253*	0.0000

R^2 = 0.97
F-statistic = 1183.986
*significant at 1 % level

caused decline in the growth rate of yield in foodgrains production in the recent past. The growth rate in yield has declined from 2.77 to 0.83 % during this period. Both our theoretical model and time series analyses have established that there is

Table 3.4 Relationship between Yield in foodgrains production (Yield) and Fertilize Use (FERT)

Engle-Granger cointegration test

Series: Yield FERT

Sample: 1970–2007

Observations (after adjustment): 38

Null Hypothesis: Series are not cointegrated

Dependent	Tau-statistic	Prob*	Z-statistic	Prob*
Yield	−3.7441	0.0287	−16.0428	0.0795
TW_IRRI	−4.1493	0.0109	−17.0238	0.0610

*Mackinnon (1996) p-values

Table 3.5 OLS Regression of Yield in Foodgrains (Yield) on Fertilizer Use (FERT)

Dependent variable: Yield

Sample: 1970–2007

Observations: 38

Variable	Coefficient	t-statistic	Prob*
FERT	9.7907	32.1049	0.0000
Constant	719.1439	31.2351	0.0000

$R^2 = 0.96$

F-statistic = 1030.72

*significant at 1 % level

Table 3.6 Relationship between Irrigation (N_IRRI_A) and Fertilizer use (FERT) Engle-Granger Cointegrated Test

Series: FERT N_IRRI_A

Sample: 1970–2007

Observations: 38

Null Hypothesis: Series are not cointegrated

Dependent	Tau-statistic	Prob*	Z-statistic	Prob*
Yield	−4.2787	0.0084	−25.0848	0.0050
N_IRRI_A	−4.5700	0.0040	−26.4452	0.0031

*Mackinnon (1996) p-values

Table 3.7 Annual average growth rates of yield per hectare in foodgrains production (Yield), area under tube-well irrigation (Tube-Well) and Fertilizer use per hectare (Fertilizer) in India

Period	Annual average growth rates		
	Yield (%)	Tube-Well (%)	Fertilizer (%)
1970–1995	2.77	5.16	7.23
1995–2005	0.83	3.65	2.28
2000–2012	2.31	2.04	4.56

Source Calculated from the data of Centre for Monitoring Indian Economy (CMIE) (1998, 2010) and Ministry of Agriculture, Government of India (2015a, b, c)

meaningful and significant relationship between tube-well irrigation and yield in foodgrains production. So, it is clear that tube-well irrigation has acted as a constraint to growth in yield in the cultivation of foodgrains in the recent past.

Ground Water Scenario of India 2009–10, Ministry of Water Resources, Government of India provides important information on the availability and utilization of ground water. It is revealed that in most of the major states of India the extraction rate of ground water is very high and in some states like Punjab, Haryana and Rajasthan, it has crossed the permissible limits. At the all India level, annual total available ground water for extraction is 398.70 billion cubic metres out of which 230.41 billion cubic metres are being presently utilized for cultivation. At the present state of development, 58 % of available ground water is being utilized for cultivation in India. So, in near future, extraction of ground water will not help much the growth in agriculture in the country. So, alternative policy measures for increasing productivity in agriculture need to be given due importance immediately. Incidentally, government measures for rain water harvest, watershed development and surface water management have helped to increase irrigation facilities from other sources to a great extent and this has led to increase in growth rate in yield of foodgrains. Area under irrigation from other sources of water supply (excluding canal, tank and tube-well etc.) has increased from 3048 thousand ha in 1990–91 to 7466 thousand ha in 2012–13. The annual average growth rate of area under such irrigation was 1.67 % in the period from 1970 to 1995 and this rate has increased to 5.67 % per annum during the period from 2000–01 to 2012–13. In effect, the annual average growth rate of yield in foodgrains has increased to 2.31 % during this period.

3.2.2.4 Summary

The extraction of ground water has played a key role in increasing productivity in Indian agriculture specially in foodgrains production in the last four decades. The time series analyses have established that yield in foodgrains production, tube-well irrigation and fertilizer use are cointegrated implying that there is a meaningful long run relationship among them. The theoretical model in our study concludes that if the agricultural production is primarily based on ground water extraction, excess depletion of ground water may eventually make agricultural growth unsustainable in the long run. It has been found that the growth rate in yield in foodgrains production has declined significantly in the recent past and this is explained by declining growth rate of tube-well irrigation and fertilizer use.

It is further revealed that in most of the Indian states, the extraction rate of ground water is very high and in some states like Punjab, Haryana and Rajasthan, the extraction rate has crossed the permissible limits. So, it may be concluded that excess dependence on ground water extraction may be a serious constraint to future growth in agriculture in the Indian context. It is suggested that rain water harvest, better management of surface water, watershed development may be helpful for enhancing productivity and sustainable growth. The empirical evidences show that the rate of expansion of area from other sources of irrigation has significantly increased in the recent years and it has largely helped the growth rate of yield in foodgrains production.

3.3 Crop-Diversification for Water Conservation and Agricultural Growth[1]

3.3.1 Introduction

The less developed countries (LDCs) have achieved remarkable success in agricultural growth specially in foodgrains production in the last four decades and it has been done largely banking on ground water extraction. The expansion of tube-well irrigation has greatly facilitated the use of High-Yielding Variety (HYV) seeds and chemical inputs leading to productivity growth in the farming sector. The World Development Report (2008) states that improved varieties have been widely adopted in the cultivation of rice, wheat, maize and sorghum in South Asia, East Asia and Pacific countries. It also notes that green revolution in Asia doubled cereal production there between 1970 and 1995. However, intensification in cultivation and excessive use of natural resources have caused serious resource degradation putting a threat to the sustainability of growth in many countries.

India too has achieved significant growth in agricultural production during this period and this growth can be largely attributed to extension of irrigation, use of HYV seeds and fertilizer use (Sawant 1997; Singh 1992, 2000). Tube-well irrigation, in particular, has played a crucial role in this growth process. The share of well irrigation in the total irrigated land has increased from 12.34 to 60.86 % during the period from 1970–71 to 2007–08 (Centre for Monitoring Indian Economy, CMIE 2010). The area under foodgrains cultivation has remained more or less constant at 124 million ha. But India's total foodgrains production has increased from 108.4 million tonnes in 1970–71 to 257 million tonnes in 2011–12. This is mainly due to productivity growth. In the whole process of this agricultural growth the government took an active role by making huge public investment for development of infrastructure, and technological change. The subsidy on agricultural inputs and minimum price support (MSP) for the major crops have also become important for investment and agricultural growth (Sasmal 2006, 2012). Pingali (1997) has observed that due to commercialization of agriculture, farmers in Asian countries are being guided more and more by market prices and profitability in agriculture. The Indian farmers also are no exception. The government support measures and higher profitability of agriculture under modern technology have prompted the Indian farmers to make huge investment on tube-well irrigation. As a result, the number of tube-wells for irrigation has increased enormously in the private sector. The Report on the Minor Irrigation Census (2000–2001) in West Bengal (an eastern state of India which has experienced remarkable growth in HYV paddy cultivation) reveals that 94 % of the tube-well irrigation schemes in the state are privately owned. But the rampant digging of tube-wells and excessive extraction

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[1] This section of the book is largely based on the paper, Sasmal (2013b).

of groundwater have become a great concern for future growth in the agricultural sector (Singh 1992, 2000; Rao 2002; Sidhu 2002; Sasmal 2005, 2012).

Rosegrant and Sombilla (1997) warned that shortage of water supply would be a major constraint towards future foodgrains production. Bhullar and Sidhu (2006) have described that the situation of Punjab agriculture is very grave due to excessive depletion of natural resources of land and ground water. The government policy of input subsidy specially on nitrogen fertilizers and electricity and minimum support price (MSP) for paddy and wheat have encouraged the cultivation of water-intensive crops putting huge stress on soil fertility and ground water stock. Such policy has grossly neglected the sustainability issue of agricultural growth. Ground water scenario of India 2009–10, Ministry of Water Resources, Government of India shows that although the stage of ground water development for the country as a whole is 58 %, it is more than 100 % in states like Punjab, Haryana and Rajasthan (145, 109 and 125 % respectively). The information indicates that ground water is being over exploited in these states. In states like Uttar Pradesh, Gujarat, Karnataka and Tamil Nadu the extraction of ground water is more than 70 % of the usable stock. Therefore to sustain agricultural growth, preservation and proper use of water resource have become very important. In this backdrop, changes in cropping pattern and agricultural research pertaining to crop-diversification in favour of less water-intensive crops, technological innovations for efficient use of water resource and changes in policy measures with respect to input subsidy and price support for crops have become very crucial and urgent for preservation of ground water stock. The experts have suggested rain-water harvest, use of appropriate irrigation technology and crop-diversification in favour of less water-intensive crops for sustainability of growth (Shah et al. 1995; Caputo 1990; Goetz 1997; Rao 2002; Ramasamy 2004; Sasmal 2006, 2011, 2013a, b). Realizing the problems of over exploitation of ground water the government of India in its annual budget 2013–14, has allocated Rs. 500 crore for crop diversification. In fact, the policy of crop diversification could not achieve much success during the last thirty years. Two-thirds of total cultivated land are still used for foodgrains production. Rice is the most important food crop of the country and it is highly water-intensive. On the other hand, area of cultivation under less water-intensive crops like oilseed, pulses, cotton, sugarcane has not increased by any significant amount. Here, we have made an attempt to demonstrate theoretically that crop-diversification in favour of less water intensive crops can help sustainable growth and conservation of the resource. We suggest that if the government increases its R&D expenditure for enhancing productivity of less water-intensive crops and provides additional incentives for cultivation of such crops in the form of input subsidy, it may be helpful for both conservation of ground water and sustainability of agricultural growth. The effect of such policies on the optimal path for ground water extraction can be shown by perturbed curves in the exercise of comparative dynamic analysis based on Variational Differential Equation (VDE) as explained and applied by Oniki (1973) and Caputo (1990). The Phase-Diagrams have been used in this work to show the qualitative results of comparative dynamic analysis with respect to the changes in policy parameters on the optimal path for ground water stock.

This work contributes to the literature of resource management and agricultural growth by conducting comparative dynamic analysis on the optimal path for ground water stock with respect to some important parameters like R&D expenditure and input price. The results of this exercise suggest that R&D expenditure and support measures of the government for crop-diversification in favour less water intensive crops will be helpful for conservation of ground water and agricultural growth. This study shows theoretically the positive impact of R&D expenditure of the government on water conservation and productivity growth in agriculture. However, for empirical relevance of this paper we may refer to the works of Griliches (1958, 1964), Fan and Pardey (1997), Thirtle et al. (2003) which explain how R&D expenditure and agricultural research have helped productivity growth in agriculture in different countries. The work has been arranged as follows: A theoretical model of agricultural growth with crop-diversification and ground water extraction has been constructed first tracing out the optimal path for resource depletion. Then comparative dynamic results have been derived on the optimal path for water extraction with respect to some policy parameters and qualitative results have been shown in Phase-Diagrams. Finally, we have provided some empirical evidences on crop-diversification.

3.3.2 Agricultural Growth with Crop-Diversification and Ground Water Extraction

3.3.2.1 The Model

Let us consider an agrarian system where two crops are cultivated using ground water for irrigation. The crops are classified as Crop 1 and Crop 2. Crop 1 is more water-intensive than Crop 2. Total land in the region is normalised to one which will be allocated between the two crops for cultivation. It is implied that crop-diversification in favour of less water-intensive crop (i.e. Crop 2), helps conservation of water stock in the aquifer.

The production functions of the two crops per hectare are as follows:

For Crop 1, $q_1 = f^1\left(\overline{W_1}, Z_1\right)$ where

W_1 requirement of water per unit of land for cultivation of Crop 1 and it is technically fixed

Z_1 use of other input, say, fertilizer in Crop 1 per unit of land

It is assumed that $f^1_{Z_1} \rangle 0, f^1_{Z_1Z_1} < 0$.

Similarly, for Crop 2, the production function is

$$q_2 = \alpha_2(R_2) f^2\left(\overline{W}_2, Z_2\right)$$

where

q_2	output of Crop 2 per unit of land
W_2	requirement of water in the production Crop 2 per unit of land and it is also technically fixed
Z_2	use of other input in Crop 2 per unit of land
α_2	efficiency in production from R&D expenditure of the government in Crop 2
R_2	R&D expenditure of the government for Crop 2 and it is exogenously given

It is assumed that

$f^2_{Z_2}\rangle 0, f^2_{Z_2Z_2}\langle 0, \alpha_2'(R)\rangle 0$ and $\alpha_2''(R)\langle 0.$

Here, one important assumption is that $W_1 > W_2$ which implies, Crop 1 is more water-intensive than Crop 2. Both $f^1(\cdot)$ and $f^2(\cdot)$ are twice differentiable continuous functions; otherwise the method of VDE can not be applied for comparative dynamic analysis.

x is the share of total land allocated to Crop 1 and $(1 - x)$ is the share of land allocated to Crop 2. The extraction of ground water in period t is $W(t)$ and it depends on $x(t)$. So, the dynamics of S is

$$\begin{aligned}\dot{S}(t) &= R(t) - W(t)\\ &= R(t) - [xW_1 + (1 - x)W_2]\end{aligned}$$

where $R(t)$ is natural recharge of ground water stock and $\dot{S}(t)$ is change in water stock over time. It may be assumed that an individual farmer or a group of farmers jointly takes decisions regarding allocation of land between the two crops and extraction of ground water in the region. It may be considered as a social planner's problem. But here we are assuming that private agents are taking decisions and they are not taking into account the social costs or external costs while taking decisions on water extraction.

C is average cost of water per unit and the cost function can be written as $C = C(S, x, P^V)$ where S is stock of ground water in the region and P^V is the given price of the variable input used for extraction of water. x is already defined. It is assumed that

$$C_S < 0, C_{SS} < 0, C_x > 0, C_{xx} > 0.$$

As water stock declines, the cost of water extraction increases at an increasing rate due to diminishing returns. The same is true for C_x. As x increases, extraction of water increases and the stock declines with the result that $C_x > 0, C_{xx} > 0$.

The extraction of water has some environmental costs which are ignored by the private agents. Since the exercise of comparative dynamic analysis gives qualitative results in Phase-diagram, only one state variable can be considered in this dynamic optimising problem. So, pollution or environmental quality is not included as an additional state variable in the model.

The farmer faces the utility function: u = u(C) where C is consumption and $u'(C)\rangle 0, U''(c)\langle 0$. It may be assumed that the whole income is spent on consumption i.e., π = C where π is income of the farmer.

Here the objective of the farmer is to optimally allocate the total land between the two crops and determine the optimal use of other inputs in such a way that income is maximised over the planning horizon [O T]. Following Goetz (1997) the income of the farmer in this diversified agriculture can be expressed as

$$\begin{aligned}\pi = & P_1 \cdot f^1(\cdot)x - C(\cdot) \cdot W_1 \cdot x + P_2\alpha_2(R_2)f^2(\cdot)(1-x) \\ & - C(\cdot) \cdot W_2 \cdot (1-x) - P_{Z_1} \cdot Z_1 \cdot x - P_{Z_2} \cdot Z_2 \cdot (1-x)\end{aligned} \tag{3.14}$$

where, P_1 is output price of Crop 1, P_2 is output price of Crop 2, P_{Z_1} is the price of the input used in Crop 1 and P_{Z_2} is the price of the input used in Crop 2. P_1, P_2, P_{Z_1}, P_{Z_2} are given. Now, the problem of the farmer is:

$$\begin{aligned}\underset{Z_1, Z_2, x}{Max\, V} = & \int_0^T [P_1 f^1(\cdot)x - C(\cdot) \cdot W_1 \cdot x + P_2\alpha_2(R_2) \cdot f^2(\cdot)(1-x) - C(\cdot)W_2(1-x) \\ & - P_{Z_1} \cdot Z_1 \cdot x - P_{Z_2} \cdot Z_2 \cdot (1-x)]e^{-rt} \cdot dt\end{aligned} \tag{3.15}$$

$$\begin{aligned}\text{s.t.} \quad & \dot{S} = R - W_1 x - W_2(1-x) \\ & S(0) = S_0 \text{ and } S(T) \geq \bar{S}\end{aligned}$$

Here, r is the discount rate of future income. Geologically, water stock at the terminal point T must not go below a minimum level $\bar{S}$.

This is an optimal control problem over a definite planning horizon which can be solved with the 'maximum principle' of optimal control theory as specified in Chiang (1992), Kamien and Schwartz (1981) and Dorfman (1969). Here the state variable is S and control variables are Z_1, Z_2 and x. λ is constate variable for S and it can be conceived as current value shadow price of S. To maintain diversification in cultivation, restriction imposed on x is: $0 < x < 1$. It is assumed that $a \leq x \leq b$ where $a > 0$ and $b < 1$. To conduct the exercise of comparative dynamics by using VDE, the set x needs to be closed and bounded. Given the geographical conditions in production of the two crops and preference in consumption it may be required that x can not go below a and exceed b. Now, the current-value Hamiltonian of the problem is:

$$\begin{aligned}H = & P_1 \cdot f^1(\cdot)x - C(\cdot)W_1 \cdot x + P_2\alpha_2(R_2) \cdot f^2(\cdot)(1-x) - C(\cdot) \cdot W_2 \cdot (1-x) \\ & - P_{Z_1} \cdot Z_1 \cdot x - P_{Z_2} \cdot Z_2 \cdot (1-x) - \lambda(W_1 x + W_2(1-x))\end{aligned}$$

The F.O.C.s for maximisation of income are:

$$\frac{\partial H}{\partial_{Z_1}} = P_1 f^1_{Z_1} \cdot x - P_{Z_1} x = 0 \quad \text{or,} \quad P_1 f^1_{Z_1} = P_{Z_1} \tag{3.16}$$

$$\frac{\partial H}{\partial Z_2} = P_2 \alpha_2(R_2) f^2_{Z_2} \cdot (1-x) - P_{Z_2}(1-x) = 0 \quad \text{or,} \quad P_2 \alpha_2(R_2) f^2_{Z_2} = P_{Z_2} \tag{3.17}$$

$$\begin{aligned}\frac{\partial H}{\partial x} = {} & P_1 f^1(\cdot) - P_2 \alpha_2(R_2) f^2(\cdot) - C(\cdot) W_1 - x \cdot W_1 C_x + W_2 C(\cdot) - (1-x) W_2 \cdot C_x \\ & - P_{Z_1} \cdot Z_1 + P_{Z_2} \cdot Z_2 - \lambda(W_1 - W_2) = 0\end{aligned} \tag{3.18}$$

$$-\frac{\partial H}{\partial S} = \dot{\lambda} = r\lambda + W_1 x \cdot C_S + W_2(1-x) C_S \tag{3.19}$$

$$\frac{\partial H}{\partial \lambda} = \dot{S} = R - [W_1 x + W_2(1-x)] \tag{3.20}$$

Transversality conditions are:

$$\lambda(T) \geq 0, \left[S(T) - \overline{S}\right] \lambda(T) = 0$$

If $S(T) \rangle \overline{S}$, the restriction placed on the stock of water in time T is non-binding. Then $\lambda(T) = 0$. But if $\lambda(T)$ is optimally non-zero (positive), the restriction is binding i.e., $S(T) = \overline{S}$. Assumptions on production and cost functions suggest that H is strictly concave in stock and control variables jointly (see Hessian determinants in Appendix 2). Then both the necessary and sufficiency conditions are fulfilled for maximisation of V in (3.15). Now given these conditions the theorems of Steinberg and Stalford (1973) and Gale and Nikaido (1965) will guarantee the existence of unique solution to this optimal control problem. Now from Eqs. (3.16)–(3.18), Z_1, Z_2 and x are globally and uniquely determined in terms of state variable (S), costate variable (λ) and set of parameters β where

$\beta = \{P_1, P_2, P_{Z_1}, P_{Z_2}, W_1, W_2, R_2, r\}$. Now we can write

$$\hat{Z}_1 = \hat{Z}_1(S, \lambda; \beta) \tag{3.21}$$

$$\hat{Z}_2 = \hat{Z}_2(S, \lambda; \beta) \tag{3.22}$$

$$\hat{x} = \hat{x}(S, \lambda; \beta) \tag{3.23}$$

Equations (3.16) and (3.17) suggest that the inputs will be used up to that level where value of marginal product is equal to the direct cost of the input. Equation (3.18) indicates that land will be allocated between the two crops in such a way that marginal net gains from the two crops are equal. Equation (3.20) gives the dynamics of ground water stock over time. Here, given W_1 and W_2, x determines W. x is again determined by P_1, P_2, R_2, P_{Z_1}, P_{Z_2} and r along with other factors in each period. If there is subsidy on Z_1, minimum support price for q_1, P_{Z_1} will be low and P_1 will be high. The private agent does not take into account the environmental cost of water extraction in the decision-making of land allocation. Naturally, low P_{Z_1} and high P_1 will encourage greater value of x leading to over exploitation of ground water. In that case if $W > R$, $\dot{S}\langle 0$. This means, the stock of ground water will decline over time putting threat to sustainable growth in agriculture.

3.3.2.2 Comparative Dynamics

Following the methods outlined in Oniki (1973) and Caputo (1990), comparative dynamic results can be obtained with respect to the parameters like P_1, P_2, P_{Z_1}, P_{Z_2} and R_2. Before we do that let us first get the following comparative static results from Appendix 3.

$$\frac{\partial \hat{x}}{\partial P_1} = \frac{P_2\alpha_2(R_2)f^2_{Z_2Z_2}\cdot(1-x)\left\{P_1f^1_{Z_1Z_1}\cdot x(-f'(\cdot)) + P1f^1_{Z_1}\cdot f^1_{Z_1}\cdot x\right\}}{|B|}\rangle 0 \tag{3.24}$$

$$\frac{\partial \hat{x}}{\partial P_2} = \frac{P_1f^1_{Z_1Z_1}\cdot x\left\{P_2\alpha_2(R_2)f^2_{Z_2Z_2}\cdot(1-x)\cdot\alpha_2(R_2)f^2(\cdot) - P_2\alpha_2(R_2)f^2_{Z_2}\cdot\alpha_2(R_2)f^2(\cdot)\right\}}{|B|}\langle 0 \tag{3.25}$$

$$\frac{\partial \hat{x}}{\partial R_2} = \frac{P_1f^1_{Z_1Z_1}\cdot x\left\{P_2\alpha_2(R_2)f^2_{Z_2Z_2}\cdot(1-x)P_2f^2\cdot\alpha^1_2(R_2)\right\}}{|B|}\langle 0 \tag{3.26}$$

$$\frac{\partial \hat{x}}{\partial P_{Z_1}} = \frac{-P_1f^1_{Z_1}\cdot xP_2\alpha_2(R_2)f^2_{Z_2Z_2}\cdot(1-x)}{|B|}\langle 0 \tag{3.27}$$

$$\frac{\partial \hat{x}}{\partial P_{Z_2}} = \frac{-(1-x)\left\{P_1f^1_{Z_1Z_2}\cdot x\left(-P_2\cdot\alpha_2(R_2)f^2_{Z_2}\right) - P_1f^1_{Z_1}\cdot P_2\alpha_2(R_2)\cdot f^2_{Z_2Z_2}\cdot(1-x)\right\}}{|B|}\rangle 0 \tag{3.28}$$

$$\frac{\partial \hat{x}}{\partial \lambda} = \frac{P_1f^1_{Z_1Z_1}\cdot xP_2\alpha_2(R_2)f^2_{Z_2Z_2}\cdot(1-x)(W_1-W_2)}{|B|}\langle 0 \tag{3.29}$$

$$\frac{\partial \hat{x}}{\partial S} = \frac{P_1f^1_{Z_1Z_1}\cdot x\left(P_2\alpha_2(R_2)f^2_{Z_2Z_2}\cdot(1-x)\right)\{C_S(W_1-W_2) + xC_{xS}(W_1-W_2) + C_SW_2\}}{|B|}\langle 0 \tag{3.30}$$

$$\text{Here,} \frac{\partial \hat{x}}{\partial P_1}\rangle 0, \frac{\partial \hat{x}}{\partial P_{Z_1}}\langle 0, \frac{\partial \hat{x}}{\partial P_2}\langle 0, \frac{\partial \hat{x}}{\partial P_{Z_2}}\rangle 0, \frac{\partial \hat{x}}{\partial R_2}\langle 0$$

These comparative static results have very interesting policy implications.

They indicate that if price of less water-intensive crop is increased or the government increases R&D expenditure for Crop 2 or subsidy is provided to the inputs used in Crop 2, the share of land allocated to the cultivation of less water intensive crop will increase and this may help conservation of water resource.

Substitution of the solutions to Z_1, Z_2 and x in conditions (3.19) and (3.20) reduces the necessary and sufficient conditions to

$$\dot{\lambda} = r\lambda + W_1 \cdot C_S \cdot x(S, \lambda; \beta) + W_2(1-x)\{S, \lambda, \beta\} \cdot C_S \tag{3.31}$$

$$\dot{S} = -[W_1 x(S, \lambda; \beta) + W_2(1-x)\{S, \lambda; \beta\}] \tag{3.32}$$

$$\text{and}\, S(0) = S_0,$$

$$\lambda(T) \geq 0,\, \left[S(T) - \overline{S}\right]\lambda(T) = 0$$

Now, for comparative dynamic analysis it is necessary to insert the solution to (3.31) and (3.32) and (S (t; β), $\lambda(t; \beta)$) back to (3.31) and (3.32) to get the following identities:

$$\begin{aligned} \dot{\lambda} &\equiv r\lambda(t;\beta) \\ &+ W_1 \cdot x(S(t;\beta), \lambda(t;\beta); P_1, P_2, P_{Z_1}, P_{Z_2}, R_2, r) \cdot C_S \left\{ \begin{matrix} S(t;\beta), x(S(t;\beta), \lambda(t;\beta)); \\ P_1, P_2, P_{Z_1}, P_{Z_2}, R_2, r \end{matrix} \right\} \\ &+ W_2(1-x)\{S(t;\beta), \lambda(t;\beta); P_1, P_2, P_{Z_1}, P_{Z_2}, R_2, r\} C_S \left\{ \begin{matrix} S(t;\beta), x(S(t;\beta), \lambda(t;\beta)); \\ P_1, P_2, P_{Z_1}, P_{Z_2}, R_2, r \end{matrix} \right\} \end{aligned} \tag{3.33}$$

$$\dot{S} \equiv R - \left[\begin{matrix} W_1 x\{S(t;\beta), \lambda(t;\beta); P_1, P_2, P_{Z_1}, P_{Z_2}, R_2, r\} + W_2(1-x) \\ \{S(t;\beta), \lambda(t;\beta); P_1, P_2, P_{Z_1}, P_{Z_2}, R_2, r\} \end{matrix} \right] \tag{3.34}$$

$$\text{and}\, S(0, \beta) \equiv S_0,$$

$$\lambda(T;\beta) \geq 0,\, \left[S(T;\beta) - \overline{S}\right]\lambda(T;\beta) \equiv 0$$

Variational Differential Equation (VDE) and Comparative Dynamics

The idea of VDE as outlined by Oniki (1973) and Caputo (1990) is that under some assumptions, solution to the Eqs. (3.31) and (3.32) will exist for given values of the parameters and the substitution of the solutions to (3.31) and (3.32) back into these differential equations will produce the identities (3.33) and (3.34). Now under the conditions of existence and uniqueness of the solutions to the ordinary differential equations and continuity and smoothness of the differential functions, the identities will allow us to have differentiation of the first order differential equations (identities) with respect to the parameter of interest. If the resulting system of equations are evaluated at some particular value of the parameter, say, $\beta = \beta_0$, then the system of differential equations is termed as VDE system.

Now using the technique of VDE as explained above, we will differentiate (3.33) and (3.34) and transversality conditions w.r.t. P_2, R_2 and P_{Z_2} to have their impact on the optimal paths for S and λ. The perturbed curve will show the changes of S and λ over time as the parameter changes. That means, this will qualitatively show the impact of P_2, R_2 or P_{Z_2} on the optimal path of S and λ. Let us now consider the effects of some specific parameters on the optimal paths for S and λ.

A. Impact of increase in R&D expense of the government for less water-intensive crop on the paths of S and λ

Differentiation of (3.33) and (3.34) and transversality conditions w.r.t. R_2 (see Appendix 4) gives

$$\begin{aligned} \dot{\lambda}_{R_2} &= a_{11}\lambda_{R_2} + a_{12}S_{R_2} + n_1 \\ \dot{S}_{R_2} &= a_{21}\lambda_{R_2} + a_{22}S_{R_2} + n_2 \\ S_{R_2}(0) &= 0, \lambda_{R_2}\left(T^0\right) = 0 \quad \text{or} \quad S_{R_2}\left(T^0\right) = 0 \end{aligned}$$

Expressions and signs of a_{ij}, i, j = 1, 2, n_1 and n_2 are given in the Appendix. Here some alternative possibilities are:

(a) for $\lambda_{R_2} = S_{R_2} = 0, \dot{S}_{R_2}\rangle 0, \dot{\lambda}_{R_2} = 0$
(b) for $\lambda_{R_2} = 0, S_{R_2}\rangle 0, \dot{S}_{R_2}\rangle 0, \dot{\lambda}_{R_2}\langle 0$
(c) for $\lambda_{R_2}\rangle 0, S_{R_2}\rangle 0, \dot{\lambda}_{R_2}\rangle\langle 0, \dot{S}_{R_2}\rangle 0$
(d) for $\lambda_{R_2}\rangle 0, S_{R_2} = 0, \dot{\lambda}_{R_2}\rangle 0, \dot{S}_{R_2}\rangle 0$
(e) for $\lambda_{R_2}\langle 0, S_{R_2}\rangle 0, \dot{\lambda}_{R_2}\rangle\langle 0, \dot{S}_{R_2}\rangle\langle 0$

Since $S_{R_2}(0) = 0$, the perturbed curve will start from λ_{R_2}-axis and it will terminate on λ_{R_2}-axis or S_{R_2}-axis depending on whether $S_{R_2}(T^0) = 0$ or $\lambda_{R_2}(T^0) = 0$. The motion of S_{R_2} and λ_{R_2} will depend on the sign of $\dot{S}_{R_2}$ and $\dot{\lambda}_{R_2}$. Thus we shall get (λ_{R_2}, S_{R_2}) path over time. Given the initial and terminal conditions, the signs of $\dot{S}_{R_2}$ and $\dot{\lambda}_{R_2}$ will trace out the movement of S_{R_2} and λ_{R_2} through time. Naturally, all the perturbed curves will not be able to return to the terminal point. Some of the possible cases are shown in Phase-diagram 1 (Fig. 3.5).

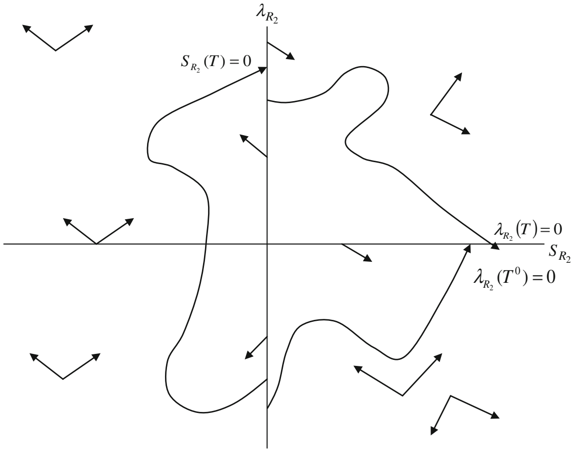

Fig. 3.5 *Phase-Diagram 1* Perturbed curves showing the effects of change in R&D expenditure for less water intensive crop on the stock and shadow price of ground water over time

Proposition 1

$$\text{For}\, \lambda_{R_2}(T)=0, (i) S_{R_2} \geq 0, (ii) \lambda_{R_2}\rangle = \langle 0$$

$$\text{For}\, S_{R_2}(T)=0, (i) S_{R_2} \leq 0, (ii) \lambda_{R_2}\rangle = \langle 0$$

The effect of R&D expenditure of the government for Crop 2 on the path of water stock is not clear and unambiguous. Only under certain conditions, ground water stock will rise if $\lambda_{R_2}(T)=0$.

B. Impact of price support for less water intensive crop

Using the same method we get the following results from Appendix 5.

$$\begin{aligned}
\dot{\lambda}_{P_2} &= a_{11}\lambda_{P_2} + a_{12}S_{P_2} + n_1 \\
\dot{S}_{P_2} &= a_{21}\lambda_{P_2} + a_{22}S_{P_2} + n_2 \\
S_{P_2}(0) &= 0, \lambda_{P_2}\left(T^0\right) = 0 \quad \text{or} \quad S_{P_2}\left(T^0\right) = 0
\end{aligned}$$

Expressions of a_{ij}, n_1 and n_2 are given in Appendix 5.

Alternative possibilities are:

(a) for $S_{P_2} = \lambda_{P_2} = 0, \quad \dot{S}_{P_2}\rangle 0, \quad \dot{\lambda}_{P_2}\rangle 0$
(b) for $S_{P_2} = 0, \lambda_{P_2}\rangle 0, \quad \dot{S}_{P_2}\rangle 0, \quad \dot{\lambda}_{P_2}\rangle 0$
(c) for $S_{P_2}\rangle 0, \quad \lambda_{P_2}\rangle 0, \quad \dot{S}_{P_2}\rangle\langle 0, \quad \dot{\lambda}_{P_2}\rangle 0$
(d) for $S_{P_2} = 0, \quad \lambda_{P_2}\langle 0, \quad \dot{S}_{P_2}\rangle\langle 0, \quad \dot{\lambda}_{P_2}\rangle\langle 0$
(e) for $S_{P_2}\rangle 0, \quad \lambda_{P_2}\langle 0, \quad \dot{S}_{P_2}\rangle\langle 0, \quad \dot{\lambda}_{P_2}\rangle\langle 0$

If $\lambda_{P_2}(T) = 0, \quad S_{P_2} \geq 0$ (see Phase-diagram 2).

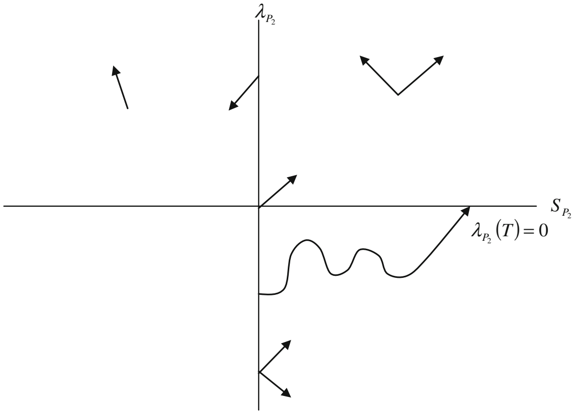

Fig. 3.6 *Phase-Diagram 2* Perturbed curves showing the effects of change in price support for less water intensive crop on the stock and shadow price of ground water over time

C. Impact of subsidy on the inputs used in less water intensive crop

From Appendix 6, we get (Fig. 3.6)

$$\dot{\lambda}_{PZ_2} = a_{11}\lambda_{PZ_2} + a_{12}S_{PZ_2} + n_1$$
$$\dot{S}_{PZ_2} = a_{21}\lambda_{PZ_2} + a_{22}S_{PZ_2} + n_2$$
$$S_{PZ_2}(0) = 0, \quad \lambda_{PZ_2}\left(T^0\right) = 0S_{PZ_2}\left(T^0\right) = 0$$

Proposition 2

$$\text{For}\, \lambda_{P_2}(T) = 0, S_{P_2}\rangle 0\, \text{and}\, \lambda_{P_2}\langle 0.$$

If the price of less water-intensive crop (Crop 2) is increased by price support or any other policy measure, the ground water stock may increase.

Expressions and sign of a_{ij}, n_1 and n_2 are given in the Appendix 6.

Various possibilities are:

(a) $S_{PZ_2} = \lambda_{PZ_2} = 0, \quad \dot{S}_{PZ_2}\rangle 0, \quad \dot{\lambda}_{PZ_2}\rangle 0$
(b) $S_{PZ_2} = 0, \quad \lambda_{PZ_2}\rangle 0, \quad \dot{S}_{PZ_2}\rangle 0, \quad \dot{\lambda}_{PZ_2}\rangle\langle 0$
(c) $S_{PZ_2}\rangle 0, \lambda_{PZ_2}\rangle 0, \quad \dot{S}_{PZ_2}\rangle\langle 0, \quad \dot{\lambda}_{PZ_2}\rangle 0$
(d) $S_{PZ_2}\rangle 0, \lambda_{PZ_2}\langle 0$

If $\lambda P_{Z_2}(T) = 0, SP_{Z_2} \geq 0$ (see Phase-diagram 3) (Fig. 3.7).

Proposition 3

$$\text{For}\, \lambda_{PZ_2}(T) = 0, S_{PZ_2}\rangle 0, \lambda_{PZ_2} > 0.$$

If input price of Crop 2 is reduced by providing subsidy, it is likely that the cultivation of less water-intensive crops will increase and it will help conservation of ground water.

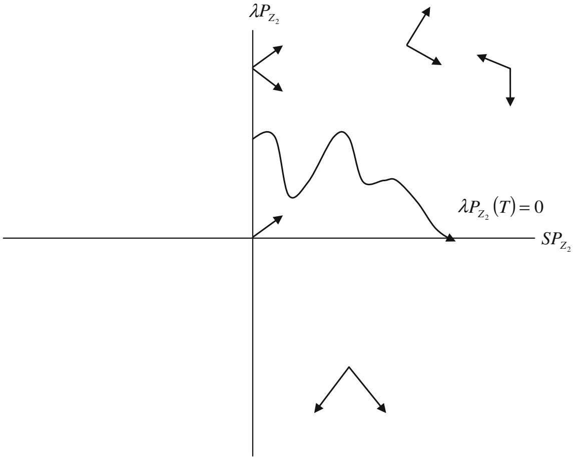

Fig. 3.7 *Phase-Diagram 3* Perturbed curves showing the effects of change in subsidy on inputs for less water intensive crops on the stock and shadow price of ground water over time

3.3.2.3 Empirical Evidences

The cropping pattern in a country or region depends on a number of factors such as rainfall, soil and geophysical conditions, agricultural technology, climate, food habit and others. So far as water conservation is concerned, it can be mentioned here that rice is the most water-intensive crop in India and it is cultivated throughout the year. In rainy season much water is not extracted from the aquifer for cultivation of rice. But, in Rabi Season (summer season) huge ground water is extracted for cultivation of rice. The alternative less water-intensive crops that can be cultivated in Rabi season are wheat, oilseeds, potato, pulses and vegetables. But the productivity of rice cultivation in summer (Rabi Season) is very high and it is 3353 kg per ha compared to an average of 2461 kg over all seasons of the year. Rice is the most important crop in the total foodgrains production of India (22.50 % in total production). The relative importance of less water-intensive crops except wheat are very small.

From Table 3.8 it is evident that much diversification has not taken place in Indian agriculture specially from the viewpoint of water conservation. The gross area under the cultivation of rice which is a water-intensive crop has increased by 13.82 % during the period of last four decades. In case of wheat the expansion of gross area is highest and it is 64.83 %. These two are the major food crops in India and in both cases the area of cultivation has increased due to significant extension of irrigation and productivity growth (see Tables 3.8 and 3.9). The gross area under the food crops like Jowar and Bajra has declined. The areas of their cultivation are not high and irrigation facilities are also very limited in these crops. Pulses are water-saving crops but they could not show much progress either in terms of area of cultivation or productivity growth. However, crops like oilseeds, potato and sugarcane have achieved significant growth both in area of cultivation and productivity.

Table 3.8 Gross area under major crops in India (million hectares)

Crops	1970–71	2012–13	Percentage change over the period
Foodgrains	124.30 (24.10 %)	120.80 (49.80 %)	−2.81
Rice	37.60 (38.40 %)	42.80 (58.70 %)	13.82
Wheat	18.20 (54.30 %)	30.00 (92.90 %)	64.83
Pulses	22.60 (8.8 %)	23.30 (16.10 %)	3.09
Maize	5.80 (15.90 %)	8.70 (25.30 %)	50.00
Bajra	12.90 (4.2 %)	7.30 (8.5 %)	−43.41
Jowar	17.40 (3.6 %)	6.20 (9.7 %)	−64.34
Oilseeds	16.60 (7.4 %)	26.50 (27.60 %)	59.63
Sugarcane	2.60 (72.40 %)	5.00 (94.30 %)	92.30
Cotton	7.60 (17.30 %)	12.00 (35.9 %)	57.89
Potato	0.50	1.90	280.00

Figures in parentheses are percentage of area under irrigation
Source Agricultural Statistics At a Glance 2014, Ministry of Agriculture, Government of India, Oxford University Press, 2015

Table 3.9 Yield of major crops in India (kilogram per hectare)

Crops	1970–71	2012–13	Percentage change over the period
Foodgrains	872	2129	144.15
Rice	1123	2393	113.08
Wheat	1307	3117	138.48
Pulses	524	789	41.03
Maize	1279	2566	100.62
Bajra	622	1198	92.60
Jowar	466	850	82.40
Oilseeds	579	1168	101.72
Potato	10	22	120.00
Sugarcane	48,322	68,254	41.24
Cotton	106	486	358.49

Source Agricultural Statistics At a Glance 2014, Ministry of Agriculture, Government of India, Oxford University Press, 2015

We do not have crop-wise data on output and input prices of water-saving crops and R&D expenditures for such crops. So, we are not in a position to make rigorous econometric analysis of the effects of individual prices on cropping pattern and water conservation. From the available data, we can only find that there has not been much change in the cropping pattern in Indian agriculture in the last forty years. But whatever changes have taken place they are related to the expansion of irrigation and productivity growth.

3.3.2.4 Summary

This section has explained the role of irrigation in agricultural growth of the developing nations and highlighted the problem of excess depletion of ground water causing threat to sustainability of growth. As a policy measure, this study tries to see whether crop-diversification in favour of less water intensive crops may be helpful for conservation of water resource and agricultural growth. This paper has constructed a theoretical model of agricultural growth using ground water in a diversified cropping system. The technique of 'variational differential equation' (VDE) has been used to derive results of comparative dynamic analysis on the optimal path for ground water stock with respect to some important policy parameters. The qualitative results of this exercise have been shown by perturbed curves in Phase-Diagrams. The results show that the effect of R&D expenditure of the government for water-saving crop on the stock of ground water is not clear. However, if input subsidy and price support on such crops are increased by the government it will encourage crop-diversification in favour of crops that require relatively less amount of water and it may be helpful for conservation of water resource and agricultural growth.

3.4 Role of Price in the Conservation of Water Resource in Agriculture: A Comparative Dynamic Analysis[2]

3.4.1 Introduction

The less developed countries (LDCs) have achieved remarkable success in agriculture specially in foodgrains production in the last four decades. The large scale adoption of High-Yielding Variety (HYV) seed, expansion of irrigation and intensive use of modern inputs have significantly contributed to productivity growth in the farming sector. According to the World Development Report (2008), improved varieties have been widely adopted in foodgrains cultivation in developing countries with the result that cereal production has been doubled there between 1970 and 1995. As a result of intensification of agriculture the use of natural resources has crossed the sustainable limits in many cases. India, for example, has been able to increase foodgrains production significantly during this period but rampant digging of tube-wells and excessive depletion of groundwater have caused environmental and resource degradation putting a threat to the sustainability of growth in the agricultural sector (Singh 2000; Rao 2002; Singh 1992; Sidhu 2002). The percentage of net irrigated area of the total cultivated land in the country has increased from 22.17 % in 1970–71 to 44.75 % in 2007–08 and the share of well-irrigation in the net irrigated land has increased from 12.34 to 60.86 % during this period

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[2] This section is based on the paper, Sasmal (2006).

(Centre or Monitoring Indian Economy (CMIE) 2010). This indicates that groundwater extraction and tube-well irrigation have played a crucial role in the whole process of agricultural growth in India. In this context, the researchers have suggested change in cropping pattern, scientific research for expansion of rainfed agriculture, dryland farming, rainwater harvesting, use of appropriate irrigation technology and crop-diversification in favour of less water-intensive crops for sustainability of agricultural growth and conservation of water resource (Shah et al. 1995; Goetz 1997; Rao 2002; Ramasamy 2004; Sasmal 2006, 2013a, b). Price has been suggested to be an effective policy instrument for resource management (Caputo 1990; Gunatileke and Chakravorty 2003; Barrett 1991; Weikard and Hein 2011).

In this section we like to address the issue of water conservation in a ground water based farming system in a dynamic perspective and examine the impact of manipulation of prices of input and output on the stock of ground water over time. Here we plan to conduct comparative dynamic analysis on the optimal path for water stock with respect to input and output prices. The purpose is to see whether output and input prices can be used as policy instruments for conservation of water resource, specifically in cases where agriculture is highly subsidized. The argument is that if support measures of the government are withdrawn or curtailed, the extraction of water will be less profitable and this may be helpful for conservation of water resource. The technique of variational differential equations as outlined and used by Oniki (1973), Caputo (1990) and Gunatileke and Chakravorty (2003) has been used in this exercise to derive perturbed curves in Phase-diagrams for qualitative results. Caputo (1990) used this technique in a dynamic model of a non-renewable resource extraction. Gunatileke and Chakravorty (2003) have used the same technique in examining the role of price in forest management in a dynamic perspective. Both studies demonstrate that output and input prices can be used as effective instruments for conservation of natural resources. Barrett (1991) however, has shown that price reform may not be of much help in soil conservation. In Weikard and Hein (2011), price is found to play an important role in the determination of optimal stocking rate and conservation of soil health. Thus, mixed results have been obtained with respect to the role played by price in resource management. Here we like to extend the same idea to the problem of ground water conservation. The government takes important role in agricultural growth in the developing nations through development of infrastructure and technological change. It encourages investment in agriculture through price support and input subsidy. Now, if price has a role in the extraction of ground water and overall growth of agriculture, it is expected that manipulation of price may be helpful for conservation of water. However, other factors like cropping pattern, public investment, climate and rainfall, soil and geo-physical conditions are also very important in this respect. In the regions which are better endowed with ground water stock and favourable geo-physical conditions, the availability of ground water will be higher and the cost of water extraction will be lower. In that case, natural factors may play more important role than price. That is why, extraction of ground water largely varies across regions. The extraction rate of ground water is different in different states of India although all the states face almost the same input and output prices (Ground Water Scenario of India 2009–10, Government of India). Feder (1980) theoretically demonstrates that favourable prices do not necessarily lead to greater allocation of land to modern cultivation. Therefore, it is not clear whether price will be an effective policy option for conservation of water resource.

