4.1 Classification of natural resources

➯ Three concepts used to classify the stock of depletable resource:

- **Current reserves**: are known resources that can profitably extracted at current price.
  - ✓ The magnitude of current reserves is expressed in number (e.g. tons of gold reserve …)
  - ✓ But it fluctuates with prices.
- **Potential reserves**: refers the relationship between a resources' market price and the amount of a resource that can be profitably extracted at that price.
  - ✓ Defined as a function rather than a number
  - ✓ The higher the price, the larger the potential reserves
- **Resource endowment:** refers to the natural occurrence of a resource in the earth's crust
  - ✓ Not related to price – it is geological, rather than an economic concept
  - ✓ This provides upper limit on the availability of resources
  - ✓ The entire resource endowment is unlikely to be fully extracted. Price would have to approach infinity.

Note:

→Current reserves ≠ Potential reserves

• Two dimensions:

- ▪ Economic: the first two concepts (current and potential reserves)
- ▪ Geological: the third concept (resource endowment)

• **Resource categories**: other distinctions among resource categories

➯ **A depletable (nonrenewable) resource**: a resource for which the rate of replenishment is so low and can be ignored

→ There is no potential for augmenting the stock in any reasonable time frame

– Examples:

- Energy resources: oil, natural gas, and coal
- Other minerals: copper, nickel

⇘ A renewable resource: a resource with a natural replenishment rate that augments its stock

→ a flow of renewable resources can possibly be maintained perpetually

– Examples:

- Plants and animals: forests, cereal grains, fish
- Other examples (nonliving): solar energy,

  surface water, soil

→ The flow of some renewable resources (plants and animals) depends on human activity.

- Stocks matter and extinction can occur

→ e.g. excessive fishing reduces the stock of fish and hence the rate of natural increase of the fish population

⇘ **A recyclable resource**: a resource, although currently being used for some particular purpose, exists in a form allowing its mass to be recovered once that purpose is no longer necessary or desirable.

– It can be depletable (e.g. copper) or renewable (e.g. water?)

Depletable, recyclable resource

– Its current reserve can be augmented by recycling

– Example: aluminum, copper, paper

– Recycling is less than 100% and the stock eventually declines to zero

– Therefore, even for depletable, recyclable resources, the stock is finite.

Depletable, non -recyclable resources

– Not all depletable resources can be recycled or reused

– Example: oil, natural gas, coal

– Such resources are consumed as they are used. Once consumed they are nonrecoverable

→ eventually, the stock of depletable (whether recyclable or non-recyclable) is of finite size.

4.2 Nonrenewable resources

Features that differentiate nonrenewable resources from reproducible goods

• **Stock constraint**

- The stock of reserves of nonrenewable resources is finite
- Total extraction over time cannot exceed the total stock of reserves

• **Scarcity rent**

- As long as the use rate is positive, nonrenewable resources are depleted
- The owner faces the opportunity cost of depletion
- Scarcity rent is the opportunity cost of forgone future net benefits

⇒ Other names of scarcity rent:

– User cost

– Resource rent

– Economic profit

– Hotelling rent

⇒ Names for scarcity rent per unit of resource extracted

– Marginal rent

– Marginal user cost

– Marginal profit

– Marginal Hotelling rent

– Net price

⇒ Profit maximization condition for a competitive firm:

– Operating reproducible good (e.g shoes)

P = MR = MC

→ Operating a nonrenewable resource

- **P = MCE + the opportunity cost of depletion**
- **P = MCE + MUC (marginal rent)**

<u>The theory of optimal depletion</u>

Efficient extraction path of a non-renewable mineral resource in a perfectly competitive market

 Simplifying assumptions

- ✓ The market price of the mineral remains constant over time (i.e. over the life span of the mine).
- ✓ The stock of reserves of the mineral is known prior to extraction.
- ✓ The mineral is of uniform quality.
- ✓ Marginal extraction cost is constant.

The economic problem:

•Determining the efficient extraction path for the resource.

•Extracting appropriate quantities of the resource in order to maximize the present value of profits from the stock of the resource.