In this work a dynamic model of ground water extraction has been constructed for agricultural production. Then a comparative dynamic analysis has been done on the optimal path for ground water stock with respect to output and input prices to get perturbed curves in Phase-diagrams for qualitative results. This shows the effect of change in price on water stock over time and also at the end of the planning period. The results demonstrate that the time path for the ground water stock does not terminate at a point where the relationship between prices and water stock is unambiguous. That means, no definite relationship between price and ground water stock is obtained from this theoretical exercise. Whether there is any relationship between price and water depletion has been empirically verified by time series econometric analysis using Indian data. The results do not show any meaningful long run relationship between the two at the national level. However, it does not rule out the existence of such a relationship at the local or regional level. Since the econometric results are based on national level aggregate data, this may mask the relationship at the local level. The scheme of the work is as follows: First, we have constructed a dynamic model of ground water extraction for agricultural growth. Then comparative dynamic analysis has been done with respect to input and output prices on the optimal path for ground water stock. After theoretical exercise, the results have been empirically verified using time series cointegration analysis on the relationship between price and groundwater extraction based on Indian data. Finally the results have been explained and the conclusions have been presented.

3.4.2 Ground Water Extraction for Agricultural Growth

3.4.2.1 The Model

We consider an agricultural system where cultivation is done by extraction of ground water. The agricultural production function can be conceived as $Q = e(G)F(W, Z)$, where Q is total output, W is extraction of ground water and Z is use of other input (say, fertilizer). It is assumed that $F_W > 0, F_{WW} < 0$, $F_Z > 0, F_{ZZ} < 0, F_{WZ} > 0$. G is public investment for agriculture and e is efficiency from G where $e > 1$ and $e'(G) > 0, e''(G) < 0$.

$F : W \times Z \rightarrow Q, F \in C^{(2)}$ has a negative definite hessian in $(w, z) \forall (w, z) \in W \times Z$.

Let the cost function for water be $C = C(W, S, N, T, I)$ where C is per unit cost of water, S is ground water stock, N is some index of natural and geo-physical conditions, T is irrigation technology and I is public investment for irrigation. Here,

$C_S < 0, C_{SS} < 0, C_W \rangle 0, C_{WW} \rangle 0, C_N < 0, C_T < 0, C_I < 0$. If extraction increases, cost of water per unit will increase. Similarly if stock of water declines the cost will go up. Higher values of N and T indicate favourable natural conditions and improved irrigation technology respectively. If natural conditions are favourable, improved technology is used for water depletion or public investment is increased for irrigation, the cost of water will decline. The parameters N, T, I vary across regions. The household utility function is U = U(ψ), where ψ is consumption and U′ (ψ) > 0, U″ (ψ) < 0. For simplicity, it is assumed that income of the farmer is fully spent for consumption. It is also assumed that the funds for subsidy and public investment for agriculture are mobilised from the non-agricultural sector. Income of the farmer is defined as

$$\pi = P \cdot e(G) \cdot F(W, Z) - C(W, S, N, T, I) \cdot W - v \cdot Z \tag{3.35}$$

Here, P and v are prices of output and fertilizer respectively and these are given. The extraction of ground water may cause some environmental costs which the private individuals disregard in the income function. Since this work makes a comparative dynamic analysis and uses Phase-diagrams to show the qualitative results, it considers only a single state variable and it is ground water stock. So, environmental quality is not considered as a second state variable. Ground water is a renewable resource. R is natural recharge of the aquifer and it is a function of rainfall, soil and geo-physical conditions of the region denoted by N. The dynamics of S is

$\dot{S} = -W + R(N)$ where R is recharge rate of ground water stock and R'(N) > 0 implies that in favourable natural conditions, recharge rate is higher. In a particular region, N is fixed.

Now, the objective of the household is:

$$Max_{W,Z} \int_0^T [P \cdot e(G) \cdot F(W, Z) - C(\cdot)W - v \cdot Z] e^{-rt} dt \tag{3.36}$$

$$\begin{aligned} \text{s.t.} \quad & \dot{S} = -W + R(N) \\ & S(0) = S_0, \mathrm{S}(T) \geq \bar{S} \end{aligned}$$

r is rate of discount of future income. $\bar{S}$ is the minimum level of water stock that must be preserved at the end of the planning period.

This is a dynamic optimisation problem over a finite planning horizon [O T]. Here, our problem is to choose the optimal paths for W and Z so that the discounted value of total income is maximised. The solution to this problem will trace out the optimal path for water stock S. Following Chiang (1992), Kamien and Schwartz (1981) and Dorfman (1969) this problem can be solved using the 'maximum principle' of the optimal control theory. The current-value Hamiltonian can be expressed as:

$$H = P \cdot e(G) \cdot F(W, Z) - C(W, S, N, T, I) \cdot W - v \cdot Z + \lambda(-W + R(N)) \quad (3.37)$$

Here, S is state variable, W and Z are control variables and λ is costate variable. λ is the current value shadow price of S.

F.O.C.s for maximisation of discounted value of total income are:

$$\frac{\partial H}{\partial W} = P \cdot e(G) \cdot F_W - C(\cdot) - C_W \cdot W - \lambda = 0 \quad (3.38)$$

$$\frac{\partial H}{\partial Z} = P \cdot e(G) \cdot F_Z - v = 0 \quad (3.39)$$

$$-\frac{\partial H}{\partial S} = \dot{\lambda} = r\lambda + W \cdot C_S \quad (3.40)$$

$$\frac{\partial H}{\partial \lambda} = \dot{S} = -W + R(N) \quad (3.41)$$

and transversality conditions are:

$$\lambda(T) \geq 0, \left[S(T) - \overline{S}\right]\lambda(T) = 0$$

Given the specifications of the production and cost functions, H is strictly concave in (S, W, Z) jointly (see Appendix 7). Now the theorems of Steinberg and Stalford (1973) and Gale and Nikaido (1965) guarantee the existence of a unique solution to this optimal control problem. The above conditions have important economic implications. Equation (3.38) equates the marginal benefit of water extraction with the cost of extraction plus the cost of not preserving the resource for future use. Equation (3.39) just equates the marginal benefit of fertilizer use to its per unit price. Equation (3.40) determines the rate of change of λ over time. Equation (3.41) indicates the dynamics of water stock. Equation (3.38) determines the optimum extraction of water at each point of time. $\{P \cdot e(G) \cdot F_W\}$ is the marginal benefit of water extraction. If G is high, marginal benefit is also high. The marginal cost of water extraction is $C(\cdot) + C_W \cdot W$. If the natural conditions are favourable, improved technology is used for water extraction and public investment for irrigation is high, the value of C will be low. In such cases, optimal extraction of water will be higher. Since there is externality problems it may lead to excess depletion of water and in that case $W > R(N)$ making $\dot{S}\langle 0$. That means, the ground water stock declines over time. If P is increased by support measures and input price is reduced by subsidy there is high possibility that depletion of water will exceed the permissible limit leading to excess depletion of water. The transversality conditions suggest that if $S(T)\rangle\overline{S}$, the restriction placed on the stock of water in time T is non-binding. Therefore, $\lambda(T) = 0$. But if $\lambda(T)$ is optimally non-zero (positive), then the restriction is binding i.e. $S(T) - \overline{S} = 0$. From Eqs. (3.38) and (3.39), W and Z are globally and uniquely determined in terms of S, λ and set of parameters β at each point of time where $\beta = \{P, v, r, G, N, T, I\}$. Therefore, W and Z are optimally solved as

$$\hat{W} = \hat{W}(S, \lambda, P, v, r, G, N, T, I)$$
$$\hat{Z} = \hat{Z}(S, \lambda, P, v, r, G, N, T, I)$$

The resulting Eqs. (3.37)–(3.41) along with the transversality conditions characterize the optimal solution to the problem in (3.36) and determine the optimal paths for S and λ.

3.4.2.2 Comparative Dynamics

Following the methods outlined and used by Oniki (1973), Caputo (1990) and Gunatileke and Chakraborty (2003) we can derive the comparative dynamic results. Before doing that let us find out the comparative static results. From Appendix 8, we get the following results:

(a) $\frac{\partial \hat{W}}{\partial v} = \frac{-P \cdot e(G) \cdot F_{WZ}}{|B|} < 0$

(b) $\frac{\partial \hat{W}}{\partial P} = \frac{-[e(G)]^2 \cdot F_W \cdot P \cdot F_{ZZ} + [e(G)]^2 F_Z \cdot P \cdot F_{WZ}}{|B|} > 0$

(c) $\frac{\partial \hat{W}}{\partial S} = \frac{P \cdot e(G) \cdot F_{ZZ} C_S}{|B|} > 0$

(d) $\frac{\partial \hat{W}}{\partial \lambda} = \frac{P \cdot e(G) \cdot F_{ZZ}}{|B|} < 0$

(e) $\frac{\partial \hat{Z}}{\partial v} = \frac{P \cdot e(G) \cdot F_{WW} - 2C_W - W \cdot C_{WW}}{|B|} < 0$

(f) $\frac{\partial \hat{Z}}{\partial P} = \frac{-(P \cdot F_{WW} - C_W - W \cdot C_{WW})(e(G))^2 \cdot F_Z + P \cdot (e(G))^2 \cdot F_{ZW} \cdot F_W}{|B|} \rangle 0$

(g) $\frac{\partial \hat{W}}{\partial G} = \frac{-\{e'(G) F_W\} P^2 \cdot e(G) F_{ZZ} + \{e'(G)\} P^2 \cdot e(G) \cdot F_{WZ} \cdot F_Z}{|B|} \rangle 0$

(h) $\frac{\partial \hat{W}}{\partial N} = \frac{C_N \cdot P \cdot e(G) \cdot F_{ZZ}}{|B|} \rangle 0$

(i) $\frac{\partial \hat{W}}{\partial I} = \frac{C_I \cdot P \cdot e(G) \cdot F_{ZZ}}{|B|} > 0$

Important implications follow from these comparative static results. If output price (P) is reduced or input price (v) is increased by policy intervention, both water extraction and fertilizer use will decline. If stock of water is higher the extraction of water will be also higher. If natural factors like rainfall, recharge rate etc. are favourable, it encourages greater extraction of water. These parameters affect the ground water extraction through their effects on marginal returns and costs of water extraction. The input and output prices may not always matter much in the depletion of ground water. The natural factors, such as rainfall, stock of water, public investment, irrigation technology may be more important in this regard.

Now the substitution of the respective solutions to W and Z into (3.40) and (3.41) gives

$$\dot{\lambda} = r\lambda + W(S, \lambda, P, v, r, G, N, T, I) \cdot C_S \tag{3.42}$$

$$\dot{S} = -W(S, \lambda, P, v, r, G, N, T, I) \tag{3.43}$$

$$\text{and}\, S(0) = S_0,$$

$$\lambda(T) \geq 0,\ \left[S(T) - \overline{S}\right]\lambda(T) = 0$$

For comparative dynamic analysis it is necessary to insert the solution to (3.42) and (3.43), $(S(t;\beta),\ and\, \lambda(t;\beta))$ back to (3.42) and (3.43) to produce the following identities:

$$\dot{\lambda} \equiv r\lambda(t;\beta) + W\big(S(t;\beta), \lambda(t;\beta); P, v, r, T, \overline{R}\big) \cdot C_S \tag{3.44}$$

$$\dot{S} \equiv -W(S(t;\beta), \lambda(t;\beta); P, v, r, G, N, T, I) \tag{3.45}$$

$$\text{and}\, S(0, \beta) \equiv S_0$$

$$\lambda(T, \beta) \geq 0,\ \left[S(t;\beta) - \overline{S}\right]\lambda(T, \beta) \equiv 0$$

3.4.2.3 Variational Differential Equation (VDE) and Comparative Dynamics

The idea of VDE as outlined by Oniki (1973) and Caputo (1990) is that under some assumptions mentioned above, solution to the Eqs. (3.42) and (3.43) will exist for given values of the parameters and the substitution of the solutions to (3.42) and (3.43) back into these differential equations will produce the identities (3.44) and (3.45). Now under the conditions of existence and uniqueness of the solutions to the ordinary differential equations and continuity and smoothness of the differential functions, the identities will allow us to have differentiation of the first order differential equations (identities) with respect to the parameter of interest. If the resulting system of equations are evaluated at some particular value of the parameter, say, $\beta = \beta_0$, then the system of differential equations is termed as VDE system.

Using the idea of VDE, we can differentiate equations (3.44) and (3.45) and the transversality conditions w.r.t. P and v respectively to get their impact on the optimal paths for S and λ. Transversality conditions suggest that (i) if $S(T;\beta) > \overline{S}, \lambda(T;\beta) \equiv 0$ and (ii) if $S(T;\beta) \equiv \overline{S}, \lambda(T;\beta) > 0$. The comparative dynamic results are obtained by using perturbed curves in phase diagrams.

Case I: Impact of Decline of Output Price on the Optimal Paths for S and λ

From Appendix 9 we get the differentiation of (3.44) and (3.45) and transversality conditions w.r.t. P as follows:

$$\dot{\lambda}_P = a_{11}\lambda_P + a_{12}S_P + n_1$$
$$\dot{S}_P = a_{21}\lambda_P + a_{22}S_P + n_2$$
$$S_P(0) = 0, \lambda_P\left(T^0\right) = 0 \quad \text{or} \quad S_P\left(T^0\right) = 0$$

λ_P and S_P are the effects of change in output price on the optimal values of shadow price and stock of ground water respectively. $\dot{\lambda}_P$ and $\dot{S}_P$ are direction of motion of λ_P and S_P over time.

Expressions of a_{ij}'s, n_1 and n_2 and their signs have been derived in the Appendix 9. Now assuming signs for λ_P and S_P and using the signs of a_{ij}'s we determine the signs of $\dot{\lambda}_P$ and $\dot{S}_P$ to indicate the direction of motion of S_P and λ_P over time. How water stock, S and shadow price of ground water λ change over time due to change in P can be shown by the perturbed curves in a Phase-diagram giving qualitative results. Different possibilities of $\dot{\lambda}_P$ and $\dot{S}_P$ are shown in Appendix 9.

Since S_P (0) = 0, the perturbed curve starts from the λ_P-axis and ends on λ_P- axis or S_P-axis depending on whether S_P (T^0) = 0 or λ_P (T^0) = 0. Since initial and terminal conditions are known, the optimal time paths for (S_P, λ_P) are easily obtained using the values of $\dot{\lambda}_P$ and $\dot{S}_P$. In the present case, we assume that output price is reduced by withdrawal of government support measures like minimum support price (MSP). The impact of decline of output price on the optimal paths for S and λ is shown by the perturbed curves of (λ_P, S_P) in Phase-diagram 1.

In Phase Diagram 1, the perturbed curves start on the λ_P-axis because S_P (0) = 0. It can not start from S_P-axis. If we assume $S_P = 0$ and $\lambda_P < 0$ or $\lambda_P = 0$, the perturbed curve starts from λ_P-axis but can not return to the terminal point at λ_P (T^0) = 0 or S_P (T^0) = 0 in the fourth quadrant. If we assume $S_P = 0$ and $\lambda_P > 0$ or $\lambda_P < 0$, the curve can return to the terminal point at $\lambda(T^0) = 0$ in the first, second and third quadrants. Thus the perturbed curves do not terminate at a point where the effect of price on water stock is unambiguous.

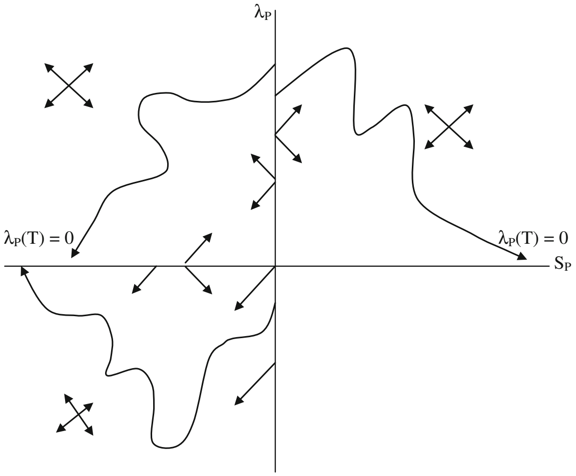
Proposition *For* $\lambda_P(T^0) = 0$, (i) $S_P\langle=\rangle 0$ *and* (ii) $\lambda_P\rangle = \langle 0$ i.e. *the impact of decline of output price on water stock over time may be positive, negative or zero.*

So, no definite effect of output price on the stock of water over time is obtained. From this result it is clear that change in price does not necessarily influence the ground water stock although the role of price in water conservation is not rejected altogether (Fig. 3.8).

Case II: Impact of Increase of Input Price (v) on the Optimal Paths for S and λ.

From Appendix 10 we get the differentiation of (3.44) and (3.45) and transversality conditions w.r.t. v as follows:

Fig. 3.8 *Phase Diagram 1* Perturbed curves showing the effects of change in output price on the stock and shadow price of ground water over time



$$\dot{\lambda}v = a_{11}\lambda_v + a_{12}S_v + n_1$$
$$\dot{S}_v = a_{21}\lambda_v + a_{22}S_v + n_2$$
$$S_v(0) = 0$$
$$\lambda_v\left(T^0\right) = 0 \quad \text{or} \quad S_v\left(T^0\right) = 0$$

λ_v and S_v are changes of λ and S due to change in input price v. $\dot{\lambda}_v$ and $\dot{S}_v$ are direction of motion of λ_v and S_v over time.

As in Case I, here also the perturbed curve starts from λ_v-axis and ends on S_v-axis at the terminal point λ_v $(T^0) = 0$. The perturbed curves show that as input price increases (say, due to imposition of tax or withdrawal of subsidy) water stock may rise, decline or remain unchanged over time. Here also, the perturbed curves do not terminate at a point where the relationship between input price and water stock is unambiguous.

Proposition *For* λ_v $(T^0) = 0$, (i) S_v >=< 0 *and* (ii) λ_v >=< 0, *implying that the impact of increase of input price on water stock may be positive, negative or zero.*

It follows from the theoretical analysis that the prices of agricultural output and input do not necessarily become effective in the conservation of water resource. The results, however, do not rule out the effect of price on water conservation. In fact, the conservation of water depends on many other factors apart from prices of input and output. From Eqs. (3.38) and (3.39) it follows that extraction of ground water depends on $e(G)$, F_W, F_Z, P, v, C, C_W and λ.

P, v and $e(G)$ are demand side factors while C and C_W are supply-side factors of water extraction. The cost function has been expressed as:

$$C = C(W, S, T, N, I) \tag{3.46}$$

where W, S, T, N and I are same as before.

Total differential of (3.46) gives

$$dC = \frac{\partial C}{\partial W}\cdot dW + \frac{\partial C}{\partial S}\cdot dS + \frac{\partial C}{\partial T}\cdot dT + \frac{\partial C}{\partial N}\cdot dN + \frac{\partial C}{\partial I}\cdot dI \tag{3.47}$$

Here, $\frac{\partial C}{\partial W}\rangle 0, \frac{\partial C}{\partial S}\langle 0, \frac{\partial C}{\partial T}\langle 0, \frac{\partial C}{\partial N}\langle 0, \frac{\partial C}{\partial I}\langle 0.$

If natural factors are very favourable, public investment and subsidy on irrigation are high, supply side factors will have a dominating role in water extraction and in that case, price may not have significant role in water conservation and extraction. On the other hand, there may be cases where price plays an important role in the depletion of water. The natural factors and geo-physical conditions are region-specific. It is plausible that in some regions natural factors are more important than price in water conservation and in other cases, the scenario is different. In fact, price should have a role in the extraction or conservation of ground water. But it may be the case that price is outweighed by other factors and price fails to play a significant role in this matter (Fig. 3.9).

3.4.2.4 Time Series Analysis

This section has tried to verify empirically whether there exits any meaningful long run relationship between the prices of output and input and extraction of ground water using cointegration analysis based on time series data in the Indian context. The percentage of irrigated land fed by tube-well irrigation (T_WELL_IRRI) has been taken as a proxy for ground water extraction and the prices of output and input

Fig. 3.9 *Phase Diagram 2* Perturbed curves showing the effects of change in input price on the shadow price and stock of ground water over time

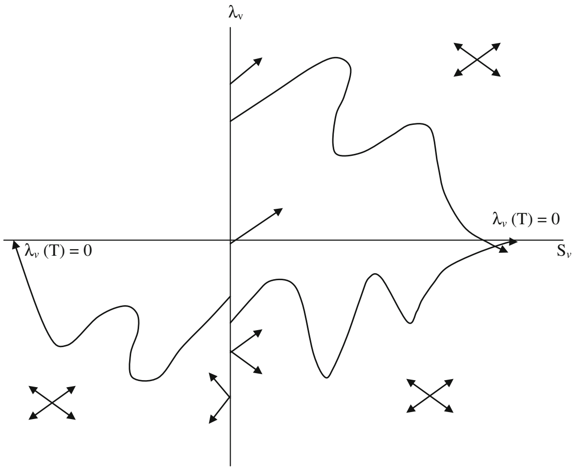


Table 3.10 Augmented Dickey-Fuller unit root test on D (T_WELL_IRRI), D (INDEX_FP) and D (INDEX_FERT_P) and stationarity of the services at 1st difference

	t-statistic**	Prob*
Null Hypothesis: D (N_IRRI_A) has a unit root		
ADF test statistic	−10.0632	0.000
Null Hypothesis: D (T_WELL_IRRI) has a unit root		
ADF test statistic	−6.0043	0.000
Null Hypothesis: D (INDEX_FP) has a unit root		
ADF test statistic	−3.9042	0.0049
Null Hypothesis: D (INDEX_FERT_P) has a unit root		
ADF test statistic	−4.0279	0.0035

**Test critical values 1 % level −3.6267; 5 % level −2.9458
*Mackinnon one sided *p*-values

have been represented by the index of foodgrains price (INDEX_FP) and index of fertilizer price (INDEX_FERT_P) respectively. The sources of data are Economic Survey, Ministry of Finance, Government of India and Centre for Monitoring Indian Economy, CMIE (several issues). These are national level data for 38 years from 1970–71 to 2007–08. The stationarity of the series of the variables has been checked by Augmened Dickey Fuller (ADF) Unit Root Test. The Engle-Granger Cointegration Test has been done to check the long-run relationship between them using the techniques specified in Enders (2004). In the ADF test, the variables are non-stationary at level but stationary at first difference (see Table 3.10). The results of cointegration (pairwise) have been presented in Table 3.11.

In Table 3.11, the Null Hypothesis: tube-well irrigation (T_WELL_IRRI) and net irrigated area (N_IRRI_A) are not cointegrated, has been rejected at 1 % level of significance. That means, these two variables are cointegrated. In other words, tube-well irrigation (ground water) has increased irrigated area in India over time.

Table 3.11 Results of Engle-Granger cointegration test between the variables

Variables: T_WELL_IRRI, N_IRRI_A		
Null Hypothesis: Series are not cointegrated		
Dependent	Z-Statistic	Prob*
T_WELL_IRRI	−22.3673	0.0123
N_IRRI_A	−23.6541	0.0081
Variables: T_WELL_IRRI, INDEX_FERT_P		
Null Hypothesis: Series are not cointegrated		
Dependent	Z-Statistic	Prob*
T_WELL_IRRI	−6.2592	0.6027
INDEX_FERT_P	−4.7616	0.7367
Variables: T_WELL_IRRI, INDEX_FP		
Null Hypothesis: Series are not cointegrated		
Dependent	Z-Statistic	Prob*
T_WELL_IRRI	−5.8768	0.6370
INDEX_FP	−3.7527	0.8210

*Mackinnon p-values

The results in Table 3.11 show that foodgrains price (INDEX_FP) and fertilizer price (INDEX_FERT_P) are not cointegrated with tube-well irrigation (T_WELL_IRRI). That is, no meaningful long run relationship is obtained between input and output prices and ground water extraction. So, price can not be considered as a policy option for water conservation. It is important to note here that the results are based on national level aggregate data which may overlook many local factors and mask the relationship between input/output price and tube-well irrigation at the regional level. Therefore, here the empirical results are not robust in the sense that we can not conclude that price has no effect on the stock of ground water. The relationship between them can very well exist at local or regional level. The other factors like rainfall, soil and geo-physical conditions, production technology, cropping pattern and government policy which vary across regions may play more important role in water conservation in many cases. The extraction of ground water in major states of India is different possibly because of different geological and hydrological features. In states like Punjab, Haryana, Rajasthan, Uttar Pradesh and Tamil Nadu, the extraction level of ground water is very high and in some cases it has crossed the permissible limits whereas in the states of Indo-Gangetic and Brahmaputra Plains and Coastal areas of India like West Bengal, Andhra Pradesh, Assam, Orissa, Bihar, Jharkhand and Kerala, which are also agriculturally important states in the country, the conservation of ground water is much higher (see Table 3.12). Thus, extraction and conservation of ground water may be largely

Table 3.12 Availability and utilization of ground water in major states of India

States	Net annual ground water availability [in billion cubic metre (bcm)]	Stage of ground[a] Water development (%)
Andhra Pradesh	32.95	45
Assam	24.89	22
Bihar	27.42	39
Gujarat	15.02	76
Haryana	8.63	109
Jharkhand	5.25	20
Karnataka	15.30	70
Kerala	6.23	47
Madhya Pradesh	35.33	48
Maharashtra	31.21	48
Orissa	21.01	18
Punjab	21.44	145
Rajasthan	10.38	125
Tamil Nadu	20.76	85
Uttar Pradesh	70.18	70
West Bengal	27.46	42

Source Ground Water Scenario of India (2009–10), Government of India

[a] Indicates the percentage of utilization of ground water potential

determined by natural factors. In such cases, price may not have significant role in water conservation.

The report on ground water in India mentioned above states that the ground water behaviour in the Indian sub-continent is highly complicated due to the occurrence of diversified geological formations. Broadly two groups of rock formations have been identified—Porous Formations and Fissured Formations. The Porous Formations are further subdivided into unconsolidated and semi-consolidated formations. In the former, areas covered by alluvial sediments of river basins and coastal tracts constitute the unconsolidated formations and these are by far the most significant ground water reservoirs for large scale and extensive development. The hydrological environment and ground water regime in the Indo-Ganga-Brahmaputra basin and coastal belts indicate the existence of potential aquifers having enormous fresh ground water reserve. Bestowed with high rainfall and covered by a thick pile of porous sediments, these ground water reservoirs get replenished every year and are being used heavily. The states which are endowed with high reserve of ground water fall in these regions. The role of natural factors in ground water consergvation is supported by similar studies (Santa Clara Valley, California: A case of arrested subsidence: US Geological Survey Professional Paper, Issue 1360, US Government Printing Office 1985; Soil and Aquifer Properties and their effect on Ground-water, http://www.co.portage.wi.us/groundwater/understand/soil.htm 2014). Therefore, if natural factors play prominent role, price may not have any significant effect on the extraction or conservation of ground water.

3.4.2.5 Summary

Agriculture in LDCs has achieved remarkable success in production in the last few decades largely banking on ground water extraction. The excess depletion of water has, however, caused resource degradation and posed a threat to future growth in the farming sector. For conservation of water resource and sustainability of growth in agriculture, direct regulatory measures, crop diversification, rain water harvest and use of effective irrigation technology have been suggested by experts and policy makers. It is also suggested that manipulation of price may be helpful for conservation of water. This section makes an attempt to see whether input and output prices can be used as policy instruments to ensure conservation of ground water specially when input subsidy and price support for the crops lead to excess depletion of water.

Here, we have developed a model of ground water extraction for agricultural growth and conducted comparative dynamic analysis on the optimal path for ground water stock with respect to input and output prices. The qualitative results of the perturbed curves in Phase-diagrams show that the impact of price on the optimal stock of water over time is ambiguous. That means, there is no guarantee that decline in output price or increase of input price will help conservation of ground water. The other factors like rainfall, soil and geological conditions, public investment, irrigation technology, etc. may play more important role in this matter. The theoretical results have been empirically verified by time series econometric analysis. The cointegration results using aggregate data in the Indian context show that there is no meaningful long run relationship between input and output prices and tube-well irrigation. However, on the basis of these results, it can not be concluded that price has no role in the extraction or conservation of water. This is because, the other factors such as agricultural technology, soil and geo-physical conditions and public investment in irrigation may play more important role in resource use. It is found that extraction rate of ground water is significantly different across states of India although all the states face almost the same price. Therefore, manipulation of price cannot be a general policy prescription for resource conservation, although at the regional or local level it can play an important role.

3.5 Rain Water Harvest and Sustainable Agricultural Growth[3]

3.5.1 Introduction

The developing countries like India have achieved remarkable success in agriculture specially in foodgrains production in the last four decades largely banking on ground water extraction. Extension of irrigation has greatly facilitated the use of high-yielding variety (HYV) seeds and chemical fertilizers in East and South East Asia and Pacific countries leading to significant productivity growth in agriculture. Favourable geo-physical conditions, higher productivity in HYV cultivation and various support measures of the government have resulted in huge investment on tube-well irrigation and depletion of ground water. In India, the share of well irrigation in net irrigated area has increased from 12.34 to 60.86 % over the period from 1970–71 to 2007–08. (Source: Centre for Monitoring Indian Economy, CMIE 2010). According to NASA report, more than 108 km of groundwater disappeared from aquifers in north India between 2002 and 2008 (Source: The Times of India, Kolkata, India, August 14 2009). The huge extraction of ground water has been very helpful for agricultural growth but excess depletion of the resource has caused severe threat to the sustainability of growth in agriculture in the country (Singh 1992, 2000; Rao 2002; Sidhu 2002; Sasmal 2012). As a result of excessive depletion of ground water, the salinity and arsenic problems in water and soil degradation have become very acute in many parts of the country.

Rosegrant and Sombilla (1997) cautioned that the major threat that might come in the way of future foodgrains production would be the shortage of water supply. While there is excess depletion of ground water, the rain water has remained largely underutilized due to lack of proper infrastructure and appropriate technology. Rain

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[3] Earlier drafts of this section were presented by Sasmal (2010, 2011 and 2013a).

water harvest, appropriate technology for surface water management and crop-diversification in favour of less water intensive crops have been suggested as alternative policy options by researchers for productivity growth in agriculture (Shah et al. 1993; Rao 2002; Ramasamy 2004; Sasmal 2006, 2013a, b). A report of the Ministry of Water Resources, Government of India reveals that in most of the major states of India almost full potential of ground water irrigation has been utilized and in certain cases it has crossed 100 % capacity of ground water irrigation potential (Ground Water Scenario of India 2009–10, Government of India). So, the effective management of surface water and harvest of rain water have become very important in the present context.

We argue for government intervention to check excess depletion of ground water and at the same time emphasize on rain water harvest specially in countries with sufficient rainfall. The data on rainfall and its use in India can provide important insight for our purpose. In India, total annual precipitation of rain water is 3,700,000 million cubic meters (mcm) out of which 1,200,000 mcm evaporates and 1,700,000 mcm flows down the rivers. Net recharge to the aquifer of groundwater is only 267,500 mcm. (Source: Ministry of Water Resources, Government of India). India experiences huge rainfall every year but only a fraction of this renewable resource is utilized for agriculture and other economic activities. Rain water can be harvested through (i) Dams, Barrage and other River Projects, (ii) Canals and reservoirs, (iii) watershed development, (iv) tanks, ponds, lakes and (v) artificial recharge to the aquifer. However, adequate physical infrastructure and appropriate technology are very essential for this purpose. Therefore, sufficient investment is necessary for the projects of rain water harvest. The projects may have multi-functional benefits like irrigation and flood control, fishing, water transportation, hydel power, eco-tourism, bio-diversity and the ecosystem services. It needs to be mentioned here that big projects involve huge environmental and human costs in the forms of destruction of forests and displacement of population. As a result, such big projects are not being encouraged on environmental grounds. In lieu, community oriented minor projects like watershed development, excavation and conservation of tanks and reservoirs etc. are getting priorities. Besides, big projects are mostly of public good nature and they have externality problems. It is difficult also to implement such projects at the individual level. For both major and minor projects it is the social planner who can make proper valuation of the social costs and benefits of the projects and can take decisions for harvesting rain water and making investments for such projects. Only those projects should be selected which are environmentally acceptable and economically viable. In fact, small and ecologically acceptable projects not only provide irrigation for agriculture, but also generate environmental services to the society. So, side by side with river projects, micro projects like watershed development, construction of reservoirs, preservation of water bodies should be given high importance. People's participation, community management and formation of social capital will be very important for managing such irrigation projects. Proper valuation of resources and making investment for irrigation projects are actually social planner's problem.

This work focuses on the need for rain water harvest for sustainable agricultural growth and demonstrates with the help of a theoretical model how the social planner can determine the optimal path for public investment so that infrastructure and social capital are created for rain water harvest in a dynamic perspective. There is a trade off between present consumption and investment for rain water harvest which is efficiently resolved by the social planner. Here the formation of social capital has been conceived in a broader sense to include physical infrastructure, technological knowhow, human skill and social network necessary for conservation and use of water resource. Here, we address the problem of market failure and the problem of excess depletion of ground water in an unregulated decentralized system. It has been shown that the government intervention in the form of taxation and subsidy can improve the situation but socially optimum result is obtained only if the problem is solved by a social planner in a macro perspective. Since the irrigation projects will generate ecological services and the social planner can make proper valuation of natural resources and the environmental quality, it is the social planner who can take right decisions in this matter. Our theoretical model demonstrates that a higher growth path can be achieved by the decision of optimal investment and the equilibrium is dynamically stable. In fact, in this work we have derived a modified Ramsey growth path. The work has been arranged as follows: First we have developed a model to show how over exploitation of ground water makes agricultural growth unsustainable in an unregulated system. It also derives some comparative static results with respect to government intervention measures on water extraction. Then we have developed a model of agricultural growth where the social planner traces out the optimal path for capital accumulation to harvest rain water and ensures sustainable growth in agriculture.

3.5.2 Over Exploitation of Ground Water and Unsustainable Agricultural Growth

3.5.2.1 The Model

Let us consider an agrarian system where the production function of a representative farmer is:

$$Q = F(W, Z) \tag{3.48}$$

where Q is agricultural output, W is extraction of ground water, Z is other input, say, fertilizer. It is assumed that $F_W > 0, F_{WW} < 0, F_Z > 0, F_{ZZ} < 0$. The availability of rain water is fixed depending on rainfall, infrastructure and natural conditions. The cost of water per unit is C^W which can be written as a function of stock of ground water (S), extraction of water (W) and tax on water extraction (τ). The cost function is:

$$C^W = C^W(S, W, \tau) \tag{3.49}$$

Here, $C_W^W \rangle 0, C_{WW}^W \rangle 0, C_S^W \langle 0, C_{SS}^W \langle 0, C_\tau^W \rangle 0$. There may be some subsidy on irrigation. Let η be the subsidy per unit of water. If the stock of water declines or extraction of water increases, cost of extraction goes up.The farmer's income is:

$$\pi = P \cdot F(\cdot) - C^W(\cdot) \cdot W - P^Z \cdot Z + \eta \cdot W \tag{3.50}$$

where P is the price of the crop, and P^Z is the price of Z and they are given. The extraction of ground water causes salinity and arsenic problems in water and soil. So, it involves some environmental costs. But the private individuals disregard such costs.

The utility function of the household is: $U = f(C, N)$ where C is consumption and N is environmental quality. The consumption depends on income and it may be assumed that the whole income is spent on consumption. An individual can not influence the quality of the environment. So the environmental quality is considered as a given public good and it drops out as an argument in utility function. Then the utility function becomes $U = f(C)$ with$f'(\text{C}) > 0, f''(\text{C}) < 0$.

The dynamics of water stock in the aquifer is:

$$\dot{S} = -W + R$$

R is natural recharge to the aquifer and it is given by natural and geo-physical conditions.

If W > R, $\dot{S} = \frac{dS}{dt} \langle 0$. That means, water stock declines over time.

The objective of the farmer is:

$$\begin{aligned} &\text{Max} \int_0^\infty \pi \cdot e^{-rt} \cdot dt \\ &\text{s.t.} \quad \dot{S} = -W + R \end{aligned} \tag{3.51}$$

$S(0) = S_0, S(T)$ free, lim T → ∞

r is rate of discount of future income.

It is a dynamic optimisation problem over a planning horizon [0 ∝] that can be solved by the maximum principle of optimal control theory as specified in Chiang (1992), Dorfman (1969), Kamien and Schwartz (1981).

The current value Hamiltonian is:

$$H = P \cdot F(\cdot) - C^W(\cdot) \cdot W - P^Z \cdot Z + \eta \cdot W + \lambda_1(-W + R) \tag{3.52}$$

S is the state variable and λ_1 is costate variable. λ_1 is the current value shadow price of S.

F.O.C.s for maximisation of H are:

$$\frac{\delta H}{\delta W} = P \cdot F_W - C^W - C^W_W \cdot W + \eta - \lambda_1 = 0 \tag{3.53}$$

$$\frac{\delta H}{\delta Z} = P \cdot F_z - P^Z = 0 \tag{3.54}$$

$$\dot{\lambda}_1 = r\lambda_1 - \frac{\delta H}{\delta S} = r\lambda_1 + W \cdot C^W_S \tag{3.55}$$

$$\dot{S} = \frac{\delta H}{\delta \lambda_1} = -W + R \tag{3.56}$$

The transversality conditions are:

$$\begin{aligned} &\lambda_1(T) \geq 0, S(T)\lambda_1(T) = 0 \\ &\lim T \to \infty \end{aligned}$$

S.O.C. is satisfied by the strict concavity of H in W, Z and S jointly (see Appendix 11).

Now, the theorems of Steinberg and Stalford (1973) and Gale and Nikaido (1965) guarantee the globally and uniquely determined optimal values of the control variables as

$$\begin{aligned} \hat{W} &= \hat{W}\left(S, \lambda_1, P, P^Z, \eta, r, S_0\right) \\ \hat{Z} &= \hat{Z}\left(S, \lambda_1, P, P^Z, \eta, r, S_0\right) \end{aligned}$$

Equation (3.53) determines the extraction of water at each point of time. The optimal values of W and Z are determined from (3.53) and (3.54) respectively at each point of time in terms of the set of parameters P, P^Z, η, r and the state and costate variables. Since the social costs of environmental degradation are ignored, there will be market failure leading to over exploitation of ground water. The depletion of water may be further encouraged by subsidy of the government. Therefore if P, η, F_W are high and P^Z is low, it is likely that $W > R$. In fact, in many states of India $W > R$.

The following two differential equations trace out the optimal paths for λ and S:

$$\dot{\lambda}_1 = r\lambda_1 + W \cdot C^W_S \tag{3.57}$$

$$\dot{S} = -W + R \tag{3.58}$$

$\dot{S}$ in Eq. (3.56) traces out the ground water stock over time. Now, if extraction exceeds recharge i.e., $W > R$, ground water stock will decline over time making $\dot{S}\langle 0$.

Again, if $\dot{S} < 0$, we get

$\dot{S} = -W + R = -E$ where E is the amount of decline of stock at each point of time.

For an exhaustible resource, the decline of stock at each point of time can be expressed as a constant ratio of the remaining stock as

$\frac{E(t)}{S(t)} = -\rho$ (see Jones 2002; Dasgupta and Heal 1974)

$$\text{or,}\quad E(t) = -\rho \cdot S(t)$$

It can be expressed as a first-order differential equation as

$$\dot{S} = -\rho \cdot S(t)$$

The solution to this differential equation gives

$$S(t) = S(0)e^{-\rho t} \tag{3.59}$$

That means, the stock declines at an exponential rate and ρ is the rate of decline (Fig. 3.10).

But here, ground water is a renewable resource. It may not follow a path of exponential decay but it is true that the water stock will gradually decline and finally this will make agricultural growth unsustainable in the long-run. As in Weikard and Hein (2011), the efficient level of use of the resource will exceed the sustainable level.

3.5.2.2 Comparative Statics with Respect to Public Intervention

Total differentiation of (3.53) and (3.54) gives

$$A + B\begin{bmatrix} \frac{\delta\hat{W}}{\delta P} & \frac{\delta\hat{W}}{\delta P^Z} & \frac{\delta\hat{W}}{\delta\tau} \\ \frac{\delta\hat{Z}}{\delta P} & \frac{\delta\hat{Z}}{\delta P^Z} & \frac{\delta\hat{Z}}{\delta\tau} \end{bmatrix} = 0$$

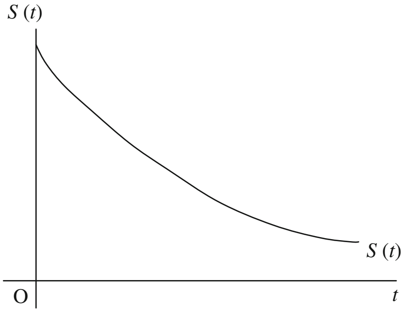

Fig. 3.10 The declining stock of ground water over time

where,

$$|B| = \begin{bmatrix} P \cdot F_{WW} - C_W^W - C_W^W - W \cdot C_{WW}^W & P \cdot F_{WZ} \\ P \cdot F_{ZW} & P \cdot F_{ZZ} \end{bmatrix}$$

$$|B| \rangle 0 \quad \text{assuming} \quad F_{WZ} = 0$$

$$A = \begin{bmatrix} F_W & 0 & -C_\tau^W \\ F_Z & -1 & 0 \end{bmatrix}$$

$$\frac{\delta \hat{W}}{\delta P} = \frac{(-F_W) \cdot P \cdot F_{ZZ}}{|B|} \rangle 0$$

$$\frac{\delta \hat{W}}{\delta t} = \frac{C_\tau^W \cdot P \cdot F_{ZZ}}{|B|} \langle 0$$

$$\frac{\delta \hat{W}}{\delta P^Z} = \frac{P \cdot F_{ZW}}{|B|} = 0 \quad \text{Since}\, F_{ZW}\ (\text{is assumed to be zero}).$$

The comparative static results have good implications for policy intervention. The government can reduce water extraction by imposition of tax. On the other hand, withdrawal of price support for the crop will also reduce the depletion of the resource.

Suppose a tax μ is imposed per unit of W and subsidy is withdrawn. Then, the profit function of the farmer will be

$$\pi = P \cdot F(\cdot) - C^W(\cdot) \cdot W - P^z \cdot Z - \mu \cdot W \tag{3.60}$$

Now Eq. (3.53) will change to

$$\frac{\partial H}{\partial W} = P \cdot F_W - C^W - C_W^W \cdot W - \mu - \lambda_1 = 0 \tag{3.61}$$

Here, the tax rate can be manipulated in such a way that optimal value of W declines to the level of R making $\dot{S} = 0$. This will help conservation of water resource but agricultural production will decline. From the viewpoint of social welfare it is not clear whether welfare increases or not. So, to have a clear improvement in welfare, side by side with conservation of ground water resource, it is necessary to take measures for increasing agricultural production with rain water harvest. It is the social planner who can do the both jobs of ground water conservation and rain water harvest properly.

3.5.2.3 Investment for Harvesting Rain Water and Sustainable Agricultural Growth

The Model

It has been already discussed that if the social planner takes the decisions regarding ground water extraction and investment for rain water harvest socially optimum growth in agriculture can be achieved. To avoid complexity, let us assume that rain water will be used for agriculture only. One important point to be noted here is that rain water harvest and conservation of waterbodies protect the ecosystem and generate ecological services and these are taken into account by the social planner. Another important assumption is that only the environmentally acceptable projects are developed by the social planner. We consider an agrarian economy where rainfall is more or less fixed per year and a fraction of the total rainfall percolates to the aquifer in the natural process. In this backdrop, the production function can be specified as:

$$Y = F(W, Z) \text{ where } Y \text{ is output, } W \text{ is water sup ply and } Z \text{ is other input.}$$

The social planner maintains a balance between the extraction of ground water and the natural recharge of the aquifer leaving the ground water stock unchanged. Let the recharge be denoted by $\overline{R}$. Here, we have two sources of water supply—ground water and rain water. The social planner takes into account the social cost of ground water extraction and fixes the use of ground water at $\overline{R}$. Therefore at time t, water supply is:

$$W(t) = \overline{R} + h(K) \tag{3.62}$$

where h is harvest of rainwater from social capital K. h is a function of K and K is defined in a broader sense including physical infrastructure, technology and social and human capital. Now, we can write production function as

$Y = F\left(\overline{R} + h(K), Z\right)$ which reduces to

$$Y = F(K, Z)$$

with

$$F_K > 0, F_{KK} < 0, F_Z > 0, F_{ZZ} < 0. \tag{3.63}$$

The budget constraint of the economy is;

$$Y = C + I + P^Z \cdot Z \tag{3.64}$$

where C is consumption, I is investment for social capital K and P^Z is price of the variable input Z.

The present consumption has a trade-off with investment for accumulation of K. The social capital K as we define here is different from physical capital of growth theory. Here, the growth of K helps future consumption by increasing agricultural production and at the same time generates environmental services through conservation of the ecology and biodiversity. So, while making investment for K, the social planner takes into account the value of ecological services rendered by K.

The dynamics of K is:

$$\dot{K} = I - \delta K \tag{3.65}$$

where δ is depreciation of K at each point of time. It can be expressed as

$$\dot{K} = Y - C - \delta K - P^Z \cdot Z \tag{3.66}$$

$K \leq K^*$ where K^* is the maximum value of K determined by the nature and technology.

The utility function is: $U = U(C,N)$ with $U_C\rangle 0, U_{CC}\langle 0, U_N\rangle 0, U_{NN}\langle 0$

where C is consumption and N is environmental quality. The social planner can influence N by choosing the values of Z and K. Here, environmental quality (N) is included in utility function as an argument.

So, the dynamics of N is:

$$\dot{N} = \psi(N) - \gamma(Z) + \beta(K) \tag{3.67}$$

where γ is pollution from input Z and β is environmental services from K via harvest of rain water. It is assumed that use of chemical input Z has some polluting effect on the environment.

$$\psi'(N)\rangle 0, \psi''(N)\langle 0, \gamma'(Z)\rangle 0, \gamma''(Z)\rangle 0, \beta'(K)\rangle 0, \beta''(K)\langle 0.$$

The environment has some assimilative capacity and ψ(N) is natural regeneration of N. It has been already mentioned that construction of big river projects and dams involves huge environmental and social costs. Huge destruction of forests and displacement of population become inevitable for such projects in most of the cases. That is why large projects are being discouraged now-a-days as far as practicable. So, the social planner considers investment only for those projects which are resource-conserving and environmentally acceptable.

Now the social planner's objective is:

$$\text{Max} \int_0^T U(C,N)e^{-rt} \cdot dt \tag{3.68}$$

$$\text{s.t.} \begin{array}{l} \dot{N} = \psi(N) - \gamma(Z) + \beta(K) \\ \dot{K} = Y - C - \delta K - P^Z \cdot Z \\ N(0) = N_0, N(T) \leq \overline{N} \\ K(0) = K_0, K(T) \geq K^* \end{array}$$

It is a dynamic optimization problem over a definite planning period [0 T] that can be solved by using optimal control theory as mentioned in the previous section. The reason behind taking a definite planning horizon is that agricultural growth can not be sustained for an infinite time period through development of infrastructure and social capital because *K* will eventually reach its maximum level K*. $\overline{N}$ is the minimum environmental quality that must be maintained at the end of the planning period.

The current value Hamiltonian of this problem is:

$$H = U(C,N) + \lambda_1\left(Y - C - \delta K - P^Z \cdot Z\right) + \lambda_2(\psi(N) - \gamma(Z) + \beta(K)) \tag{3.69}$$

In this setting we have two state variables, *K* and *N*. λ_1 and λ_2 are their respective costate variables. The control variables are *C* and *Z*. As usual, λ_1 and λ_2 are current value shadow prices of *K* and *N* respectively.

The necessary F.O.Cs for maximization of *H* are:

$$\frac{\delta H}{\delta C} = U_C - \lambda_1 = 0 \tag{3.70}$$

$$\frac{\delta H}{\delta Z} = \lambda_1\left(Y_Z - P^Z\right) - \lambda_2\gamma'(Z) = 0 \tag{3.71}$$

or

$$Y_Z = P^Z + \frac{\lambda_2}{\lambda_1}\gamma'(Z)$$

$$-\frac{\delta H}{\delta K} = \dot{\lambda}_1 = \lambda_1 r - \lambda_1(Y_K - \delta) - \lambda_2\beta'(K) \tag{3.72}$$

$$-\frac{\delta H}{\delta N} = \dot{\lambda}_2 = \lambda_2 r - U_N - \lambda_2\psi'(N) \tag{3.73}$$

$$\frac{\delta H}{\delta \lambda_1} = \dot{K} = Y - C - \delta K - P^Z \cdot Z \tag{3.74}$$

$$\frac{\delta H}{\delta \lambda_2} = \dot{N} = \psi(N) - \gamma(Z) + \beta(K) \tag{3.75}$$

Equation (3.70) has very good economic implication. The marginal utility of *C* is equal to the current value shadow price of *K*. It determines optimal consumption at each point of time. Equation (3.74) traces out the path for *K* over time. The accumulation of *K* determines future consumption and environmental standard via its effect on rain water harvest.

Transversality conditions are:

$$\lambda_1(T) \geq 0, \lambda_1(T)K(T) = 0, \lambda_2(T) \geq 0, \lambda_2(T)N(T) = 0$$

Since $K(T) \leq K^*$, $\lambda_1(T) > 0$ if $K(T) = K^*$ i.e., constraint is binding.Otherwise, λ_1 (T) = 0.

λ_2(T) N(T) = 0 can be explained in a similar fashion.

S.O.C. is satisfied by concavity of *H* in *C, Z, K* and *N* jointly (see Appendix 12). The optimal values of *C, Z* are determined in terms of state and costate variables and set of parameters at each point of time from Eqs. (3.70) and (3.71) as

$$\hat{C} = \hat{C}\{K, N, \lambda_1, \lambda_2, P^Z, \delta, r, K_0, N_0\}$$
$$\hat{Z} = \hat{Z}\{K, N, \lambda_1, \lambda_2, P^Z, \delta, r, K_0, N_0\}$$

Now, the optimal solution to this dynamic optimisation problem is described by the resulting Eqs. (3.70)–(3.75).

The differential equations trace out the optimal paths for state, costate and control variables.

The differentiation of Eq. (3.70) w.r.t. time gives

$$\dot{\lambda}_1 = U_{CC}\dot{C} \text{ where } \dot{C} = \frac{dC}{dt}$$

Now, substitution of the values of $\dot{\lambda}_1$ and λ_1 in (3.72) gives

$$U_{CC}\dot{C} = U_C r - U_C(Y_K - \delta) - \lambda_2\beta'(K)$$

After rearrangement, we get
$r - \frac{U_{CC}}{U_C} \cdot C\left(\frac{\dot{C}}{C}\right) = (Y_K - \delta) + \frac{\lambda_2}{U_C}\beta'(K)$ which reduces to

$$\frac{\dot{C}}{C} = \frac{1}{\theta}\left\{Y_K + \frac{\lambda_2}{\lambda_1}\beta'(K) - \delta - r\right\} \tag{3.76}$$

Here $\left(\frac{\dot{C}}{C}\right)$ is the rate of growth of consumption and $-\left(\frac{U_{CC}}{U_C} \cdot C\right)$ is the reciprocal of the elasticity of inter-temporal substitution of consumption in utility denoted by θ (Barro and Sala-i-martin 1995). This is actually the modified Ramsey rule of optimal consumption in a dynamic perspective.

Equation (3.76) gives growth rate of consumption over time. Given the elasticity of inter-temporal substitution in consumption, production technology, time preference and depreciation of social capital, growth rate in consumption depends on the valuation of environmental services rendered by social capital.

Here, rate of return on *K* includes a positive term $\left[\frac{\lambda_2}{\lambda_1}\beta'(K)\right]$ in addition to Y_K. This term is absent in a market solution. Therefore, the social planner not only ensures sustainable growth in agriculture, but also makes the growth rate higher and socially optimal. This is because the social planner takes into account the ecological benefits of water conservation while making investment for rain water projects. Here, K plays twin role of increasing production and rendering environmental services as conservation capital in Harrington et al. (2005).

Equation (3.71) has similar interpretation. Unlike in decentralised system, the social planner's optimization problem determines the optimal use of Z in such a way that the value of marginal product of the input is not just equal to its market price. The marginal cost of pollution (measured in terms of relative shadow price of environmental quality) is also added to the price of the input. Thus the social planner reduces the use of the polluting input.

In balanced growth all the variables grow at the same rate i.e., in our case, $g_C = g_Y = g_K = g_Z$. Here, g_i is the growth rate of the ith variable and $i = Y$, C, I, K, Z, N.

The growth is sustainable if $\dot{N} = 0$. Again, $\dot{N} = 0$ if

$$\psi(N) + \beta(K) = \gamma(Z) \tag{3.77}$$

Total differential of (3.77) gives

$$\begin{aligned}
&\psi'(N)dN + \beta'(K)dK = \gamma'(Z)dZ \\
\text{or,}\quad &\frac{\delta\psi}{dN}\cdot\frac{N}{\psi}\cdot\frac{dN}{N}\cdot\psi + \frac{d\beta}{dK}\cdot\frac{K}{\beta}\cdot\frac{dK}{K}\cdot\beta = \frac{d\gamma}{dZ}\cdot\frac{Z}{\gamma}\cdot\frac{dZ}{Z}\cdot\gamma \\
\text{or,}\quad &\varepsilon_N\cdot g_N\cdot\psi + \varepsilon_K\cdot g_K\cdot\beta = \varepsilon_Z\cdot g_Z\cdot\gamma
\end{aligned}$$

ε_N is the elasticity of regeneration of N in natural process.

ε_K is elasticity of change in environmental quality w.r.t. K.

ε_Z is elasticity of pollution emission w.r.t. Z.

In sustainable growth $\dot{N} = 0$, $g_N = 0$. Now, if $g_K = g_Z$, then we can write $g_K(\varepsilon_K \cdot \beta - \varepsilon_Z \cdot \gamma) = 0$. After rearrangement, we get

$$\frac{\varepsilon_K}{\varepsilon_Z} = \frac{\gamma}{\beta}.$$

Since $\psi(N) > 0$ according to Eq. (27), $\beta\,(K)\langle\gamma(Z)$. The values of Z and K will be such that the condition $\beta < \gamma$ is satisfied. Thus, if $\dot{N} = 0$, a sustainable growth is feasible and in balanced growth, $\varepsilon_K\rangle\varepsilon_Z$.

That means, in a sustainable balanced growth path the elasticity of change in environmental quality w.r.t. K is greater than the elasticity of pollution from Z. Since our model is based on the assumption that water projects have significant positive impact on the ecology and the environment, this condition is compatible with the assumption of the model.

In balanced growth $g_Y = g_C = g_K = g_Z$ if the production function $Y = F(K, Z)$ exhibits CRS and the sum of production elasticities of K and Z is equal to one i.e., $E_K + E_Z = 1$ (Harrington et al. 2005).

From (3.74) we get

$$\frac{\dot{K}}{K} = \frac{Y}{K} - \frac{C}{K} - \delta - P^Z \cdot \frac{Z}{K} \tag{3.78}$$

$\frac{Y}{K}, \frac{C}{K}, \frac{Z}{K}$ are constant in balanced growth and the values of δ and P^Z are given. Therefore $\frac{\dot{K}}{K}$ is also constant.

The above conditions will ensure sustainable balanced growth in the long-run. K and Z are growing in such a way that N remains constant. As N is constant λ_2 also converges to a constant value in the long-run. Therefore, the long-run equilibrium is characterized by

$$\dot{\lambda}_2 = -U_N - \lambda_2 \psi'(N) + \lambda_2 r = 0 \tag{3.79}$$

$$\dot{N} = \psi(N) - \gamma(Z) + \beta(K) = 0 \tag{3.80}$$

Stability of the Equilibrium

Following Chiang (1992) and Goetz (1997), we form the Jacobian matrix and evaluate it at the steady state point $\left(\dot{N} = 0, \dot{\lambda}_2 = 0\right)$ and use the phase diagram to show the stability of equilibrium using qualitative results.

$$J_E = \begin{bmatrix} \frac{\delta \dot{N}}{N} & \frac{\delta \dot{N}}{\delta \lambda_2} \\ \frac{\delta \dot{\lambda}_2}{\delta N} & \frac{\delta \dot{\lambda}_2}{\delta \lambda_2} \end{bmatrix}$$

$$\left[\dot{N} = 0, \dot{\lambda}_2 = 0\right]$$

$$\frac{\delta \dot{N}}{\delta N} = \psi'(N)\rangle 0, \frac{\delta \dot{N}}{\delta \lambda_2} = 0$$

$$\frac{\delta \dot{\lambda}_2}{\delta N} = -U_{NN} - \lambda_2 \psi''(N)\rangle 0, \frac{\delta \dot{\lambda}_2}{\delta \lambda_2} = -\psi'(N) + r > 0$$

(follows from implicit function $\dot{\lambda}_2 = 0$)

The signs of the slopes of the two isoclines $\dot{N} = 0$ and $\dot{\lambda}_2 = 0$ can be specified by applying the implicit function theorem as (Fig. 3.11)

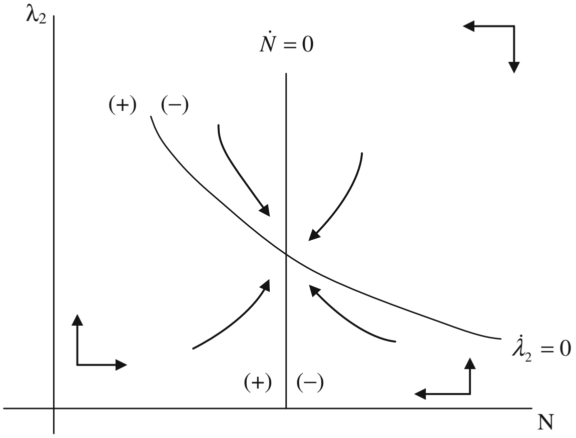

Fig. 3.11 The stability of equilibrium of sustainable balanced growth

$$\left.\frac{\delta \lambda_2}{\delta N}\right|_{\dot{N}=0} = -\frac{\frac{\delta \dot{N}}{\delta N}}{\frac{\delta \dot{N}}{\delta \lambda_2}} = \propto$$

$$\left.\frac{\delta \lambda_2}{\delta N}\right|_{\dot{\lambda}_2=0} = -\frac{\frac{\delta \dot{\lambda}_2}{\delta N}}{\frac{\delta \dot{\lambda}_2}{\delta \lambda_2}} = \langle 0$$

The qualitative results in the Phase-diagram show that the sustainable growth in steady state path is dynamically stable.

3.5.3 Summary

Agriculture in east and south east Asia and pacific countries has achieved remarkable success, specially, in foodgrains production in the last few decades largely banking on ground water extraction. The over exploitation of ground water in an unregulated system has caused severe damage to the resource base putting a question mark before the future growth in agriculture. In a market mechanism, social and environmental costs are overlooked by private agents. As a result, excess depletion of the resource takes place and agriculture becomes unsustainable in the long-run. The government intervention can regulate the water use but socially optimum outcome may not come out of that intervention.

This section emphasizes on rain water harvest for agricultural growth and suggests sufficient investment for developing physical infrastructure and social capital to harvest rain water in countries that experience sufficient rainfall every year. Rain water is a renewable resource and it has multi-functional social benefits including irrigation, flood control and conservation of the eco-system. Since the projects for rain water harvest have externality problems and they involve lump-sum investment and technical expertise, the problem of rain water harvest can not be handled at the individual level. Here, in this work the problem has been addressed in a macro framework and from the viewpoint of a social planner.

The rain water can be harvested through development of social capital like dams and river projects, canals, reservoirs, watershed development, artificial recharge to the aquifer, etc. which generally involve environmental and human costs. At the same time, rain water harvest and conservation of waterbodies protect the ecology and biodiversity and generate environmental services to the society. So, the social planner selects only those projects which are environmentally acceptable. There is a trade off between present consumption and investment for irrigation projects for future growth which is efficiently resolved by the social planner on the basis of proper valuation of natural resources and the environment.

The present work has developed two theoretical models. The first one shows that private agent makes excess depletion of ground water making agricultural growth unsustainable in the long run. The results of the second model demonstrate that the social planner can determine the optimal path for capital accumulation to harvest rain water and thereby can ensure sustainable balanced growth in agriculture. The modified Ramsey rule applies here in determining the optimal paths for consumption and social capital. The model ensures a steady state equilibrium in agricultural growth which is dynamically stable. The results also show that since the social planner takes into account the environmental benefits of resource conservation, growth rate becomes higher compared to that under decentralized system.

Appendix 1

Differentiation of Eqs. (3.5), (3.6) and (3.7) w.r.t. W, Z and S gives the matrix as follows:

$$\begin{bmatrix} P\cdot Q_{WW} - \tau_W - W\cdot\tau_{WW} & 0 & -\tau_S \\ P\cdot Q_{ZW} & P\cdot Q_{ZZ} & 0 \\ \tau_S & 0 & W\cdot\tau_{SS} \end{bmatrix}$$

where $|D_1|\langle 0, |D_2|\rangle 0$ and $|D_3|\langle 0$
assuming $Q_{ZW} = 0$ and $\tau_{WS} = 0$.

Appendix 2

Differentiation of Eqs. (3.16)–(3.19) w.r.t. z_1, z_2, x and S gives

$$\begin{bmatrix} P_1 f^1_{Z_1 Z_1} & 0 & 0 & 0 \\ 0 & \alpha_2(R_2)\cdot P_2 f^2_{Z_2 Z_2} & 0 & 0 \\ 0 & 0 & -C_x\cdot W_1 - W_1 C_x + C_x\cdot W_2 + C_x W_2 - (1-x)C_{xx}\cdot W_2 & -C_S\cdot W_1 + W_2\cdot C_S \\ 0 & 0 & W_1 C_S + W_2 C_S & W_1\cdot x\cdot C_{SS} + (1-x)C_{SS}\cdot W_2 \end{bmatrix}$$

$$|D_1| < 0, |D_2| > 0, |D_3| < 0, |D_4| > 0.$$

given $C_x > 0$, $C_{xx} > 0$, $C_S < 0$, $C_{SS} < 0$.

Appendix 3

Total differentiation of Eqs. (3.16)–(3.18) in Sect. 3.2 yields

$$A + B\begin{bmatrix} \frac{\partial\hat{Z}_1}{\partial P_1} & \frac{\partial\hat{Z}_1}{\partial P_2} & \frac{\partial\hat{Z}_1}{\partial P_{Z_1}} & \frac{\partial\hat{Z}_1}{\partial P_{Z_2}} & \frac{\partial\hat{Z}_1}{\partial R_2} & \frac{\partial\hat{Z}_1}{\partial S} & \frac{\partial\hat{Z}_1}{\partial\lambda} \\ \frac{\partial\hat{Z}_2}{\partial P_1} & \frac{\partial\hat{Z}_2}{\partial P_2} & \frac{\partial\hat{Z}_2}{\partial P_{Z_1}} & \frac{\partial\hat{Z}_2}{\partial P_{Z_2}} & \frac{\partial\hat{Z}_2}{\partial R_2} & \frac{\partial\hat{Z}_2}{\partial S} & \frac{\partial\hat{Z}_2}{\partial\lambda} \\ \frac{\partial\hat{x}}{\partial P_2} & \frac{\partial\hat{x}}{\partial P_2} & \frac{\partial\hat{x}}{\partial P_{Z_1}} & \frac{\partial\hat{x}}{\partial P_{Z_2}} & \frac{\partial\hat{x}}{\partial R_2} & \frac{\partial\hat{x}}{\partial S} & \frac{\partial\hat{x}}{\partial\lambda} \end{bmatrix} = 0$$

$$A = \begin{bmatrix} f^1_{Z_1}\cdot x & 0 & -x & 0 & 0 \\ & & 0 & & 0 \\ 0 & f^2{}_{Z_2}\alpha_2(R_2)(1-x) & 0 & -(1-x) & x\cdot P_2 f^2{}_{Z_2}\alpha_2'(R_2) \\ & & 0 & & 0 \\ f^1(\cdot) & -\alpha_2(R_2)f^2(\cdot) & 0 & 0 & -P_2 f^2\alpha_2'(R_2) \\ & & \multicolumn{2}{c}{-C_S(W_1 - W_2) - C_{xS}\cdot x\,(W_1 - W_2) - C_{xS}W_2} & -(W_1 - W_2) \end{bmatrix}$$

$$B = \begin{bmatrix} P_1 f^1_{Z_1 Z_1}\cdot x & 0 & P_1 f^1_{Z_1} - P_{Z_1} \\ 0 & P_2\alpha_2(R_2)f^2_{Z_2\cdot Z_2}(1-x) & -P_2\alpha_2(R_2)f^2_{Z_2} + P_{Z_2} \\ P_1 f^1_{Z_1} & -P_2\alpha_2(R_2)f^2_{Z_2} & -W_1 C_x - x\cdot W_1\cdot C_{xx} - W_1 C_x \\ & & + W_2 C_x + CxW_2 - (1-x)C_{xx}\cdot W_2 \end{bmatrix}$$

$|B| < 0$.

Appendix 4

Differentiation of (3.33) and (3.34) and transversality conditions w.r.t. R_2 gives

$\dot{\lambda}_{R_2} = a_{11}\lambda_{R_2} + a_{12}S_{R_2} + n_1$where
$a_{11} = r + C_S\frac{\partial x}{\partial \lambda} + xC_{S\lambda} + (1-x)C_{S\lambda} - C_S\frac{\partial x}{\partial \lambda}\rangle 0$ assuming $C_{S\lambda}$ = 0.
$a_{12} = C_S\frac{\partial x}{\partial S} + xC_{SS} + (1-x)C_{SS} - C_S\frac{\partial x}{\partial S}\langle 0$
$n_1 = C_S\frac{\partial x}{\partial R_2} + xC_{SR_2} + (1-x)C_{SR_2} - C_S\frac{\partial x}{\partial R_2} = 0$ (assuming $C_{SR_2} = 0$)
$\dot{S}_{R_2} = a_{21}\lambda_{R_2} + a_{22}S_{R_2} + n_2$ where $a_{21} = W_2\frac{\partial x}{\partial \lambda} - W_1\frac{\partial x}{\partial \lambda}\rangle 0$,
$a_{22} = W_2\frac{\partial x}{\partial S} - W_1\frac{\partial x}{\partial S}\langle 0$ and $n_2 = W_2\frac{\partial x}{\partial R_2} - W_1\frac{\partial x}{\partial R_2}\rangle 0$
and $S_{R_2}(0) = 0, \lambda_{R_2}(T^0) = 0$ or $S_{R_2}(T^0) = 0$

Appendix 5

Differentiation of (3.33) and (3.34) and transversality conditions w.r.t. P_2 gives

$$\dot{\lambda}_{P_2} = a_{11}\lambda_{P_2} + a_{12}S_{P_2} + n_1$$

where $a_{11} = r + W_1 \cdot C_{Sx}\frac{\partial x}{\partial \lambda} + W_1 \cdot x \cdot C_{S\lambda} - W_2 \cdot C_S \cdot \frac{\partial x}{\partial \lambda} + W_2(1-x)C_{S\lambda}\rangle 0$

assuming $C_{S_\lambda} = 0$.

$$a_{12} = W_1 \cdot C_S \cdot \frac{\partial x}{\partial S} + W_1 \cdot x.C_{SS} - W_2 \cdot \frac{\delta x}{\delta S} \cdot C_S + W_2 \cdot (1-x)C_{SS}\langle 0$$

$$n_1 = W_1 \cdot C_S\frac{\partial x}{\partial P_2} + W_1 \cdot x\, C_{SP_2} - W_2 \cdot C_S\frac{\partial x}{\partial P_2} + W_2 \cdot (1-x)\, C_{SP_2}\rangle 0$$

assuming $C_{S_\lambda} = 0$.

$\dot{S}_{P_2} = a_{21}\lambda_{P_2} + a_{22}S_{P_2} + n_2$ where $a_{21} = -W_1\frac{\partial x}{\partial \lambda} + W_2\frac{\partial x}{\partial \lambda}\rangle 0$,
$a_{22} = -W_1\frac{\partial x}{\partial S} + W_2\frac{\partial x}{\partial S}\langle 0$, $n_2 = -W_1\frac{\partial x}{\partial P_2} + W_2\frac{\partial x}{\partial P_2}\rangle 0$ and
$S_{P_2}(0) = 0, \lambda_{P_2}(T^0) = 0$ or $S_{P_2}(T^0) = 0$

Appendix 6

Differentiation of (3.33) and (3.34) and transversality conditions w.r.t. P_{Z_2} gives

$$\dot{\lambda}_{P_{Z_2}} = a_{11}\lambda_{P_{Z_2}} + a_{12}S_{P_{Z_2}} + n_1$$

$a_{11} = r + W_1 \cdot C_S \cdot \frac{\partial x}{\partial \lambda} + W_1 \cdot x \cdot C_{S\lambda} - W_2 \cdot C_S \cdot \frac{\partial x}{\partial \lambda} + W_2 \cdot (1-x) \cdot C_{S\lambda} \rangle 0$, assuming $C_{S\lambda} = 0$.

$$a_{12} = r + W_1 \cdot C_S \cdot \frac{\partial x}{\partial S} + W_1 \cdot x \cdot C_{SS} - W_2 \cdot C_S \cdot \frac{\partial x}{\partial S} + W_2 \cdot (1-x) \cdot C_{SS} \langle 0$$

$$n_1 = W_1 \cdot \frac{\partial x}{\partial P_{Z_2}} \cdot C_S - W_2 \cdot \frac{\partial x}{\partial P_{Z_2}} \cdot C_S \langle 0.$$

$$a_{21} = -W_1 \frac{\partial x}{\partial \lambda} + W_2 \frac{\partial x}{\partial \lambda} \rangle 0$$

$$a_{22} = -W_1 \frac{\partial x}{\partial S} + W_2 \frac{\partial x}{\partial S} \rangle 0$$

$$n_2 = -W_1 \frac{\partial x}{\partial P_Z} + W_2 \frac{\partial x}{\partial P_Z} \rangle 0$$

Appendix 7

Differentiation of Eqs. (3.38)–(3.40) w.r.t. W, Z and S gives

$$\begin{bmatrix} P \cdot e(G) \cdot F_{WW} - C_W - C_{WW} \cdot W & P.e(G) \cdot F_{WZ} & -W \cdot C_S \\ P \cdot e(G) \cdot F_{ZW} & P \cdot e(G) \cdot F_{ZZ} & 0 \\ C_S & 0 & W \cdot C_{SS} \end{bmatrix}$$

$|D_1| < 0, |D_2| > 0, |D_3| < 0$ (follows from concavity of the production function).

Appendix 8

Total differentiation of Eqs. (3.38) and (3.39) gives

$$A + B \begin{bmatrix} \frac{\delta \hat{W}}{\partial P} & \frac{\delta \hat{W}}{\partial S} & \frac{\delta \hat{W}}{\partial \lambda} & \frac{\delta \hat{W}}{\partial v} & \frac{\delta \hat{W}}{\partial G} & \frac{\delta \hat{W}}{\partial N} & \frac{\delta \hat{W}}{\partial I} \\ \frac{\partial \hat{Z}}{\partial P} & \frac{\partial \hat{Z}}{\partial S} & \frac{\partial \hat{Z}}{\partial \lambda} & \frac{\partial \hat{Z}}{\partial v} & \frac{\partial \hat{Z}}{\partial G} & \frac{\partial \hat{Z}}{\partial N} & \frac{\partial \hat{Z}}{\partial I} \end{bmatrix} = 0$$

where, $B = \begin{bmatrix} P \cdot e(G) \cdot F_{WW} - C_W - W \cdot C_{WW} - C_W & P \cdot e(G) \cdot F_{WZ} \\ P \cdot e(G) \cdot F_{ZW} & P \cdot e(G) \cdot F_{ZZ} \end{bmatrix}$

and A = $\begin{bmatrix} e(G) \cdot F_W & -C_S & -1 & 0 & P \cdot e'(G) F_W & -C_N & -C_I \\ e(G) \cdot F_Z & 0 & 0 & -1 & P \cdot e'(G) F_Z & 0 & 0 \end{bmatrix}$

where,

$$|B| = \left\{P^2 \cdot (e(G))^2 \left[F_{WW}F_{ZZ} - F_{WZ}^2\right] - P \cdot e(G)(2C_W + W \cdot C_{WW})F_{ZZ}\right\}\rangle 0$$

where $P^2\left[F_{WW} \cdot F_{ZZ} - F_{FZ}^2\right]\rangle 0$ (follows from concavity of production function).

Appendix 9

Differentiation of (3.44) and (3.45) and transversality conditions w.r.t. P gives

$$\dot{\lambda}_P = a_{11}\lambda_P + a_{12}S_P + n_1$$

$$\dot{S}_P = a_{21}\lambda_P + a_{22}S_P + n_2$$

where, $a_{11} = r + \frac{\delta\hat{W}}{\delta\lambda} \cdot C_S\rangle 0, a_{12} = \frac{\delta\hat{W}}{\delta S} \cdot C_S + W.C_{SS}\langle 0$

$$n_1 = \frac{\delta\hat{W}}{\delta P} \cdot C_S\langle 0$$

$$a_{21} = -\frac{\hat{W}}{\delta\lambda}\rangle 0, a_{22} = \frac{-\delta\hat{W}}{\delta S}\langle 0, n_2 = -\frac{\delta W}{\delta P}\langle 0$$

And $S_P(0) = 0 \quad \lambda_P(T^0) = 0 \quad or \quad S_P(T^0) = 0$

Signs of $\dot{\lambda}_P$ and $\dot{S}_P$ under different situations:

$$\lambda_P = S_P = 0, \quad \dot{\lambda}_P\langle 0 \quad and \quad \dot{S}_P\langle 0$$

$$\lambda_P\rangle 0, S_P = 0, \quad \dot{\lambda}_P\rangle\langle 0 \quad and \quad \dot{S}_P\rangle\langle 0$$

$$\lambda_P\langle 0, S_P = 0, \quad \dot{\lambda}_P\langle 0 \quad and \quad \dot{S}_P\langle 0$$

$$\lambda_P\rangle 0, S_P\rangle 0, \quad \dot{\lambda}_P\rangle\langle 0 \quad and \quad \dot{S}_P\rangle\langle 0$$

$$\lambda_P\langle 0, S_P\langle 0, \quad \dot{\lambda}_P\rangle\langle 0 \quad and \quad \dot{S}_P\rangle\langle 0$$

$$\lambda_P\rangle 0, S_P\langle 0, \quad \dot{\lambda}_P\rangle\langle 0 \quad and \quad \dot{S}_P\rangle\langle 0$$

$$\lambda_P\langle 0, S_P\rangle 0, \quad \dot{\lambda}_P\langle 0 \quad and \quad \dot{S}_P\langle 0$$

Appendix 10

Differentiation of (3.44) and (3.45) and transversality conditions w.r.t. v gives

$$\dot{\lambda}_v = a_{11}\lambda_v + a_{12}S_v + n_1$$

$$\dot{S}_v = a_{21}\lambda_v + a_{22}S_v + n_2$$

where

$$a_{11} = r + \frac{\partial W}{\partial \lambda}\cdot C_S \rangle 0, a_{12} = \frac{\partial W}{\partial S}\cdot C_S + W\cdot C_{SS}\langle 0$$

$$n_1 = \frac{\partial W}{\partial v}\cdot C_S \rangle 0$$

$$a_{21} = -\frac{\partial W}{\partial \lambda}\rangle 0, a_{22} = -\frac{\partial W}{\partial S}\langle 0, n_2 = -\frac{\partial W}{\partial v}\rangle 0$$

And $S_v(0) = 0, \lambda_P(T^0) = 0 \quad or \quad S_P(T^0) = 0$

Signs of $\dot{\lambda}_v$ and $\dot{S}_v$ under different situations:

$$\lambda_v = 0, S_v = 0, \dot{\lambda}_v \rangle 0, \dot{S}_v \rangle 0$$

$$\lambda_v \rangle 0, S_v = 0, \dot{\lambda}_v \rangle 0, \dot{S}_v \rangle 0$$

$$\lambda_v \langle 0, S_v = 0, \dot{\lambda}_v \rangle \langle 0, \dot{S}_v \rangle \langle 0$$

$$\lambda_v \rangle 0, S_v \rangle 0, \dot{\lambda}_v \rangle \langle 0, \dot{S}_v \rangle \langle 0$$

$$\lambda_v \langle 0, S_v \rangle 0, \dot{\lambda}_v \rangle \langle 0, \dot{S}_v \rangle \langle 0$$

Appendix 11

Differentiation of (3.53)–(3.55) w.r.t. W, Z and S gives

$$\begin{bmatrix} P \cdot F_{WW} - C_W^W - C_W^W - W\cdot C_{WW}^W & P \cdot F_{WZ} & -C_S^W \\ P \cdot F_{ZW} & P.F_{ZZ} & 0 \\ C_S^W & 0 & W\cdot C_{SS}^W \end{bmatrix}$$

$$|\mathrm{D}_1| < 0, |\mathrm{D}_2| > 0, |\mathrm{D}_3| < 0.$$

Appendix 12

Differentiation of (3.70)–(3.73) w.r.t. *C, Z*, *K* and *N* gives

$$\begin{bmatrix} U_{CC} & 0 & 0 & 0 \\ 0 & \lambda_1 Y_{ZZ} - \lambda_2 \gamma''(Z) & 0 & 0 \\ 0 & 0 & \lambda_1 F_{KK} + \lambda_2 \beta''(K) & 0 \\ 0 & 0 & 0 & -U_{NN} - \lambda_2 \psi''(N) \end{bmatrix}$$

$$|\mathrm{D}_1| < 0, |\mathrm{D}_2| > 0, |\mathrm{D}_3| < 0, \mathrm{D}_4| > 0.$$

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Chapter 4
Soil Health and Sustainable Growth in Agriculture

Abstract This chapter deals with the problems of soil degradation due to intensive cultivation, excessive use of chemical inputs and lack of soil treatment measures. There are externality problems in land use. The market distortions are also created by support measures of the government. A theoretical model has been developed to show that if the depletion rate of soil nutrients exceeds the rate of their natural regeneration, there will be degradation of land with the result that agricultural growth will become unsustainable. If the stock of soil fertility falls below certain threshold level, the resource will collapse and land will turn into barren fields. However, longer fallow period, use of organic and green manures and crop rotation may be helpful for maintaining soil health. Since the conservation of soil protects the ecology and renders environmental services to the society, public intervention is necessary and it can help soil conservation by encouraging resource friendly inputs and discouraging the polluting inputs through taxes and subsidies. A theoretical model has been constructed to show that if public support measures encourage the use of organic manures, the range of resilience of the resource will increase. At the optimal level, it can totally avoid the problem of soil degradation and ensure a sustainable growth in agriculture. The simulation results confirm this hypothesis and show that growth rate of output in agriculture will increase with increase in use of organic manures.

4.1 Introduction

Land and water are the major two components of agricultural production. Apart from excess depletion ground water, degradation of land has also become a matter of concern for future growth in agriculture. As a result of intensive cultivation and use of chemical inputs in excessive doses, there has been degradation of land. Land has some natural process of regeneration of soil micro nutrients. But due to intensive cultivation, mono-cropping and short fallow system, the depletion rate of soil organic matters (SOM) exceeds the natural rate of their regeneration. This has resulted in degradation of land. Soil degradation has taken place in many parts of

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India although it is not always due to intensive farming. Anyway, salinization, nutrient deficiency and loss of soil organic matters are becoming very common in the country. Soil fertility is a renewable resource and the resource structure is non-linear, non-convex and logistic-shaped. If soil fertility falls below a threshold level, there is the possibility that the resource base will collapse and land will turn into barren fields (Barrett 2006; Sasmal 2013). Soil treatment measures like use of green and organic manures, longer fallow period, crop rotation will be helpful for conservation of soil fertility. There are externality problems in resource use and agricultural production. In addition, the farmers, in most cases, do not have the necessary fund or access to the appropriate technology for soil conservation. But conservation of soil not only increases productivity of land but protects the ecology and renders environmental services to the society as well. So, public intervention and investment are necessary in the conservation of soil fertility. This chapter analyses how soil degradation makes agricultural growth unsustainable. It also demonstrates using theoretical model and empirical results that public intervention can ensure sustainable growth in agriculture by helping conservation of soil fertility.

4.2 Intensive Cultivation, Land Degradation and the Problem of Sustainable Growth in Agriculture

4.2.1 Introduction

Excessive depletion of ground water and declining soil fertility consequent upon intensive cultivation and continuous use of chemical inputs in increasing doses are causing serious damage to the resource base and putting a question mark before the sustainability of growth in agriculture in the developing nations. Poverty and population pressure are important causes of resource degradation in many cases. The poor typically depend far more heavily on natural assets than do the rich. The deepening poverty seems to go hand-in-hand with resource dependence and degradation (Barrett 2006; Sasmal 2013). The lack of proper resource policies and institutions to enforce the regulations both at the national and international levels are equally responsible for resource degradation. Lack of appropriate scientific knowledge and adequate investment for conservation and replenishment of the resources are also important constraints towards resource management.

The agriculture in less developed countries (LDCs) has undergone massive technological changes with large scale use of high yielding variety (HYV) seeds, chemical fertilizers and pesticides. The World Development Report (2008) informs that improved varieties have been widely adopted in the cultivation of rice, wheat, maize and sorghum in South Asia, East Asia and Pacific countries. As a result of green revolution in Asia cereal production has been doubled there between 1970 and 1995. But intensification has brought environmental problems of its own. In the system of intensive cropping, the excessive and inappropriate use of agrochemicals pollutes waterways, poisons people and upsets ecosystems. The onsite and offsite effects of this intensive agriculture have caused soil degradation (salinization, nutrient depletion, loss of soil organic matter (SOM)), ground water depletion, agrochemical pollution and loss of local biodiversity (World Development Report 2008). The study of Sasmal (1992) in the Indian context shows that the adoption rate of HYV technology in agriculture is higher among the small farmers and it is largely due to support measures of the government and the advantage of family labour in small farms. To ensure food security for the family is also an important reason for the small farmers to adopt modern technology at a higher rate. Sasmal (2006), has shown with the help of time series analysis using Indian data that subsidized input prices and various support measures of the government for major crops have significantly influenced ground water extraction and fertilizer use. In Indian states like Punjab, Haryana, Rajasthan, Uttar Pradesh, Tamil Nadu, Karnataka and Gujarat, ground water extraction is very high and in some cases it has crossed the permissible limits. As a result, the states are facing serious resource constraint in water availability and soil fertility (Source: Ground Water Scenario of India, 2009–10, Government of India 2010).

Soil fertility has a natural cycle of regeneration and replenishment. Crop rotation, fallow system, soil treatment by compost and organic manures largely help the regeneration process of soil nutrients. Various species of insects and weed also help the soil to get its nutrients replenished. But the continuous use of chemical inputs, monocropping and high intensity of cultivation have seriously damaged this natural regeneration process (Sasmal 2013). The poor farmers not only make intensive cultivation but also fail to make necessary investment for conservation of soil fertility. In the absence of any effective soil treatment measure the intensive cultivation causes soil degradation and eventually land may turn into barren fields. The World Development Report (2008) also confirms that intensive farming and continuous monoculture have led to serious soil and water degradation and it has negated many of the productivity gains from the green revolution. Soil salinization, soil-nutrient mining and declining organic matter are compounded by depletion of groundwater, build-up of pest and weed populations and resistance to pesticides. In the state of Punjab, extensive use of nitrogen fertilizers and pesticides is found to have increased concentration of nitrates and pesticides residues in water and food above tolerance limits. This report also observes that subsidies on water and fertilizer encourage to be more wasteful in input use and discourage a shift to alternative cropping patterns. The empirical findings of Sasmal (1992, 2003b, 2006) are also consistent with these observations. Bhullar and Sidhu (2006) describes fertility status of soil in Punjab as very critical pointing out the imbalances of nitrogen, phosphorus and potassium in the chemical composition of soil.

The problem of soil management has been addressed in various ways (Goetz 1997; Lafforgue and Queslati 2007; Feinerman and Komen 2005; Barrett 2006). Goetz (1997) has suggested crop-diversification and optimal choice of soil depth to minimize soil erosion. Feinerman and Komen (2005) have analysed the effects of organic vs. chemical fertilizers on the soil quality. Barrett (2006) rightly points out that renewable resource dynamics are typically highly non-linear, non-convex and generally logistic-shaped. So, there is every possibility that the resource base may totally collapse. He explains that an exponential decay function seems to describe soil organic matter (SOM) and closely related nutrient dynamics in cultivated lands without soil fertility replenishment treatments. He has suggested appropriate management interventions (e.g., long fallows, application of green manures or organic fertilizers) during the early stages of degradation to reverse the degradation process. Eichner and Pethig (2006) have demonstrated how land use and size of habitat determine the diversity and abundance of species.

The Indian experience has provided valuable insight into this problem. The field survey of Sasmal (2003b) in some parts of West Bengal where HYV paddy cultivation has achieved remarkable success reveals that the chemical composition of soil has significantly changed over the years and the natural process of regeneration of soil nutrients has got weakened in the absence of soil treatment measures. In effect, the productivity of land has declined by 6–16.5 % over a period of 13 years despite 25–50 % increase of fertilizer use during the same period. The poor farmers are interested in immediate gain from intensive cultivation and they are least bothered about deteriorating soil health. In the one hand, they have the compulsion of growing maximum food from limited land through intensive cultivation and on the other hand, their financial condition in most cases does not permit them to take necessary measures for soil treatment. It is also the case that measures for conservation of soil fertility are not always economically profitable. Excess depletion of soil nutrients is not always confined to the poor farmers only. In most cases, it is a common problem. In the event of declining agricultural productivity, the government of India granted a subsidy of Rs. 22,452 crore on fertilizer in the annual budget 2007–08 which was a big share of the total subsidy of the government in the annual budget. In the next annual budget (2008–09), the government allocated Rs. 72,000 crore to the farmers as loan waiver and it constituted 10 % of total plan outlay. But the scientific research and resource management for agriculture were not given adequate importance by the government.

Zilberman (2006) mentions three types of reforms for conservation of natural resources: (a) price reform, (b) policy reform and (c) technological reform. If subsidization of inputs and price support measures for the crops by the government lead to over-exploitation of resources, price reform in the forms of withdrawal of subsidy, imposition of taxation and sale of permits may be helpful for conservation of the resources. But in a poor agrarian system in countries like India such measures may not always be very appropriate or desirable. Technological reform is somewhat analogous to the idea of Solow (1992) who argues for substitution of natural capital by man-made capital and puts emphasis on scientific inventionsfor getting along with less natural resource use. In such situations, there is strong argument for resource and environment conserving technological progress in the public sector. Since favourable technological changes have strong positive externalities, the public policies need to be redesigned to meet the requirements of agriculture. The necessary technological changes have to be made in the public sector because such technological knowledge are generally of public good nature. If they are generated in the private sector the farmers may not have access to that. In this context, it may be mentioned that the misallocation of resources is not just a question of market failure; sometimes it is a government failure too. There is the risk that some ecologically relevant externalities are overlooked by government also (Pearce and Turner 1990). So, there is need for taking appropriate policy intervention at the government level. Harrington et al. (2005) have introduced the concept of a new input known as 'conservation capital' into the production technology in an endogenous growth framework where the conservation capital plays the twin role of enhancing the efficiency of production capital as well as helping the abatement of pollution and environmental degradation. In another paper, Zilberman et al. (2006) propose a Payment for Environmental Services (PES) programme for undertaking actions that promote environmental services to the society. These programmes may include the policy of shifting land from more resource intensive crops to less resource intensive crops and providing greater encouragement to the use of resource and environment friendly inputs. In the state of Punjab in India, incentive payments to the farmers has been recommended by an Expert Committee to encourage changes in cropping pattern in favour of resource conservation (Bhullar and Sidhu 2006).

India is passing through a phase of economic reform with downsizing of the public sector and increasing role of the market and of the private agents in agricultural production and marketing. It is argued that if private entrepreneurs are allowed to operate in the agricultural sector, it may help increase farmers' income by encouraging the use of modern technology, crop-diversification in favour of high value products, development of infrastructure and better marketing network. But this may not be helpful for conservation of natural resources like land and water. In addition, resource use and agricultural activities have externality problems. So the public sector will have to play a big role in this context. The private individuals make under valuation of natural resources and they make over use of the resources because they do not take into account the social benefits of resource conservation. In India, 80 % of the cultivators are small and marginal farmers. The share of agriculture in GDP has declined to less than 15 % although nearly 50 % of the population of the country are still dependent on agriculture for their livelihood. Sasmal (2013) explains how poverty causes soil degradation and makes agricultural growth unsustainable in the long run. In an agricultural system where the farmers are poor there will be a tendency to use land resource beyond permissible limits leading to loss of soil organic matters (SOM). Here, the government and the public sector will have to play an impotant role. The World Development Report (2008) states that 94 % of the agricultural R&D in the developing world is conducted by the Public Sector.

So, it is suggested that agricultural research and resource management should be given high priority in the public sector. The scheme of transfer payments for ecological services and payment of subsidies may be introduced to encourage the use of resource and environment friendly inputs. At the same time tax may be imposed on polluting inputs to reduce their uses. Since the conservation of resources has strong positive externalities and they generate environmental and ecological services to the whole society the necessary funds may be collected from other sectors of the economy. This section will demonstrate theoretically how intensive cultivation and excessive use of chemical inputs lead to soil degradation and make agricultural growth unsustainable in the long run. It will also suggest policy intervention of the government so that depletion of soil nutrients does not exceed the sustainable limits. At the same time incentives are to be provided to increase the use of resource-friendly inputs like green manures and organic fertilizers for the replenishment of soil fertility.

4.2.2 Agricultural Growth Using Chemical Inputs

4.2.2.1 The Model

We consider the following production function for a representative farmer in a poor agrarian system:

$$Q = F(N, Z) \tag{4.1}$$

where Q is agricultural output, N is stock of natural fertility of soil and Z is variable input, say, chemical fertilizer. It is assumed that $F_N > 0, F_{NN} < 0, F_Z > 0$ and $F_{ZZ} < 0$. Here, Q = 0 if N = 0 but Q > 0 even if Z = 0. That means, Q = F(0, Z) = 0. The implication is that soil fertility is essential for agricultural production. The value of Z may be conceived as an index of the intensity of farming.

Soil fertility is a renewable resource and it has a natural growth of regeneration which may be specified as

$$G = G(N) \text{ where N is the stock of soil fertility with } G'(N) > 0, G''(N) < 0.$$

The use of Z increases production and at the same time causes depletion of soil nutrients. The depletion of soil fertility due to use of *Z* is denoted by L. It may be written as

$L = L(Z)$ where $Lz > 0, Lzz > 0$. That means, soil organic matters (SOM) are depleted at an increasing rate with the use of Z.

The dynamics of the soil fertility is:

$$\dot{N} = G(N) - L(Z) \tag{4.2}$$

If G(N) < L(Z) there will be soil degradation i.e., $\dot{N} < 0$.

Investment may be made for soil treatment and conservation of soil fertility and in that case, $\dot{N} = G(N) - L(Z) + \beta(K)$ where *K* is investment for artificial regeneration of soil fertility and β is growth of soil fertility from *K*. Here, $\beta'(K) > 0$ and

$\beta''(K) < 0$. But here we assume that K > 0 only if income of the farmer exceeds some minimum level denoted by π*. Since our major focus is on the problems of poor farmers, it may be mentioned that the income of the farmer does not generally cross π*. So, for simplicity, it may be assumed that the farmers do not make such investment.

The utility function of the representative household is U = U (C, E) where C is consumption and E is environmental quality. Since an individual can not influence the environmental quality E may be dropped from the utility function and we express utility as a function of C only and assume that environment level is given. Therefore, $U = U\ (C)$ with $U'(C) > 0, U''(C) < 0$. Here, we may further assume that the whole agricultural income (π) of the farmer is spent for consumption. The income of the farmer is defined as

$$\pi = \mathrm{P} \cdot \mathrm{F}(\cdot) - \mathrm{P_Z} \cdot \mathrm{Z} \tag{4.3}$$

where P is price of output and P_Z is price of the chemical input Z. We assume that the individual farmers operate in a competitive market where output and input prices are given.

Now, the objective of the representative farmer becomes maximization of the discounted value of agricultural income over an infinite planning horizon [0 ∝] subject to the given constraints. In proper form, it can be written as

$$\text{Max} \int_0^\infty \pi\, e^{-\rho t} \cdot dt \tag{4.4}$$

$$\begin{aligned} \text{s.t.}\quad & \dot{N} = \mathrm{G(N) - L(Z)} \\ & \mathrm{N(0) = N0, N(t)} \quad \text{free} \\ & \lim \mathrm{t} \to \propto \end{aligned}$$

ρ is the discount rate of future income. It is a dynamic optimization problem over an infinite planning horizon [0 ∝] that can be solved by optimal control theory as explained in Dorfman (1969), Kamien and Schwartz (1981) and Chiang (1992). Following the Maximum Principle of the optimal control theory, the current-value Hamiltonian of the above problem can be written as

$$\mathrm{H} = \mathrm{P} \cdot \mathrm{F(N, Z)} - \mathrm{P_Z Z} + \lambda[\mathrm{G(N)} - \mathrm{L(Z)}] \tag{4.5}$$

In this model, N is stock variable and Z is control variable. λ is costate variable for N and it is conceived as current value shadow price of the state variable N.

For maximization of the discounted value of income over the planning horizon [0 ∝] the necessary first order conditions are:

$$\frac{\delta H}{\delta Z} = P \cdot F_Z - P_Z - \lambda L'(Z) = 0 \tag{4.6}$$

$$\frac{\delta H}{\delta \lambda} = \dot{N} = G(N) - L(Z) \tag{4.7}$$

$$\dot{\lambda} = -\frac{\delta H}{\delta N} = \rho\,\lambda_1 - P \cdot F_N - \lambda \cdot G_N \tag{4.8}$$

And transversality conditions are:

$$\mathrm{N(0)} = \mathrm{N_0}, \lim_{\mathrm{t}\to\propto} \lambda\,(\mathrm{t}) = 0$$

The Mangasarian sufficiency condition (Chiang 1992) is fulfilled by strict concavity of H in (N, Z) jointly (see the Appendix 1). Now the theorems of Steinberg and Stalford (1973) and Gale and Nikaido (1965) guarantee the existence of the globally unique solution to this optimal control problem.