Consider a competitive mining firm that owns and operates a mineral resource.

•The total stock = Q tons

•The price of the mineral resource is constant = P

•The quantity extracted at any time t = qt

•Marginal cost of extraction (MCE) is constant = C

But total extraction costs (TC) are an increasing functions of the quantity extracted in each period. At any time t,

TCt= MCE X qt= C (qt)

•The discount rate = r

•The life span of the mine is n years, i.e. t goes from 0 to n years

Ατ ανψ τιμε τ,
π_t= TRt-TCt
π_t-Profit (rent)
TRt-Total revenue at any time t
TCt-Total cost at any time t
TRt= Pqt;
TCt=C(qt)
Thus, π_t = Pqt-C(qt)

→ Total profit (π) form the mine (i.e. profit over all periods of extraction):

$$\pi = \sum_{t=0}^{n} [Pq_t - C(q_t)]$$
$$= Pq_0 - C(q_0) + Pq_1 - C(q_1) + ... + Pq_n - C(q_n)$$

→ The present value of total profit $(\pi *)$from the mine (i.e. the sum of the present value of profits over all periods of extraction):

$$\pi * = \sum_{t=0}^{n} \left[\frac{Pq_t - C(q_t)}{(1+r)^t} \right]$$
$$= \frac{Pq_0 - C(q_0)}{(1+r)^0} + \frac{Pq_1 - C(q_1)}{(1+r)^1} + \frac{Pq_2 - C(q_2)}{(1+r)^2} + ... + \frac{Pq_n - C(q_n)}{(1+r)^n}$$

Maximize $(\pi *)$ - the sum of the present values of profit.

• First order conditions:

$$\frac{\partial \pi *}{\partial q_0} = \frac{P - MC(q_0)}{(1+r)^0} = 0$$

$$\frac{\partial \pi *}{\partial q_1} = \frac{P - MC(q_1)}{(1+r)^1} = 0$$

$$\frac{\partial \pi *}{\partial q_2} = \frac{P - MC(q_2)}{(1+r)^2} = 0$$

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$$\frac{\partial \pi *}{\partial q_n} = \frac{P - MC(q_n)}{(1+r)^n} = 0$$

• Note: MC(qt) = C = MCE

• P - MCE = Marginal profit (marginal user cost)

• $\frac{\partial \pi^*}{\partial q_t}$ - PV of marginal profit (MUC) in any period t.

$$\frac{P - MC(q_0)}{(1+r)^0} = \frac{P - MC(q_1)}{(1+r)^1} = \frac{P - MC(q_2)}{(1+r)^2} = \ldots = \frac{P - MC(q_n)}{(1+r)^n}$$

$$i.e. - PV(M \arg inal.profit)_0 = PV(MP)_1 = PV(MP)_2 = \ldots = PV(MP)_n$$

Thus, profit maximization requires that the present value of marginal profit (MUC) be equal across periods.

That is, at any time t:

$$[P - MC(q_t)] = \frac{[P - MC(q_{t+1})]}{(1+r)^{t+1}}$$

$$\Rightarrow r = \frac{[P - MC(q_{t+1})] - [P - MC(q_t)]}{[P - MC(q_t)]}$$

$\rightarrow$ **Equality of the PV of marginal profit/ marginal user cost**

- ✓ **marginal user cost [P - MC (qt)] increaser at the rate of r (discount rate)**
- ✓ **this is called the r percent rule of extraction or Hoteling rule**
- ✓ **prices grow at a rate less than r percent if MCE is constant over time**

Example: Consider the solution values to the previous exercise.

- **P_0 = 3.91; P_1= 4.1; MCE = 2; r = 10%**
- **MUC (λ) = P - MCE**

– Year 0: 3.91 - 2 = 1.91

– Year 1: 4.1 – 2 = 2.1

• Present value of the MUC

– PV (MUC_0) = 1.91/1.1 = 1.91

– PV (MUC_1) = 2.1/1.1 = 1.91

• PV of the MUC is equal in both/all periods

• The undiscounted MUC rises at r (10) percent (r% or Hotelling rule) due to increased scarcity. Price increases at 4.9% (less than r/10%)

Implications of the Hotelling rule

• If the resource rent increase at a rate less than the

discount rate

– The owner would extract the resource as quickly as is

technically feasible

– No need to keep a resource in a ground that is increasing in value at a rate less than can be earned in alternative investment (discount rate)

• If the resource rent is growing at a rate greater than the discount rate

– No incentive to extract the resource

– Resource left in the ground is more valuable to the owner than resource extracted

• For efficient resource extraction, the resource rent should grow at the rate of r (the discount rate

• How fast should a firm extract its stock of a mineral resource?