Equation (4.6) gives the marginal condition for optimal use of fertilizer at each point of time. It states that the marginal gain from the input use is equal to the direct cost of the input plus the cost of loss of soil fertility due to use of chemical input. The private individual makes under valuation of natural resources. So, in Eq. (4.6) λ will be assigned a low value. Furthermore, the farmer will disregard environmental costs of using *Z*. The set of parameters is defined as $\Omega = \{P, P_Z, \rho, N_0\}$. After the optimal value of the control variable $(\hat{Z})$ is globally and uniquely determined in terms of the state and costate variables and set of parameters (Ω) the necessary and sufficient conditions for optimal solution to the optimal control problem in (4) can be expressed in terms of the following differential equations along with the terminal conditions:

$$\dot{N} = G(N) - L(Z) \tag{4.9}$$

$$\dot{\lambda} = \rho\,\lambda - P \cdot F_N - \lambda \cdot G_N \tag{4.10}$$

$$\text{and}\,\mathrm{N(0)} = \mathrm{N_0}, \lim_{t\to\propto} \lambda(\mathrm{t}) = 0.$$

Now, the differential equations in (4.7) and (4.8) will give the optimal paths for N and λ. Since Z and Q are linked in the system their optimal paths are also determined from these equations. Now, we have to see whether this growth is sustainable or not.

4.2.3 Soil Degradation and Unsustainable Growth

If there is balanced growth, the variables N, Z and Q will grow at the same rate, i.e. $g_N = g_Z = g_Q$. Here, g_N, g_Z and g_Q are growth rates of N, Z and Q respectively.

But this is very unlikely that all the variables will grow at the same rate. If G(N) = L(Z), $\dot{N} = 0$. That means, N remains unchanged at a constant level. It may be the case that the optimal use of Z will exceed its sustainable level because the environmental costs of using Z will not be taken into consideration by the private farmers. In the developing countries, Z is subsidized instead of being taxed for its negative external effects. So, P_Z will be lower than the market price which will make over use of Z. On the other hand, P may be raised by price support system of the government. Therefore, the optimal value of Z in Eq. (4.6) is very likely to exceed its sustainable limit due to market distortion and externality problems. Again, Z will increase over time due to intensive farming, i.e. $\dot{Z} > 0$. In effect, $L(Z)$ will also grow over time.

On the whole, there is high probability that $L(Z) > G(N)$ and $\dot{N} < 0$. In other words, as G(N) < L(Z), there will be erosion of the soil fertility. We can write it as

$$\dot{N} = G(N) - L(Z) = -E \tag{4.11}$$

As explained in Jones (2002), $\frac{E}{N}$ can be conceived as the constant fraction of the existing resource stock that is being eroded at each point of time in case of exhaustible resource. In that case, $\frac{E}{N}$ can be denoted by a constant γ. Then, we can write,

$$\frac{\dot{N}}{N} = \frac{-E}{N} = -\gamma \tag{4.12}$$

More clearly it can be expressed as

$$\dot{N} = -\gamma N(t) \tag{4.12$'$}$$

where $\dot{N} = \frac{dN}{dt}$

The solution to the differential equation in (4.12′) gives the dynamics of the resource stock as:

$$N(t) = N_0 \cdot e^{-\gamma t} \tag{4.13}$$

This shows exponential decay of the soil fertility at the rate γ over time as shown in Fig. 4.1. But here, soil fertility is a renewable resource. So, this may not exhibit exponential decay. However, there is no doubt that there will be gradual degradation of soil which in turn will make agricultural growth unsustainable in the long-run.

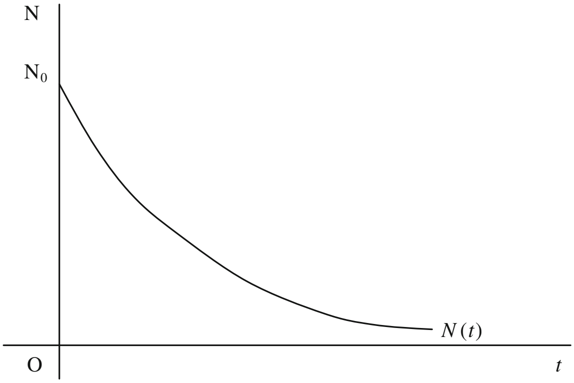

Fig. 4.1 Exponential decay of soil fertility over time

To explain the growth path in the event of resource degradation more precisely, let us define the production function in Cobb-Douglas form as

$$Q = N^{\alpha} Z^{1-\alpha} \tag{4.14}$$

This function exhibits constant returns to scale (CRS) with diminishing returns. Now taking log and derivative of (4.14) w.r.t. time we can get

$$\frac{\dot{Q}}{Q} = \alpha \frac{\dot{N}}{N} + (1 - \alpha) \frac{\dot{Z}}{Z} \tag{4.15}$$

Now the Eq. (4.15) gives the growth rate

$$\mu = g_Q = \alpha g_N + (1 - \alpha) g_Z \tag{4.16}$$

Balanced growth requires that $g_Q = g_N = g_Z$. But if there is degradation of soil, $g_N < 0$. Now, given the value of α, if the stock of N declines or g_N is negative, the growth rate of output (g_Q) will decline and it may be even negative. Thus agricultural growth will become unsustainable due to soil degradation. Due to externality problems, depletion of soil nutrients exceeds their natural regeneration. Thus if output is increased by intensive cultivation without taking any measure for maintaining soil health, the growth in agriculture will eventually become unsustainable in the long-run.

4.2.4 Policy Intervention and Sustainable Growth

Soil degradation can be checked by reducing the use of Z and taking measures for artificial regeneration of soil nutrients. To discourage the use of Z, tax may be imposed on this input although it is not always possible for the government to impose taxes on agricultural inputs. The resource-friendly input K may be subsidized to encourage its use and this is justified on the ground that K has positive externalities in the society. To maintain soil health, the government can mobilise resources from other sectors and in fact, it is done as cross subsidy in most of the developing countries. After taxes and subsidies the production function changes to

$$Q = F(N, Z, K) \tag{4.17}$$

where some degree of substitution is assumed between Z and K. If K is used it will directly help regeneration of soil fertility and at the same time reduce depletion of soil nutrients by reducing the use of Z. Now the profit function will change to

$$\pi = P \cdot F(\cdot) - \mathrm{P_Z} \cdot \mathrm{Z} - t \cdot \mathrm{Z} - \mathrm{P_K} \cdot \mathrm{K} + \mathrm{R} \cdot \mathrm{K} \tag{4.18}$$

where $\mathrm{P_K}$ is price of K, t is tax per unit of Z and R is subsidy per unit on the use of K. The dynamics of N now becomes

$$\dot{N} = G(N) - L(Z) + \beta(K) \tag{4.19}$$

Now, through policy intervention, the government can influence the use of Z and K in such a way that $\dot{N} = G(N) - L(Z) + \beta(K) = 0$

i.e., $\mathrm{G(N)} + \beta(\mathrm{K}) = \mathrm{L(Z)}$ and it makes $\dot{N} = 0$.

Thus resource level remain unchanged at a constant level and agricultural growth becomes sustainable.

In Cobb-Douglas form, the production function now becomes

$$Q = N^{\alpha} Z^{\delta} K^{1-\alpha-\delta} \tag{4.20}$$

Now taking log of (4.20) and differentiating w.r.t. time we get

$$\frac{\dot{Q}}{Q} = \alpha \frac{\dot{N}}{N} + \delta \frac{\dot{Z}}{Z} + (1 - \alpha - \delta) \frac{\dot{K}}{K} \tag{4.21}$$

After simplification (4.21) can be written as

$$g_Q = \alpha g_N + \delta g_Z + (1 - \alpha - \delta) g_K \tag{4.22}$$

where g_Q, g_Z and g_K are growth rates of Q, Z and K respectively.

Now as $G(N) + \beta(K) = L(Z), \dot{N} = 0$. That means, $g_N = 0$.

So, $g_Q = \delta g_Z + (1 - \alpha - \delta) g_K$

Since N remains constant, agricultural growth becomes sustainable.

4.2.5 Summary

This section addresses the problems of sustainable growth in agriculture due to soil degradation consequent upon intensive farming and excessive use of chemical inputs. The poor farmers are financially constrained to make necessary investment for maintaining soil health and improving soil fertility. Moreover, they are more interested in immediate consumption rather than making investment for conservation of the resources for future use. The farmers are also encouraged to make excessive use of the natural resources by the support measures of the government. All these result in resource degradation putting a question mark before the sustainability of agricultural growth.

This work constructs a theoretical model to demonstrate that if depletion rate of soil nutrients exceeds their natural regeneration rate, there will be decay of fertility of soil. This will make agricultural growth unsustainable in the long-run in the absence of any replenishment measure. This work advocates for policy intervention of the government to encourage the use of resource friendly inputs and check the over use of polluting inputs through taxes and subsidies so that soil health is maintained and growth in agriculture becomes sustainable. The theoretical results of this section show that taxation on polluting inputs and subsidy on resource-friendly inputs can ensure sustainable growth in agriculture.

4.3 Public Intervention, Soil Treatment and Sustainable Agricultural Growth[1]

4.3.1 Introduction

The declining soil fertility consequent upon intensive cultivation and excessive use of chemical inputs are causing serious threats to the sustainability of agricultural growth in developing countries like India. The World Development Report (2008) states that modern varieties have been widely adopted in the cultivation of rice, wheat, maize and sorghum in South Asia, East Asia and Pacific countries. The green revolution in Asia has increased foodgrains production significantly in the last three decades. But intensification has brought environmental problems of its own. In intensive cropping systems the excessive and inappropriate uses of agrochemicals pollutes waterways, poisons people and upsets ecosystems. The onsite and offsite effects of intensive agriculture have caused soil degradation (salinization, nutrient depletion, loss of soil organic matter (SOM), ground water depletion, agrochemical pollution and loss of local biodiversity). Tilman et al. (2002) inform that since 1945, approximately 17 % of vegetated land has undergone

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[1] This section largely draws from Sasmal and Weikard (2013), DLG-Verlag, Frankfurt/M.

human-induced soil degradation and loss of productivity, often from poor fertilizer and water management, soil erosion and shortened fallow periods. Continuous cultivation and inadequate replenishment of nutrients have caused soil organic matter (SOM) levels to decline.

Land is the most important ingredient of agricultural production and the level of soil fertility depends on rate of depletion, natural regeneration and artificial replenishment of soil nutrients. The artificial regeneration depends on various soil treatment measures like crop rotation, fallow system, application of green manures and organic fertilizers. The depletion rate is determined by intensity and technique of farming which are determined by human decisions. There is a human-nature interaction in natural resource use. The soil fertility level regenerates at a natural rate that can depend upon the current soil fertility level (Krautkraemer 1994; Barrett 1991). Barrett (1991) notes that in traditional agriculture soil fertility is maintained by returning cropland to fallow. But under the pressure of rising human population fallow periods have grown shorter. Crop rotation may be another mode of soil conservation. While mono-cropping of high yielding (HYV) paddy throughout the year may be a cause of soil degradation another method of replenishment of soil nutrients is the application of farm yard manure, plant leaves and compost manures (Sasmal and Weikard 2013). In the Indian state of Punjab extensive use of nitrogen fertilizers and pesticides is found to have increased concentration of nitrates and pesticides residues in water and food above tolerance limits (Sidhu 2002; Bhullar and Sidhu 2006). Tietenberg (2005) mentions similar problems in other countries and describes how the persistence of residues of pesticides in the environment kill many useful species and contaminate water supplies. Tietenberg further notes that the private property owners do not find it profitable to adopt suitable conservation measures and they prefer subsidized fertilizers to replace the lost nutrients of the soil. This is consistent with the empirical findings of Sasmal (2003b; 2006) that productivity of land in West Bengal, where HYV paddy has been cultivated intensively for a long time, has declined by 6–16.5 % over a period of 13 years despite 25–50 % increase of fertilizer use during this period. As a response to declining productivity in agriculture the government has undertaken a project to prepare a soil nutrient (deficiency) map. The Indian experience provides lot of insight for our purpose. The Steering Committee of the Planning Commission of India observes that as nitrogenous fertilizers (N) are subsidized more than potassium (K) and phosphate (P) fertilizers, urea is used in excessive doses adversely affecting soil profile and causing deficiency in P, K and other micronutrients. The same picture is found in the studies of Sidhu (2002) and Bhullar and Sidhu (2006) for the state of Punjab in India. These studies indicate that perverse incentives may cause distortions in resource use and input applications. So, the misallocation of resources is not just a question of market failure, it is rather one of government failures too. So, we need to analyse how the policies of the government can be reoriented towards conservation of soil fertility in the line of growth in agricultural production.

Dasgupta (2009) draw attention to the externality problems associated with the use of natural resources. He also points to the problem of under valuation of natural resources and the importance of shadow price in the proper valuation of ecological services and natural assets. A suitably chosen set of taxes and subsidies may be helpful in this context to reach the second best social optimum. Furthermore, poverty and non-convex ecosystem structure are of great relevance in the analysis of resource management. Given the non-linear and non-convex structure of the ecosystem, the market fails to deliver an efficient resource allocation. However, non-market institutions (governmental policy measures) also fail in many cases (Dasgupta 2009). Poverty remains to be one important cause of resource degradation. The poor typically depend far more heavily on natural assets than the rich and deepening poverty seems to go hand-in-hand with resource dependence and degradation (Barrett 2006; Sasmal 2003a, 2009; Sasmal and Weikard 2013). The poor are more concerned about their immediate consumption and least bothered about sustained soil fertility and future return from land. So, poverty and support measures of the government are important factors in the management of soil fertility. Non-convex resource structure has the implication that the resource base potentially collapses if its use crosses a threshold level. Barrett (2006) notes that renewable resource dynamics are typically highly non-linear, non-convex and generally logistic-shaped. He suggests taking appropriate management interventions (e.g. long fallows, application of green manures or organic fertilisers) during the early stages of degradation.

The issue of soil management has been addressed in different ways. Goetz (1997) has suggested crop-diversification and optimal choice of soil depth to minimize soil erosion. Feinerman and Komen (2005) have analysed the effects of organic versus chemical fertilizers on the soil quality. Weikard and Hein (2011) study a Sahelian rangeland and suggest to reduce grazing pressure. Zilberman (2006) suggests (a) price reform (b) policy reform and (c) technological reform for the conservation of resources. If subsidization of inputs and price support for the crops result in over-exploitation of resources, withdrawal of subsidy, taxation and permits may support resource conservation. But in a poor agrarian system it may not be a desirable solution in the absence of any effective alternative policy option (Sasmal 2009). Therefore, it is necessary to encourage farmers to use resource conserving inputs and farming practices. Public support for longer fallow period, suitable crop rotation or use of resource-friendly inputs like organic or green manures may be the alternative policy options. Sasmal and Weikard (2013) have demonstrated using a dynamic optimisation framework that taxation on polluting inputs and subsidy for resource friendly organic manures can ensure sustainable growth in agriculture. Technological reform is somewhat analogous to the idea of Solow (1992) who argues for substitution of natural capital by man-made capital and puts emphasis on scientific inventions for getting along with less natural resource use.

Harrington et al. (2005) have introduced an input known as conservation capital into the production technology of an endogenous growth model where conservation capital plays the twin role of enhancing the efficiency of production capital as well as helping the abatement of pollution. Zilberman et al. (2006) propose Payments for Environmental Services (PES) programmes for encouraging resource-augmenting inputs and techniques. These programmes may include shifting of land from more resource intensive crops to less resource intensive crops and encourage the use of resource and environment conserving inputs and techniques. In the state of Punjab in India incentive payments to the farmers have been recommended by an Expert Committee to encourage changes in cropping pattern in favour of resource preservation (Bhullar and Sidhu 2006) .

This section argues for adopting public policies in favour of conservation of natural resources pertaining to growth in agriculture and proposes incentive payments to encourage the use of resource and environment conserving inputs and farming practices. The state of soil fertility can be described in a variety of ways—soil depth, soil moisture, organic matter, soil nitrogen or a combination or index of relevant soil characteristics. The natural rate of regeneration of soil fertility depends upon the current soil fertility level. Soil fertility affects soil regeneration through the deposition of residue organic matter whose quantity can depend on the level of soil fertility. Consequently, the natural rate of soil regeneration can be low when soil fertility level is low, increase over some range of fertility levels, reach a peak and then decline. As a whole, the natural regeneration of the resource takes the shape of logistic growth function. Soil fertility on fallow land or in an undisturbed landscape is in equilibrium at the maximum level (Krautkraemer 1994; Eliasson and Turnovsky 2004; Sasmal and Weikard 2013). Given the characteristics of non-linearity and non-convexity in the natural regeneration function, there will be multiple equilibria and threshold effects indicating that if the resource stock declines below a critical level, there will be irreversible damage to the resource base. Again, if the resource stock can cross that threshold limit, stable equilibrium can be reached at the maximum level of the resource (Barrett 2006; May 1977; Dasgupta and Mäler 2003). In fact, the interaction between human decision of harvesting soil fertility and natural rate of regeneration of the resource will trace out the dynamics of the resource stock. The human decision of optimal harvest of soil fertility may not be compatible with the level permissible in nature. The problem is that the harvest level is determined by socio-economic factors and market forces whereas the nature determines its permissible level according to its own law. Naturally, market failure due to externality and perverse government intervention leading to excessive depletion of the resource makes a mismatch between the two. The harvesting of natural resource requires economic resource which is chemical fertilizer in the present context. If the use of chemical fertilizer is taken as a measure of intensity of farming, and rate of depletion of soil fertility is directly related to that then the dynamics of soil fertility will be related to the use of the input. Here we determine the optimal path for the use of the input in a dynamic perspective because it will trace out the optimal paths for depletion and regeneration of the resource. The regeneration and depletion rates at different points of time are linked together. Essentially this is a dynamic optimization problem because the optimal path for the use of the input will finally determine the dynamics of the resource stock. The government may subsidize soil conserving inputs or provide incentive payments for adopting suitable measures for replenishment of soil fertility. The main focus of this section is to see how the policy instruments of the government can be manipulated to avoid multiple equilibria in a non-linear, non-convex resource structure and stabilize agricultural growth at the maximum soil fertility level by adopting suitable soil treatment measures. Sasmal and Weikard (2013) have constructed a theoretical model to demonstrate that policy intervention through taxation and subsidy can increase the use of resource friendly input and reduce the use of polluting input and thereby can increase the range of resilience of natural resource. The model shows that use of organic manure can ensure sustainable growth in agriculture. Here, in this section, we will use the theoretical model of Sasmal and Weikard (2013) as analytical framework for our empirical study and simulation results. After presentation of the theoretical arguments, we will use data and simulation results for empirical verification and practical relevance of the hypothesis of the model.

4.3.2 Soil Degradation and Unsustainable Agricultural Growth

4.3.2.1 The Model

The theoretical structure of this section will be based on Sasmal and Weikard (2013). Let Q be agricultural output, N the stock of natural fertility of soil and Z some variable input, say, chemical fertilizer which captures the intensity of farming. We consider the following production function for a representative farmer in a decentralised agrarian system:

$$Q = Q(N \cdot Z) \tag{4.23}$$

We assume that $Q_N > 0$, $Q_{NN} < 0$, $Q_Z > 0$, $Q_{ZZ} < 0$ and also that $Q = 0$ if $N = 0$, $Q > 0$ if $Z = 0$ such that soil fertility is an essential input for agricultural production.

Soil fertility is a renewable resource and it has its natural regeneration at each point of time. Following Eliasson and Turnovsky (2004) and Krautkraemer (1994) it may be stated that the dynamics of the resource depends on natural regeneration and depletion rates. At any point of time, the net rate of change of the resource is given by

$$\dot{N} = G(N) - L(Z) \tag{4.24}$$

where $G(N)$ describes the gross regeneration rate of the resource and L is the rate of depletion determined by the intensity of farming denoted by Z. The natural rate of soil regeneration can be low when soil fertility level is low, increase over some range of fertility levels, reach a peak and then decline. This allows for both a maximum level of soil fertility denoted by $\overline{N}$ and a minimum level denoted by $\underline{N}$ below which soil degradation is irreversible. It may be assumed that $\underline{S} = 0$ and the growth of the resource, $G(N)$ is governed by the logistic function as

$$G(N) = \rho N\left(1 - N/\overline{N}\right)$$

where ρ is the intrinsic rate of growth of the resource.

In an undisturbed landscape where harvest of the resource is zero (i.e. $L = 0$), the soil fertility, N converges to its maximum sustainable level $\overline{N}$. Given this resource structure, the depletion of the resource is determined by the economic decisions of the human being. Human-nature interaction will trace out the path for the resource stock.

Some soil conservation inputs like green manure or organic fertilizer may be used or soil treatment measures like fallow system may be adopted by the individual farmers. As a base case we assume that the farmers do not take any such measure for soil treatment because this is not profitable for them.

For simplicity, we may assume linearity of L in Z i.e., $L = h \cdot Z$ where h is harvest of soil fertility per unit of use of Z. Here, h is constant and $h > 0$. Intensive agriculture, as measured by Z, causes soil and environmental degradation by depletion of nutrients and creating pollution and loss of bio-diversity. But the private individuals do not take the external cost of environmental degradation into their consideration while making decisions on the quantities of Z to be used in production. The utility function of the representative household is $U = U(\pi, E)$ where π is income and E is environmental quality.

Income is defined as

$$\pi = pQ - vz \tag{4.25}$$

where p is the price of agricultural produce and v is the price of the input. Pollution is an external cost and is, therefore, not directly reflected in the income function. So, externality problem is there.

Since environmental quality is conceived as a public good an individual can not influence it. So, it may be dropped from the utility function. Then the objective of household finally becomes maximisation of income. In a decentralised system output and input prices are given although there may be subsidies on inputs and support measures for output.

The representative farmer disregards social costs of using Z and maximizes discounted total income from agricultural production over an infinite planning horizon by choosing the optimal path for Z. In proper form, the optimisation problem of the farmer can be expressed as

$$\underset{z}{\text{Max}} \int_0^{\propto} \pi \cdot e^{-rt} \cdot dt \tag{4.26}$$

$$\begin{aligned} &\text{s.t.} \quad \dot{N} = G(N) - L(Z) \\ &\text{and} \quad N(0) = N_0, \ N(t)\,\text{free} \quad \text{as}\, t \to \infty. \end{aligned}$$

Here r is the discount rate of future income. This is a dynamic optimisation problem which can be solved by optimal control theory. The regeneration of soil fertility depends on the deposition of residue of organic matter whose quantity depends on the level of soil fertility and the rate of its depletion over time. The rate of depletion again depends on some economic factors which is here the intensity of farming denoted by Z. So, the optimal path for Z as determined by the private individual in a dynamic perspective will give $L(Z)$ and $\dot{N}$. Therefore, we need to solve the problem in (4.26) and trace out the optimal path for Z. For the mathematical underpinnings in the solution of the problem in (4.26), we refer the reader to Dorfman (1969), Kamien and Schwartz (1981) and Chiang (1992).

Following the Maximum Principle of the optimal control theory, the current value Hamiltonian of the above problem can be written as

$$H = pQ(N,Z) - vZ + \lambda(G(N) - L(Z)) \tag{4.27}$$

In this model, N is stock variable, Z is control variable and λ is the co-state variable which is interpreted as shadow price of the state variable N.

We obtain the first order necessary conditions:

$$\frac{\partial H}{\partial Z} = pQ_Z - v - \lambda L_Z = 0 \tag{4.28}$$

$$-\frac{\partial H}{\partial N} = \dot{\lambda} = r\lambda - pQ_N - \lambda G_N \tag{4.29}$$

$$\dot{N} = \frac{\partial H}{\partial \lambda} = G(N) - L(Z) \tag{4.30}$$

The transversality conditions are:

$$N(0) = N_0;\ \lim_{t\to\infty} \lambda = 0$$

The specifications of the production function, soil fertility regeneration and harvest functions jointly satisfy the conditions of strict concavity of H in N and Z (see Appendix 2). So, the Mangasarian sufficiency condition (Chiang 1992) is satisfied. Furthermore, the theorems of Steinberg and Stalford (1973) and Gale and Nikaido (1965) guarantee the existence of the globally unique solution to this optimal control problem.

Equation (4.28) provides a condition for optimal use of chemical fertilizer at each point in time. The optimal value of the control variable Z^* is globally and uniquely determined in terms of the state and co-state variables and parameters. Now, the necessary and sufficient conditions for a solution to this optimal control problem can be expressed by the differential equations (4.29) and (4.30) along with the transversality conditions. The resulting system of equations will give the optimal paths for N and λ. Since Z and Q are linked in the system their optimal paths are also determined from these equations.

We are now interested to see whether whether the solution to (4.26) will yield a sustainable growth path. Consider $\dot{N} = 0$ i.e. resource is maintained at constant level. Then we have from (4.30), $G(N) = L(z)$. If efficient level of Z exceeds ecologically sustainable level, there will be degradation of N i.e., $\dot{N} < 0$. Agricultural growth through intensification means that $\dot{Z} > 0$. Then $L(Z)$ would be growing over time and constant level of soil fertility N cannot be maintained. In addition to that, Z may be used at a level exceeding the sustainable limit due to externality and government support measures. That means, there will be overuse of Z due to market failure of market distortion. From (4.28), we can determine optimum value of Z at each point of time in terms of the state and costate variables and set of parameters as

$$Z^* = Z^*\{N, \lambda, r, p, v\}$$

In the presence of externality (private individual disregards environmental cost), subsidy on the input reduces v and price support for p the optimal value of the input Z^* may be higher than the sustainable value $\overline{Z}$. In that case, it is very likely that $L\ (Z) > G\ (N)$ and $\dot{N} < 0$. Now, we can write

$$\begin{aligned} L &= L[Z\{N, \lambda, v/p, r, v\}] \\ &= \psi(N, \lambda, v/p\ldots) \end{aligned}$$

Clearly the depletion rate depends on the resource stock, shadow price of the resource and the input-output rice ratio along with other parameters. Given the parameters and ratio of input-output prices, depletion rate ψ can be expressed as a positive and linear function of N.

Given the non-linear and non-convex resource structure, there will be multiple equilibria and threshold level of soil fertility which will determine whether agricultural growth is sustainable or not.

If the harvest rate is such that $N < N^*$, then $\dot{N} < 0$. Here, not only the resource base will degrade, it will collapse and stabilise at zero. If $N > N^*$, $\dot{N} > 0$, and then the equilibrium stabilises at the maximum level of soil fertility $\overline{N}$. N^* is the threshold level of soil fertility at which equilibrium is unstable. The term resilience refers to the stability of ecosystems. Therefore, the harvest of soil fertility must not reduce the fertility level below N^* if resilience is to be maintained at $N > 0$ (See Fig. 4.2).

4.3.3 Policy Intervention, Soil Treatment and Sustainable Agricultural Growth

In the first section, we mentioned that there might be some soil conserving inputs like green manure or organic fertilizer which the farmers do not use simply because they are not profitable. Now, we can consider the use of such an input if the government provides some incentive payment to the farmers for using it. The payment is justified on the ground that it enhances soil fertility and at the same it protects the bio-diversity and generates ecological services to the society. In many countries the policy of payment for ecological service (PES) has been introduced. This input is very similar as the conservation capital in Harrington et al. (2005). Following Sasmal and Weikard (2013) let us now define the production function with some modifications:

$$Q = Q(N, Z, M) \tag{4.31}$$

where M is soil conservation input having dual role of enhancement of soil fertility and generation of environmental services. For our convenience we assume that M is organic manure. It is also assumed that $Q_M > 0$, $Q_{MM} < 0$ and there is some degree of substitution between Z and M. The specifications about N and Z are same as before.

The resource dynamics changes to

$$\dot{N} = G(N) - L(Z) + \mu(M) \tag{4.32}$$

where, as before G is gross regeneration rate of soil fertility, L is depletion rate of soil nutrients and μ is artificial regeneration rate of soil fertility from M. It is assumed that $\mu_M > 0$, $\mu_{MM} < 0$.

The direct marginal return from M may not be profitable for the farmers. But social marginal benefits of M are greater than its private marginal returns; so, the use of M may be subsidized. Since M has positive externalities and it generates environmental services, the government introduces a subsidy $\gamma(M)$ as a policy instrument encouraging the use of M. The incentive function for using M is assumed to be concave, $\gamma_M > 0$ and $\gamma_{MM} < 0$.

Now, agricultural income can be written as

$$\pi = pQ - vZ - cM + \gamma(M) - \tau(Z) \tag{4.33}$$

where c is the price of organic manure M and $\tau(Z)$ is an environmental (Pigovian) tax that reflects the environmental cost of using Z. We assume $\tau_Z > 0$ and $\tau_{ZZ} > 0$.

The utility function is as before a function of income and environmental quality $U = U(\pi, E)$. However, we drop E from the function for the reason stated earlier and it is provided exogenously as a public good.

Since the use of z and M has externalities, public intervention imposes tax on z and introduces incentive payments for the use of M. Here the objective of the private agent is to maximize the discounted total income over the infinite planning horizon subject to the given constraints as

$$\underset{Z,M}{Max} \int_0^{\propto} \pi \cdot e^{-rt} \cdot dt \tag{4.34}$$

s.t. $\dot{N} = G(N) - L(Z) + \mu(M)$ and $N(0) = N_0$, $N(t)$ free as $t \to \infty$.

This dynamic optimization problem can be solved by using optimal control theory as in previous section and it will give a second best solution. The current value Hamiltonian of the problem in (4.34) is:

$$H = pQ(N, Z, M) - vZ - cM + \gamma(M) - \tau(Z) + \lambda(G(N) - L(Z) + \mu(M)) \quad (4.35)$$

The necessary and sufficient conditions for solution to this optimal control problem can now be expressed in terms of the following differential equations along with transversality conditions:

$$\frac{\partial H}{\partial Z} = pQ_Z - v - \tau_Z - \lambda L_Z = 0 \quad (4.36)$$

$$\frac{\partial H}{\partial M} = pQ_M - c - \gamma_M + \lambda\mu_M = 0 \quad (4.37)$$

$$-\frac{\partial H}{\partial N} = \dot{\lambda} = r\lambda - pQ_N - \lambda G_N \quad (4.38)$$

$$\frac{\partial H}{\partial \lambda} = \dot{N} = G(N) - L(Z) + \mu(M) \quad (4.39)$$

$$\text{and} \lim_{t\to\infty} \lambda = 0;$$

$$N(0) = N_0, N(t) \text{ free as } t \to \infty$$

The Mangasarian sufficiency condition is fulfilled by strict concavity of H in state and control variables (N, Z and M) jointly (See Appendix 3). The conditions (4.36) and (4.37) have important economic implications. The marginal gain of using Z is equal to its (after tax) price plus cost of not preserving the resource for future use at each point of time. In case of M, the marginal benefit includes the value of marginal product of M, future gain in income due to conservation of soil fertility and marginal incentive payment from the government. The cost of using M is c. Equation (4.38) shows the rate at which shadow price of the stock variable N changes over time. It is not a closed form model. So, the amount of incentive payment for M is not necessarily equal to the tax proceeds from Z. The deficit, if any, is financed from outside the agricultural sector because the whole system is benefitted by the use of M.

Like in previous section, using the theorems of Steinberg and Stalford (1973) and Gale and Nikaido (1965) the optimal values of the control variables can be globally and uniquely determined in terms of state, costate variables and set of parameters as

$$Z^* = Z(N, \lambda; \beta)$$
$$M^* = M(N, \lambda; \beta)$$

Here, β is the set of parameters where

$$\beta = \{N_0, p, v, c, r, \rho\}$$

Equations (4.36)–(4.39) will give the optimal paths for N, λ, Z and M.

Significant implications follow from the first order conditions. Equations (4.36) and (4.37) determine the optimal values of Z and M and suggest that use of inputs is socially optimal. In the previous section, there was no public intervention. As a result, social cost of using Z was ignored by the private agent with the result that there was over use of the input. On the other hand, the resource-preserving input M was not used because private benefit was less than the price of M and there was no provision for subsidy to encourage the use of the input. In the current setting, a subsidy encourages the use of M whereas the tax reduces the use of Z. As a result of public intervention in the form of taxation and subsidies, there will be some substitution between Z and M. The use of M will reduce the use of Z. The use of M not only helps regeneration of soil fertility it also acts as an input in production. Therefore it will partly replace the use of Z and offset the effect on soil harvest. Besides, M will have its direct effect on regeneration of soil fertility.

On a sustainable growth path it is required that soil depletion is balanced by its regeneration and the resource is maintained at a constant level. Here, given the functions $L(Z)$ and $\mu(M)$, Z and M are to grow in such a way that $\dot{N} = 0$. Again we have three equilibrium points where $\dot{N} = 0$ i.e., $G(N) + \mu(M) = L(Z)$.

The dynamic implication of this result is that in a non-convex resource structure, we will get three such equilibrium (as shown in Fig. 4.2). Out of these three equilibria, one is unstable at $N = N^*$ and another is stable at $N = 0$. So, policy manipulation will be such that equilibrium is reached at $N = \overline{N}$. After the use of M that reduces the use of Z, the depletion curve moves downward and the regeneration curve shifts upward. If the shift of the curves are significant, we can escape the threshold point by avoiding the intersection of the two curves at the threshold level, N^*. Even if they intersect the range of resilience will increase (Fig. 4.3).

Thus if $\dot{N} = 0$ and soil fertility level is maintained at the maximum level $\overline{N}$, agricultural growth is sustainable. Here, as a result of policy intervention N remains constant at a higher level $\overline{N}_1$ (See Fig. 4.3). However as N remains constant, it will not be a balanced growth even if Z and M grow at the same rate. In balanced growth all the related variables grow at the same rate. In the present case, balanced growth requires that

$$g_Q = g_N = g_z = g_m$$

But, for sustainability $g_N = 0$.

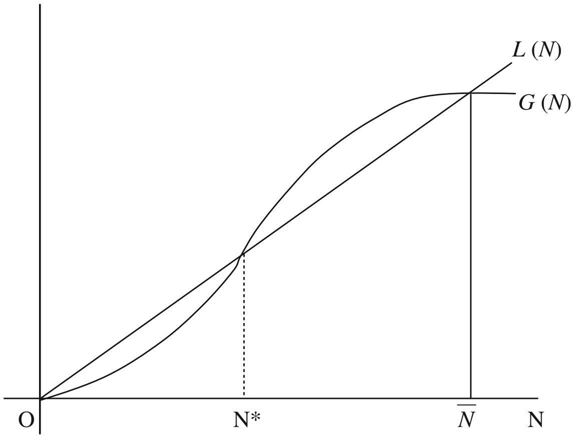

Fig. 4.2 Non-convex Resource structure and threshold level of soil fertility

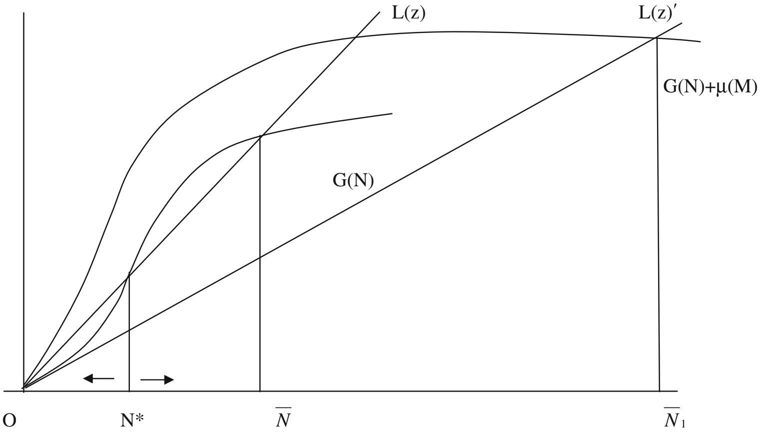

Fig. 4.3 Policy intervention and conservation of soil fertility

The balanced growth is feasible if the production function exhibits constant returns to scale and the sum of the production elasticities of the inputs is equal to unity i.e. $\varepsilon_N + \varepsilon_Z + \varepsilon_M = 1$ (see Harrington et al. 2005). Here, if we consider a CRS production function and N is measured in efficiency term (efficiency follows from exogenous technological progress), we can get sustainable balanced growth. Let us take the production function in Cobb-Douglas form as

$$Q = (TN)^{\alpha} Z^{\beta} (M)^{1-\alpha-\beta} \tag{4.40}$$

where T is efficiency from exogenous technological progress.

Taking log in (4.40) and differentiating w.r.t. time we get

$$\frac{\dot{Q}}{Q} = \alpha\frac{\dot{T}}{T} + \alpha\frac{\dot{N}}{N} + \beta\frac{\dot{Z}}{Z} + (1 - \alpha - \beta)\frac{\dot{M}}{M} \tag{4.41}$$

$$g_Q = \alpha g_T + \alpha g_N + \beta g_z + (1 - \alpha - \beta)g_M \tag{4.42}$$

where g_Q, g_Z and g_M are growth rates of Q, T, Z and M respectively.

In sustainable growth $g_N = 0$. Now, in an ideal situation, if there is technological progress (exogenous) at the same rate with Z and M, we get sustainable balanced growth with the result that $g_Q = g_T = g_Z = g_M$. However, if technological progress does not take place, $g_T = 0$ and then

$$g_Q = \beta g_z + (1 - \alpha - \beta)g_M$$

That means, the growth rate of output depends on growth rates of Z and M and the parameters α and β. The overall implication is that if two inputs grow and technological progress is there, $g_T > 0, g_Z > 0$ and $g_M > 0$. In that case g_Q is also positive. It may be unbalanced growth, but growth is sustainable.

4.3.4 Comparative Statics

After the values of Z and M are globally and uniquely determined from (4.36)–(4.37) we derive the following comparative static results (see Appendix 4).

$$\begin{aligned}
\frac{\delta z^*}{\delta N} &= 0\\
\frac{\partial z^*}{\partial v} &= [p \cdot Q_{mm} + \gamma_{mm} + \lambda\mu_{mm}] \; < 0\\
\frac{\partial z^*}{\partial c} &= 0\\
\frac{\partial z^*}{\partial p} &= [-Q_z(pQ_{mm} + \gamma_{mm} + \lambda\mu_{mm})] \; > \; 0\\
\frac{\partial M^*}{\partial N} &= 0\\
\frac{\partial M^*}{\partial c} &= [p \cdot Q_{zz} - \tau_{zz} - \lambda L_{zz}] < 0\\
\frac{\partial M^*}{\partial v} &= 0\\
\frac{\delta M^*}{\delta p} &= [-Q_z \cdot (pQ_{zz} - \tau_{zz} - \lambda L_{zz})] \; > \; 0
\end{aligned}$$

The comparative static results have very clear policy implications. The taxation on soil degrading inputs will discourage their use. On the other hand, subsidies can encourage the use of resource friendly inputs. So, government intervention in the form of taxes and subsidies can help soil conservation and sustainability of agricultural growth. It is also revealed that increase in output price as a result of support measures of the government increases the optimal use of Z and M at each point of time because income rises as a result of it.

4.3.5 Stability of the Steady-State Equilibrium

Here, the equilibrium of sustainable growth is dynamically stable.

In the long-run the state and co-state variables converge to stationary values where

$$\dot{N} = 0, \dot{\lambda} = 0$$

In this dynamic optimization problem, the state, co-state and control variables are so interlinked that optimal paths for their equilibrium values are simultaneously determined with the stationary values of N and λ in the long run.

We check the stability of the equilibrium path by characteristic roots of the Jacobian matrix for the system of the differential equations:

$$\begin{aligned} \dot{N} &= G(N) - L(Z) + \mu(M) \\ \dot{\lambda}_N &= r\lambda - pQ_N - \lambda G_N \end{aligned}$$

We form the Jacobian matrix and evaluate it at the maximum value of $N = \overline{N}$ with $\dot{N} = 0, \dot{\lambda} = 0$ as

$$J_E = \begin{bmatrix} \frac{\partial \dot{N}}{\partial N} & \frac{\partial \dot{N}}{\partial \lambda} \\ \frac{\partial \dot{\lambda}}{\partial N} & \frac{\partial \dot{\lambda}}{\partial \lambda} \end{bmatrix}_{(\dot{N}=0,\ \dot{\lambda}=0)}$$

According to Chaing (1992), the qualitative information about the characteristic roots r_1 and r_2 are needed to confirm a saddle point by the result:

$$r_1 r_2 = |J_E|$$

If $|J_E|$ is negative, the roots have opposite signs and the equilibrium is locally a stable point.

To show the stable or saddle branches in a phase-diagram the signs of the two isoclines $\dot{N} = 0$ and $\dot{\lambda} = 0$ can be specified by applying the implicit function rule as in Chiang (1984) and Goetz (1997).

The long run equilibrium is characterised by the following two differential equations:

$$\dot{N} = G(N) - L(Z) + \mu(M)$$
$$\dot{\lambda} = r\lambda - pQ - \lambda G_N$$

$$\text{Here, } \frac{\partial \dot{N}}{\partial N} = G_N > 0, \ \frac{\partial \dot{N}}{\partial \lambda} = 0$$

$$\frac{\partial \dot{\lambda}}{\partial N} = -p\, Q_{NN} - \lambda\, G_{NN} > 0$$
$$\frac{\partial \dot{\lambda}}{\partial \lambda} = r - G_N > \ = \ < 0.$$

The sufficient condition for $\frac{\partial \dot{\lambda}}{\partial \lambda} < 0$ is $G_N > r$

Therefore, $|J_E| < 0$ and it ensures that the steady state equilibrium is locally stable.

In phase-diagram we get,

$$\left.\frac{\partial \lambda}{\partial N}\right|_{\dot{N}=0} = -\frac{\frac{\partial \dot{N}}{\partial N}}{\frac{\partial \dot{N}}{\partial \lambda}} = \propto$$
$$\left.\frac{\partial \lambda}{\partial N}\right|_{\dot{\lambda}=0} = -\frac{\frac{\partial \dot{\lambda}}{\partial N}}{\frac{\partial \dot{\lambda}}{\partial \lambda}} > 0$$

The qualitative result of the phase-diagram in Fig. 4.4 shows that the equilibrium is dynamically stable.

The results in the last two sections, demonstrate that government intervention in the form of taxation, subsidy and technological progress can ensure a dynamically stable sustainable balanced growth in agriculture. It is not a closed form growth model with a binding budget constraint. Here, technological progress takes place exogenously and its cost is covered by the non-agricultural sector which enjoys the positive externalities of resource management in agriculture. The tax revenue from polluting inputs used in agriculture is usually not equal to the subsidy paid for the use of resource and environment friendly inputs. The deficit may be covered by the other sector because the ecological benefits of using resource preserving inputs like *M* are enjoyed by the whole society. However, a closed model with a budget balancing condition may be considered in an endogenous framework in further extension of the work.

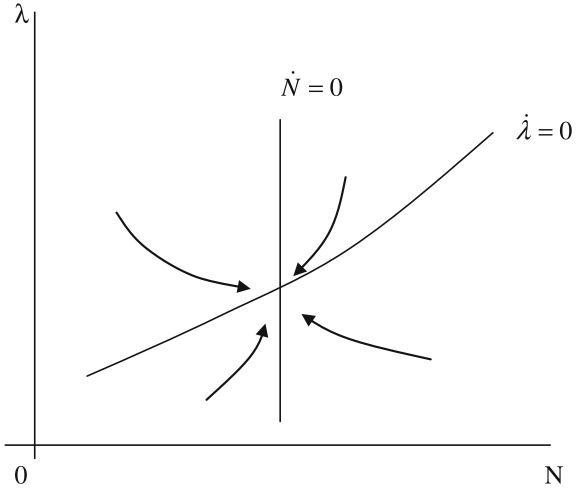

Fig. 4.4 Stability of the dynamic equilibrium

4.3.6 *Empirical Verification*

The theoretical propositions of the previous sections suggest that intensive farming and uses of chemical inputs like fertilizers and pesticides result in soil degradation in the absence of effective soil treatment measures. The results also show that policy intervention in the form of taxation and subsidy can ensure sustainable growth in agriculture by encouraging the use of resource friendly inputs and restricting the use of resource damaging inputs. In this part we like to empirically verify the magnitude and causes of soil degradation and the effectiveness of policy intervention in maintaining soil fertility in India. We also investigate the impact of organic manure on the growth of agricultural output. However, sufficient data are not available for undertaking rigorous econometric exercises in these matters. So, have to discuss and analyse the problems using the available information in somewhat descriptive manner. The percentage of degraded land varies across the states of India and it is found that degradation of land is not always related to the intensity of cultivation and use of chemical fertilizers on one to one basis (see Table 4.1). Here, the data on the percentage of degraded land in Table 4.1 includes all kinds of land degradation. It does not include only the degradation caused by intensive farming. In fact, land degradation takes place due to many factors specially in environmentally fragile areas. So, it becomes difficult to get the correct picture of land degradation due to intensive cultivation and use of chemical inputs. Here, the available data just gives an idea of the problem of land degradation in India. The OLS regression of soil degradation on cropping intensity shows that higher intensity of cultivation is a cause of soil degradation in the Indian states but the result is not very robust (see Table 4.4a).

Table 4.1 Area of degraded land in states of India (2011)

States	Degraded area (ha)	Degraded area as % of operated area
Andhra Pradesh	6,06,945	4.21
Bihar	2,36,838	3.51
Gujarat	5,49,647	5.56
Himachal Pradesh	3,33,365	34.05
Karnataka	7,79,348	6.33
Kerala	16,204	1.03
Madhya Pradesh	16,63,365	10.15
Maharashtra	7,66,703	3.81
Rajasthan	9,78,419	4.6
Tamil Nadu	3,34,130	4.79
Uttar Pradesh	3,37,524	1.87
West Bengal	5,26,316	0.01

Source Compendium of Environment Statistics India (2011), Ministry of Statistics and Programme Implementation, Government of India

If the cropping intensity is high, the use of chemical inputs will be also high. The cropping intensity is highest in the states like Punjab, Haryana, West Bengal and Uttar Pradesh and in these states, the use of chemical fertilizers per hectare is also very high. However, there are states where cropping intensity is not so high but use of fertilizers is high (Andhra Pradesh, Tamil Nadu and Bihar). Again, there are states like Himachal Pradesh, Madhya Pradesh and Rajasthan where cropping intensity is high but fertilizer use is low. So, we do not find a one to one relationship between them. This is because cropping pattern is different in different states and some crops are fertilizer-intensive while others are not. Besides, soil and geo-physical conditions are also different in different regions of the country. On the other hand, we find a positive and statistically significant relationship between cropping intensity and use of pesticides per hectare (see Table 4.4c). It is revealed from Table 4.2 that in states like Punjab and Haryana where resource degradation has become a serious constraint to future growth in agriculture (Bhullar and Sidhu, 2006) , the cropping intensity is highest and in these states, the uses of chemical fertilizers and pesticides are also found to be the highest. So, it establishes that cropping intensity and excess use of chemical inputs have some impact on resource degradation. Soil degradation as such has become a serious problem all over the world. But land degradation due to intensive farming and use of chemical inputs is a different kind of problem and we need experimental data for analyzing such a problem. Unfortunately, we do not have the required data. So, we can just have some idea of the problem.

So far as conservation of soil fertility is concerned, it is suggested that fallow system of land and use of organic manures are helpful for soil treatment. The current fallow as percentage of net cropped area differs across states of India (see

Table 4.2 Cropping intensity and use of chemical inputs in the major states of India

States	Cropping intensity, 2011–12	Use of chemical fertilizers (kg/ha) 2012–13	Use of Pesticides (kilogram/hectare) 2008–09
Andhra Pradesh	123.3	246.12	0.12
Bihar	141.7	282.98	0.16
Gujarat	127.1	130.26	0.25
Haryana	184.1	384.28	1.21
Himachal Pradesh	176.6	89.21	0.59
Karnataka	121.3	154.00	0.16
Kerala	130.5	135.78	0.13
Madhya Pradesh	147.8	122.66	0.04
Maharashtra	126.1	142.18	0.13
Orissa	113.0	111.51	0.19
Punjab	191.2	477.01	13.5
Rajasthan	135.9	74.52	0.18
Tamil Nadu	118.1	189.93	0.46
Uttar Pradesh	153.3	279.79	0.53
West Bengal	179.9	300.11	0.78
All India	138.7	198.50	0.31

Source (i) Agricultural Statistics at a Glance 2014, Ministry of Agriculture, Government of India, Oxford 2015

(ii) Compendium of Environment Statistics, India (2011), Ministry of Statistics and Programme Implementation, Government of India

Table 4.3). It is interesting to note that in intensively cultivated states like Punjab, Haryana, Uttar Pradesh, Madhya Pradesh, Kerala and Gujarat, the ratio of fallow land is low. That means, the land is engaged for cultivation for most of the time of the year and this hampers the natural process of regeneration of soil nutrients. However, the cropping pattern, rainfall, soil conditions and irrigation system are also important in this regard. The regression results in Table 4.4b show that the ratio of fallow land depends on the cropping intensity. The regression coefficient of cropping intensity is negative and statistically significant implying that if cropping intensity is higher the ratio of fallow land is lower. The implication is very clear. Since land remains busy with cultivation for most of the time, it gets little scope for getting its nutrients replenished in natural process.

The use of organic manures is another important measure for maintaining soil fertility. Sufficient and appropriate data are not available for econometric analysis on the effects of organic manure on soil fertility. However, descriptive analysis explains the pattern of use of this input in agriculture and helps us to understand the importance of using this input. Farm Yard Manure (FYM) is an important component of organic manure widely used in Indian agriculture. If FYM is used in combination with chemical fertilizers, it increases productivity and at the same time

Table 4.3 Fallow land (current) in states of India, 2011–12

States	Current Fallow Land (000 hectare)	Current fallow as % of cropped area
Andhra Pradesh	2273	20.36
Assam	81	2.88
Bihar	781	14.47
Gujarat	379	3.67
Haryana	21	0.01
Himachal Pradesh	60	11.15
Jammu and Kashmir	108	14.47
Karnataka	1672	16.81
Kerala	77	3.77
Madhya Pradesh	424	2.78
Maharashtra	1373	7.89
Orissa	997	2.26
Punjab	45	1.08
Rajasthan	1477	8.19
Tamil Nadu	967	19.39
Uttar Pradesh	533	3.20
West Bengal	399	7.67
All India	14,715	10.45

Source Agricultural statistics at a glance 2014, Ministry of Agriculture, Government of India, Oxford 2015

helps conservation of soil fertility. Table 4.5 shows the uses of FYM and chemical fertilizers by different size groups of farmers in India. It shows that small and marginal farmers use higher amounts of both FYM and chemical fertilizers per hectare compared to the large farmers. However, the use of chemical fertilizers is higher than FYM in all size groups of farms. But the interesting point is that while the use of chemical fertilizers by small and marginal farmers on irrigated land is 5 to 7 times higher than FYM, in large farms, it is only 2.4 times higher. That means, the small and marginal farmers cultivate land more intensively. Although the small farmers use more FYM than the large farmers in absolute terms, relative to the use of chemical inputs, the use of FYM is low in small farms. The higher intensity of cultivation in small farms is also observed by Hariss (1972) and Sasmal (1992). In India only 10 % of cultivable land is cultivated by large farmers and the remaining 90 % of land is cultivated by marginal, small and medium farmers who do not use sufficient quantities of organic manures relative to chemical fertilizers. This information gives some idea of the problems of soil conservation. The small and marginal farmers cultivate land intensively to grow as much food as possible from limited land. Although they are very interested in increasing immediate gain from land, they are not much concerned about soil health and future production. Besides,

Table 4.4 Bi-variate OLS regression of soil degradation, current fallow land and use of pesticide on cropping intensity using state level data in Indian context[a]

(a)	Dependent variable: soil degradation (y_1)
	Explanatory variable: cropping intensity (x_1)
	Regression equation is: $y_1 = \alpha_0 + \alpha_1\, x_1$
	Estimated results:
	$R^2 = 0.19$, $F = 2.48$, $n = 12$
	t-value of estimated $\alpha_1 = 1.57$, p-value $= 0.14$
(b)	Dependent variable: ratio of current fallow land (y_2)
	Explanatory variable: cropping intensity (x_2)
	Regression equation is:
	$y_2 = \beta_0 + \beta_2\, x_2$
	Estimated results:
	$R^2 = 0.26$, $F = 4.77$, $n = 15$
	t-value of estimated $\beta_2 = -2.18$, p-value $= 0.04$
(c)	Dependent variable: use of pesticide per hectare (y_3)
	Explanatory variable: cropping intensity (x_3)
	Regression equation is:
	$y_3 = \gamma_0 + \gamma_3\, x_3$
	Estimated results:
	$R^2 = 0.70$, $F = 31.28$, $n = 15$
	t-value of estimated $\gamma_3 = 5.59$, p-value $= 0.00$

[a] The estimates are based on data from

(i) Agricultural Statistics at a Glance 2014, Government of India, Oxford 2015

(ii) Compendium of Environment Statistics, India (2011), Ministry of Statistics and Programme Implementation, Government of India

the small farmers have financial constraints and less access to the technologies for soil conservation. In this context, the government should come forward for maintaining soil health of the country because soil fertility is the main ingredient of agricultural production. Apart from agricultural production, soil conservation has positive externalities to the society in various forms. So, policy intervention and public expenditure for soil conservation need to be emphasised.

In fact, the government has taken several measures for conservation of soil fertility. In addition to the measures for popularizing the use of resource friendly inputs the government has adopted various other measures for soil conservation and protecting the ecology and biodiversity. Table 4.6 shows the increase of areas covered under these schemes over the years. Compared to the net cropped area of roughly 140 million hectares, the area brought under soil conservation scheme so far is really insignificant. So the government needs to be more active in this matter. Secondly, the government has introduced the scheme of detailed soil survey under River Valley Projects (RVP) and Flood Prone Rivers (FPR) Projects. Table 4.7 shows that such projects cover an area of 12.45 million hectares which constitutes a

Table 4.5 Application of chemical fertilizers and Farm Yard Manures (FYM) by size-holding groups of farmers, 2006–07 (tonnes per thousand hectares)

Size groups of farmers	Use of FYM on irrigated and non-irrigated land (combined)	Use of FYM on irrigated land	Use of chemical fertilizers on irrigated land	Ratio of chemical fertilizers and FYM on irrigated land
(1)	(2)	(3)	(4)	(5)[a]
Marginal (below 1.00 ha)	5.37	6.26	39.68	6.33
Small (1.00–1.99 ha)	4.38	5.59	40.03	7.16
Semi-Medium (2.00–3.99 ha)	3.86	5.14	27.05	5.26
Medium (4.00–9.99 ha)	3.15	4.21	20.93	4.97
Large (10.00 ha and above)	2.16	3.36	8.09	2.40

Source Compendium of Environment Statistics India (2011), Ministry of Statistics and Programme Implementation, Government of India

[a] Column (5) is Column (4) divided by Column (3)

Table 4.6 Area covered under soil conservation scheme in India (lakh hectares)

Year	Area addition
2000–01	4.36
2001–02	4.70
2002–03	4.30
2003–04	5.55
2004–05	7.37
2005–06	8.67
2006–07	11.41
2007–08	7.34
2008–09	6.90
2009–10	5.32
2010–11	7.49
2011–12	4.72
2012–13	5.46

Source Agricultural Statistics at a Glance 2014, Ministry of Agriculture, Government of India, Oxford 2015

small fraction of the total cultivable land of the country. But what is important is that the government has realized the importance of soil conservation and it is expected that various public projects and scientific measures will help the conservation of soil fertility in the country.

Table 4.7 Detailed soil survey under River Valley Project (RVP) and Flood Prone Rivers (FPR) projects in the states of India, 2008–09

States	Area (ha)
Andhra Pradesh	747,111
Assam	24,241
Bihar	60,426
Gujarat	228,125
Haryana	22,352
Himachal Pradesh	485,030
Karnataka	1,695,941
Kerala	88,078
Madhya Pradesh	1,933,863
Maharashtra	1,636,787
Orissa	1,129,263
Punjab	1350
Rajasthan	697,162
Tamil Nadu	118,856
Uttar Pradesh	379,324
West Bengal	712,967
All India	12,455,647

Source Compendium of Environment Statistics India (2011), Ministry of Statistics and Programme Implementation, Government of India

4.3.7 *Simulation on the Role of Organic Manure in Agricultural Growth*

It has been theoretically suggested that use of organic manure (M) is helpful for both conservation of soil and agricultural growth. This acts as an input of agricultural production and at the same time it helps regeneration of soil fertility. Therefore if public policies are oriented towards encouraging the use of organic manures agricultural growth can be sustained. But sufficient data on the use of organic fertilizers like farm yard manure or green manure are not available for testing the above hypothesis through econometric exercises. Only some descriptive analyses could be done on the use of such inputs. Here, we are trying to capture the effect of increasing the use of organic manure on the output growth in agriculture with the help of a simulation using Matlab software.

In our exercise we see that given the production elasticities of technology, chemical fertilizer and organic manure (α, β, $1 - \alpha - \beta$ respectively), growth rate of output (g_Q) depends on the growth rates of technology (g_T), chemical fertilizers (g_Z) and organic manures (g_M) (see Eq. (4.42) in Sect. 4.3). In our simulation exercise in Fig. 4.5, it has been assumed that g_T is increasing at an exponential rate up to certain point and after that the growth rate remains constant. Secondly, g_Z is also increasing up to certain level and then remains constant although both growth

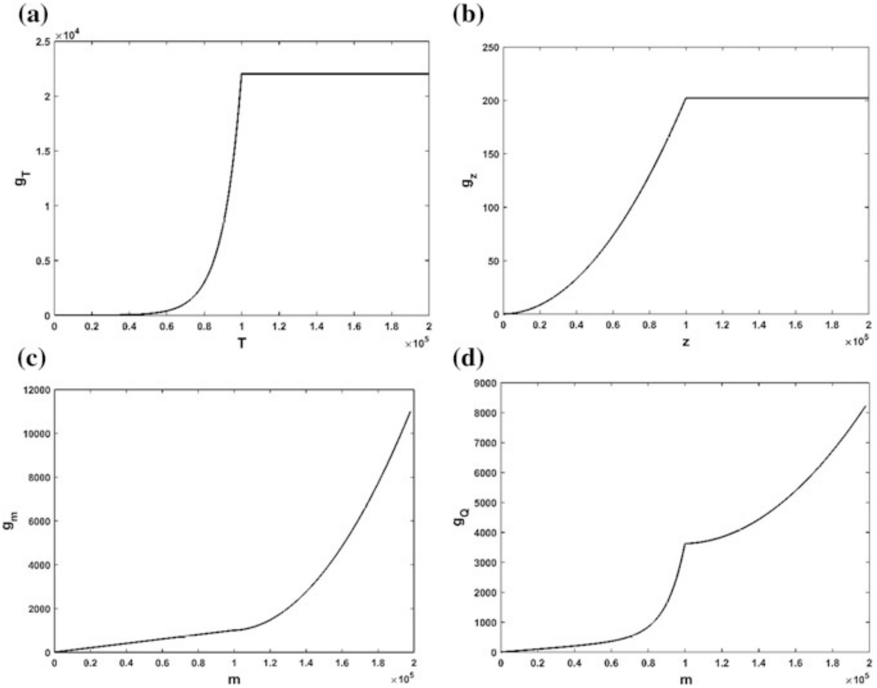

Fig. 4.5 The growth rates of T, Z, M and Q

rates are positive all the time. On the other hand, the growth rate of M (g_M) is increasing exponentially throughout. The combined effects of g_T, g_Z and g_M are determining the value of g_Q. It is found that as all three determinants are increasing g_Q is also increasing. To examine the impact of g_M on g_Q, the values of g_T and g_Z are kept constant at positive levels after certain point (see panel a and b of Fig. 4.5). In panel c, g_M is increasing throughout. In panel d it is found that although g_T and g_Z are kept constant, g_Q continues to increase after a kink point with increase in g_M. This establishes our hypothesis that if the growth rate of use of M is increased, the growth rate of Q will also increase.

4.3.8 The Effects of Change in the Value of α and β on G_Q

In Fig. 4.6 it has been examined what happens to g_Q if the values of α and β change with same g_T, g_Z and g_M as specified above. It is found that as the values α increases g_Q declines with same g_M. When α = 0.1, g_Q is shown by lower solid line in panel a of Fig. 4.6. As the value of α increases, g_Q curve shifts upward and

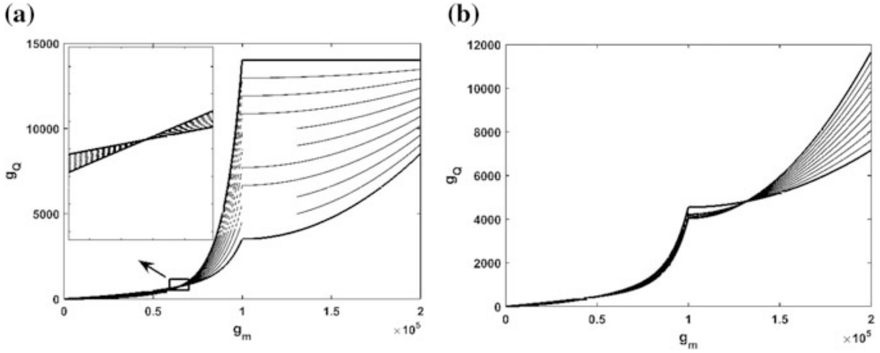

Fig. 4.6 The effects of change in α and β on the growth rate of *Q*

finally become constant at the level where α = 0.6. The implication is that if production elasticities of technology and chemical fertilizers are high, the production elasticity of *M* (i.e. 1 − α − β) will be low. In that case for same g_M, the value of g_Q will be lower. Conversely, if the values of α and β are low, (1 − α − β) will be high and then the impact of *M* on the growth of output will be also higher.

4.3.8.1 Effect of g_m on g_Q

Let us take $g_T = \begin{cases} e^{a^*T}, & \text{if } a \le T \le c \\ g_T(c), & \text{if } c < T \le b \end{cases}; g_z = \begin{cases} a_1 z^2 + a_2 z + a_3, & \text{if } a \le z \le c \\ g_z(c), & \text{if } c < z \le b \end{cases}$ and $g_m = \begin{cases} 10m, & \text{if } a \le m \le c \\ 10c + m^2, & \text{if } c < m \le b. \end{cases}$

From the Fig. 4.5, it can easily verify the nature of g_Q as

Figure 4.5: the panels (a), (b) and (c) in fact, visually describes the functions: g_T,g_z and g_m. In each case, The range of x-axis taken in same scale. (d) represents the function g_Q.

In Fig. 4.5, it is observed that whenever g_T, g_z possesses constant values, values of g_Q is affected by g_m. In fact, after ‘1’ in x-axis an increasing trend can be seen for g_Q.

For this functions, we have observed the nature of g_Q for variable α and β in Fig. 4.6.

Figure 4.6: the panels (a) and (b) represents the values of g_Q for different values of α and β respectively. All curves are drawn for $\alpha, \beta \in [0.1, 0.6]$. The Blue and red line indicates the values of g_Q for $\alpha, \beta = 0.1$ and $\alpha, \beta = 0.6$ respectively.

In panel *b* of Fig. 4.6 as β rises, g_Q curve remains positively sloped but shifts downward. That is, the slope of g_Q curve changes (i.e., rate of change of g_Q declines). As β reaches the value equal to 0.6, g_Q curve becomes a solid line at the lowest level. The implication is that if β is high, it means higher production elasticity of the chemical fertilizer *Z*. Since the effect of *Z* on *Q* becomes higher, the effect of *M* on g_Q declines. This is because the production elasticity of *M* is

$1 - \alpha - \beta$. As β rises, $1 - \alpha - \beta$ declines. α and β have been considered over a range from 0.1 to 0.6. As technology and chemical fertilizers become powerful, the effect of M on g_Q becomes weak. From this simulation it follows that given the moderate values of α and β, the use of organic manure will be effective in increasing output. But if the effect of technological change is maximum, g_M fails to increase g_Q. In case of β, if it is maximum, the value of g_Q increases with g_M but rate of change of g_Q declines. On the whole, the effect of the input of M on g_Q will depend on the values of α and β.

4.3.9 Summary

This section addresses the problems of soil degradation and sustainable agricultural growth consequent upon intensive cultivation and externalities in production. It demonstrates with the help of theoretical models that if the harvest rate of soil nutrients exceeds its natural regeneration rate, the stock of soil fertility will decline in the absence of any soil treatment measure. So, there will be decay of the resource base making agricultural growth unsustainable in the long-run. Since individual agents in a decentralized system do not take into account the social cost of environmental degradation, resource-damaging inputs will be used in excess doses. It argues for public intervention in resource use and emphasises on technological progress to sustain agricultural growth. It is suggested that the government can adopt direct incentive payment scheme to encourage the use of resource and environment friendly inputs. Such payments can be justified on the ground that externality problems are there and use of such inputs generate environmental and ecological services to the whole society. If sufficient funds cannot be raised from the agricultural sector, it may be collected from other sectors of the economy. In fact, agriculture and resource management are financed by the non-agricultural sector in most of the cases.

Using the growth framework of Sasmal and Weikard (2013) this chapter demonstrates that an input like green manure or organic fertilizer can ensure sustainable growth in production by enhancing productivity and helping conservation of soil fertility. Apart from incentive payment, subsidy can be paid to the farmers to encourage the use of resource and environment friendly inputs in agriculture. The hypothesis of the model has been tested in a limited way using available data. Since sufficient data are not available simulation has been done to examine the effect of organic fertilizer on the growth of agricultural output. The results show that organic fertilizer becomes effective in increasing production under certain conditions.

Appendix 1

Differentiation of (4.6) and (4.8) w.r.t. Z and N gives

$$\begin{bmatrix} P \cdot F_{ZZ} - \lambda L''(Z) & P \cdot F_{ZN} \\ P \cdot F_{NZ} & P \cdot F_{NN} + \lambda G_{NN} \end{bmatrix}$$

We get the determinants as $|D_1| < 0$, $|D_2| > 0$ assuming $F_{ZN} = F_{NZ} = 0$.

Appendix 2

Differentiation of (4.28) and (4.29) w.r.t. Z and N gives

$$\begin{bmatrix} p\,Q_{zz} - \lambda\,L_{zz} & p\,Q_{zN} \\ p\,Q_{Nz} & p\,Q_{NN} \end{bmatrix}$$

$|D_1| < 0, |D_2| > 0$ assuming $Q_{zN} = 0$.

Appendix 3

Differentiation of (4.36)–(4.38) w.r.t. Z, M and N

$$\begin{bmatrix} p\,Q_{zz} - \tau_{zz} - \lambda\,L_{zz} & p\,Q_{zm} & p\,Q_{zN} \\ p\,Q_{mz} & p\,Q_{mm} + \gamma_{mm} + \lambda\mu_{mm} & Q_{mN} \\ p\,Q_{Nz} & p\,Q_{Nm} & q\,Q_{NN} + \lambda\,G_{NN} \end{bmatrix}$$

So, $|D_1| < 0, |D_2| > 0, |D_3| < 0.$
Assuming $Q_{zm} = Q_{Nz} = Q_{Nm} = 0$

Appendix 4

Total differentiation of (4.36)–(4.37) gives

$$A + B\begin{bmatrix} \frac{\delta\hat{z}}{\delta N} & \frac{\delta\hat{z}}{\delta\lambda} & \frac{\delta\hat{z}}{\delta v} & \frac{\lambda\hat{z}}{\delta c} & \frac{\delta\hat{z}}{\delta p} \\ \frac{\delta\hat{m}}{\delta N} & \frac{\delta\hat{m}}{\delta\lambda} & \frac{\delta\hat{m}}{\delta v} & \frac{\delta\hat{m}}{\delta c} & \frac{\delta\hat{m}}{\delta p} \end{bmatrix} = 0$$

$$B = \begin{bmatrix} p\,Q_{zz} - \tau_{zz} - \lambda\,L_{zz} & p\,Q_{zm} \\ p\,Q_{mz} & p\,Q_{mm} + \gamma_{mm} + \lambda\mu_{mm} \end{bmatrix}$$

$$|B| = [(p\,Q_{zz} - \tau_{zz} - \lambda\,L_{zz})(p\,Q_{mm} + \gamma_{mm} + \lambda\mu_{mm})]$$

$|B| > 0$ (assuming $Q_{zm} = Q_{mz} = 0$)

$$A = \begin{bmatrix} p\,Q_{zN} & -L_z & -1 & 0 & Q_z \\ p\,Q_{mN} & \gamma_m & 0 & -1 & Q_m \end{bmatrix}$$

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Chapter 5
Uses of Land, Agricultural Price and Food Security

Abstract The competing uses of land for agriculture, industry, housing and urbanization have great relevance for agricultural production and food security, specially in an era of trade liberalization. This chapter theoretically shows using a Two-Sector General Equilibrium Model that if the capital intensive industrial sector expands due to inflow of capital, the land intensive agricultural sector will decline due to Rybczynsky effect. But this will not affect food security of the country if the trade surplus of the industrial sector can sufficiently finance the import of foodgrains. Technological progress in the agricultural sector may be also helpful in this context. Agricultural production largely depends on public investment and there is some complementarity between public and private investments. The public investment for agriculture in India has declined in 1990s and it has created shortage in the supply of foodgrains leading to food price inflation in the country. The demand is growing rapidly with high rate of GDP growth but supply fails to grow proportionately. Food security depends on the prices of food items also. This chapter has shown theoretically and using time series econometric results that sluggishness in agricultural production has led to price rise in the event of growing demand. It also shows that public policies have failed to maintain price stability in the market for foodgrains.

5.1 Introduction

The question of food security is closely related to land use and agricultural production. Land is the most important factor for agriculture and foodgrains production. With inflow of capital and expansion of non-agricultural sector after trade liberalization, the demand for land for the development of industry, housing, special economic zone (SEZ) and urbanization is increasing day by day. If more and more land is transferred from agriculture to non-agricultural uses, it may hamper agricultural production and food security of the country. This issue has been analysed in a two-sector general equilibrium model in this chapter. There are various possibilities with respect to production of foodgrains in the context of land transfer. If the

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non-food sector expands, the food-sector will decline to release land for the expanding non-agricultural sector. However, this may not hamper food security if trade surplus can sufficiently finance the required food import of the country. Another alternative way to avoid the problem of food shortage is technological progress in agriculture. If technological progress takes peace in agriculture, the requirement of land per unit of production will decline and then even if land available in the farming sector declines, the agricultural production will not suffer.

The other aspects of food security are wage rate and food price. If production of foodgrains declines or fails to increase sufficiently, it may lead to price rise in the food-grains market. India is experiencing high rate of GDP growth and it has been associated with rising prices of food items. Since foodgrains production has failed to increase sufficiently, in the event of growing demand there is mismatch between demand and supply and this has resulted in price rise. This chapter has analysed the problem of food price inflation in detail.

Apart from the use and availability of land, public investment and public policy are also very important for food price stability and food security. But public investment has declined in India in 1990s and it has affected foodgrains production adversely in the recent past. Besides, the public expenditure and the export-import policy of the government could not be helpful for combating inflation in the food market. This chapter has been devoted to the analysis of all these issues.

5.2 Land Use and Food Security in a Two-Sector General Equilibrium Model[1]

5.2.1 Introduction

Agriculture is a natural resource-based activity and production of foodgrains largely depends on the use of land, soil fertility, conservation of natural resources, technology and ecological factors. The developing countries have achieved remarkable success in foodgrains production in the last few decades. The green revolution coupled with expansion of irrigation and use of modern inputs has resulted in significant growth of foodgrains production. However, intensive cultivation, excessive ground water extraction and continuous use of chemical inputs have caused severe damage to the resource base putting a threat to future growth in agricultural production. In particular, soil degradation and excess depletion of ground water and loss of biodiversity have become matters of serious concern for future growth in foodgrains production.

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[1] The earlier version of this section titled, Sasmal (2015).

Another important aspect of food security is the competing uses of land and the availability of amount of land for agriculture. The production of foodgrains does not depend on the agricultural sector alone. The growth of the non-agricultural sector and the factors outside the farming sector are also important in this matter. Land is the main ingredient of agricultural production. But the growing industrialization and rapid expansion of the service sector have become very powerful contenders for land. Acquisition of land for the development of industrial hub, special economic zone (SEZ), urbanization, housing and real estate has become an important issue in the developing countries like India. This not only causes displacement of population from land and loss of livelihood of the farmers but also it reduces the amount of land available for agriculture. The area of land under non-agricultural uses in India has increased from 9.36 million hectares in 1950–51 to 26.29 million hectares in 2011–12 (Source: Agricultural Statistics at a Glance 2014, Ministry of Agriculture, Government of India 2015a, b). With expansion of non-agricultural activities, the area under cultivation is declining. In many cases, the most fertile lands are also being used for industries, housing, entertainment parks and various service sector activities. Now the question is: does the expansion of non-agricultural sector put pressure on the use of land and affect food security of the country? This section addresses the issue of land use and food security in a two-sector general equilibrium framework. We have considered a model consisting of two sectors: Agriculture and Non-agriculture. For simplicity, it is assumed that agriculture produces only food. The non-agricultural sector includes all activities other than agriculture. There are three factors of productions in the system—land, capital and labour. Let us assume that both sectors use land and capital and the factors are mobile between the sectors. Labour is not included just to avoid complexity of the model. However, labour can be used as an input in a more general framework. It may be further assumed that the non-agricultural sector is more capital intensive than the food sector. Given these specifications, it is proposed that in an era of trade liberalization if capital inflow increases, the non-agricultural sector will expand and the food sector will decline due to Rybczynski effect. The Rybczynski Theorem states that if some factor endowment intensively used in one good increases, the production of the other good using the other factor intensively declines. In the present case, as the non-agricultural sector expands, the food sector will decline to release land for the growth of the industrial sector and this may cause problems for food security of the country. Since there is an interdependence between the sectors, the issue needs to be considered in a general equilibrium framework. Here, in this section, the whole idea has been analysed in the framework of Rybczynski Theorem as outlined in Jones (1965). For security of food in a country, the production of foodgrains is important. At the same time, the purchasing power of the consumers, specially of the workers, is equally important. So, in order to examine the effect of decline of the food sector on the wage rate of labour, we have considered the framework of Specific Factor Trade Model of Jones (1971) and Jones and Marjit (2003) where labour is considered as a specific factor to agriculture.

5.2.2 Production of Food in a Two-Sector General Equilibrium Framework

5.2.2.1 The Model

The availability of land and its productivity are very important for production of foodgrains and food security. Following Jones (1965) we have considered a two-sector general equilibrium framework where land is used for production of foodgrains as well as for industrial and other non-agricultural activities. So, we assume that there are two sectors in the economy: Agriculture and Non-Agriculture. Agriculture produces foodgrains (F) and the output of the Non-Agricultural sector is denoted by N. It may be conceived that N is industrial or service sector product which is consumed domestically and exported to other countries. Foodgrains may be exported. But it may be assumed that there is no surplus food for export. There are two factors of the production in the system—Land (T) and Capital (K). Both factors are used in the production of food (F) and Non-food items (N). We can generalize the production system in such a way that unskilled labour is used in food production and skilled labour is used in non-agricultural sector. The wage of unskilled labour may be fixed by subsistence wage and wage of skilled workers may be fixed by trade union. Thus we can include labour in the system. But to avoid complexity, we decide not to include labour in this framework.

Let a_{ij} be the *i*th input used in per unit output of *j*th product. That means,
a_{TF} = amount of land used per unit of food production.

Similarly,
a_{KF} = amount of capital per unit of food production.
a_{TN} = amount of land used per unit production of N.
a_{KN} = amount of capital used per unit production of N.

There are given amounts of Capital (K) and land (T) in the economy and full employment of both factors is assumed. The production functions are:

$$\mathrm{F} = \mathrm{F}(\mathrm{T}, \mathrm{K}) \tag{5.1}$$

$$\mathrm{N} = \mathrm{N}(\mathrm{T}, \mathrm{K}) \tag{5.2}$$

It is assumed that N is more capital intensive than F,

$$\text{i.e.,} \left(\frac{a_{KN}}{a_{TN}}\right) > \left(\frac{a_{KF}}{a_{TF}}\right)$$

There is substitution between land and capital in the production of both commodities. The production functions exhibit constant returns to scale with diminishing returns.

The conditions of full employment of the factors:

$$a_{TF} \cdot F + a_{TN} \cdot N = T \tag{5.3}$$

$$a_{KF} \cdot F + a_{KN} \cdot N = K \tag{5.4}$$

The prices of F and N are P_F and P_N respectively and in competitive market equilibrium the prices are:

$$R \cdot a_{TF} + r \cdot a_{KF} = P_F \tag{5.5}$$

$$R \cdot a_{TN} + r \cdot a_{KN} = P_N \tag{5.6}$$

where R is rental per unit of land and r is rate of return on capital. So four unknowns R, r, F and N are determined from four Eqs. (5.3)–(5.6). For a small country, commodity prices are given. If factor endowment increases, there will be adjustment in output.

Let us consider the situation that domestic rate of return on capital (r) is greater than international rate r^*. Now, with trade liberalization, inflow of capital is allowed up to certain limit such that capital increases, r falls but r remains greater than r^*. That means, $r > r^*$ is maintained. The commodity prices remaining unchanged as K increases the capital intensive sector N will expand by Rybczynski effect. To allow the expansion of N-sector, the food sector will shrink to release land for the growth of Non-Food Sector. At the same price ratio the equilibrium production point will change on the bowed out transformation curve shown in Fig. 5.1. Before inflow of capital, production possibility frontier (PPF) is AB. As supply of capital increases and N is more capital-intensive, PPF changes from AB to A′B′.

Let the price ratio $\left(\frac{P_F}{P_N}\right)$ be denoted as P. Figure 5.1 shows that as a result of inflow of capital. The production in the capital intensive Non-Food Sector (N) increases from N_0 to N_1 at the same commodity price ratio $1/p$. As the Non-Food

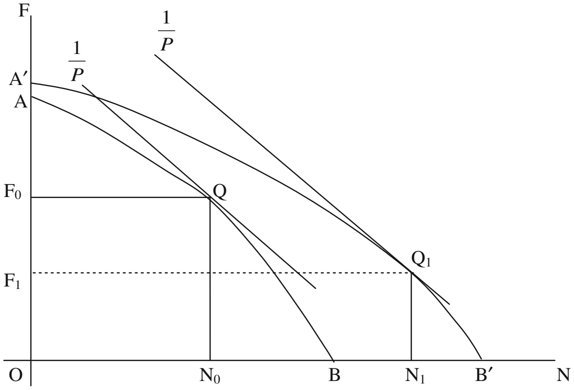


Fig. 5.1 Equilibrium production of food and non-food items at the given price

sector expands, the Food Sector (F) declines from F_0 to F_1. The production point on bowed out transformation curve changes from Q to Q_1.

Following Jones (1965) we can write

λ : factor share in output
θ : factor share in price

Therefore,

$$\frac{a_{TF}\cdot F}{T}=\lambda_{TF},\ \frac{a_{TN}\cdot N}{T}=\lambda_{TN}\quad\text{and}\quad\lambda_{TF}+L_{TN}=1.$$

$$\frac{a_{KF}\cdot F}{K}=\lambda_{KF},\ \frac{a_{KN}\cdot N}{K}=\lambda_{KN}\quad\text{and}\quad\lambda_{KF}+\lambda_{KN}=1.$$

Similarly,

$$\frac{R\cdot a_{TF}}{P_F}=\theta_{TF},\ \frac{r\cdot a_{KF}}{P_F}=\theta_{KF}\quad\text{and}\quad\theta_{TF}+\theta_{KF}=1.$$

$$\frac{R\cdot a_{TN}}{P_N}=\theta_{TN},\ \frac{r\cdot a_{KN}}{P_N}=\theta_{KN}\quad\text{and}\quad\theta_{TN}+\theta_{KN}=1.$$

Symbol '∧' indicates relative change. For example, $\frac{dF}{F}=\hat{F}$, $\frac{dN}{N}=\hat{N}$ and so on.

Given factor prices, a_{ij}s are adjusted optimally to minimize cost of production. The cost-minimising conditions suggest that

$$\theta_{TF}\hat{R}+\theta_{KF}\hat{r}=\hat{P}_F \tag{5.7}$$

$$\theta_{TN}\hat{R}+\theta_{KN}\hat{r}=\hat{P}_N \tag{5.8}$$

Land (T) remaining constant and with inflow of capital the total differential of Eqs. (5.3) and (5.4) give the following expressions after simplification.

$$\lambda_{TF}\hat{F}+\lambda_{TN}\hat{N}+\lambda_{TF}\,\hat{a}_{TF}+\lambda_{TN}\,\hat{a}_{TN}=0 \tag{5.9}$$

$$\lambda_{KF}\hat{F}+\lambda_{KN}\hat{N}+\lambda_{KF}\,\hat{a}_{KF}+\lambda_{KN}\,\hat{a}_{KN}=\hat{K} \tag{5.10}$$

Following Jones (1965) Eqs. (5.7) and (5.8) can be written as

$$|\theta|\left(\hat{R}-\hat{r}\right)=\left(\hat{P}_F-\hat{P}_N\right) \tag{5.11}$$

where $|\theta| > 0$ because $\left(\frac{a_{KN}}{a_{TN}}\right) > \left(\frac{a_{KF}}{a_{TF}}\right)$.

σ_F and σ_N are elasticities of substitution between T and K in the production of F and N respectively.

$$\sigma_F = \frac{\hat{a}_{KF} - \hat{a}_{TF}}{\hat{R} - \hat{r}}, \quad \sigma_N = \frac{\hat{a}_{KN} - \hat{a}_{TN}}{\hat{R} - \hat{r}}$$

Using the values of σ_F and σ_N and cost minimizing conditions we can solve $\hat{a}_{TF}$ and $\hat{a}_{KF}$ as

$$\hat{a}_{TF} = -\theta_{KF} \cdot \sigma_F \left(\hat{R} - \hat{r}\right) \tag{5.12}$$

$$\hat{a}_{KF} = \theta_{TF} \cdot \sigma_F \left(\hat{R} - \hat{r}\right) \tag{5.13}$$

The other $\hat{a}_{ij}$ s are solved in a similar way. We can change the expressions in (5.12) and (5.13) using the relation in (5.11)

$$\left(\hat{R} - \hat{r}\right) = \frac{1}{|\theta|}\left(\hat{P}_F - \hat{P}_N\right) \tag{5.14}$$

Prices and terms of trade remaining unchanged we can write

$$\lambda_{TF}\hat{F} + \lambda_{TN}\hat{N} = 0 \tag{5.15}$$

$$\lambda_{KF}\hat{F} + \lambda_{KN}\hat{N} = \hat{K} \tag{5.16}$$

In matrix form (5.15) and (5.16) can be written as

$$\begin{bmatrix} \lambda_{TF} & \lambda_{TN} \\ \lambda_{KF} & \lambda_{KN} \end{bmatrix} \begin{bmatrix} \hat{F} \\ \hat{N} \end{bmatrix} = \begin{bmatrix} 0 \\ \hat{K} \end{bmatrix} \tag{5.17}$$

From (5.17), $\hat{F}$ and $\hat{N}$ can be solved as

$$\hat{F} = \frac{-\hat{K} \cdot \lambda_{TN}}{|\lambda|} < 0$$

$$\hat{N} = \frac{\hat{K} \cdot \lambda_{TF}}{|\lambda|} > 0 \quad \text{because} \quad |\lambda| > 0.$$

Thus as a result of inflow of capital the food sector declines and non-food sector expands due to Rybczynski effect.

5.2.3 *Effect on Food Security*

Now the question arises whether the decline of the food sector will affect the food security of the economy. This will not affect food security so long as trade surplus is sufficient to finance the necessary food import at the same price. Food may be exportable but if the country does not have sufficient production, it can not export food. In fact, after the decline of the food sector the country imports food. The income of the country is defined as $\Omega = P_F \cdot F + P_N \cdot N$.

Putting $P_N = 1$, income can be written as

$$\Omega = P \cdot X + N \tag{5.18}$$

Given the prices and other things, demand for Food and Non-Food items depends on income. i.e.,

$$\mathrm{D_F} = \mathrm{D_F}(\Omega) \text{ and } \mathrm{D_N} = \mathrm{D_N}(\Omega)$$

Here, both F and N are assumed to be normal goods. Therefore, $D'_F(\Omega) > 0$ and $D'_N(\Omega) > 0$ implying that demand for both food and non-food items will increase as income increases.

N is exportable good and export surplus is $(\mathrm{N} - \mathrm{D_N})$. On the other hand, value of import of food is $\mathrm{P}\,(\mathrm{D_F} - \mathrm{F})$ where $\mathrm{D_F}$ domestic demand for food and F is domestic production. Although food sector declines as a result of capital inflow, there will be no problem in food security if

$$(\mathrm{N} - \mathrm{D_N}) = \mathrm{P}(\mathrm{D_F} - \mathrm{F}) \tag{5.19}$$

The implication of Eq. (5.19) is very significant. The international trade theory suggests that in the rest of the world there will be food surplus and if export surplus of the home country can finance the required amount of food import, output adjustments in the two sectors of a country will not hamper overall food security. This conclusion is based on the assumption that there is free movement of food items between countries. However, if there are barriers to free trade in food in any form, the decline of the food sector may create problem for food security of the country.

Another point to note here is that if it is a big country, its import demand will be high and in that case it may affect the international price and terms of trade. The higher amount of import of food may lead to increase in the price of food, P in the international market and then there is possibility that $(\mathrm{N} - \mathrm{D_N}) < \mathrm{P}\,(\mathrm{D_F} - \mathrm{F})$. That means, export earning is insufficient to finance the required amount of food import and as a result food security of the country will be disturbed.

The total value of demand for food is

$$\mathrm{P} \cdot \mathrm{D_F} = \mathrm{P} \cdot \mathrm{F} + (\mathrm{N} - \mathrm{D_N}) \tag{5.20}$$

where $\mathrm{P} \cdot \mathrm{F}$ is value domestic production of food and $(\mathrm{N} - \mathrm{D_N})$ is export earning from Non-Food items. Equation (5.20) can be simplified as

$$D_F = \frac{N - D_N}{P} + F \tag{5.21}$$

Here N rises and F falls. So, whether the demand for food can be met or not it depends on the export balance ($N - D_N$) and terms of Trade (P). For a small country, P is given. So, D_F depends on the fall of F and increase of N. Here, we may conceive of a minimum demand for food denoted by $\left(\overline{D_F}\right)$ where

$$\overline{D_F} = \frac{N - D_N}{P} + F \tag{5.22}$$

Given P in Eq. (5.22), $\overline{D_F}$ depends on F, N and D_N. As a result of output adjustment, the fall in food production and increase of non-food production will determine whether the minimum food requirement is met or not. This again depends on production technology in the two sectors.

On the other hand, D_N depends on income. In our case, income increases after the inflow of capital. Now income elasticity of D_N may be higher than that of D_F. If D_N is sufficiently high due to increase of income but increase of N is not so high, then it is not clear whether the minimum food requirement can be met by export surplus. That means, a kind of food insecurity may arise in that case. So, the expansion of Non-food sector and the consequent decline of the food-sector may create some uncertainty in food security.

5.2.4 Technological Change in the Food Sector

Given the commodity prices, as supply of capital increases, r declines and R increases in the capital intensive Non-food sector (N). This attracts land from Food sector to Non-food sector and as a result, supply of land in Food-Sector declines and R rises. Since the availability of land declines the food sector shrinks. If technological progress takes place in agriculture it will enhance productivity of land so that greater amount of food can be produced from less amount of land. With technological progress as the productivity of land increases the requirement of land per unit of output declines. That means, a_{TF} will decline. Now, the effect of technological change on Food-sector can be analysed by using the framework of Jones (1965) in a two-sector framework. As shown in Jones (1965) a_{TF} can change due to change in factor price (R/r) or technological change denoted by t. So,

a_{TF} can be expressed as a function of R/r and t, i.e.

$$a_{TF} = a_{TF}\left(\frac{R}{r}, t\right) \tag{5.23}$$

Equation (5.23) can be converted to

$$\hat{a}_{TF} = \alpha\left(\hat{R} - \hat{r}\right) - \beta\hat{t} \tag{5.24}$$

where α is a fraction of change in relative factor price and β is fraction of technological change.

Here, we assume that β > 0 and $\frac{\theta_{KN}}{\theta_{TN}} > \frac{\theta_{KF}}{\theta_{TF}}$.

From cost-minimising conditions we can write

$$\theta_{TF}\hat{R} + \theta_{KF}\hat{r} = \beta\hat{t} \tag{5.25}$$

$$\theta_{TN}\hat{R} + \theta_{KN}\hat{r} = 0 \tag{5.26}$$

Total differential of Eqs. (5.3) and (5.4) gives the following expressions after simplification

$$\lambda_{TF}\,\hat{F} + \lambda_{TN}\,\hat{N} + \lambda_{TF}\,\hat{a}_{TF} + \lambda_{TN}\,\hat{a}_{TN} = \lambda_{TF}\,\beta\hat{t} \tag{5.27}$$

$$\lambda_{KF}\,\hat{F} + \lambda_{KN}\,\hat{N} + \lambda_{KF}\,\hat{a}_{KF} + \lambda_{KN}\,\hat{a}_{KN} = \lambda_{KF}\,\beta\hat{t} + \hat{K} \tag{5.28}$$

Following Jones (1965), we can express

$$\hat{a}_{TF} = -\theta_{KF}\,\sigma_F\left(\hat{R} - \hat{r}\right)$$
$$\hat{a}_{KF} = \theta_{TF}\,\sigma_F\left(\hat{R} - \hat{r}\right)$$

Other $\hat{a}_{ij}$ s are similarly expressed. Here, σ_F is elasticity of substitution between land and capital in production of food.

Then we can write Eqs. (5.27) and (5.28) as

$$\lambda_{TF}\,\hat{F} + \lambda_{TN}\,\hat{N} = \beta\hat{t}\,A \tag{5.29}$$

$$\lambda_{KF}\,\hat{F} + \lambda_{KN}\,\hat{N} = \beta\,\hat{t}\,B + \hat{K} \tag{5.30}$$

(see the expressions of A and B in appendix).

In matrix form Eqs. (5.29) and (5.30) can be written as

$$\begin{bmatrix} \lambda_{TF} & \lambda_{TN} \\ \lambda_{KF} & \lambda_{KN} \end{bmatrix} \begin{bmatrix} \hat{F} \\ \hat{N} \end{bmatrix} = \begin{bmatrix} \beta\,\hat{t}\,A \\ \beta\,\hat{t}\,B + \hat{K} \end{bmatrix} \tag{5.31}$$

$$\begin{aligned}|\lambda| &= \lambda_{TF}\lambda_{KN} - \lambda_{KF}\lambda_{TN}\\ &= \lambda_{TF}(1-\lambda_{KF}) - \lambda_{KF}(1-\lambda_{TF})\\ &= \lambda_{TF} - \lambda_{TF}\lambda_{KF} - \lambda_{KF} + \lambda_{TF}\lambda_{KF}\\ &= \lambda_{TF} - \lambda_{KF} \; > \; 0 \text{ on the assumption that}\\ &\quad \frac{a_{TF}}{a_{KF}} > \frac{a_{TN}}{a_{KN}}, \text{ so, } |\lambda| \; > \; 0.\end{aligned}$$

$$\text{Now,} \quad \hat{F} = \frac{\begin{vmatrix} \beta\hat{t}A & \lambda_{TN} \\ \beta\hat{t}B + \hat{K} & \lambda_{KN} \end{vmatrix}}{|\lambda|}$$

$$= \frac{(\lambda_{KN}A - \lambda_{TN}B)\hat{t}\beta - \hat{K}\lambda_{TN}}{|\lambda|}$$

$\hat{F} > 0$ or food sector will increase as a result of technological progress if $(\lambda_{KN}A - \lambda_{TN}B)\hat{t}\,\beta$ is positive and $\{(\lambda_{KN}A - \lambda_{TN}B)\hat{t}\,\beta\} > \hat{K}\,\lambda_{TN}$.

Let $(\lambda_{KN}A - \lambda_{TN}B)$ be denoted as C.

$$\hat{F} < 0 \quad \text{iff} \quad C\hat{t}\,\beta < \hat{K}\lambda_{TN}$$

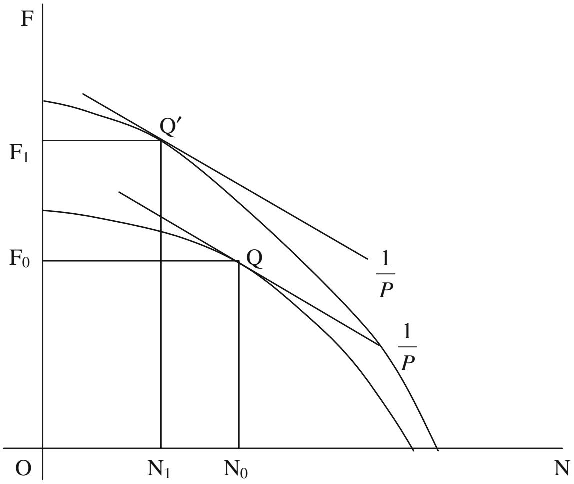
$$\text{or,} \quad \hat{t} < \frac{\hat{K}\lambda_{TN}}{C\,\beta}$$

Given the elasticity of substitution between T and K in the production of F and N, if the effect of increase in capital supply is greater than the effect of technological change, food sector will decline; otherwise, food-sector will expand due to technological change and in that case food security will not suffer.