– At a rate that increase the marginal user cost (marginal rent) at r%.

4.2.1 Energy resources

• Non-renewable energy resources such as coal, oil, and gas are depletable, nonrecyclable resources.

– Exist in the form of fixed stocks (finite size) of reserves

– Once used, cannot be recovered

– The sum of resource use equals the available stock.

– Thus, the resources will be depleted as long as the use rate is positive.

** Efficient extraction path of a non-renewable energy resource, such as oil in a perfectly competitive market**

- **Two period model for a competitive oil firm:**

– Consider a firm that owns and operates an oil field. Suppose the fixed stock of oil is 41.16 million barrels. Assume that demand for the resource is linear and the same over time given by $q_t = 100 – 4p_t$. Marginal cost of extraction is constant and equal to Birr 5. The rate of interest at which rents are discounted is 10%. The firm operates for two periods only - the current period, year 0 and the subsequent period, year 1.

• Determine the efficient extraction path of the resource - derive the path of oil output, prices and marginal user cost over the two time periods?

4.2.2 Non-energy minerals

• Depletable, recyclable resources

– The effect of recycling is to increase the size of the available resource.

• Suppose there are 100 units of a resource with a useful life of one year. Suppose further that 90% of the resource could be recovered and reused after one year.

– During the first year, the full 100 units could be used.

– At the end of the first year, 90% of the resource could be recovered, leaving 90 units for the second year.

– At the end of the second year, 90% of the remaining 90 units could once again be recovered, leaving 81 units for the third year, and so on.

– How much more of this resource was made available by recycling?

• Let the original stock be A and the recycling/recovery rate be a.

• Then the total amount used would be A + Aa +Aa

2

+ Aa

3

+.... -an infinite sum.

• As time becomes infinitely long, the sum of this series is given by A/(1 - a).

• For non-recyclable resources a = 0. Hence the sum of resource use equals the available stock, A [A/(1-0) = A].

• For recyclable resources a > 0. Hence the sum of the resource flows exceeds the size of the (original) stock. The closer to 1.0 a is, the larger the sum of the resource flows

• For example, if a=0.9, the sum of the flows is 10A, 10 times of the stock [A/(1-0.9)=A/0.1=10A).

• In this case, the effect of recycling is to increase the size of the available resource by a factor of 10.

• However, unless the recycling rate is 100% (a = 1.0), the sum of the resource flows is finite. While some recycled materials can be recycled forever, the amount will become infinitesimally small as time goes on

□ The effect of changing parameters on the rate of resource extraction

• Effects of unanticipated new discoveries

– Other things remaining the same, unexpected discoveries of additional reserves implies:

– The time to depletion will be longer.

(The time horizon/path to depletion is extended)

– A slower rate of growth in rents and prices than before.

(The entire rent and price schedules are shifted downwards)

– Current consumption (extraction) levels are increased.

– Initial rents and prices will be higher

• Effects of a change in r

• Other things remaining the same, a decline in r implies:

– A slower rate of growth in rents and prices than before.

(The entire rent and price schedules are shifted downwards)

– Initial rents and prices will be higher and the

time to depletion will be longer.

(The time horizon/path to depletion is extended)

- **An increase in r implies a shortened time to depletion (depletion schedule) and lower initial prices and rents.**

(The higher is r, the faster should be the rate of growth of the resource price.)

- **Effect of a change extraction cost**
- **Other things remaining the same, a decline in extraction cost implies:**

– Rent will increase and price decrease

– The time to depletion will be shorter.

(The resource is exhausted earlier)