5.2.5 Capital Intensive Food Sector

We have so far assumed that food-sector is less capital intensive. But if we consider a situation where food-sector is more capital intensive than the Non-food sector due to commercialization and high degree of modernization of the farming sector, the result may be different. Whether foreign direct investment (FDI) will be allowed in agriculture remains a controversial issue in the developing countries. In fact, in many countries agricultural productivity is declining due to lack of sufficient capital investment and proper modernization of the sector. Now, if we consider a situation where FDI is allowed in agriculture and the Food-sector becomes highly capital intensive, then we get

Fig. 5.2 Equilibrium production of food and non-food items when food is more capital-intensive



$$\left(\frac{a_{KF}}{a_{TF}}\right) > \left(\frac{a_{KN}}{a_{TN}}\right)$$

That means, food-sector becomes more capital intensive than the Non-food sector. Since food sector is more capital intensive and capital endowment in Food-sector is increasing, the food-sector will expand and Non-food sector will decline due to the same Rybczynski effect. To make the expansion of the food sector feasible, land will be released from the Non-food sector to the food sector. As a result, Non-food sector will decline but food-sector will expand. In such a situation, what happens to the whole economy is not known. But it is clear that domestic food production will increase. This can be shown in Fig. 5.2 using production possibility frontier.

In Fig. 5.2, at the same price, food production increases from F_0 to F_1 after foreign capital flowing to the Food-sector. This is due to Rybczynski effect.

5.2.6 *Specific Factor Trade Model and Effect on Factor Income*

We have so far explored the possible effects of change in capital endowment and technological progress in agriculture on the production of food-sector. For food security of the country, total production is important. But at the same time, the purchasing power of the workers is also very important in this matter. Unless the workers have the necessary income and purchasing power, they will not have access to food although food is available in the country. To analyse this aspect we need to examine what happens to wage rate following an increase in the supply of capital. To explain this matter, let us consider a specific factor trade model following Jones (1971) and Jones and Marjit (2003) and reset the earlier model as follows:

As before there are two sectors in the economy—Food Sector (F) and Non-Food Sector (N). There are three factors of production—land (T), labour (L) and capital (K). Labour is specific to the Food-sector. That means, labour is used only in food production. Similarly capital is used only in Non-food sector. But land is mobile between the two sectors. The production functions are:

$$\mathrm{F} = \mathrm{F(T, L)} \tag{5.32}$$

$$\mathrm{N} = \mathrm{N(T, K)} \tag{5.33}$$

The functions have normal properties as usual. The full employment conditions are:

$$a_{TF} \cdot F + a_{TN} \cdot N = T \tag{5.34}$$

$$a_{LF} \cdot F = L \tag{5.35}$$

$$a_{KN} \cdot N = K \tag{5.36}$$

The prices in competitive market equilibrium are:

$$W \cdot a_{LF} + R \cdot a_{TF} = P_F \tag{5.37}$$

$$r \cdot a_{KN} + R \cdot a_{TN} = P_N \tag{5.38}$$

where R and r are rates of rental on land and capital respectively and W is wage rate of labour. For a small economy the prices ($\mathrm{P_F}$, $\mathrm{P_N}$) are given. Land is optimally allocated between the two sectors by the condition

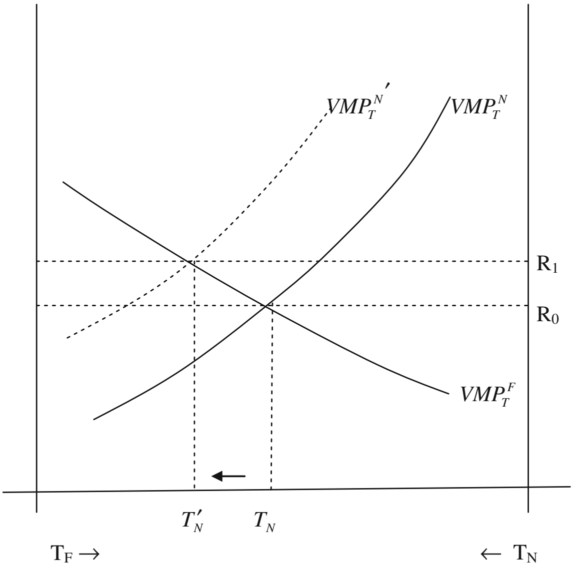
$$VMP_T^F = VMP_T^N$$

where VMP_T^F and VMP_T^N are value of marginal product of land in Food-sector and Non-Food sector respectively.

Given K, T and L and prices $\mathrm{P_F}$ and $\mathrm{P_N}$, rental rate on land (R) optimal allocation of land between the two sectors is determined in Fig. 5.3. So, five unknowns F, N, R, r, W are determined from five Eqs. (5.34)–(5.38). Figure 5.3 shows that as VMP_T^N increases, rental on land (R) also increases.

Now suppose, capital endowment in Non-food sector increases due to inflow of capital from other countries and inflow is allowed up to a level where $r > r^*$. That means, domestic rate of return on capital is still higher than international level r^*. In fact, huge FDI is flowing to the industrial and service sector of the developing countries after trade liberalization. After the inflow of capital which is specific to the Non-food sector in the present situation, r declines and the Non-food sector

Fig. 5.3 Optimal allocation of land between food and non-food sectors



expands. As Non-food sector expands, demand for land in this sector increases and higher VMP_T^N makes the reallocation of land between the two sectors (see Fig. 5.3). As more capital is employed, marginal product of land in Non-food sector increases leading to higher rental rate on land (R) in that sector. As a result, land moves from Food Sector to the Non-food sector. Labour is specific to the Food-sector. Now less amount of land will be available for the same amount of labour in the Food-sector. So, land-labour ratio will decline with the result that marginal product of labour will decline. As a result, wage rate (W) will decline. On the other hand, capital which is specific to the Non-food sector increases in the Non-food sector. As a result, rental rate on capital (r) also declines. Only the mobile factor (Land) gains in higher rental rate denoted by R_1 in Fig. 5.3. The importance of this result is that here not only the Food-sector declines, but also the workers who are specific to this sector, will lose in wage rate. In fact, both specific factors will lose in factor income. As wage rate declines, purchasing power of the labourers also declines and this may cause insecurity of food for the workers. This result has greater implication. With the growth of the skill-based non-agricultural sector, the unskilled workers who are basically attached to agriculture and can not move to skill-based sector, are actually losers in the process of economic growth.

5.2.7 Summary

This section has addressed the issue of food security in a perspective of trade liberalization and unbalanced growth. There are competing uses of land for agriculture and industry in an expanding economy. The growing industrial and service sectors have become strong contenders for land. With inflow of foreign capital in an era of trade liberalization, the increasing demand for land for the development of industrial hub, Special Economic Zone (SEZ) and urbanization and real estate development is increasing and it is leaving less amount of land for agriculture. This section examines whether this creates any problem for food security of the country. The issue has been analysed in a Two-Sector General Equilibrium Framework where the two sectors are: Agriculture and Non-agriculture. There are two factors of production-land and capital. Industrial sector has been assumed to be more capital intensive. The paper shows that as industrial sector expands with the inflow of capital the agricultural sector shrinks due to Rybczynski effect. But this does not put any threat to food security so long as export surplus is sufficient to finance the necessary food import from other countries. However if balance of trade is insufficient or terms of trade worsens due large import of food for a big economy, it may become a problem for the country and food security is hampered. However, the land-augmenting technological progress can help in this respect. As technology improves in agriculture, the requirement of land per unit production in the food sector declines. In such a situation, food production may increase despite transfer of land from food-sector to non-food sector. Only under special cases where effects of technological progress are weaker than the effects of capital inflow, food production may decline even with technological progress.

Not only the total domestic production but also the purchasing power of the workers matters significantly in food security of a country. If the labourers do not have sufficient purchasing power, they can not have access to food. To examine the effect of growth of the Non-agricultural sector on factor income we have considered a Specific Factor Trade model where labour is specific to agriculture. The result shows that as food sector declines as a result of inflow of capital, the wage rate declines as land-labour ratio declines and it adversely affects food security of the workers.

5.3 Public Investment and Production of Foodgrains in India

5.3.1 Introduction

One important aspect of food security is production of foodgrains. The government has to play a key role in agricultural growth through its involvement in the development of infrastructure, technological progress and extension services. Again private investment may depend upon public investment. The agriculture in the developing countries are characterized by low capital investment, low productivity and technological backwardness. The technological progress and development of infrastructure like irrigation and extension services are basically public goods and these are not provided by the private individuals. So, the government has to play important role in these matters. A significant technological breakthrough has taken place in the Indian agriculture with the adoption of high yielding variety (HYV) technology in mid-sixties. In the diffusion of the technology the government took a very crucial role and after this technological change the productivity in Indian agriculture has remarkably increased specially in foodgrains production. The use of HYV seeds, chemical fertilizers and tube-well irrigation have significantly contributed to the productivity growth in agriculture. However, the growth rate in yield in foodgrain production is showing a declining trend in India since 1990s and this is due to declining growth rate of irrigation and technological stagnation (Sasmal 2012; Bhullar and Sidhu 2006). In the last few years the situation has, however, slightly improved. The effect of green revolution technology on productivityhas almost exhausted by this time. A new technological change is urgently needed in the country. The country is waiting for a second green revolution. But what is important here is that public investment for agriculture has gradually declined in India in the 1990s and it has exerted adverse impact on foodgrains production in the country. This section will give an account of per capita availability of foodgrains in India over the years. In this section we will analyse how the decline in public investment has adversely affected the growth rate of foodgrains production in the country.

5.3.2 Public Investment and Agricultural Production—A Theoretical Note

Let us consider the production function in agriculture as

$$Q = Q(L, X) \tag{5.39}$$

L is land and X is set of inputs. For simplicity, it is assumed that X is chemical fertilizer. The production function is characterized by the following features:

$$Q_L > 0, Q_{LL} < 0, Q_X > 0 \text{ and } Q_{XX} < 0.$$

In Cobb-Douglas form the production function is:

$$Q = A(GL)^{\alpha} X^{1-\alpha} \tag{5.40}$$

where A is efficiency from infrastructure like irrigation, G is land-augmenting technological progress and it is a function of public investment. Here, G is perfect substitute for land and $G = G(I)$, $G'(I) > 0$ and $G''(I) = 0$ where I is public investment for agriculture.

Taking log of (5.40) and differentiating w.r.t. time we get

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + \alpha\frac{\dot{G}}{G} + \alpha\frac{\dot{L}}{L} + (1-\alpha)\frac{\dot{X}}{X} \tag{5.41}$$

After simplification, it is expressed as

$$g_Q = g_A + \alpha g_G + \alpha g_L + (1-\alpha)g_X \tag{5.42}$$

where g_i is growth rate of i-th variable and i = Q, A, G, L and X.

If land is fixed, $g_L = 0$. Public investment influences both infrastructure and technology. But for simplicity, we assume that I influences only G. Now, g_G can be replaced g_I. g_I is growth rate of public investment. If we consider a situation where A specifically depends on irrigation and there is one to one relation between A and irrigation (R), we can replace g_A by g_R. Then we can write

$$g_Q = g_R + \alpha g_I + (1-\alpha)g_X \tag{5.43}$$

Here, if g_R, g_I and g_X decline or any of them become zero or negative then g_Q will also decline. So, from the view point of supply, if public policy fails to increase irrigation and fertilizer use and promote technological change, agricultural production will suffer.

From 1990s, growth rate of net capital formation for agriculture in the public sector in India has declined and remained negative for a long period. The growth rates of irrigation and fertilizer use are also found to decline during this period. The area under canal irrigation which is basically owned and managed by the government has remained more or less unchanged over the last twenty years. The growth rate of tube-well irrigation on the other hand has also declined during this period. Besides, the potential of high yielding variety (HYV) technology has almost reached its maximum level. The declining growth rates of fertilizer use and irrigation indicate that the effects of technological change are also declining. On the other hand, gross area under foodgrains cultivation has remained more or less fixed for the last four decades. Thus, so far as foodgrains production is concerned the public policy could not play the proper role in maintaining the growth rate in agriculture in the recent past.

5.3.3 *Empirical Evidences*

Table 5.1 shows the per capita availability of foodgrains per day in India. In 1970–71 it was 468.8 g and from 1997–98 onwards it has declined to less than 468.8 g up to 2011–12 except the year 2001–02. It has been reflected in Fig. 5.4 also. The amount of per capita availability has been mentioned here including import of foodgrains. The figures indicate that the production per capita could not increase

Table 5.1 Per capita availability of foodgrains per day in India (gram)

Year	Amount	Year	Amount
1970–71	468.8	1992–93	464.1
1971–72	466.1	1993–94	471.2
1972–73	421.6	1994–95	495.4
1973–74	451.2	1995–96	475.2
1975–76	405.5	1996–97	503.1
1976–77	424.3	1997–98	447.0
1977–78	429.6	1998–99	465.7
1978–79	468.0	1999–2000	454.4
1979–80	476.5	2000–01	416.2
1980–81	410.4	2001–02	494.1
1981–82	454.8	2002–03	437.6
1982–83	454.8	2003–04	462.7
1983–84	437.3	2004–05	422.4
1984–85	479.7	2005–06	445.3
1985–86	454.0	2006–07	442.8
1986–87	478.1	2007–08	436.0
1987–88	471.8	2008–09	444.0
1988–89	448.5	2009–10	437.1
1989–90	494.5	2010–11	453.6
1990–91	510.1	2011–12	450.3
1991–92	468.8		

Source Economic survey, 2013–14, Government of India

Fig. 5.4 Per capita availability of foodgrains per day in India (gram) over the period from 1970–71 to 2011–12. *Source* Based on data, Economic Survey 2013–14, Government of India (2014a, b)

much. This may due to various reasons of which the declining rates of public investment is a major one. The net capital formation in agriculture in the public sector at constant (2004–05) prices has actually declined for a long period. It has declined from Rs. 12,769 crore in 1980–81 to Rs. 4309 crore in 1990–91 and again from Rs. 6349 crore in 1994–95 to Rs. 3827 crore in 2000–01. In the recent years however it has increased significantly (Source: National Accounts Statistics, 2011

Table 5.2 Net domestic capital formation in agriculture in the public sector in India at 2004–05 prices (rupees crore)

Year	Amount	Year	Amount
1970–71	5049	1990–91	5483
1971–72	5473	1991–92	4309
1972–73	7523	1992–93	5088
1973–74	6416	1993–94	5590
1974–75	5769	1994–95	6349
1975–76	6415	1995–96	6149
1976–77	9346	1996–97	5564
1977–78	10,385	1997–98	5011
1978–79	11,202	1998–99	4118
1979–80	11,620	1999–2000	4680
1980–81	12,769	2000–01	5790
1981–82	11,624	2001–02	4614
1982–83	11,050	2002–03	5997
1983–84	11,082	2003–04	10,019
1984–85	10,417	2004–05	13,265
1985–86	8954	2005–06	15,806
1986–87	8652	2006–07	16,155
1987–88	8534	2007–08	13,361
1988–89	7410	2008–09	15,352
1989–90	5721	2009–10	13,865

Source National Accounts Statistics, CSO, Ministry of Statistics and Programme Implementation, Government of India (2011, 2012a, b)

and 2012, Government of India, see Table 5.2). The argument we like to put here is that private investment in agriculture depends largely on public investment. So, to increase agricultural production, the government is required to make investment for technological change, resource management and development of infrastructure. The calculations from Table 5.2 show that net capital formation in agriculture in the public sector has increased at an annual rate of 3.59 % per annum for the period from 1970 to 1987. During the period from 1988 to 2003, it has declined at the rate of 0.70 % per annum on an average and from 2004 to 2010 the average rate of annual decline was 0.16 %. As a result of decline of public expenditure, the rates of growth of feretilizer use and irrigation have also declined.

5.3.4 *Time Series Analysis*

The time series analyses have been done on the relationship between the variables using data from Economic survey, 2013–14, Government of India (2014a, b), National Accounts Statistics, Government of India (2012a, b) and Centre for Monitoring Indian Economy (CMIE) (2010), for the period from 1970–71 to

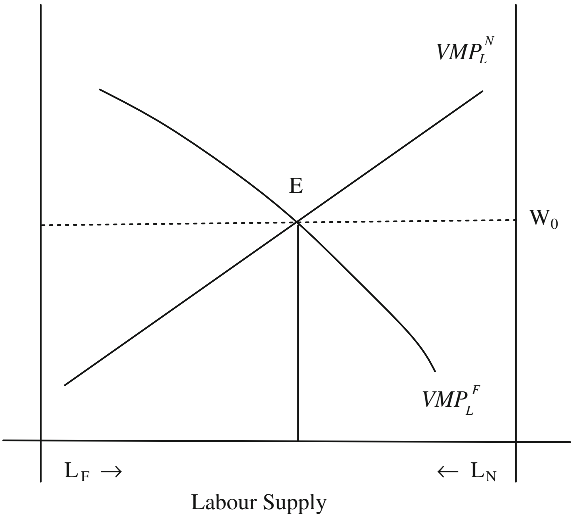


Fig. 5.5 Determination of optimal allocation of labour between two sectors and wage rate

Table 5.3 Cointegration between growth rate of food-grains (GR_PROD_F) and growth rate of net public sector capital formation in agriculture (GR_N_CAP_PUB) in India

Johansen cointegration test				
Sample (adjusted): 1974–2010				
Included observations: 37 after adjustments				
Trend assumption: Linear deterministic trend				
Series: GR_PROD_F GR_N_CAP_PUB				
Lags interval (in first differences): 1–1				
Unrestricted cointegration rank test (trace)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.[b]
None[a]	0.591962	42.49362	15.49471	0.0000
At most 1[a]	0.222818	9.326994	3.841466	0.0023
Unrestricted cointegration rank test (maximum Eigenvalue)				
Hypothesized no. of CE (s)	Eigenvalue	Max-Eigen statistic	0.05 critical value	Prob.[b]
None[a]	0.591962	33.16663	14.26460	0.0000
At most 1[a]	0.222818	9.326994	3.841466	0.0023

Trace test indicates 2 cointegrating eqn(s) at the 0.05 level
Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
[a]denotes rejection of the hypothesis at the 0.05 level
[b]MacKinnon-Haug-Michelis (1999) p-values

2012–13 and following the techniques explained in Enders (2004). In Dickey Fuller Unit Root Test the series of growth rate of net capital formation for agriculture in public sector (GR_N_CAP_PUB), growth rate of production of foodgrains (GR_PROD_F), growth rate of net irrigated area (N_IRRI_A) and growth rate of fertilizer use (GR_FERT) are found stationary at level.

Table 5.4 Cointegration between growth rate of net capital for agriculture in the public sector (GR_N_CAP_PUB) and growth rate of net irrigated area (GR_IRRI_A) in India

Johansen cointegration test				
Sample (adjusted): 1974–2008				
Included observations: 35 after adjustments				
Trend assumption: Linear deterministic trend				
Series: GR_IRRI_A GR_N_CAP_PUB				
Lags interval (in first differences): 1–1				
Unrestricted cointegration rank test (trace)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.[b]
None[a]	0.543004	36.08706	15.49471	0.0000
At most 1[a]	0.219624	8.679267	3.841466	0.0032
Unrestricted cointegration rank test (Maximum Eigenvalue)				
Hypothesized no. of CE (s)	Eigenvalue	Max-Eigen statistic	0.05 critical value	Prob.[b]
None[a]	0.543004	27.40779	14.26460	0.0000
At most 1[a]	0.219624	8.679267	3.841466	0.0032

Trace test indicates 2 cointegrating eqn(s) at the 0.05 level
Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
[a]denotes rejection of the hypothesis at the 0.05 level
[b]MacKinnon-Haug-Michelis (1999) p-values

In Johansen Cointegration Test the variables GR_PROD_F and GR_N_CAP_PUB are found to be cointegrated (see Table 5.3). That means, there is long run relationship between them. Net capital formation for agriculture in the public sector (N_CAP_PUB) has declined in India from late 1980s and it has exerted negative impact on the use of fertilizer use, irrigation and overall production of foodgrains in the country. Since public investment in agriculture influences fertilizer use and irrigation, in Johansen Cointegration Test, GR_N_CAP_PUB is found to be cointegration with GR_IRRI-A and GR_FERT (see Tables 5.4 and 5.5) implying that there is long term relationship between public investment, irrigation and fertilizer use. Since the variables are cointegrated, the OLS estimates among them will give efficient estimates. In Table 5.6, the coefficient of the regression of GR_FERT on GR_N_CAP_PUB is negative and statistically significant. It means that the declining growth rate of public investment has exerted a negative impact on fertilizer use. As a result of decline of public investment, growth rate of fertilizer use per hectare has declined from 7.64 % in 1971–95 to 3.67 % in 1990–2013. Similarly, growth rate of irrigated area has declined from 2.18 to 1.28 % during this period. The annual average growth rate of foodgrains production has declined from 2.80 % in 1971–90 to 1.53 % in the period 1991–2012. (Source: Economic survey, Government of India, various issues; Centre for Monitoring Indian Economy 2010; Ministry of Agriculture, Government of India 2015a, b).

Table 5.5 Cointegration between growth rate of net capital formation for agriculture in public sector (GR_N_CAP_PUB) and growth rate of fertilizer use (GR_FERT) in India

Johansen cointegration test				
Sample (adjusted): 1974–2010				
Included observations: 37 after adjustments				
Trend assumption: Linear deterministic trend				
Series: GR_FERT GR_N_CAP_PUB				
Lags interval (in first differences): 1–1				
Unrestricted cointegration rank test (trace)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.[b]
None[a]	0.355048	27.92840	15.49471	0.0004
At most 1[a]	0.271117	11.70097	3.841466	0.0006
Unrestricted cointegration rank test (maximum Eigenvalue)				
Hypothesized no. of CE (s)	Eigenvalue	Max-Eigen statistic	0.05 critical value	Prob.[b]
None[a]	0.355048	16.22743	14.26460	0.0242
At most 1[a]	0.271117	11.70097	3.841466	0.0006

Trace test indicates 2 cointegrating eqn(s) at the 0.05 level
Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
[a] denotes rejection of the hypothesis at the 0.05 level
[b] MacKinnon-Haug-Michelis (1999) p-values

Table 5.6 OLS regression of GR_FERT on GR_N_CAP_PUB

Dependent variable: GR_FERT				
Method: Least squares				
Sample (adjusted): 1972–2010				
Included observations: 39 after adjustments				
Variable	Coefficient	Std. error	*t*-statistic	Prob.
GR_N_CAP_PUB	−0.119765	0.051843	−2.310709	0.0265
C	6.074823	1.109831	5.473647	0.000
R-squared	0.126109			
F-statistic	5.339375			

5.3.5 Summary

From theoretical and empirical results of this section, it is established that net capital formation for agriculture in the public sector in India has declined from late 1980s. This has adversely affected expansion of irrigation and fertilizer use in the country. In effect, foodgrains production could not increase significantly. The results of time series analysis show that there is long run meaningful relationship between net public investment, irrigation, fertilizer use and overall production of foodgrains.

5.4 Food Price, Food Security and the Poor[2]

5.4.1 Introduction

India is experiencing high rate of food price inflation in the recent years. The prices of food articles has started increasing from the time of economic liberalization in 1990s. In the last few years, the food price inflation has been very acute. The food price inflation in India has been analysed in this section. The analysis largely draws from Sasmal (2015b). From January 2008 to July 2010, the food price inflation rate year-on-year basis was recorded 10.20 % (Nair and Eapen 2012). From October 2009 to March 2010 food price inflation announced every week hovered around 20 % (Basu 2011). This price rise has been explained in different ways by different scholars (Gulati and Saini 2013; Basu 2011; Nair and Eapen 2012). In some studies, food price inflation in India has been cited as the effect of high prices in the international market. Robles (2011) and Carrasco and Mukhopadhyay (2012) state that there is evidence of positive transmission of high international prices into the domestic agricultural markets of Asian and Latin American countries. Baltzer (2013) however, observes that all countries are not equally hit by global food crisis. Although the link between international market and domestic prices in some countries is very close, the price pass-through from international to domestic market in China and India is almost nil. The level of transmission of international prices to domestic prices largely depends on a country's dependence on imports of food items. But India's dependence on the imports of agricultural products is not high except certain specific items. In fact, India is a net exporter of foodgrains for the last 30 years although India's dependence on the import of edible oils, pulses, petroleum and petro products including fertilizers is very high. Apart from the effects of high prices in the international market, the intervention of the government into the food market through procurement and public distribution is also important for stabilization of agricultural prices. A sizeable amount of buffer stock of foodgrains is maintained in India to keep food prices under control in the event of crop failure and shortage in supply. But Basu (2011) shows that, the release of foodgrains was inadequate in the time of price rise although the food reserve in the country was above normal limit.

Like the price of any other commodity, food price also is determined by demand and supply in the market. However, market imperfection can create temporary distortion in the functioning of the market and influence price by controlling supply. A typical agricultural marketing channel is: Farmer → Local Assembler → Central Wholesaler → Retailer → Consumer. The retail prices are determined nearly in an atmosphere of perfectly competitive market. The wholesale market, however, is dominated by few traders who act as oligopolists and oligopsonists at the bottleneck

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[2] This section draws largely from J. Sasmal (2015a, b) 'Food price inflation in India: The growing economy with sluggish agriculture', Journal of Economics, Finance and Administrative Science, Elsevier, 20(38): 30–40.

of the marketing process (Nicholls 1955). It needs to be noted here that market imperfection can influence the price temporarily but price rise can not be sustained for a long period if there is no real shortage. There may be some seasonal variations in the prices of agricultural commodities. According to Sarkar (1993), prices are low in harvest season and high in lean season. Therefore, it is finally the supply and demand which play the most important role in the determination of agricultural price. The supply is related to agricultural production. If production and supply fail to keep pace with growing demand, there will be mismatch between demand and supply leading to price rise. This has actually happened in India in the recent time. Foodgrains production in India has increased at an annual rate of less than 2 % during the last 20 years and the growth rate has remained low due to various reasons like resource degradation, decline in public investment and technological stagnation (Sasmal 2012; Bhullar and Sidhu 2006; Mani et al. 2011). But the demand for food items is increasing at a very high rate following a steady increase in per capita income. The GDP in India has increased at an annual rate of 6–8 % in the period of economic liberalization. Higher disposable income has not only significantly increased the overall demand for agricultural commodities but also changed the pattern of consumption. Gulati and Saini (2013) have shown that the pressure on prices is more on protein foods like pulses, milk and milk products, egg, fish and meat and vegetables. This indicates a shift in consumption pattern from cereal based diets to protein based diets due to rise in income. There has been nearly threefold increase of per capita income (at constant prices) in India in the last two decades and poverty has declined from 45 % in 1993–94 to 22 % in 2011–12 (Source: Planning Commission, Government of India 2013; Economic survey, 2013–14, Government of India). The overall demand has been further magnified by huge public expenditure of the government on various welfare schemes like rural employment, poverty alleviation, subsidies, pension and various allowances. A lion's share of this expenditure is spent on unproductive and less productive heads This has increased demand significantly without making much addition to aggregate supply. Naturally, an imbalance arises between the growing demand and the actual production. The supply response studies in agriculture explain that just increase in price can not raise production. Adequate infrastructure, proper technology and various supporting factors are needed for increasing production (Nerlove 1958; Schultz 1964; Mellor 1966; Rajkrishna 1963; Narain 1965; Feder, 1980). Many of these facilities are of public good nature and they need to be provided by the government. But the government has failed to provide these things. Actually, net public investment in agriculture has declined in India in the recent past (Mani et al. 2011).

In this section, we like to analyse the nature and magnitude of food price inflation in India in the last two decades. The main objective of this study will be to investigate into the factors responsible for this price rise. The probable factors responsible for price rise of foodgrains in India are high rate of GDP growth, low rate of growth in foodgrains production, increase in public expenditure and money supply. Here, our endeavor will be to see, both theoretically and empirically, which of these factors are really responsible for food price inflation in India.

5.4.2 Agricultural Price in a Two-Sector General Equilibrium Model—A Theoretical Framework

Agricultural prices exhibit sharp fluctuations over time compared to non-agricultural prices because in agriculture supply can not immediately adjust itself with the changes in demand. The elasticity of demand for most of the agricultural commodities is very low. As a result, a small change in supply with demand remaining constant or a small change in demand with supply remaining unchanged causes a large change in price.

A theoretical framework for explaining food price inflation in a two-sector general equilibrium framework has been constructed here using the model of Sasmal (2015b). The model has been developed using the structure of specific factor model of international trade developed by Jones (1971) and Jones and Marjit (2003). We have considered an economy with two production sectors—Agriculture and Non-Agriculture. For simplicity, it is assumed that agricultural sector produces only foodgrains and the production of foodgrains is denoted by F. The production of the Non-Agricultural sector is denoted by N. The production of F depends on Land (Z) and Labour (L) along with other factors like soil fertility, irrigation, public investment, technology and variable inputs which are assumed to be constant. The supply of land is fixed and it is specific to agriculture. On the other hand, the production of N depends on Capital (K), Labour (L) and a set of parameters consisting of technology, infrastructure, human skill and so on. K is fixed and specific to N. L is mobile between sectors and it is used in the production of both F and N.

The production functions of the two commodities are:

$$F = F(Z, L) \tag{5.44}$$

$$N = N(K, L) \tag{5.45}$$

The production functions follow constant returns to scale with diminishing returns. If more labour (L) is used with the fixed amount of land (Z) there will be diminishing returns in the production of F. The same is true for N.

There is full employment of factors.

$$a_{Z_F} \cdot F = \overline{Z} \tag{5.46}$$

$$a_{K_N} \cdot N = \overline{K} \tag{5.47}$$

where a_{Z_F} and a_{K_N} are per unit requirements of Z and K in the production of F and N respectively.

The prices of F and N are P_F and P_N respectively and in competitive market equilibrium the prices are:

$$W \cdot a_{L_F} + R \cdot a_{Z_F} \tag{5.48}$$

$$W \cdot a_{L_N} + r \cdot a_{K_N} \tag{5.49}$$

where, *W*, *R* and *r* are wage rate for labour, rental on land and rental on capital respectively. Labour is allocated between the two sectors following the condition

$$VMP_L^F = VMP_L^N$$

where VMP_L^F *and* VMP_L^N are value of marginal product of labour in the production in food and non-food respectively.

Here, P_N is numeriere and $P = \frac{P_F}{P_N}$ is relative price of *F* and $P_Y/P_Y = 1$.

The optimal allocation of labour between the two sectors and equilibrium wage rate are determined in Fig. 5.5.

The productions of *F* and *N* are determined as

$$\begin{aligned} F &= F(Z, L_F) \\ N &= N(K, L_N) \\ \text{and } \overline{L} &= L_F + L_N \text{ (full-employment)} \end{aligned}$$

If *P* rises L_F increases and this leads to increase in production of *F*. So, the relative supply of *F* $(F/N)^S$ is an increasing function *P*.

The total income of the economy is *P.F* + N and fraction *α* of this income is spent on *F* i.e.

$$\alpha(P \cdot F + N) = P \cdot F \tag{5.50}$$

where α is the fraction of income.

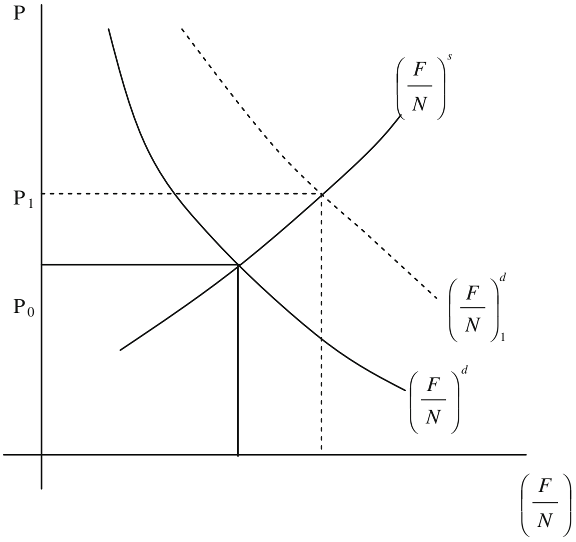


Fig. 5.6 Determination of equilibrium price (P)

After rearrangement, we get

$$P = \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{N}{F}\right)^{d} \tag{5.51}$$

Here, the relative demand for F, $\left(\frac{F}{N}\right)^{d}$ inversely varies with P. We assume that demand is homothetic implying that the two goods will be consumed at a constant ratio at all levels of income. The equilibrium P is determined in Fig. 5.6. $\left(\frac{F}{N}\right)^{d}$ and $\left(\frac{F}{N}\right)^{S}$ curves may shift due to change in external factors and as a result, price may change. In Fig. 5.6, as relative demand for F rises, the relative price of F increased from P_0 to P_1.

Let us now introduce money supply into the system and determine the nominal price of F (P_F). Suppose, there is a given supply of money denoted by $\overline{M}$. The velocity of circulation of money is also given and it is $\frac{1}{v}$. So, in equilibrium in the money market, we have

$$\overline{M} = v[P_F \cdot F + P_N \cdot N] \tag{5.52}$$

The Eq. (5.52) can be expressed as

$$\overline{M} = v\left[P_F \cdot F + \frac{P_N}{P_F} P_F \cdot Y\right]$$

It is further simplified to

$$\overline{M} = vP_F\left[F + \frac{1}{P} N\right]$$

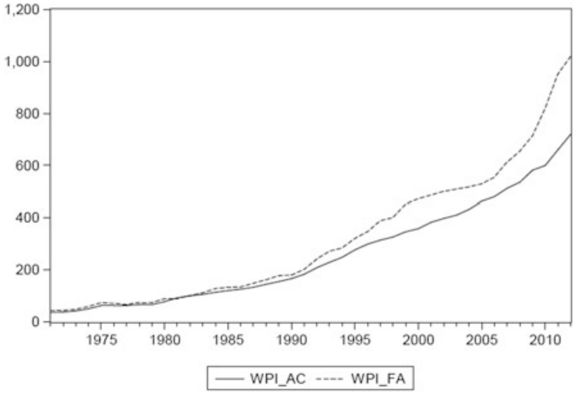


Fig. 5.7 Trend of wholesale price index for all csommodities (WPI_AC), food articles (WPI_FA) with base year 1981–82 = 100

and

$$P_F = \frac{\overline{M}}{v}\left[\frac{1}{F + \frac{1}{P}N}\right] \tag{5.53}$$

Here, P_F is determined in terms of F, N, M and P. P_F is directly related to relative price, P and inversely related to F. On the other hand, money supply has positive effect on P_F. Given money supply if F declines, P rises.

Following Jones (1965), let us now consider the relative change in F, N, P and M as $\hat{F} = \frac{dF}{F}, \hat{N} = \frac{dN}{N}, \hat{P} = \frac{dP}{P}$.

The change in Relative Supply of F is:

$$\left(\hat{F} - \hat{N}\right)^S = \gamma\hat{P} + \gamma_S \tag{5.54}$$

The change in Relative demand for F is:

$$\left(\hat{F} - \hat{N}\right)^d = -\beta\hat{P} + \beta_d \tag{5.55}$$

where γ is elasticity of relative supply with respect to P and β is elasticity of relative demand with respect to P. γ_S and β_d are elasticity of relative supply and elasticity of relative demand respectively with respect to external factors. γ_S and β_d depend on the factors other than price. These factors may be technology, public investment, income, preference, crop failure, external effects which are taken as parameters in the model.

In equilibrium,

$$\left(\hat{F} - \hat{N}\right)^S = \left(\hat{F} - \hat{N}\right)^d \tag{5.56}$$

The Eq. (5.56) can be solved as

$$\gamma\hat{P} + \gamma_S = -\beta\hat{P} + \beta d$$

and

$$\hat{P} = \frac{\beta_d - \gamma_S}{\gamma + \beta} \tag{5.57}$$

The elasticities of both supply and demand of food items w.r.t. price are low. So, the values of γ and β are low. Here $(\gamma + \beta)$ is positive. Now, if γ_S remains low and β_d becomes high, $(\beta_d - \beta_S)$ will be positive making $\hat{P}$ positive. That means, if relative supply of F is less elastic w.r.t. external factors and relative demand is more elastic, the relative price of F will increase.

In other words, if $(\gamma + \beta)$ is low and $(\beta_d - \gamma_S)$ is positive and high, $\hat{P}$ will be positive implying that relative price of foodgrains increases. γ and β are low by nature. γ_S may be low due to lack of irrigation, decline of public investment, technological backwardness etc. On the other hand, β_d may be high due to higher per capita income, change of preference and external factors like public expenditure, export demand etc.

Equations (5.53) and (5.57) have very good implications for analyzing food price inflation in Indian context. In Eq. (5.53), P_F is in direct relation with money supply. Other things remaining unchanged, if money supply increases, food price will increase and this is in line with inflation caused by money supply. β_d is highly positive in a growing economy. The demand is triggered by increase in income, export demand, government purchase and so on. On the other hand, γ_S remains low due to lack of public investment, technological stagnation, resource degradation etc. As a whole $(\beta_d - \gamma_S)$ is likely to be highly positive with the result that the increase in price $(\hat{P})$ is very high.

5.4.3 Empirical Evidences and Econometric Results

This section gives the nature, trend and magnitude of food price inflation in India in the last four decades and makes econometric analyses using Time Series techniques to provide explanations for the food price inflation in the country. Table 5.7 and Fig. 5.7 show that food inflation was moderate in India up to 1990 but the price index of food articles started rising sharply from mid-nineties and from 2005 onward the prices have remained strikingly high. It is indicated in Fig. 5.7 that increase of wholesale price index for food articles (WPI_FA) was higher than the general inflation denoted by the wholesale price index for all commodities (WPI_AC). While wholesale price index for all commodities (base 1981–82 = 100) has reached 719.16 in 2011–12, the index for food articles has risen to 1019.16 in the same period (see Table 5.7 and Fig. 5.7). It indicates that while general price level has increased more than seven times, the increase of prices of food articles is more than 10 times in the same period.

Table 5.8 shows the annual growth rates of wholesale price index for food articles (GR_WPI_FA), production of foodgrains (GR_Prod_Food), per capita NNP at constant prices (GR_NNP_CP) and public expenditure of the central and state governments (GR_EXP_CS). It indicates that annual price rise of food articles ranges from 6 to 16 % for most of the time and prices remained continuously high over the period from 2005 to 2011. The annual growth rate of foodgrains productions exhibits sharp fluctuations and in some years the growth rate has been been highly negative. In contrast, growth rate of per capita NNP (at constant prices)

Table 5.7 Wholesale price index for all commodities (WPI_AC), and food articles (WPI_FA) in India with base year 1981–82 = 100[a]

Year	WPI_AC	WPI_FA
1971	35.59	42.55
1972	37.37	42.98
1973	41.28	47.23
1974	49.47	58.30
1975	61.92	73.19
1976	61.57	69.79
1977	62.63	65.96
1978	65.84	74.04
1979	65.84	73.19
1980	77.22	88.51
1981	91.46	88.51
1982	100.00	100.00
1983	104.90	111.00
1984	112.80	127.00
1985	120.10	132.00
1986	125.40	134.00
1987	132.70	148.00
1988	143.50	161.00
1989	154.20	177.00
1990	165.70	179.00
1991	182.70	201.00
1992	207.80	241.00
1993	228.70	271.00
1994	247.80	284.00
1995	276.64	320.92
1996	298.87	346.48
1997	313.69	389.08
1998	326.04	400.44
1999	345.80	451.56
2000	358.15	471.44
2001	382.85	485.64
2002	397.67	499.84
2003	410.02	508.36
2004	432.25	516.88
2005	461.89	528.24
2006	479.44	554.40
2007	511.71	612.48
2008	534.76	654.72

(continued)

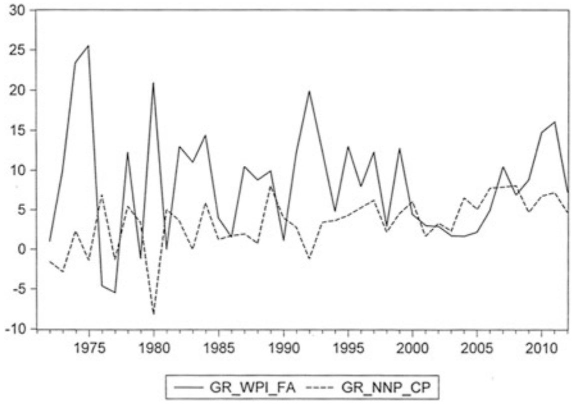
Table 5.7 (continued)

Year	WPI_AC	WPI_FA
2009	580.86	712.80
2010	599.30	818.40
2011	659.23	950.40
2012	719.16	1019.04

Source Economic survey of India, 2012–13, Government of India and Hand Book of Statistics on the Indian Economy, Reserve Bank of India (2010)

[a]Financial year 1981–82 has been mentioned as 1982 and other years have been mentioned in the same way

Fig. 5.8 Growth rates of wholesale price index for food articles (GR_WPI_FA) and per capital NNP at constant prices (GR_NNP_CP)



has remained consistently positive and sufficiently high throughout the period since 1993. The growth rate of public expenditure of the central and state governments taken together is very high for the entire period.[3]

The information in Table 5.9 are very revealing. The figures show that the growth rates in production of cereal and non-cereal agricultural items are much lower than the growth rate of per capita NNP (at constant prices). While the per capita NNP has increased by 165 % during the period from 1990–91 to 2011–12, the growth rates of foodgrains, cereal, pulses and oilseeds are found to be much lower than the growth rate of per capita NNP.

Figure 5.7 shows that food price inflation has been greater than general price inflation. Figures 5.8 and 5.9 shows fluctuations in growth rates of whole price index for food articles, production of foodgrains, per capita NNP and public expenditures of the central and state governments. These give some ideas about the direction of their movements.

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[3] Since same data source has been used, many of the information in this section are also in Sasmal (2015a).

Table 5.8 Annual growth rates of wholesale price index of food articles (GR_WPI_FA), production of foodgrains (GR_PROD_FOOD), per capita NNP at constant price (GR_PC_NNP) and expenditure of central and state governments (combined) at current prices (GR_EXP_CS)

Year[a]	GR_WPI_FA	GR_Prod_Food	GR_PC_NNP	GR_EXP_CS
1972	1.00	−3.00	−1.61	20.97
1973	9.85	−7.74	−2.88	15.88
1974	23.42	7.87	2.31	8.65
1975	25.55	−4.62	−1.37	12.79
1976	−4.65	21.24	6.92	22.16
1977	−5.49	−8.15	−1.30	12.52
1978	12.26	13.71	5.46	12.82
1979	−1.15	4.34	3.38	19.78
1980	20.93	−16.83	−8.19	7.05
1981	12.98	18.13	5.01	23.18
1982	11.00	2.86	3.54	11.01
1983	14.41	−2.84	−0.02	18.04
1984	3.94	17.64	5.89	16.03
1985	1.52	−4.48	1.25	20.87
1986	10.45	3.37	1.73	16.82
1987	8.78	−4.67	1.93	17.60
1988	9.94	−2.14	0.72	11.71
1989	1.13	21.07	8.06	14.09
1990	12.29	0.66	3.94	11.86
1991	19.90	3.13	2.75	13.69
1992	12.45	−4.54	−1.21	9.22
1993	4.80	6.59	3.43	14.58
1994	13.00	2.66	3.67	17.29
1995	7.96	3.93	4.31	11.25
1996	12.30	−5.79	5.30	13.16
1997	2.92	10.54	6.23	12.15
1998	12.77	−3.16	2.20	20.41
1999	4.40	5.43	4.59	16.48
2000	3.01	3.04	5.59	10.21
2001	2.92	−6.19	1.85	9.63
2002	1.70	8.15	3.45	7.95
2003	1.68	−17.89	2.42	12.98
2004	2.20	21.98	6.63	9.21
2005	4.95	−6.96	4.95	10.36
2006	10.48	5.16	7.75	15.56
2007	6.90	4.17	7.89	18.58

(continued)

Table 5.8 (continued)

Year[a]	GR_WPI_FA	GR_Prod_Food	GR_PC_NNP	GR_EXP_CS
2008	8.87	6.21	8.07	21.62
2009	14.81	1.60	4.69	15.78
2010	16.13	−6.98	6.58	15.82
2011	7.22	12.23	6.35	17.42
2012	1.08	5.17	5.16	12.59

Source Calculated from the data in Economics Survey, 2012–13, Government of India and Hand Book of Statistics on the Indian Economy, Reserve Bank of India (2010)

[a] Financial year 1971–72 has expressed as 1972. The other years also have been mentioned in the same way

Table 5.9 Growth rates of per capita NNP (at constant prices), production of foodgrains and some important agricultural commodities in India over the years

Agricultural products	Growth during the period from 1970–71 to 1990–91 (%)	Growth during the period from 1990–91 to 2011–12 (%)
Foodgrains	63	42
Cereals	103	22
Pulses	21	20
Oilseeds	94	61
Potato	217	206
Milk	145	137
Egg (number in million)	242	215
Per capita NNP (at constant prices) (Rupees)	43	165

Source Compiled from Economic survey, 2012–13, Government of India

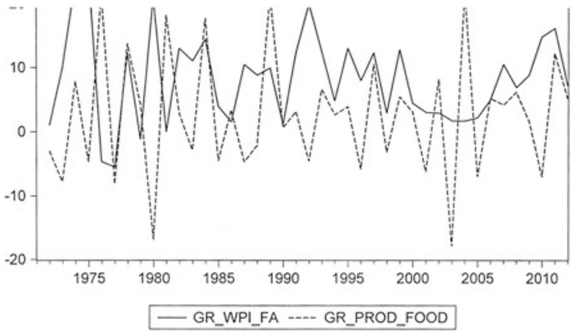

Fig. 5.9 Growth rates of whole price index for food articles (GR_WPI_FA) and production of foodgrains (GR_PROD_FOOD)

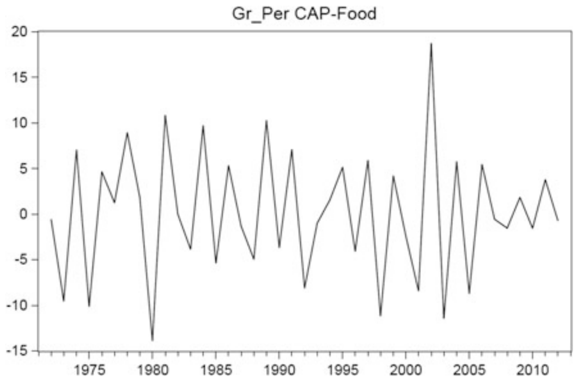

Fig. 5.10 Growth rate of per capita availability of foodgrains in India during the period from 1970–71 to 2011–12. *Source* Based on data, Economic survey 2013–14, Government of India (2014a, b)

5.4.4 Time Series Analysis

The stationarity of the series WPI_FA, GR_WPI_FA, PC_NNP_CP, growth rate of production of foodgrains (GR_PROD_FOOD), growth rate of public expenditure (GR_EXP_CS) and growth rate of money supply (GR_MS3_BN) have been checked by using Augmented Dickey-Fuller Test. The results show that WPI_FA and PC_NNP_CP are stationary at 2nd difference (see Table 5.10). In Johansen Cointegration Test WPI_FA and PC_NNP_CP are found to be cointegrated of the same order i.e., C(2,2) and in Granger Causality Test, the result shows that PC_NNP_CP causes WPI_FA (see Tables 5.11 and 5.12). This is a very significant result of this study. It establishes that there is meaningful long-run relationship

Table 5.10 Augmented Dickey-Fuller unit root test on D(WPI_FA, 2) and D (PC_NNP_CP, 2)

		t-statistic	Prob.*
Null hypothesis: D(WPI_FA, 2) has a unit root			
Exogenous: Constant			
Lag Length: 0 (automatic-based on SIC, maxlag = 9)			
Augmented Dickey-Fuller test statistic		−7.665442	0.0000
Test critical values:	1 % level	−3.610453	
	5 % level	−2.938987	
	10 % level	−2.607932	
Null hypothesis: D(PC_NNP_CP, 2) has a unit root			
Exogenous: Constant			
Lag length: 0 (automatic-based on SIC, maxlag = 9)			
Augmented Dickey-Fuller test statistic		−10.95341	0.0000
Test critical values:	1 % level	−3.610453	
	5 % level	−2.938987	
	10 % level	−2.607932	

*MacKinnon (1996) one-sided p-values

Table 5.11 Johansen cointegration test between WPI_FA and PC_NNP_CP

Sample (adjusted): 1973–2012				
Included observations: 40 after adjustments				
Trend assumption: Linear deterministic trend				
Series: WPI_FA PC_NNP_CP				
Lags interval (in first differences): 1–1				
Unrestricted cointegration rank test (trace)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.[b]
None[a]	0.482207	31.10806	15.49471	0.0001
At most 1[a]	0.112655	4.780847	3.841466	0.0288
Unrestricted cointegration rank test (Maximum Eigenvalue)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.[b]
None[a]	0.482207	26.32722	14.26460	0.0004
At most 1[a]	0.112655	4.780847	3.841466	0.0288

Trace test indicates 2 cointegrating eqn(s) at the 0.05 level
Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
[a]denotes rejection of the hypothesis at the 0.05 level
[b]MacKinnon-Haug-Michelis (1999) p-values

Table 5.12 Pairwise Granger causality tests

Null hypothesis	Obs	F-statistic	Prob.
PC_NNP_CP does not Granger cause WPI_FA	40	7.64831	0.0018
WPI_FA does not Granger cause PC_NNP_CP		0.19227	0.8259

between PC_NNP_CP and WPI_FA and increase in per capita income is an important cause of price rise of food articles in the long-run. Furthermore if variables are cointegrated of the same order the OLS regression will give efficient estimates. In Table 5.13, OLS regression results show that coefficient of PC_NNP_CP is positive and highly significant implying that increase in per capita NNP is an important cause food price inflation in India.

Table 5.13 OLS regression of WPI_FA on PC_NNP_CP

Dependent variable: WPI_FA				
Sample: 1971–2012				
Included observations: 42				
Variable	Coefficient	Std. Error	*t*-statistic	Prob.
PC_NNP_CP	0.032431	0.000800	40.55098	0.0000
C	−242.8709	15.12902	−16.05332	0.0000
R-squared	0.976252		Mean dependent var	315.0327
Adjusted R-squared	0.975659		S.D. dependent var	261.4047
F-statistic	1644.382		Durbin-Watson stat	0.256021

Table 5.14 Engle-Granger cointegration test between GR_WPI_FA and GR_PROD_FOOD

Series: GR_WPI_FA GR_PROD_FOOD				
Sample (adjusted): 1972–2012				
Included observations: 41				
Null hypothesis: Series are not cointegrated				
Automatic lags specification based on Schwarz criterion (max lag = 9)				
Dependent	Tau-statistic	Prob.*	Z-statistic	Prob.*
GR_WPI_FA	−6.0912	0.000	−38.4292	0.000
GR_PROD_FOOD	−12.1448	0.000	−63.0771	0.000

*MacKinnon (1996) p-values

Table 5.15 Engle-Granger cointegration test between GR_WPI_FA and GR_EXP_CS

Series: GR_WPI_FA GR_EXP_CS				
Sample (adjusted): 1972–2012				
Included observations: 41				
Null hypothesis: Series are not cointegrated				
Automatic lags specification based on Schwarz criterion (max lag = 9)				
Dependent	Tau-statistic	Prob.*	Z-statistic	Prob.*
GR_WPI_FA	−5.0687	0.001	−31.9728	0.000
GR_EXP_CS	−6.1211	0.000	−38.5265	0.000

*MacKinnon (1996) p-values

The growth rate of foodgrains production (GR_PROD_FOOD) and the growth rate of wholesale prices of food articles (GR_WPI_FA) are stationary at level in Augmented Dickey-Fuller (ADF) Test and they are cointegrated in Engle-Granger Cointegration Test (see Tables 5.14 and 5.16). There is negative relationship between GR_PROD_FOOD and GR_WPI_FA in OLS Regression (Sasmal 2015a, b) . The significance of this result is that if supply of foodgrains declines due to crop failure or any other reasons, price will rise. India has experienced high rate of GDP growth in the post-liberalisation period, the annual growth rate remaining 6–8 %. This has created significant increase in demand in the market. On the other hand, the growth rate of foodgrains production in India has remained very low from 1990s. It was less than 2 % per annum. The service sector growth has been very high and it is around 10–12 % per annum. This sectoral imbalance in growth has created mismatch between demand and supply in the agricultural market. The inevitable consequence has been the continuous increase in price level of foodgrains (see Fig. 5.10).

The other two important factors which have caused increase in demand and price rise are growth in public expenditure of the central and state governments (GR_EXP_CS) and increase in money supply (GR_MS3_BN). GR_EXP_CS, GR_MS3_BN and GR_WPI_FA are stationary at level in ADF Test and

Table 5.16 Augmented Dickey-Fuller unit root test on GR_WPI_FA, GR_PROD_FOOD, GR_EXP_CS and growth rate of money supply (GR_MS3_BN)

		t-statistic	Prob.*
Null hypothesis: GR_WPI_FA has a unit root			
Exogenous: Constant			
Lag length: 0 (automatic-based on SIC, max lag = 9)			
Augmented Dickey-Fuller test statistics		−5.370715	0.0001
Test critical values	1 % level	−3.605593	
	5 % level	−2.936942	
	10 % level	−2.606857	
Null hypothesis: GR_PROD_FOOD has a unit root.			
Exogenous: Constant			
Lag length: 0 (automatic-based on SIC, max lag = 9)			
Augmented Dickey-Fuller test statistics		−12.01695	0.0000
Test critical values	1 % level	−3.605593	
	5 % level	−2.936942	
	10 % level	−2.606857	
Null hypothesis: GR_EXP_CS has a unit root.			
Exogenous: Constant			
Lag length: 0 (Automatic-based on SIC, max lag = 9)			
Augmented Dickey-Fuller test statistics		−6.457376	0.0000
Test critical values	1 % level	−3.605593	
	5 % level	−2.936942	
	10 % level	−2.606857	
Null hypothesis: GR_MS3_BN has a unit root.			
Exogenous: Constant			
Lag length: 0 (automatic-based on SIC, max lag = 9)			
Augmented Dickey-Fuller test statistics		−4.427031	0.0011
Test critical values	1 % level	−3.610453	
	5 % level	−2.938987	
	10 % level	−2.607932	

*Mackinnon (1996) one-sided p-values

GR_WPI_FA and GR_EXP_CS are found to be cointegrated in Johansen Test (see Tables 5.15 and 5.16). That means, there is meaningful long run relationship between public expenditure and agricultural prices although we have found no causality between them. We have found similar results between GR_WPI_FA and GR_MS3_BN (see Tables 5.16 and 5.17). That means, there is meaningful relationship between them in the long run.

It is clear from the above results, both theoretical and empirical that the growth of per capita NNP significantly explains the food price inflation in India. The sluggishness of agricultural production also accounts for the price rise to a great extent. The market imperfection and government intervention do not seem to have

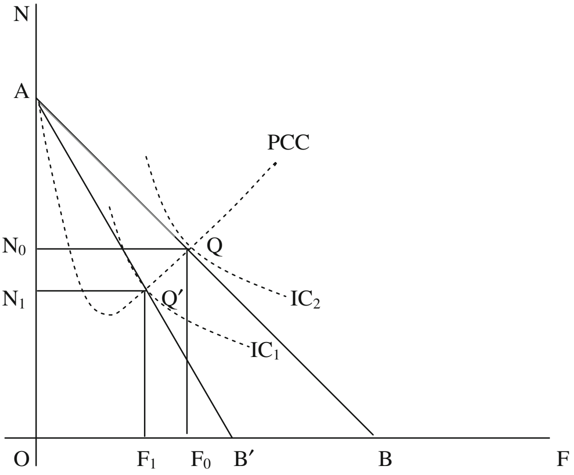

Fig. 5.11 Consumer's equilibrium and the effect of increase of food price

Table 5.17 Johansen cointegration test between GR_WPI_FA and GR_MS3_BN

Sample (adjusted): 1974–2012				
Included observations: 39				
Trend assumption: Linear deterministic trend				
Series: GR_WPI_FA GR_MS3_BN				
Lags interval (in first difference): 1–1				
Unrestricted cointegration rank test (trace)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.[b]
None[a]	0.4684	31.6968	15.4947	0.001
At most 1[a]	0.1653	7.0489	3.8414	0.007
Unrestricted cointegration rank test (Maximum Eigenvalue)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.[b]
None[a]	0.4644	24.3570	14.26461	0.000
At most 1[a]	0.3352	7.9231	3.8414	0.009

Trace test indicates 2 cointegrating equations at the 0.05 level
Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
[a] denotes rejection of the hypothesis at the 0.05 level
[b] MacKinnon-Haug-Michelis (1999) p-values

much influence on food prices in the long run. However, the effects of growing public expenditure and increase in money supply are found to have some effects on agricultural price although the results are not very robust. The effect of increase of income on the prices of food articles needs further elaboration. In a country like India where income of a large section of the population is low, with increase in income demand for foodgrains will significantly increase. What is more interesting is that income elasticity of demand for high protein and high value products like pulses, vegetables, edible oils, fruits, meat and fish and milk is very high. So, if income rises, demand for these goods will significantly increase leading to overall increase of price index for food articles.

The sectoral imbalance in GDP growth has serious consequences on the whole economy. Ray (2010) provides a framework for research in development economics in the context of uneven growth. India has achieved high rate of overall growth in the post-liberalization period. The service sector is growing at the rate of 10–12 % per annum against less than 2 % growth of the agricultural sector. The government has remained complacent with overall GDP growth and less attention has been given to the production sector. Specially agricultural sector has been grossly neglected by the government in the recent past. Overall growth and private investment in agriculture are conditional on public investment. Mani et al. (2011) have shown that real public investment in agriculture in India (in billion Rupees) has declined from 104.96 in the period from 1979–80 to 1981–82 to 37.15 in 1999–2000. The net capital formation in agriculture in the public sector (at 2004–05 prices) has declined at the rate of 0.70 % per annum over the period from 1988 to 2003 and at the rate of 0.16 % per annum from 2004 to 2010 (Source: National Accounts Statistics, CSO, Government of India 2011, 2012a, b). Due to lack of sufficient public investment, agricultural production could not grow proportionately with increase in demand. On the other hand, the increasing public expenditure of the Central and State governments has further increased demand for food articles. The expenditure has increased at a rate of 10–20 % per annum. But nearly 50 % of this expenditure is spent on non-developmental purposes. More than 80 % of the total expenditure of the Central government is spent on revenue expenditure which includes salaries and wages, subsidies, pension and interest payment on loan. This huge expenditure increases demand in the market without contributing much to production.

Food price inflation has significant political implications also specially with respect to poverty and food security to the poor. It reduces purchasing power and consumption level of the poor. Pinstrup-Anderson (1985) has found that low income consumers in developing countries typically spend 60–80 % of their incomes on food and due to increase of food prices, real income decreases by 5.5 % to 9 % at the lowest decile. He has also shown that price elasticity of demand for rice for low income groups ranges from −1.23 to −4.31. Therefore, increasing food prices have serious welfare implications for the poor. The government has adopted several measures to give some relief and provide food security to the poor. The subsidy on food is one important measure of the government. The government of India allocates a big amount of subsidy on food every year and it has significantly increased in the post-reform period. In the year 2011–12, the amount of subsidy on food was Rupees 72,283 crore. This amount has been further increased to Rupees

115,000 crore in 2014–15 (Source: Union Budget, Government of India 2014a, b). But the problem is that this huge subsidy does not property reach the target groups due to corruption, lack of good governance and proper delivery mechanism.

5.4.5 Consumption of Food and the Poor

In a very simple connotation, food security means that the people get the required amounts of food and they have the necessary income to purchase the food items. If the income of a person falls short of the expenditure for basic needs, the person is treated as poor. In the analysis of poverty and food security, two factors are very important—(a) income of the consumer and (b) prices of food items. Given the prices, if income is low, the person will not be able to purchase the required amount of food. On the other hand, given income, if prices of food items increase, there will be food insecurity. The total expenditure on food depends on the amount of food-intake and the prices of food items. National Sample Survey (NSS), India, collects data on per capita consumption expenditure from time to time and on the basis of this data, poverty line and percentage of population below poverty line are calculated. Using 68th round of NSS data state-wise monthly per capita consumption expenditure has been calculated by NSS separately for rural and urban areas of the states of India for the year 2011–12. The figures have been presented in Table 5.18. Following the methodology of Suresh Tendulkar and using the NSS data poverty ratio has been estimated for the year 2011–12 (see Table 5.19).

Table 5.18 shows that average monthly per capita consumption expenditure (mpce) differs significantly across states of India and between rural and urban areas of the country. In states like Bihar, Chattisgarh, Orissa, Uttar Pradesh, Madhya Pradesh and Assam mpce is very low specially in rural areas. This is consistent with poverty estimates of the respective states. In Table 5.19, it is revealed that poverty ratio is highest in the states like Bihar, Chattisgarh, Orissa, Madhya Pradesh, Uttar Pradesh and Assam. In the fast growing state like Karnataka and highly projected state like Gujarat, mpce in rural areas is moderate and overall poverty is high. It is interesting to note that in the state of Kerala monthly per capita consumption expenditure is significantly high both in rural and urban areas and overall poverty is very low. Here, poverty is only 7.05 % against national average of nearly 22 %. According to this estimate, the total number of poor people in the country in 2011–12 is 269.78 million which is 21.92 % of the total population of the country (see Table 5.19).

The purpose of having a look at the picture of poverty in India in our discussion of food security is that 270 million people of the country are already below the poverty line and they are incapable of having the minimum amount of food at their present income levels. Now, if food prices increase further, their conditions will deteriorate and more people will come under the category of poor.

Table 5.18 Estimates of average monthly per capita Consumption Expenditure in major states of India for the year 2011–12 (Rupees)[a]

States	Rural	Urban
Andhra Pradesh	1563.21	2559.30
Arunachal Pradesh	1455.87	2241.63
Assam	1056.98	2090.18
Bihar	970.41	1396.65
Chattisgarh	904.04	1776.21
Delhi	2690.24	3160.76
Goa	2460.77	2934.87
Gujrat	1430.12	2472.49
Haryana	1925.96	3346.32
Himachal Pradesh	1800.62	3173.30
Jammu & Kashmir	1601.51	2320.28
Karnataka	1395.10	2898.94
Kerala	2355.53	3044.22
Madhya Pradesh	1024.14	1842.35
Maharashtra	1445.89	2937.06
Nagaland	1756.70	2279.42
Orissa	904.78	1830.33
Punjab	2136.39	2743.07
Rajasthan	1445.74	2528.11
Tamil Nadu	1570.61	2534.32
Tripura	1194.14	1996.66
Uttar Pradesh	1072.93	1942.25
West Bengal	1170.11	2489.89
All India	1287.17	2477.02

Source NSS Report No. KI. (68/1.0) on household consumer expenditure in India, 2011–12, NSS 68th Round

[a] Reproduced from Press Note on Poverty Estimates, 2011–12, Planning Commission, Government of India (2013)

5.4.6 The Effect of Price on Food Security—A Theoretical Exposition

Here, in this section, we will show using well-known simple theoretical framework how food price inflation causes food insecurity to the poor. The income of the poor is not only low but also remains unchanged in the short run. Now, given income if prices of food items increase, the real income of the poor declines. It is also true that lion's share of income is spent on food consumption (Pinstrup-Anderson 1985). Here, we assume that the poor people, consume both food (F) and Non-food (N) items. So, the utility function is:

Table 5.19 Number and percentage of population below poverty line in major states of India (Tendulkar methodology), 2011–12

States	% of population	No. of persons (lakh)
Andhra Pradesh	9.20	78.78
Arunachal Pradesh	34.67	4.91
Assam	31.98	101.27
Bihar	33.74	358.15
Chattisgarh	39.93	104.11
Delhi	9.91	16.96
Goa	5.09	0.75
Gujrat	16.63	102.23
Haryana	11.16	28.83
Himachal Pradesh	8.06	5.59
Jammu & Kashmir	10.35	13.27
Karnataka	20.91	129.76
Kerala	7.05	23.95
Madhya Pradesh	31.65	234.06
Maharashtra	17.35	197.92
Nagaland	18.88	3.76
Orissa	32.59	138.53
Punjab	8.26	23.18
Rajasthan	14.71	102.92
Tamil Nadu	11.28	82.63
Tripura	14.05	5.24
Uttar Pradesh	29.43	598.19
West Bengal	19.98	184.98
All India	21.92	2697.83

Source Press Note on Poverty Estimates, 2011–12, Government of India, Planning Commission, July 2013

$$U = U(F, N) \tag{5.58}$$

The prices of these two commodities are P_F and P_N respectively. The income is M. So, the budget equation is:

$$\mathrm{P_F \cdot F + P_N \cdot N = M} \tag{5.59}$$

The individual maximizes utility subject to the budget constraint in (5.45) i.e.,

$$\begin{aligned} &\text{Max}\, U(F, N) \\ &\text{s.t.} P_F \cdot F + P_N \cdot N = M \end{aligned} \tag{5.60}$$

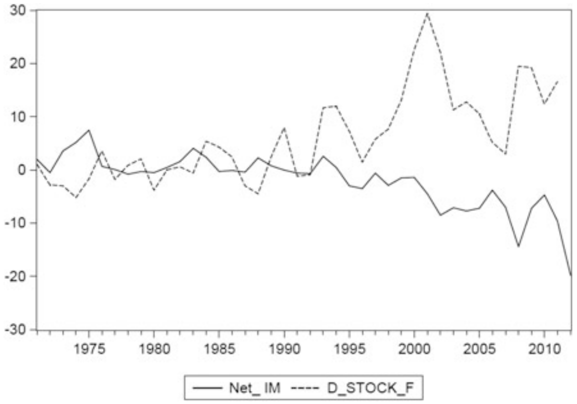

Fig. 5.12 Net import of foodgrains (Net_IM) and change in buffer stock of foodgrains (D_STOCK_F) in India. *Source* Economic Survey 2013–14, Government of India

The utility function in (5.58) gives indifference curves and the budget constraint in (5.59) gives the budget line. The graphical solution to the problem in (5.60) is obtained in Fig. 5.11.

Given M, P_F and P_N, the initial equilibrium is at Q where the individual's consumption of food is F_0. As P_F rises, the budget line swings downward from AB to AB and the equilibrium changes to the point at Q'. At the new equilibrium food consumption declines from F_0 to F_1. The consumption of non-food items also declines from N_0 to N_1. As the equilibrium takes place on a lower indifference curve, the overall welfare declines.

The demand for food is generally inelastic and in that case the price (P_F) and total expenditure on food (E) will move in same direction. The total expenditure on food is:

$$E = P_F \cdot F \tag{5.61}$$

Differentiating (5.61) w.r.t. P_F we get

$$\frac{dE}{dP_F} = F + P_F \cdot \frac{dF}{dP_F}$$

In case of inelastic demand,

$$F + P_F \cdot \frac{dF}{dP_F} \;>\; 0$$

Or,

$$P_F \cdot \frac{dF}{dP_F} \;>\; -F$$

Or,

$$\frac{dF}{dP_F} \cdot \frac{P_F}{F} \; > \; -1$$

Or, $|e_F| < 1$ where e_F is price elasticity of demand for food and it is negative. Total differentiation of the budget Eq. (5.59) gives

$$dP_F \cdot F + P_F \cdot dF + dP_N \cdot N + P_N \cdot dN = dM \tag{5.62}$$

Here, $dP_N = dM = 0$, So,

$$dP_F \cdot F + P_F \cdot dF + P_N \cdot dN = 0$$

After rearrangement, we can write

$$\left(\frac{dF}{dP_F} \cdot \frac{P_F}{F}\right) + \frac{P_N \cdot dN}{F \cdot dP_F} + 1 = 0 \tag{5.63}$$

Or,

$$e_F + \frac{P_N \cdot dN}{F \cdot dP_F} + 1 = 0 \tag{5.64}$$

In (5.64), $P_N \cdot dN$ is change in expenditure on N and $F \cdot dP_F$ is change of expenditure on $F \cdot M$ remaining constant, as P_F rises and $|e_F| < 1, F \cdot dP_F$ is positive. That is, expenditure share on food rises. Naturally, $P_N \cdot N$ is negative and $|P_N \cdot dN| < F \cdot dP_F$. So, $\left(\frac{P_N \cdot dN}{F \cdot dP_F}\right)$ is a negative fraction. The implication is that since demand for food (F) is inelastic, as price of food rises, the expenditure on food will increase but the consumption of both food and non-food items will decline. In effect, the poor will be poorer and non-poor may become poor as food price rises.

5.5 Policy Intervention and Managing the Food Economy[4]

5.5.1 *Introduction*

The production, procurement, storage and distribution, export and import of food items are very important for price stability in the economy. The government has to play a key role in agricultural growth and also for maintaining stability of food prices.

It is important for the government to ensure that the farmers get remunerative prices for their crops and consumers can buy food items at reasonable prices. Thus,

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[4] The draft version of this section titled Sasmal and Sasmal (2016).

the public policy should be such that it can protect the interests of both the farmers and the consumers. The elasticities of demand and supply of food articles are low. Naturally, a small change in demand or supply results in significant change in price. So, agricultural prices exhibit sharp fluctuations and to iron out such fluctuations, public procurement and public distribution can play an important role. In time of bad harvest or crop failure, there will be shortage in supply in the market. In that time, the government is required to release more foodgrains from buffer stock through public distribution system (PDS) and procure less to avoid price rise. Similarly, restrictions should be imposed on the export of foodgrains and import of foodgrains should be encouraged. Side by side with public distribution policy, appropriate trade policy needs to be adopted in such situations. The opposite policies should be adopted in the years of good harvest. India is experiencing high rate of food price inflation from the time of economic liberalization in 1990s. From January 2008 to June 2010, India recorded a very high rate of food price inflation (Nair and Eapen 2012). Basu (2011) shows that the release of foodgrains was inadequate during the time of recent price rise although the food reserve in the country was above normal limit. From this information it appears that it was a failure on the part of the government in managing the food economy.

In fact, the trade policy of the government is equally important for managing the food economy. Higher export and lower import reduce supply in the domestic market with the result that the prices of the food items rise. Therefore, at the time of price rise net export should not increase. After the green revolution India has become self-sufficient in foodgrains production at least in terms of existing purchasing power although there has not been any significant improvement in per capita availability of foodgrains. The net import of foodgrains on the other hand, has remained negative for most of the time after 1970–71. That means, export has exceeded the import leading to decline in domestic supply. Sasmal (2015a, b) shows that the sectoral imbalance in growth in India in the recent years is one important cause of food price inflation in the country. The overall economy is growing at a rate of 7–8 % since 1990s while food production is rising at the rate of less than 2 % per year. As a result of growing demand due to high GDP growth and sluggish agricultural production, there has been acute shortage in the food market. The inevitable consequence has been the high price rise. The higher amount of net exports has further aggravated the situation.

So far as food price inflation in India in the recent years is concerned, the growing public expenditure of the government and increase in money supply are also found to be responsible for the price rise. The point is that if public expenditure is increased it will increase aggregate demand and price in the market, if supply does not increase proportionately. Similar is the case for money supply. If money supply increases without a matching increase in supply of commodities, an inflationary situation is quite inevitable. Here also, we find the importance of the public policy with respect to monetary and fiscal policy in maintaining stability of food prices. The objective of this section is to examine how the public policies relating to procurement, public distribution and net import can affect the food price.

5.5.2 Agricultural Prices—An Analytical Framework

Like other commodities, prices of foodgrains are also determined by supply and demand in the market. The commodities reach the final consumers through a typical supply chain:

Farmer → Local Assembler → Wholesaler → Retailer → Consumer (Nicholls 1955).

The wholesale market is imperfect and it is controlled by a few traders. The wholesalers behave like oligopsonists as buyers and oligopolists as sellers. The traders exploit both the producers and consumers. The difference between the price paid by the consumers (P_c) and the price received by the producers (P_f) is called marketing margin and it is denoted by M, i.e., M = Price paid by the consumers (P_c) − Price received by the farmers (P_f).

M includes the costs of transportation, storage and packaging, wastage and the profit of the middlemen and traders. If the market is highly imperfect the profit margin of the traders will be very high and then M will be also very high. That means, the consumers will have to pay a high price although the producers will get only a fraction of it. The prices in the retail market are determined in an atmosphere of perfect competition. Here, price is determined by aggregate demand (AD) and aggregate supply (AS). The aggregate supply can be written as

$$AS = Q(P) - H + NM - PR \tag{5.65}$$

where Q (P) is production of the commodity and it is a function of price.

H is hoarding by the traders. NM is net import of the good and PR is net procurement of the government. NM is the import minus export. If export is greater than import NM will be negative. Similarly PR is government procurement minus release (distribution) through public distribution system. $Q(P)$ can be written as

$$Q = -\alpha + \beta P \tag{5.66}$$

On the other hand,

$$AD = C(P) \tag{5.67}$$

where C (P) is consumer demand and it is a function of price. C (P) can be written as

$$C = \gamma - \delta P \tag{5.68}$$

In equilibrium

$$AS = AD \tag{5.69}$$

or,

$$-\alpha + \beta P - H + NM - PR = \gamma - \delta P \tag{5.70}$$

or,

$$\beta P + \delta P = (\gamma + \alpha) + H - NM + PR$$

or,

$$P(\beta + \delta) = (\gamma + \alpha) + H - NM + PR$$

or,

$$P = \frac{(\gamma + \alpha)}{(\beta + \delta)} + \frac{H - NM + PR}{(\beta + \delta)} \tag{5.71}$$

In Eq. (5.71) *H* indicates market control of the traders, *NM* is related to trade policy and *PR* is related to the procurement and public distribution policy of the government. Here,

$$\frac{dP}{dH} = \frac{1}{\beta + \delta} > 0 \tag{5.72}$$

$$\frac{dP}{dNM} = -\frac{1}{\beta + \delta} < 0 \tag{5.73}$$

$$\frac{dP}{dPR} = \frac{1}{\beta + \delta} > 0 \tag{5.74}$$

The Eq. (5.72) implies that if hoarding (*H*) increases, price will increase. If the government fails to control hoarding and artificial shortage, there will be food price inflation in the economy. The Eq. (5.73) suggests that if net import declines due to increase in export, price will rise. Therefore, in time of food inflation, the government will have to decide whether it will allow export or increase the amount of import to check price rise. Similarly, if the government increases procurement and reduces release of foodgrains through public distribution system the net government procurement will increase and this will increase prices of the food items. *NM* and *PR* need some clarifications. If export of foodgrains exceeds imports, *NM* will be negative and this has actually happened in India after 1970–71. The increase in net export has resulted in increase of food prices. On the other hand, if the government procurement of foodgrains is greater than public distribution, PR will be positive and this will increase price. The government of India has adopted a wrong policy by increasing the stock of foodgrains at the time of high food price inflation for most of the time.

5.5.3 Empirical Evidences

The management of the food economy refers to production, procurement, distribution and net import of food items. But, food security depends not only on the availability of foodgrains but also on the prices of food items. India is experiencing high rate of food price inflation after economic liberalization. The wholesale price index of all commodities (WPI_AC) and wholesale price index of Food Articles (WPI_FA) with base year 1981–82 = 100, have increased to 719.16 and 1019.04 respectively in 2012–13. There has been more than 10 times increase of prices of food items in the last three decades and food price inflation is found to be higher than general inflation. During the period from 2008 to 2010, the increase in food prices was very high. But instead of releasing more foodgrains from the buffer stock the government increased the amounts of procurement and the buffer stock (see Tables 5.20 and 5.21). In respect of trade policy also, the government could not take appropriate policy measures. From Table 5.22, it is evident that net import of foodgrains from the year 2000–01 has remained negative and high. That means, export has remained much higher than import. We will explain using time series analysis in the next section how net export and change in buffer stock have caused food price inflation in India in the recent past.

5.5.4 Time Series Analysis

The time series analysis of the variables has been done using data from Economic survey, Government of India, National Accounts Statistics, Government of India for the period from 1970–71 to 2012–13 and following the techniques outlined in Enders (2004). The Dickey Fuller Unit Root Test has been done to check the stationarity of the series of wholesale price index of food articles (WPI_FA), change in stock of foodgrains of the government (D_STOCK_F) and Net import of foodgrains (Net_IM). It is found that the series WPI_FA, D_STOCK_F and Net_IM are stationary at first difference.

In Johansen Cointegration Test, it is found that WPI_FA and D_STOCK_F are cointegrated i.e., CI (1,1). That means, there is a meangingful long run relationship between them (see Table 5.23). Since the variables are cointegrated, OLS regression of WPI_FA on D_STOCK_F will give efficient estimates. In Table 5.24, it is found that the relationship between WPI_FA and D_STOCK_F is positive and statistically significant. This is consistent with our theoretical explanations. If the government procurement exceeds the amount of public distribution, the buffer stock will increase with the result that shortage in market supply will increase and this will lead to price rise. In Tables 5.23 and 5.24, it is evident that in the years of high food price inflation (2008–2010), the change in food stock was much higher and this was a wrong policy on the part of the government (Table 5.25).

Table 5.20 Production, procurement and public distribution in India (million tonnes)

Year	Production	Procurement	Public distribution
1971	105.17	8.9	7.8
1972	97.03	7.7	10.5
1973	104.67	8.4	11.4
1974	99.83	5.6	10.8
1975	121.03	9.6	11.3
1976	111.17	12.8	9.2
1977	126.41	9.9	11.7
1978	131.90	11.1	10.2
1979	109.70	13.8	11.7
1980	129.59	11.2	15.0
1981	133.30	13.0	13.0
1982	129.52	15.4	14.8
1983	152.37	15.6	16.2
1984	145.54	18.7	13.3
1985	150.44	20.1	15.8
1986	143.42	19.7	17.3
1987	140.35	15.7	18.7
1988	169.92	14.1	18.6
1989	171.04	18.9	16.4
1990	176.39	24.0	16.0
1991	168.38	19.6	20.8
1992	179.48	17.9	18.8
1993	184.26	28.1	16.4
1994	191.50	26.0	14.0
1995	180.42	22.6	15.3
1996	199.43	19.8	18.3
1997	193.12	23.6	17.8
1998	203.61	26.3	18.6
1999	209.80	30.8	17.7
2000	196.81	35.6	13.0
2001	212.85	42.6	13.2
2002	174.78	40.3	18.2
2003	213.19	34.5	23.2
2004	198.36	41.1	28.3
2005	208.59	41.5	31.0
2006	217.28	37.0	31.8
2007	230.78	35.8	32.8
2008	234.47	54.2	34.7
2009	218.11	60.5	41.3
2010	244.49	56.1	43.7
2011	259.29	64.5	47.9

Source Economic survey, 2012–13, Government of India

[a] The years has been written as 1971–72 = 1971

Table 5.21 Change in buffer stock of foodgrains in India (million tonnes)

Year	Amount	Year	Amount
1970–71	1.1	1991–92	−0.9
1971–72	−2.8	1992–93	11.7
1972–73	−3.0	1993–94	12.0
1973–74	−5.2	1994–95	7.3
1974–75	−1.7	1995–96	1.5
1975–76	3.6	1996–97	5.8
1976–77	−1.8	1997–98	7.7
1977–78	0.9	1998–99	13.1
1978–79	2.1	1999–2000	22.6
1979–80	−3.8	2000–01	29.4
1980–81	0.0	2001–02	22.1
1981–82	0.6	2002–03	11.3
1982–83	−0.6	2003–04	12.8
1983–84	5.4	2004–05	10.5
1984–85	4.3	2005–06	5.2
1985–86	2.4	2006–07	3.0
1986–87	−3.0	2007–08	19.5
1987–88	−4.5	2008–09	19.2
1988–89	2.5	2009–10	12.4
1989–90	8.0	2010–11	16.6
1990–91	−1.2	2011–12	28.5

Source Economic survey 2013–14, Government of India

[a] Negative sign implies that public distribution is greater than procurement

The results in Table 5.25 show that the series WPI_FA and NET_IM are cointegrated in Johansen Cointegration Test i.e. the variables are CI (1,1). As the variables are cointegrated, there is long run relationship between them and OLS regression of WPI_FA on NET_IM will give efficient estimates. In Table 5.26, we find negative and significant relationship between WPI_FA and NET_IM. The implication is that if net import rises, the supply in the domestic market will increase and this will reduce price. This is also consistent with our theoretical result. In Table 5.22 the figures show that net import is negative for almost the entire period from 1970–71 to 2012–13. Negative net import actually means positive net export. Now, if we regress WPI_FA on positive net export, we will find a positive relation between them giving the same implication that if net export rises WPI_FA will rise. From Tables 5.20, 5.21 and 5.22, it is also evident that net import is gradually declining and government stock is increasing from 1994–95 and these are reflected in Fig. 5.12. The increase in buffer stock and decline in net import have further fueled the price rise in the foodgrains market.

Table 5.22 Net import of foodgrains of India (million tonnes)

Year	Amount	Year	Amount
1970–71	2.0	1991–92	−0.7
1971–72	−0.5	1992–93	2.6
1972–73	3.6	1993–94	0.5
1973–74	5.2	1994–95	−3.0
1974–75	7.5	1995–96	−3.5
1975–76	0.7	1996–97	−0.6
1976–77	0.1	1997–98	−2.9
1977–78	−0.8	1998–99	−1.5
1978–79	−0.3	1999–2000	−1.4
1979–80	−0.5	2000–01	−4.5
1980–81	0.5	2001–02	−8.5
1981–82	1.6	2002–03	−7.1
1982–83	4.1	2003–04	−7.7
1983–84	2.4	2004–05	−7.2
1984–85	−0.3	2005–06	−3.8
1985–86	−0.1	2006–07	−7.0
1986–87	−0.4	2007–08	−14.4
1987–88	2.3	2008–09	−7.2
1988–89	0.8	2009–10	−4.7
1989–90	0.0	2010–11	−9.6
1990–91	−0.6	2011–12	−19.8

Source Economic survey 2013–14, Government of India

[a] Negative sign implies that export is greater than import

Table 5.23 Cointegration between wholesale price index for food articles (WPI_FA) and change in buffer stock (D_Stock_F) in India

Johansen cointegration test				
Sample (adjusted): 1973–2011				
Included observations: 39 after adjustments				
Trend assumption: Linear deterministic trend				
Series: WPI_FA D_STOCK_F				
Lags interval (in first differences): 1–1				
Unrestricted cointegration rank test (trace)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.[b]
None[a]	0.590554	38.92771	15.49471	0.0000
At most 1[a]	0.099851	4.102620	3.841466	0.0428
Unrestricted cointegration rank test (maximum Eigenvalue)				
Hypothesized no. of CE (s)	Eigenvalue	Max-Eigen statistic	0.05 critical value	Prob.[b]
None[a]	0.590554	34.82509	14.26460	0.0000
At most 1[a]	0.099851	4.102620	3.841466	0.0428

Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
Trace test indicates 2 cointegrating eqn(s) at the 0.05 level

[a] Denotes rejection of the hypothesis at the 0.05 level

[b] MacKinnon-Haug-Michelis (1999) p-values

Table 5.24 OLS regression of WPI_FA and D_Stock_F

Dependent variable: WPI_FA				
Method: Least squares				
Sample (adjusted): 1971–2011				
Included observations: 41 after adjustments				
Variable	Coefficient	Std. error	*t*-statistic	Prob.
D_STOCK-F	22.30564	3.469282	6.429468	0.0000
C	186.6694	35.61247	5.241687	0.0000
R-squared	0.514551			
F-statistic	41.33806			

Table 5.25 Cointegration between wholesale price index for food articles (WPI_FA) and net import of foodgrains (NET_IM) in India. Johansen cointegration test

Sample (adjusted): 1973–2012				
Included observations: 40 after adjustments				
Trend assumption: Linear deterministic trend				
Series: WPI_FA NET_IM				
Lags interval (in first differences): 1–1				
Unrestricted cointegration rank test (trace)				
Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.[b]
None[a]	0.589556	42.35068	15.49471	0.0000
At most 1[a]	0.154859	6.730072	3.841466	0.0095
Unrestricted cointegration rank test (maximum Eigenvalue)				
Hypothesized no. of CE (s)	Eigenvalue	Max-Eigen statistic	0.05 critical value	Prob.[b]
None[a]	0.589556	35.62060	14.26460	0.0000
At most 1[a]	0.154859	6.730072	3.841466	0.0095

Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
Trace test indicates 2 cointegrating eqn(s) at the 0.05 level
[a]denotes rejection of the hypothesis at the 0.05 level
[b]MacKinnon-Haug-Michelis (1999) p-values

5.5.5 Summary

This section establishes that food security depends not only on production of foodgrains but also on availability of foodgrains and prices of food items. The food prices again are determined by aggregate demand and aggregate supply in the market. Since the elasticities of both demand and supply of agricultural commodities, specially of foodgrains, are low, a small change in supply or demand causes a large change in food price. India is experiencing a high rate of food price inflation from the beginning of economic liberalization in 1990s. In the recent years the price rise has been very acute. This section examines the role of public policy in

Table 5.26 OLS Regression of WPI_FA and NET_IM

Dependent Variable: WPI_FA				
Method: Least Squares				
Sample (adjusted): 1971–2012				
Included observations: 42				
Variable	Coefficient	Std. Error	*t*-statistic	Prob.
NET_IM	−45.67948	4.722915	−9.671882	0.0000
C	245.3289	25.85420	9.488937	0.0000
R-squared	0.700476			
F-statistic	93.54529			

combating the price rise. The policies of public procurement, public distribution and net export can influence the prices of agricultural commodities. The theoretical and empirical results of this section demonstrate that if the government does not release sufficient foodgrains from buffer stock or procurement of the government exceeds the public distribution or net export increases, these will have positive impact on the prices of foodgrains. But the government in India has failed to adopt the right policy in this regard. In the last few years the government has procured more than the release of foodgrains from buffer stock and the net import of the country has declined. All these have added further fuel to food price inflation in the country.

Appendix

Following Jones (1965), we have obtained

$$\begin{aligned}\hat{a}_{TF} &= -\theta_{KF}\,\sigma_F\big(\hat{R}-\hat{r}\big)\\ \hat{a}_{KF} &= \theta_{TF}\,\sigma_F\big(\hat{R}-\hat{r}\big)\\ \hat{a}_{TN} &= \theta_{KN}\,\sigma_N\big(\hat{R}-\hat{r}\big)\\ \hat{a}_{KN} &= -\theta_{TN}\,\sigma_N\big(\hat{R}-\hat{r}\big)\end{aligned}$$

Using the above values in (5.27) and (5.28) we get

$$\begin{aligned}&-\lambda_{TF}\left\{-\theta_{KF}\sigma_F\left(\hat{R}-\hat{r}\right)\right\}-\lambda_{TN}\left\{\theta_{KN}\,\sigma_N\left(\hat{R}-\hat{r}\right)\right\}\\ &=\left[-\lambda_{TN}\,\theta_{KN}\,\sigma_N+\lambda_{TF}\,\theta_{KF}\,\sigma_F\right]\left(\hat{R}-\hat{r}\right)\\ &=\gamma_1\left(\hat{R}-\hat{r}\right)=\gamma_1\eta\,\beta\hat{t}\end{aligned}$$

Here,

$$
\begin{aligned}
&\left(\hat{R}-\hat{r}\right)=\eta\cdot\beta\hat{t}\\
&\quad\eta>0\\
&A=\left[\lambda_{TF}+\gamma_1\eta\right]\\
&\lambda_{KF}\left\{-\theta_{TF}\,\sigma_F\left(\hat{R}-\hat{r}\right)\right\}+\lambda_{KN}\left\{\theta_{TN}\,\sigma_N\left(\hat{R}-\hat{r}\right)\right\}\\
&\left(\hat{R}-\hat{r}\right)\left[-\lambda_{KF}\,\theta_{TF}\,\sigma_F+\lambda_{KN}\,\theta_{KN}\,\sigma_N\right]\\
&\quad=\eta\,\beta\,\hat{t}\,\gamma_2\\
&B=\left[\lambda_{KF}-\gamma_2\eta\right]
\end{aligned}
$$

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Chapter 6
Frontiers of Technology, Natural Resources and Sustainable Growth

Abstract The technological change and productivity growth in agriculture in the last four decades have caused huge stress on natural resources. The growth in agricultural production could be achieved largely banking on ground water extraction. In most of the states of India, the rate of depletion of ground water is very high and in some states, it has crossed the limits permissible by nature. Actually shortage of water and degradation of soil are going to be serious constraints to future growth. This chapter suggests that instead of searching for supply side solution to the problems of resource constraints, we need to apply appropriate technologies so that demand for water in agricultural production decline and the productivity of water increases. It shows that side by side with efficient management and proper utilization of surface water, emphasis should be given on efficient irrigation technology, dryland farming and cultivation of water-saving crops. This chapter has shown that the frontiers of technology are going to play very important role in resource management and agricultural growth. Biotechnology has great promises for future growth in agriculture. Nano technology, information technology, geographic and information science (GIS), remote sensing and irrigation technology will take very important role in future growth of agriculture.

6.1 Introduction

In course of technological change and productivity growth in agriculture, resource degradation is taking place and it is putting a question mark before the sustainability of growth in the farming sector. Rosegrant and Sombilla (1997) remarked that water shortage would become the major threat to future growth in agriculture. Addressing the issue of resource constraint in Indian context, Sasmal (2014) shows that availability of water will be a limiting factor for future growth in agriculture in the country. However, he ends up with the conclusion that technological advancements in various fields related to agriculture will be of great help in removing the constraints and accelerating future growth. Greater efficiency in water use and higher productivity of water will reduce the demand for water and help increase

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production. So, appropriate irrigation technology powered by modern biotechnology will be of great help in solving the problems of future growth. Solow (1974, 1992) suggests that man-made capital and knowledge will be used as substitute for natural resources. He remarks that apart from optimal use of natural resources, the elasticity of substitution between natural resources and man-made assets will be very important for maintaining intergenerational equity. Stiglitz (1974) notes that there are at least three economic forces offsetting the limitations imposed by natural resources—technical change, the substitution of man-made factors of production (capital) for natural resources and returns to scale. Zilberman (2006) also expresses similar view. He suggests three policies for conservation of natural resources will be helpful: (i) price policy, (ii) technological policy, (iii) government policy. So, it is very clear that technology will have to play a crucial role in resource management for sustainable agricultural growth. This section will analyse the importance and limitations of natural resources, particularly of water supply in agricultural growth. At the same time, it will show how technological innovations can remove the limitations and help sustainable growth.

India has achieved remarkable success in foodgrains production in the last four decades although this growth has caused huge stress on natural resources like land and water. Excessive depletion of ground water, greater intensity of cultivation and use of chemical inputs in increasing doses have resulted in water scarcity, soil degradation and loss of biodiversity. In fact, the growth has been achieved largely banking on ground water extraction. The extension of irrigation has greatly facilitated the use of high-yielding varieties (HYV) seeds and chemical inputs leading to significant growth in yield in the farming sector. The net cropped area under foodgrains in the country has remained more or less constant at 124 million hectares. But total production of foodgrains has increased from 108 million tonnes in 1970–71 to 257 million tonnes in 2011–12 due to increase in productivity of land. The yield per hectare has increased from 872 kg in 1970–1971 to 2129 kg in 2012–13 (Agricultural Statistics at a Glance 2014, Ministry of Agriculture, Government of India 2015a, b) and in this growth process, tube-well irrigation has played a vital role. The net irrigated area in the country has increased from 22.1 % of the cultivated land in 1970–1971 to 47 % in 2012–2013 and in total net irrigated area, the share of well-irrigation has increased from 12.34 to 62 % during this period (Source: Ministry of Water Resource, Government of India 2015a, b; Centre for Monitoring Indian Economy 2010). The huge extraction of ground water has put a question mark before the sustainability of growth (Singh 1992, 2000; Rao 2002; Sidhu 2002; Sasmal 2012). Not only the irrigation potential of ground water is going to be exhausted but also the over exploitation of ground water has caused salinity and arsenic problems in water, decline of water table in the aquifer and degradation of soil in many parts of the country. Agriculturally important states like Punjab and Haryana where the green revolution has been very successful, are found to be worst affected by excessive ground water extraction and intensive farming. The study of Bhullar and Sidhu (2006) in Punjab states that the over exploitation of ground water in the last three decades has played havoc with the resources of the state. The proportion of area where the water table is below the critical depth of

10 m has increased from 3 % in 1973 to 53 % in 2000. Ruttan (2002), while explaining the sources and constraints of productivity growth in world agriculture, remarks that water scarcity will be a serious problem towards increasing food production in many countries. Expressing concern for sustainability of agricultural growth, Tilman et al. (2002) report that roughly 20 % of the irrigated area of the United States is supplied by ground water pumped in excess of recharge and overpumping is a serious concern in China, India and Bangladesh. Now, the question is: how serious is the problem of water shortage for future growth in production of foodgrains in countries like India? Sasmal (2014) provides some answers to this question. Apart from utilizing the available resource optimally, the technological advancements in various fields relating to agriculture will have to be utilized in future growth (Table 6.1).

In the context of excessive dependence on ground water for irrigation, rain water harvest crop-diversification in favour of less water intensive crops, greater efficiency in water use, watershed development and dryland farming have been suggested as alternative policy options for sustaining growth in agriculture (Shah et al. 1995; Rao 2000, 2002; Ramasamy 2004; Sasmal 2013; Nadkarni 1993). In fact, the growth rate in yield in foodgrains production in India has shown a declining trend since 1990s although the situation has slightly improved very recently. The declining trend in the growth rate of productivity is attributed to the scarcity of water supply (Sasmal 2012, 2014). Ground Water Scenario of India 2009–10 (Ministry of Water Resources, Government of India) shows that in certain parts of the country, ground water is overexploited although in some states of the country, there is still some scope for increasing ground water irrigation (see Table 6.2). On the whole, opportunities left in ground water irrigation are really limited. On the other hand, utilization of surface water is conditional on many factors. In this backdrop, technological advancements for enhancing the productivity of water and achieving greater efficiency in water use are very important. Not only water, the availability and productivity of land are also very important for sustaining growth in agriculture. Technology has a very significant role both for productivity growth and conservation of resources. The frontiers of biotechnology, irrigation technology, information technology, GIS and Remote Sensing will play a vital role in the coming days.

6.2 Future Potential of Ground Water Irrigation in India

The ground water irrigation has been found to be the main driving force of agricultural growth in India in the last 4 decades. Total net irrigated area in the country has increased from 31,103 thousand hectares in 1970–71 to 66,103 thousand hectares in 2012–13. It is important to note the share of canal irrigation in net irrigated area of the country has declined from 41.28 % in 1970–71 to 23 % in 2012–13 and the area under tank water irrigation has declined at an annual average

Table 6.1 Sources of irrigation in India (‘000 ha)[a]

Year	Area under canal irrigation	Area under tube-well irrigation	Total net irrigated area
1970–71	12,838 (41.28)	4461 (14.34)	31,103
2007–08	16,531 (26.54)	26,105 (41.91)	62,286
2012–13	15,628 (23)	30,497 (46)	66,103

Source Centre for Monitoring Indian Economy (CMIE) (2010), Ministry of Water Resources, Government of India (2015a, b)

[a] Figures in brackets indicate percentage share in total net irrigated land

Table 6.2 Availability and utilization of ground water resource in major states of India (Billion Cubic Metre, BCM), 2009–10

States	Net annual replenishable ground water availability	Annual ground water utilization (including irrigation)	Ground water availability for future irrigation	Percentage of utilization of available water	% of wells showing 10–20 m water depth below ground level
Andhra Pradesh	32.95	14.90	17.65	45	13.13
Assam	24.89	5.44	19.06	22	2.82
Bihar	27.42	10.77	16.01	39	2.86
Gujarat	15.02	11.49	3.05	76[a]	27.76
Haryana	8.63	9.45	−1.07[b]	109[b]	30.71
Jharkhand	5.25	1.06	3.99	20	5.14
Karnataka	15.30	10.71	6.48	70[a]	14.09
Kerala	6.23	2.92	3.07	47	11.27
Madhya Pradesh	35.33	17.12	17.51	48	22.01
Maharashtra	31.21	15.09	15.10	48	11.29
Orissa	21.01	3.85	16.78	18	1.42
Punjab	21.44	31.16	−9.89[b]	145[b]	39.00
Rajasthan	10.38	12.99	−3.94[b]	125[b]	29.27
Tamil Nadu	20.76	17.65	3.08	85[a]	12.50
Uttar Pradesh	70.18	48.78	19.52	70[a]	17.09
West Bengal	27.46	11.65	15.33	42	11.27
Total States	398.70	230.41	161.06	58	–

Source Ground Water Scenario of India, 2009–10, Ministry of Water Resource, Government of India (2010)

[a] States with high rate of ground water exploitation

[b] States with over exploitation of ground water

rate of 0.19 % during this period. But area under tube-well irrigation has increased at the rate of 2.56 % per year (Source: Ministry of Water Resources, Government of India 2015a, b).

Among foodcrops, rice is the most water-intensive crop followed by wheat. The production of these two crops has significantly increased in the last four decades. It is to be noted here that production of foodgrains in Kharif (rainy) season has increased from 68.9 million tonnes in 1970–71 to 129.9 million tonnes in 2011–12 while in Rabi (dry) season it has increased from 35.9 million tonnes to 127.5 million tonnes in the same period. The implication is that there has been significant increase of rice production in Rabi season and it has been possible due to expansion of ground water irrigation. Furthermore, the elasticity of foodgrains production with respect to irrigation has been calculated to be 1.18. This means, one percent increase in irrigation has resulted in 1.18 percent increase in foodgrains production. All these signify the importance of irrigation in foodgrains production of India. Now, we have to see whether this growth is sustainable in view of the fact that there is serious water resource constraint in the country.

Table 6.2 provides valuable information for our purpose. In most of the major food producing states like Punjab, Haryana, Uttar Pradesh, Rajasthan, Karnataka and Tamil Nadu, extraction of ground water is very high and in some states it has crossed the naturally permissible limits although in the states of eastern India like Bihar, West Bengal, Assam, Jharkhand and Orissa there is scope for further expansion of ground water irrigation. Table 6.2 also shows that net annual replenishable available ground water in the country is 398.70 billion cubic metres (bcm) out of which, 230.41 bcm is depleted every year (212.37 bcm is used for irrigation and the rest for other purposes). The remaining 161.06 bcm is available for future use. It indicates that 58 % of ground water is being utilized at present and the remaining 42 % is available for future use. But this is not enough for future food security (see Table 6.2). So, we have to think on appropriate policy measures for utilizing the resources effectively so that the growth in the country becomes sustainable.

6.3 Scope for Utilizing Surface Water

India experiences huge rainfall every year and it is a renewable resource. But only a fraction of this resource is utilized for irrigation purposes. The total annual precipitation of rain water in India is 37,00,000 million cubic metres (mcm) out of which 17,00,000 mcm flows down the rivers and only 2,67,500 mcm percolates to the ground water aquifer as natural recharge (Source: Ministry of Water Resources, Government of India). But construction of Dams or big River Projects for utilizing this renewable resource is difficult and has become highly controversial. This is because such projects involve huge environmental and human costs in terms of displacement of population and destruction of forests and biodiversity. However, the experiences of minor irrigation projects are encouraging. The studies by Rao (2000), Chandrakanth et al. (2004), Joshi (2006), Shah et al. (2009) and Birthal (2013) show that watershed development, rainwater harvesting, technology for dryland farming and artificial recharge to the ground water aquifer can significantly contribute to productivity growth in agriculture. According to their estimates, the increase in yield may range from 12 to 50 % as a result of these measures The development of minor irrigation projects not only enhances productivity in agriculture but also helps conservation of natural resources and the ecology.

From econometric analysis it is revealed that there is meaningful long run relationship between tube-well irrigation, fertilizer use and productivity growth and it is also evident that tube-well irrigation has played the most important role in agricultural growth in India. It is important to note that irrigation area from other sources has increased from 3048 thousand hectares in 1990–91 to 7466 thousand hectares in 2012–13 indicating that initiatives for utilizing the surface water for irrigation, development of watershed and minor irrigation projects and measures for using water in efficient manners are becoming effective. This is a very positive sign for future growth. The use of water-saving technology also may be very helpful in this matter. Hornbaker and Mapp (1988) show how the use of low pressure irrigation technology reduces water use and increases water efficiency. As a result, cost of water use declines and at the same time, it helps savings of water. Their research also suggests that the use of dynamic programming for ground water management and irrigation scheduling may be introduced to economise on water resource.

6.4 Technology for Increasing Productivity of Water—A Theoretical Exposition

In the backdrop of declining ground water stock and various constraints towards utilizing surface water, appropriate technological advancement and agricultural research are very important for agricultural growth. Instead of following the traditional path of seeking only supply-side solution to the problem of water shortage, frontiers of technological progress and agricultural innovations can be applied to reduce demand for water in cultivation, increase overall productivity in the farming sector, reduce water losses in irrigation and enhance productivity of water in agricultural production. Birthal (2013) summarises the significant positive contributions of irrigation technology, biotechnology and information technology in enhancing agricultural productivity. His study empirically shows that improved irrigation technology can save 20–35 % water input in agriculture. However, such technological progress has to come as a public good and for that matter, the government will have to make sufficient public investment for agricultural research. At the same time, the research has to be region-specific and crop-specific.

The improved irrigation technology can help agricultural growth by increasing productivity of water in cultivation. To demonstrate it theoretically let us consider a production function:

$$Q = A(TW)^{\alpha} Z^{1-\alpha} \tag{6.1}$$

where Q is output, T is improved irrigation technology, W is water supply, A is general efficiency from production technology and infrastructure and Z is chemical fertilizer. It may be assumed that T comes from public sector investment. The governments in developing countries make such investments. Here, water is measured in efficiency term and T is perfect substitute for W.

Now, taking log of (6.1) and differentiating w.r.t. time we get

$$g_Q = g_A + \alpha g_T + \alpha g_W + (1 - \alpha) g_Z \tag{6.2}$$

where g_Q, g_A, g_T, g_W and g_Z are growth rates of Q, A, T, W and Z respectively. Given production elasticities of water and fertilizer, growth rate of output (g_Q) depends on growth rate of A, T and Z. If availability of water remains constant, $g_W = 0$. As water substituting irrigation technology has been adopted, we can write (6.2) as

$$g_Q = g_A + \alpha g_T + (1 - \alpha) g_Z \tag{6.3}$$

Here, g_A, g_T and g_Z are positive. Although, water supply remains constant, agricultural growth can be sustained by increasing the efficiency of water supply. Thus shortage of water no longer becomes a constraint to future growth in agriculture.

6.5 Reference of Some Important Studies

Headley (1972) explains the role of technology in raising agricultural productivity and at the same time draws our attention to the environmental problems arising out of it. There are environmental problems which are related to the pressure of productivity growth and the resulting adoption of industrial inputs and techniques. So, there is an additional challenge of finding and maintaining the right relationship between agriculture and the natural environment. Although there is no objective way of knowing whether the farmers are applying equilibrium amounts of inputs, in many cases, the inputs are not used in optimal doses. So, there is scope for introducing biological and cultural controls and good farm management practices to profitably reduce the chemical inputs. The effective and appropriate cultivation practice may be helpful in this regard.

In an interesting paper, Ciriacy-Wantrup (1946) has tried to relate resource conservation with economic instability long before. He notes that in periods of rising prices, cultivated acreage has frequently expanded in regions whose arid and erratic climate or steep slope make them unfit for permanent cultivation. Soil depletion has often occurred during and after a period of prosperity for certain cash crops. If declining prices would cause land to be shifted quickly to those types of use which are better suited to the physical conditions, depletion of soil would not become serious. The failure of agricultural production to respond significantly and quickly to decrease of product prices is important for resource conservation. So, cropping pattern and cultivation practices are important in resource management.

The choice of irrigation technology has a big role in water conservation. It has been long argued that increasing water prices can encourage agricultural water conservation. This is because increasing prices of water resource will encourage the adoption of efficient irrigation technologies. Adopting efficient irrigation technologies is one potential response to an increase in the price of water. Green and Sunding (1997) show that the technology adoption decision depends on water price and land quality. Caswell and Zilberman (1986) theoretically show that the adoption of appropriate irrigation technology depends on well depth. They demonstrate that when soil quality is sufficiently high, increases in the depth to ground water will not induce adoption of low-pressure irrigation technologies. Therefore, in addition to water price, quality of soil is also important in the choice of appropriate irrigation technology.

According to Hueth and Just (1987) biotechnology promises to have a greater impact on society than any other presently foreseeable technological development. Agricultural production stands to realize one of the largest effects of this new technology. Very important policy implications follow from this technological change. These changes are related to development of new products, environmental concerns and potential replacement of trade in agricultural products by technological inputs. The new biotechnology will have tremendous yield-increasing effects on agricultural production as well as on the market equilibrium. In addition to public investment, participation of private players in the market for technological innovations and output change and market adjustments will be the new phenomenon in this process. The chemical industry will take a leading role in the development of agricultural innovations. Food self-sufficiency may become within reach in many countries. According to Hueth and Just, biotechnology promises to change the structure of agriculture and the set of resources that limit production.

It is now clear that adoption and diffusion of natural-resource-conserving agricultural technology has great relevance for future growth in agriculture. Fuglie and Kascak (2001) mention that growing awareness and concern about the environmental costs of agricultural production have given new impetus to increasing the use of farm practices that reduce production externalities. In crop agriculture, conservation tillage, integrated pest management (IPM), soil nutrient testing and precision agriculture are examples of technologies that are being promoted to help conservation of natural resources by reducing soil erosion and excessive application of chemical inputs.

Qaim (2005) show that over the last ten years, modern agricultural biotechnology has been adopted rapidly at the global level including in several developing countries. The trend has been most apparent for genetically modified (GM) crops. The GM technologies are different from previous crop innovations like high yielding varieties (HYVs) of the green revolution in many respects. Naturally, the pattern of adoption of GM technologies is also different. Two aspects of GM technology are: (i) availability of the technology and (ii) access to this technology. The range of desirable crop traits that could potentially be developed by use of modern biotechnology is very broad. However, the suitability of GM crops for developing countries remains a controversial issue in the public debate. For example, in India, adoption of GM technology is almost nil except Bt cotton. The farmers' access to GM technologies that have been commercialized at the national level depends not only on technological characteristics but also on agronomic and socioeconomic factors. Qaim notes that in the first years after Bt cotton commercialization in India, only three Bt hybrids had been approved and these were grown on large areas of the region. However, these hybrids are not well adapted to all environments. Apart from technical and environmental aspects of adaptation, the GM technologies have patent related complexities also. Naturally, they could not reach the stage of mass adoption yet although there is the possibility that these technologies will be adopted widely in future.

With respect to the role of frontiers of technology in conservation of natural resources and productivity growth in agriculture, very insightful information and analyses have been provided by Birthal (2013). He states that balancing the growing food demand with domestic production is unlikely to be as smooth as in the past. Agricultural production system will come under the confluence of biotic and abiotic stresses. So, the future growth in agriculture has to come from acceleration in the rate of technological change and sustainable intensification of the production systems. Birthal remarks that frontier sciences like biotechnology, nanotechnology, remote sensing and information technology can take a leading role in raising productivity in the agricultural sector. An estimate shows that harvesting of rain water can increase 12–45 % output if properly implemented. In the same study, Birthal notes that the pressurized irrigation systems such as sprinkler and drip systems possess considerable potential to improve water use efficiency and agricultural productivity. Sprinkler irrigation in foodgrains crops can save water to the extent of 40 % and improve yields up to 20 %. Laser land levelling and reduced tillage too have significant impact on soil conservation and productivity growth. Similarly, remote sensing and geographic information system (GIS) can be largely helpful in the management of natural resources through monitoring of land and water resources. Thus the biotechnology has the biggest promise for agricultural growth in future. Following Birthal (2013), it can be mentioned here that modern biotechnology has two main advantages over the traditional breeding methods of crops—(i) it provides a means to precisely select the gene for a particular trait in the crop and (ii) it allows transfer of gene for a particular trait across species using genetic engineering, tissue culture and other scientific methods. Biotechnology also contributes towards improving the quality of natural resources. Similarly, nanotechnology and information technology can largely influence agricultural production and farmers' income by generating greater efficiency in production and marketing.

While focusing the importance of modern bioscience and physical science in developing new crop varieties and accelerating growth in production without harming the ecosystem, Balasubramanian (2014) puts emphasis on agricultural research and extension services. Like many other scholars he is also of the opinion that new innovations and modern technologies will be the prime movers of agricultural productivity and growth. Sufficient public research expenditures are needed side by side with public-private collaborations. According to World Development

Report 2008, 94 % of the agricultural R&D expenditures are done by the public sector. But the recent trend shows that private investment on the head of agricultural research is increasing. Balasubramanian reports that agricultural R&D spending by the private sector in India has increased five folds since mid 1990s. He further notes that India has one of the largest and well-coordinated public research systems in the world. If this system can perform effectively, science and technology will be able to change the agricultural scenario of the country.

6.6 Summary

Technological change, the use of chemical inputs and productivity growth in agriculture have caused serious damage to natural resources. Excessive depletion of ground water and soil degradation are putting question mark before the sustainability of agricultural growth. From the viewpoint of supply, there is limited scope for increasing the supply of water resource. But it is possible to reduce the demand for water and enhance the productivity of water by using appropriate irrigation technology. It is also clear from the studies of eminent scholars that agricultural research, scientific innovations and new technologies will play crucial role both in resource management and future agricultural growth. Particularly, biotechnology, irrigation technology, nanoscience, remote sensing and GIS have great promises for agriculture. The idea of Solow (1992) with respect to sustainable growth has great relevance here. The man-made capital will be substitute for natural resources. So, it is expected that resource constraints can be removed and agriculture will continue to grow.

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Chapter 7
Summary and Conclusions

Abstract This chapter has summarized the results and conclusions of theoretical analysis and econometric exercises on the issues of technological change, conservation of natural resources and sustainability of agricultural growth in this book. In the objective and scheme of this book, the importance of the above three issues have been discussed in an interrelated and comprehensive manner using sound analytical frameworks and econometric evidences. In fact, the problems of agricultural growth can not be analysed independent of resource management and technological progress. Agriculture in India, like in many other developing countries, has achieved remarkable growth in the last four decades by large scale adoption of high yielding variety seed, use of chemical inputs and expansion of irrigation. These factors have caused serious damage to natural resources like land and water. So, conservation of soil fertility, use of resource friendly inputs, efficient management of water resource have become very important. Major aspects of technological change, crop diversification, soil health, rain water harvest, externality problems in resource use, role of the government in resource management have been the main focus of this study. The sustainability of growth in agriculture has been viewed from a broader perspective encompassing geography, soil and agro-climatic conditions, rainfall, cropping pattern and overall environment. Both for productivity growth and conservation of resources, the role of technology, particularly the frontiers of biotechnology, irrigation technology, information technology has been highly emphasized. The results obtained in this study are very relevant to all other developing countries.

7.1 Objectives and Scheme

The three main issues of Indian agriculture that have been addressed in this book are technology, natural resources and sustainability of agricultural growth. Agriculture is a natural resource based activity. Apart from land and water, geographical and agro-physical conditions, climate, rainfall, biodiversity and physical environment are also very important in agricultural production. The technological

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change during the period from 1970 to 1990 has significantly increased foodgrains production, in the developing countries including India. Millions of population have been saved from starvation and many of the countries have turned into food-surplus countries from food-deficit ones. But the technological change and the consequent productivity growth have put huge stress on natural resources. As a result, the sustainability of growth in agriculture is facing a big question mark. The sustainability is defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own requirements. The agricultural activities are different from those in the industrial sector. The use and conservation of natural resources involve many theoretical and conceptual issues that need to be addressed in a proper way. The resources are mostly common property resources and many of them are of public good nature. Both the use and conservation of natural resources have externalities. So, there are market failures in such cases. Market distortions are also created by subsidies and support measures of the government. The farmers are private agents and they disregard social and environmental costs of resource use. They also make under valuation of natural resources. All these lead to excess depletion of ground water, degradation of land and soil fertility and loss of biodiversity. So, who is the optimizing agent in resource use, what is the optimal rate of extraction of a resource and what are the constraints in resource conservation are relevant questions in resource management. A sound theoretical framework is needed to analyse these questions. The individuals will not take initiatives for resource management in many cases due to externality problems. Besides, there are financial constraints and lack of access to the necessary technology and scientific innovations. In such cases the role of the social planner or community participation may be important. Various incentive measures of the government may be also helpful in these matters.

The technology is an important focus of this book. It has dual role in agriculture —(i) to enhance productivity in agriculture and (ii) to help conservation of natural resources. In the period of green revolution from 1970 to 1990, the high yielding variety (HYV) technology has resulted in remarkable growth in agricultural productivity through the use of HYV seeds, chemical inputs and assured irrigation. In the early phase of this technological change almost no attention was given to the issues of preservation of resources and sustainability of growth. The main emphasis was on increasing the production of foodgrains to feed the starving population. After the phase of acute food shortage is over, it was realized that the policy of increasing productivity in agriculture by using the modern technology and chemical inputs has caused serious damage to the resource base and the sustainability of growth is at stake. Now, much greater attention is being given to the conservation of natural resources with the help of nature and resource friendly technologies. In fact, technology has a very crucial role in resource management. The appropriate irrigation technology can reduce the water demand for cultivation and enhance the productivity of water. Similarly, various techniques of water management can help rain water harvesting, watershed development and so on. On the other hand, the practice of reduced tillage, use of green manures, fallow system, crop rotation, crop diversification etc. can protect the soil health and land quality. So far as productivity of land is concerned, the frontiers of biotechnology have great promises for agriculture. So, in brief, technology is not only important for increasing productivity in agriculture, it is equally important for conservation of natural resources.

The objective of this book is to analyse the problems of technological change, resource management and sustainability of growth in agriculture in an interrelated manner and it has been done in this book using sound theoretical frameworks. The theoretical arguments have been substantiated by empirical findings of econometric exercises. There are studies which deal with the above problems of agriculture in the Indian context. But hardly there is any study that is based on rigorous analytical framework. In that sense, this book is unique in its treatment of the problems relating to Indian agriculture. We have tried to explain how market failures can be corrected through government intervention and the economic agents can be motivated to adopt resource friendly inputs, technology and farming practices in agriculture through taxation, subsidies and incentive payments. The importance of technology in resource management and productivity growth has been properly highlighted. We have also analysed how the social planner can determine the optimal solution in resource use in case of common property rights, macro problems, and market failures. Although the problems have been addressed in the Indian context, the propositions, results and conclusions have great relevance for all other developing countries. The book has tried to fill up many of the gaps in the literature.

Here, in this book, we have applied a supply-side approach in explaining the problems of sustainable growth in agriculture. Naturally, Land, soil fertility, ground water extraction, surface water utilization, use of fertilizers and HYV seeds, and state of technology are the main issues of this study and these factors determine production in the agricultural sector. How excess depletion of ground water and degradation of soil make agricultural growth unsustainable in the long run has become one central focus of this book. This work also demonstrates using mathematical models and econometric results that public intervention and appropriate technology can ensure sustainability of growth in agriculture. Mathematical models have been constructed to analyse the problems in a very rigorous and logical manner and optimal control theory has been used extensively to derive results in dynamic perspective. Time series econometric analysis has been done to have results on the test of cointegration and test of causality among the variables.

Chapter 1 gives an overview of the Indian agriculture and describes the objectives and the scheme of the book. A technological breakthrough is a necessary condition for increasing productivity in traditional agriculture. Chapter 2 analyses various aspects of technological change in agriculture. The production under a new technology is uncertain for various reasons. Although productivity is higher, cultivation under the new technology is risky and the farmers are basically risk averse. So, how the optimal rate of adoption of a new technology is determined under production uncertainty is a pertinent question. Chapter 2 is devoted to the analysis of the relationship between the rate of adoption of a new technology and the degree of risk, farm size, credit constraint and irrigation. The degree of risk and the risk preference of the farmers are important determinants of adoption of a new technology. So, the theory of decision making under uncertainty has been applied to analyse this problem. Uncertainty in production varies under different modes of irrigation. Again, there are input related risks. So, generalized stochastic production function has been estimated to show that an input which has positive marginal product does not necessarily increase risk in production. This chapter identifies the determinants of technology adoption and examines the effect of technological change on agricultural productivity and the state of natural resources.

Chapter 3 focuses on the use of water resource and sustainability of agricultural growth. In countries like India significant growth in agricultural productivity could be achieved largely banking on ground water extraction. This chapter examines whether excess depletion of ground water will lead to unsustainability of growth in the farming sector. It explores theoretically and using empirical evidences whether extraction of ground water can be reduced by regulatory measures like price control and crop diversification in favour of less water intensive crops. This chapter also analyses whether public investment for harvesting rain water can be helpful for sustainable growth in agriculture. The social planner can make proper valuation of natural resources. So, it is the social planner who can trace out the optimal path for investment to build up infrastructure for harvesting rain water.

Chapter 4 deals with the problems of soil degradation due to intensive cultivation and excessive use of chemical inputs. Poverty is an important cause of resource degradation because the poor depends far more heavily on natural resources than the rich. Proper soil treatment measures are not taken up by the farmers due to shortage of funds and lack of access to appropriate technology. So, one important query of this chapter is whether policy intervention and support measures of the government will be effective in protecting soil health and sustaining growth in agriculture.

Land is the most important natural resource for agricultural production. With expansion of the industrial sector in an era of trade liberalization the competing uses of land for agriculture, industry, housing and real estate and urbanisation have created problems for agricultural growth. Chapter 5 explains using a two sector general equilibrium framework, whether inflow of foreign capital and consequent growth of the non-agricultural sector leaves less land for agriculture and hamper food security of the country. It highlights the importance of food security specially for the poor. So, it also addresses the problem of food price inflation and its impact on food security. After all, rise in food prices is related to agricultural production and food supply. Chapter 6 summarises the recent developments of biotechnology, irrigation technology, information technology and agricultural science and makes an assessment of how the frontiers of technology can be helpful for conservation of natural resources and agricultural growth in the future days. Chapter 7 gives a summary of the results of theoretical and empirical analysis and conclusions of the book.

The above issues related to sustainable growth in agriculture have been addressed in this book using theoretical models and econometric results based on Indian data. The techniques of dynamic optimization, choice under uncertainty, theory of general equilibrium and growth theory have been used in developing theoretical models. In econometric exercises, mainly time series analysis has been done. The results of unit root test, test of cointegration, test of causality and regression analysis have established the hypotheses and theoretical propositions of the study.

7.2 Analysis and the Findings

Chapter 1 provides an outline of the present scenario of Indian agriculture and describes the changes that have taken place in the farming sector of the country during the last 3–4 decades. The productivity in Indian agriculture has increased significantly in the period from 1970–71 to 2012–13. Total production of foodgrains has increased from 108.42 million tonnes to 257.13 million tonnes during this period. The net cropped area under foodgrains has remained more or less constant at 124 million hectares for the last four decades. But total production has increased mainly due to growth in yield per hectare. The yield per hectare has increased from 872 kg in 1970–71 to 2129 kg in 2012–13. This spectacular increase in productivity can be attributed to technological change, use of HYV seeds and chemical fertilizers and extension of irrigation. The expansion of irrigation has played a key role in the whole process of agricultural growth. The area under irrigation has increased from 22.10 % of the total cultivated land in 1970–71 to 47 % in 2012–13. The extraction of ground water has been the main source of extension of irrigation. The share of well irrigation in net irrigated area in the country has increased from 12.34 to 62 % during this period. This assured irrigation has greatly facilitated the use of HYV seeds and modern inputs. It has also helped greater intensity of cultivation particularly in the dry season. On the whole, the country has achieved a noticeable increase in production. However, at the same time, the growth in agriculture has caused huge stress on natural resources like land and water and it puts a serious question mark before the sustainability of growth in the farming sector. One important objective of this book is to analyse the factors that have facilitated the technological change in Indian agriculture and review the impact of technological change on productivity and resource use. Two factors land and water have been very intensively used in this process of technological change and productivity growth. So, conservation of water resource and maintaining soil health have become very crucial for future growth. This book has tried to find answers to the question of sustainable growth in agriculture by addressing the issues like crop diversification in favour of resource conservation, rain water harvest, surface water utilization, management of soil health, use of organic and green manures, public intervention for encouraging greater use of resource friendly inputs and the role of the frontiers of technology in resource management and productivity growth. Thus the agenda has been set to analyse the problems of sustainable agricultural growth in a very comprehensive and interrelated manner.

Chapter 2 analyses the major aspects of technological change in agriculture. One important reason for low productivity in traditional agriculture is technological backwardness. So, in 1960s and 1970s when productivity was very low in Indian agriculture and the country was facing serious food crisis it was necessary for the scientists, economic planners and the policy makers to expedite a technological breakthrough in Indian agriculture. Accordingly the new technology, known as HYV technology, was first introduced in certain parts of India in 1965–66. The major constraints towards large scale adoption of the new technology were risk and uncertainty associated with the new technology and modern inputs, lack of irrigation, small farm size, lack of proper information and so on. Technically HYV cultivation was scale neutral but given the socio-economic characteristics, the new technology has a bias in favour of large farms. So, There was a debate whether the small and marginal farmers would be able to adopt this new technology. One technical requirement of this new technology was assured irrigation and for this reason, high priority was given on tube-well irrigation. Various support measures and extension services were extended to the agricultural sector to popularize the use of the HYV technology among the farmers.

Risk and uncertainty was an important element of production under the new technology. Agricultural production is always uncertain. But input related risk under the new technology was something new. The modern inputs may increase risk in production unless they are used in a proper way. However, all the modern inputs are not risk-raising. So, a new production function described as 'Generalised Stochastic Formulation' (GSF) of production function' has been used to accommodate the flexibility in production function that an input which increases mean output does not necessarily increase uncertainty in production. On the contrary, the input may be risk-reducing also. Thus differential effects of an input on the mean and variance of output have been estimated. In Chap. 2 of this book, production functions have been estimated for HYV paddy in dry and rainy seasons using farm level primary data. Quite naturally, fertilizer, labour, quality of seed and quality of irrigation are found to have positive marginal effect on mean output. But they have failed to explain the variability of output by an significant extent. May be that the factors like agro-climatic and geo-physical conditions are more important in this regard than the inputs considered in the function. With respect to the factors that explain the rate of adoption of the new technology by the farmer, the regression results based on primary data show that irrigation, farm size and credit supply are significant determinants of technology adoption. Irrigation has the most significant positive impact on the adoption rate. However, irrigation fails to explain the adoption rate in the rainy season and this is possibly due to non-suitable agro-climatic conditions for cultivation of HYV paddy in the rainy season. The more interesting result is that adoption rate is higher in small farms compared to the large farms and it is explained by adequate support measures of the government and greater advantage of family labour.

The time series analysis of Chap. 2 establishes that irrigation, specially tube-well irrigation, has played a crucial role in technological change and productivity growth in Indian agriculture. It follows from cointegration analysis that there is meaningful long run relationship between irrigation, fertilizer use and yield per hectare in foodgrains production. The production elasticity of irrigation has been estimated to be 1.18. It means that one percent increase in irrigated area results in more than one percent increase of output in foodgrains. Thus irrigation is found to play a very significant role in India's agricultural growth. At the same time, excess depletion of ground water in some parts of the country like Punjab, Haryana, Rajasthan, Tamil Nadu, Uttar Pradesh etc. has weakened the resource base and posed a threat to future growth in agriculture. The extraction of ground water beyond permissible limits, continuous use of chemical inputs and intensive farming have caused soil degradation also.

In Chap. 3 a mathematical model has been constructed to demonstrate theoretically that if rate of extraction of ground water exceeds the natural recharge rate, the stock of ground water in aquifer will decline and eventually it will make agricultural growth unsustainable in the long run. The depletion of ground water has externality problems and the private individuals disregard the external and environmental costs of water extraction. The support measures of the government also make market distortions in this matter. As a result, the excess depletion of ground water has taken place in the country and it has put a threat to future growth in agriculture. Time series analysis has been done to have empirical verifications of the theoretical propositions on the above problems. The yield in foodgrains production per hectare and tube-well irrigation are found to be cointegrated implying that there is meaningful long run relationship between them. In OLS regression, the effect of tube-well irrigation on the yield in foodgrains production is highly significant and positive. This explains the importance of expansion of tube-well irrigation in India in increasing the production of foodgrains. Another component of productivity growth is fertilizer use. The test of cointegration between tube-well irrigation and fertilizer use suggested that these two variables are highly cointegrated and fertilizer use is significantly influenced by expansion of tube-well irrigation. But from 1990 onwards, the annual average growth rate of tube-well irrigation has started declining and this has led to decline in growth rates of fertilizer use and yield in foodgrains production. From 2004–05 onwards, the situation has, however, little improved. Although the growth rate of tube-well irrigation continues to decline in the growth rates of fertilizer use and yield in foodgrains production have increased in the recent years. This is due to greater utilization of surface water, watershed development and changes in technology and cropping pattern. So, it may be summarized that the growth in agriculture is highly dependent on the expansion of tube-well irrigation although, the potential of ground water irrigation has almost exhausted at least in certain parts of the country. That is why, the growth rate of tube-well irrigation is declining with its adverse effect on productivity. However, the situation has improved recently and that is possibly due to utilization of other sources of water supply, change in cropping pattern and technological change.

It is true that agricultural growth in India is largely dependent on ground water irrigation and the declining growth rate of tube-well irrigation has become a serious constraint to future growth. To ease this constraint, a number of alternative policy measures have been suggested and analysed in Chap. 3. These are: (i) crop-diversification in favour of less water-intensive crops, (ii) change in price policy towards conservation of water resource and (iii) policy measures for harvesting rain water. In Sect. 3 of Chap. 3, a theoretical model of crop-diversification has been developed to show that if crop-diversification is encouraged in favour of water-saving crops through price support, R&D expenditure for productivity growth and input subsidy, greater share of land will be devoted to the cultivation of less water intensive crops. As a result, the water demand for cultivation of the same amount of land will decline. This will lead to conservation of ground water. The comparative dynamic analysis has been done on the optimal path for ground water stock with respect to input subsidy, price support and R&D expenditure for the crop. The qualitative results in phase-diagrams show that price support and input subsidy for the less water intensive crop have positive impact on ground water stock while the effect of R&D expenditure is ambiguous. Anyway, it follows from theoretical results that crop-diversification may be helpful for conservation of water resource. The empirical evidences show that much diversification has not taken in the cropping pattern of India in the last 40 years. The conservation of water resource through crop-diversification is relevant in the dry season. Rice is a very water-intensive crop and if it is partly replaced by less water-intensive crops like oilseeds, wheat, pulses and vegetables, then the scope for saving water in irrigation increases. But for various reasons, much changes have not taken place in the cropping pattern in Indian agriculture. Besides, the cropping pattern in a particular region of the country depends on many factors such soil and geophysical conditions, climate and rainfall, available agricultural technology, food habit and so on. So, it is not always very easy to switch over from one crop to another. Nevertheless, crop-diversification is necessary and it should be encouraged whenever possible, not only for resource conservation but also for increasing agricultural income.

Prices are also used as policy instruments for management of natural resources. Generally, price support for the crops and subsidy on inputs result in market distortion leading to excess depletion of resources. A theoretical model of agricultural growth has been constructed to determine the optimal path for ground water extraction in Sect. 4 of Chap. 3. Then comparative dynamic analysis has been done on the optimal path for ground water stock with respect to output and input prices. The objective is to examine the effect of withdrawal of input subsidy and price support on the optimal path for ground water stock in a dynamic perspective. The perturbed curves in phase-diagrams in the present study do not give any unambiguous result. It does not suggest that price reform will be surely effective in water conservation. Neither does it rule out the effect of price change on ground water stock altogether. The time series cointegration results based on national level data also give similar picture. No cointegration is obtained between price and water stock. Thus, here, we do not get clear answer to whether price can be used as an effective instrument for water conservation.

Nevertheless, we can not rule out the role of price in resource management. Here we have econometric results from national level aggregate data which may mask many regional or local factors. In fact, the extraction or conservation of water depends on many region specific factors like rainfall, nature of soil, cropping pattern, irrigation technology, public investment etc. If the effects of geographical and agro-climatic conditions are stronger, then price may not be so important in water conservation. Otherwise, price is expected to play an important role and the government should adopt appropriate price policy in this regard.

Rain water harvest is another important measure of removing the constraint on water availability, specially in countries that experience high rainfall every year. Total annual precipitation of rain water in India is 37,00,000 million cubic metres out of which only a faction is utilized for irrigation purposes. So, rain water harvest has huge potential for irrigation and agricultural growth. The construction of dams and river projects are being discouraged on the grounds of environmental damage and displacement of population from land. But resource and environment friendly projects, watershed development, artificial recharge to the aquifer and micro projects may be suitably used for harvesting rain water. For this purpose, public investment is necessary for the development of infrastructure and capacity building. It is the social planner who can make proper valuation of costs and benefits of harvesting rain water. So, the social planner will be able to determine the optimal path for such investment. In this section, it has been shown with the help of a theoretical model that over exploitation of water by private individuals leads to unsustainability of growth in agriculture. But if the decisions are taken by social planner, extraction rate of water will not exceed the permissible limits.

A second theoretical model has been constructed to demonstrate that social planner can determine the optimal path for investment to develop infrastructure for harvesting rain water and thereby can ensure sustainable growth in agriculture. The infrastructure can be described as a kind of social capital that includes physical capital, human skill and social network. There is a trade-off between present consumption and accumulation of social capital for future production. The projects for harvesting rain water generates ecological services to the society which is taken into account by the social planner. So, the model shows that investment for rain water harvest by social planner not only ensures a sustainable balanced growth in agriculture but also, the growth rate is higher compared to market solution. This gives actually a Ramsey modified growth path. Therefore, it follows from this theoretical exercise that if investment is done for development of infrastructure to harvest rain water, it will be helpful for conservation of resources as well as for agricultural growth.

Land is the most important factor for agricultural production and in that sense quality of land and soil fertility are very important for sustainability of growth in agriculture. The technological change, intensive cultivation and use of chemical inputs have helped to increase agricultural production significantly and at the same time, all these have caused serious damage to the fertility of land, Chap. 4 of this book has analysed the causes of soil degradation, the problems of conservation of soil fertility and the importance of government intervention in maintaining soil health. The issues have been addressed theoretically and the theoretical propositions have been verified by empirical evidences. Soil fertility is a renewable resource and it has a process of natural regeneration. If depletion of soil organic matters (SOM) exceeds the natural growth rate of their regeneration, it will lead to land degradation in the absence of any soil treatment measures. The dynamics of this renewable resource are non-linear, non-convex and typically logistic-shaped. So, if the resource stock falls below a threshold limit, then there is the possibility that the resource will collapse and the land will turn into barren fields. So, treatment of soil through fallow system, crop rotation, use of organic and green manures are being suggested for maintaining soil health. Poverty is identified as one important factor behind land degradation because the poor depend far more heavily on natural resources than the rich. But in most cases they are not in a position to take appropriate measures for soil treatment and replenishment of soil nutrients.

In Sect. 2 of Chap 4 a theoretical model has been constructed to show that due to intensive farming and use of chemical inputs in excessive doses, the depletion of soil nutrients exceeds the natural regeneration rate. As a result, degradation of land takes place and it makes agricultural growth unsustainable in the long run. The model, however, suggests that if investment is made for artificial regeneration of soil nutrients, it may help land recover its fertility and maintain sustainability in growth. But in most cases, the poor farmers do not have the necessary fund or they do not find it profitable to make such investments. The conservation of soil fertility has positive externality. It protects the ecology and biodiversity and renders environmental services to the society. So, the government can intervene into the problem of land degradation and help conservation of soil by discouraging the use of polluting inputs and encouraging the use of resource and environment friendly inputs. In Sect. 3 of Chap. 4, a second model has been constructed to demonstrate theoretically that sustainable balanced growth is feasible if proper policies are adopted by the government. Here, in this model, organic manure has been included as an input in production function, in addition to chemical fertilizer. While the use of chemical fertilizer makes depletion of soil nutrients, the organic manures increase production and at the same time help regeneration of soil fertility. It is an environment friendly input. There is some degree of substitution between these two types of fertilizers. Now, if the use of chemical fertilizer is discouraged by imposing tax or withdrawing subsidy and the use of organic manure is encouraged by providing subsidy on the input and making some incentive payment, soil health can be maintained and this will ensure sustainability of growth. The theoretical results also establish that the range of resilience of the resource will increase if the use of organic fertilizer is increased.

From empirical information, it is found that there is land degradation in various parts of the country. But it is not always due to intensive cultivation. There are many other factors which cause land degradation. It has been revealed that the small and marginal farmers use greater amounts of chemical fertilizers per hectare than the large farmers. But the use of organic fertilizer is much less than chemical fertilizers in small farms. That means, the small farmers cultivate land more intensively without taking measures for soil treatment. It is also found that the ratio of fallow land is less in states where cropping intensity is higher. These are the general observations on soil health in the country. No rigorous econometric analysis could be done due to non-availability of appropriate data. So, we have derived some results from simulation using the software Matlab.

In the exercise of simulation, the growth rate of agricultural output (g_Q) has been specified to depend on the growth rate of use of chemical fertilizer (g_Z) and growth rate of use of organic manure (g_m). It has been tested whether the increase in the growth rate of use of organic fertilizer can increase the growth rate of output. The result confirms it. That means, growth rate of use of chemical fertilizer remaining unchanged at some positive level if the growth rate of use of organic fertilizer increases, the growth rate of output will also increase. So, organic fertilizer not only helps conservation of soil fertility, but also helps sustainability of growth in agriculture.

Apart from the quality of land, the available quantity and competing uses of land have great relevance for agricultural production and food security. So far as food security is concerned, agricultural price and purchasing power of the consumers are also important in addition to production of foodgrains. Chapter 5 has been devoted to the analysis of all these issues. The question of land use and food security has been theoretically discussed in a two sector general equilibrium framework. The area of land under non-agricultural use has been increasing over time with the expansion of the non-agricultural sector. After the introduction of the policy of trade liberalization in 1990s, the acquisition of land for industry, special economic zone (SEZ), housing and real estate and urbanisation has got high importance and it has reduced the availability of land for agricultural production. Now, the question is whether the acquisition of land for the expansion of non-agricultural activities will affect the food security of the country. To get answer to this question, the problem has been addressed theoretically in a two sector general equilibrium framework. Two production sectors have been considered in an economy—Food sector and Non-food sector. Both sectors use land and capital. Food sector is land-intensive while the Non-food sector is capital-intensive. The supply of land is constant and it is optimally allocated between the two sectors. The domestic rate of return on capital is assumed to be higher than the rate at the international level. Now, in an atmosphere of free trade if inflow of capital takes place, the supply of capital will increase in the domestic market. As a result, the capital-intensive Non-food sector will expand due to Rybczynsky effect. To allow expansion of the Non-food sector the food sector will decline. Now, whether this will affect food security depends on a number of factors. First of all, if trade surplus of the Non-food sector is sufficient to finance the necessary food import and there is no barrier to the imports of food, the decline of the food sector will not hamper the food security of the country. Secondly, if there is technological progress in the Food Sector, less amount of land will be required per unit of food production. In that case, the loss in production due to less amount of land available for agriculture may be over compensated by higher productivity of land and the problem of food insecurity can be avoided. The third aspect of food security is purchasing power of the labourers. Here, we have used the framework of Specific Factor Trade Model to explain this problem. Labour is specific to agriculture and capital is specific to Non-food sector. Land is mobile between the two sectors. Now, as the Non-food sector expands due to inflow of capital, and Food sector declines, the availability of land per labour declines. This leads to decline in marginal product and wage rate of labour. So, with decline in the wage rate the purchasing power of the workers attached with agriculture will decline. This may create food insecurity to the workers.

Public investment has a big role in agricultural production. Private investment largely depends on public investment and there is some complementarity between them. Many of the infrastructural facilities are of public good nature and these are developed by the government. The net capital formation in Indian agriculture in the public sector (at constant prices) has declined in 1980s and late 1990s. Time Series Cointegration results show that there is meaningful long run relationship between the growth rates of net capital formation in the public sector, fertilizer use and foodgrains production. In fact, agriculture has been neglected by the government in 1990s although from 2004–05, the situation has improved.

Another aspect of food security is food price. India is facing high rate of food price inflation since mid-nineties and in recent years, the inflation rate has been very high. Many factors are put forward in explaining this price rise. The factors include increase in per capita income (at constant prices), low growth rate of foodgrains production, increase in public expenditure and money supply. It follows from both theoretical and empirical studies in Sect. 4 of Chap. 5 that increase in per capita income has created additional demand for foodgrains in the market but supply has failed to keep pace with the growing demand. Foodgrains production could not increase proportionately due to lack of irrigation, resource degradation, technological stagnation and decline in public expenditure. The increases in public expenditure and money supply are also responsible for this price rise. It is also found that there has been policy failure on the part of the government in combating price rise of food items. In time of rising prices, the procurement of foodgrains by the government has remained higher than the release of foodgrains from buffer stock through public distribution system (PDS). It has increased the deficit in the food market. Similar is the case for trade policy in foodgrains movement. The net import has remained negative throughout the period. That means, export has remained higher than import. As a result, it has failed to arrest the price rise.

It is true that resource degradation has taken place in the process of agricultural growth in the last four decades and in many places, the problem has been very acute. Specifically in India, agricultural growth is largely dependent on ground water extraction and limited scope is left there for further extraction of this resource. Then in reply to the question what will happen to future growth in agriculture, it may be mentioned that very high importance should be given on the conservation and efficient use of existing resources. With respect to water resource various measures need to be taken for utilization and management of surface water, development of dryland farming, watershed development and micro irrigation projects. At the same time technology will play a very crucial role in future growth of agriculture. Particularly, biotechnology has great promises for agriculture. Besides, the frontiers of nano technology, information technology, geographic and information science (GIS) and remote sensing, irrigation technology will be of great help in the sustainability of growth in agriculture. The technology will reduce the demand for natural resources and at the same time will enhance the productivity of resources. In many cases, natural resources will be substituted by man-made capital. Thus the constraints of natural resources can be eased by technological change.

7.3 Conclusions

The major conclusions we draw from the analysis of this book are as follows:

(i) India has achieved remarkable growth in foodgrains production in the last four decades. The HYV technology, expansion of irrigation and use of chemical inputs have contributed significantly to the growth.

(ii) Tube-well irrigation has played a very crucial role in the whole process of India's agricultural growth. In fact, the growth has been achieved largely banking on ground water irrigation. But maximum potential of ground water irrigation has already been utilized in most of the states of the country. In certain parts of India the extraction of ground water has crossed the permissible limits of the nature. So, alternative ways of irrigation and appropriate technological progress should be given adequate importance to overcome this resource constraint.

(iii) Excessive depletion of ground water, intensive cultivation and continuous use of chemical inputs in increasing doses have caused serious damage to the resource base particularly of land and water and this puts a threat to the sustainability of growth in agriculture in the country.

(iv) The conservation of natural resources has become very important and urgent not only for agricultural growth but also for protecting the ecology, environment and biodiversity. Naturally, the issues like soil health, crop diversification, rain water harvest, surface water management, use of resource-friendly inputs and system of organic farming have come into prominence.

(v) The food crisis was so acute in 1960s and 1970s that it was compelling for country to produce more food as quickly as possible. Naturally, damage of natural resources, the problems of health and hygiene and the question of sustainability were not taken into consideration. On the contrary, the government extended support to the farmers in various forms without taking note that government measures may create market distortions leading to degradation of resources and the environment.

(vi) In the event of resource degradation and declining productivity, a second phase of green revolution has become very necessary. But we need such a technological progress which will enhance productivity in the farming sector and at the same time will ensure sustainability of growth by helping conservation of natural resources. So, it is very important to address the issues of technological change, conservation of natural resources and sustainability of growth in an integrated and comprehensive manner.

(vii) The problem of resource degradation is no longer confined to agricultural production only. The problems of sustainable growth in agriculture need to be addressed in a broader perspective encompassing land, water, forest, rivers, climate, rainfall, ecology and biodiversity. We have to take a holistic approach in dealing with the problems. Biotechnology, geography, remote sensing, nano technology, information technology, food technology are supposed to play very important role in future agriculture.

(viii) Given the biodiversity of nature across regions, scientific research for agriculture should be region specific, crop specific and resource specific. The government will have to play a crucial role in this regard. Many of the scientific innovations will come out of private research. So, we have to think over how the farmers can have access to the new knowledge in agriculture and resource management in an era of patent rights and WTO regulations.

(ix) The individual farmers have their own objective functions and they try to maximize their own profits without taking into consideration the social cost of resource use. So, market failure is there due to externalities. Sometimes market distortions are created by government support measures. So, reorientation of government policy with respect to public support to the farming sector is very necessary.

(x) In the event of expansion of the non-agricultural sector, and growing demand for land for industry, special economic zone (SEZ), housing and urbanization, many fertile lands are being transferred from agriculture to non-agricultural use. Land is very precious resource and fertile land has very clear comparative advantage for agricultural production. At the same time, land is necessary for the development of industries and other non-agricultural activities. So, we need to be very careful in land use.

(xi) Side by side with conservation of natural resources, public investment is also very important for agricultural growth. It is found that in 1990s when net capital formation in agriculture in the public sector declined, the productivity in agriculture also declined. Since there is some complementarity between public and private investments, to boost up private investment, the government must make necessary investment in agriculture.

Index

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