

This single stand model with a finite time horizon of one rotation illustrates basic economic concepts. The central question facing a forest manager is to select an optimal harvesting period and corresponding volume that maximises net returns and maintains the flow of products. A more complex economic model would still address this central question but have a larger forest with many individual stands over an infinite time horizon. In this dynamic model, income is represented by the net gains from the current harvest plus the value of future income from subsequent forests grown on the same area. Thus, we are dealing with an income stream over infinite rotations.

There are many economic issues involved. Delaying the harvest brings an opportunity cost of deferring income from both the current and future harvests. However, depending on the age-structure, the current forest may also continue growing in volume. With constant timber prices, this means incremental increases in income by waiting. At the same time, this will add to the opportunity cost of having to wait to harvest second-growth stands in the future. An optimal harvesting period would equate the present value of marginal income gained from delaying current harvesting with the present value of the opportunity costs incurred.

Relaxing the assumption about constant timber prices adds another dimension to the dynamic model. The optimal harvesting rule would equate the marginal productivity of the forest (incremental growth in volume and value) plus the marginal capital gains of real price increases, with the discount rate. If the growth in value (incremental growth plus capital gains) of the standing forest is increasing faster than the discount rate, then it makes sense to delay the harvest. The asset value will continue to grow. On the other hand, if the growth in value is less than the discount rate, the logical decision is to increase harvesting. The interplay of prices, discount rate and forest growth rates becomes critical to the harvesting decision⁶. Increasing the discount rate tends to favour increased harvesting and a decrease in the optimal rotation age. Increasing prices tends to enhance the incremental value of current stands but also the opportunity costs.

Looking beyond fibre production, amenity benefits such as recreation and aesthetics should be included in forest economics. Amenity benefits can be sustained only by delaying the harvest of the forest. If the amenity benefits are high enough, they can offset the opportunity costs of delaying harvesting to the point where the forest should be designated a wilderness area.

c) Management issues

The goal of modern forest management is to create a regulated forest containing the same number of equally-sized blocks as the rotation age. If the rotation age is 40 years, there would be 40 blocks representing all 40 age classes. Each year, the one block of trees at age 40 with a volume of mature forest is harvested, then replanted. Next year, another block moves into the 40-year age class and is then cut and replanted. Efficient property rights usually exist. Over one rotation period (equal to the harvesting age – biological or economic), the entire forest would have been harvested. The block first cut 40 years previously would now have a regenerated forest ready to harvest in the second cycle. This pattern of harvesting and planting reflects the concept of sustained yield forest management. Where human harvesting is planned to equal the average level of forest growth, sustainability problems can arise when forest depletions occur from fire, insects, disease and illegal cutting. While a regulated forest may be slightly over-harvested one year, say because of a bad fire, careful management can balance the flow of outputs by reducing the human harvest in the next year and/or investing in intensive practices such as thinning or fertilisation to increase future yields. Whether these management approaches are based on strict biological rules or incorporate economics is a matter of debate in the forestry community. In reality, biological criteria still dominate the selection of the rotation age and harvest level.

Where forests are not well-regulated, such as in communal areas in Africa, efficient property rights are problematic. More often, open-access common property rights are the case, which frustrates basic management efforts. As well, a lack of explicit timber values, for example on fuelwood, only increases the incentive for people to harvest beyond sustainable limits. Improving

⁶ For readers who like to solve these kinds of problems with mathematics, there are numerous references that illustrate these points through calculus. See for example Pearce *et al* (1990); Pearce and Turner (1990); Howe

property rights is an essential component of more effective forest management through direct title to forests by communities, long-term leases renewable every few years upon performance, or shared property rights with government. When communities maintain real or de facto property rights and retain forest revenues, there is a stronger incentive for protection and sustainable harvesting.

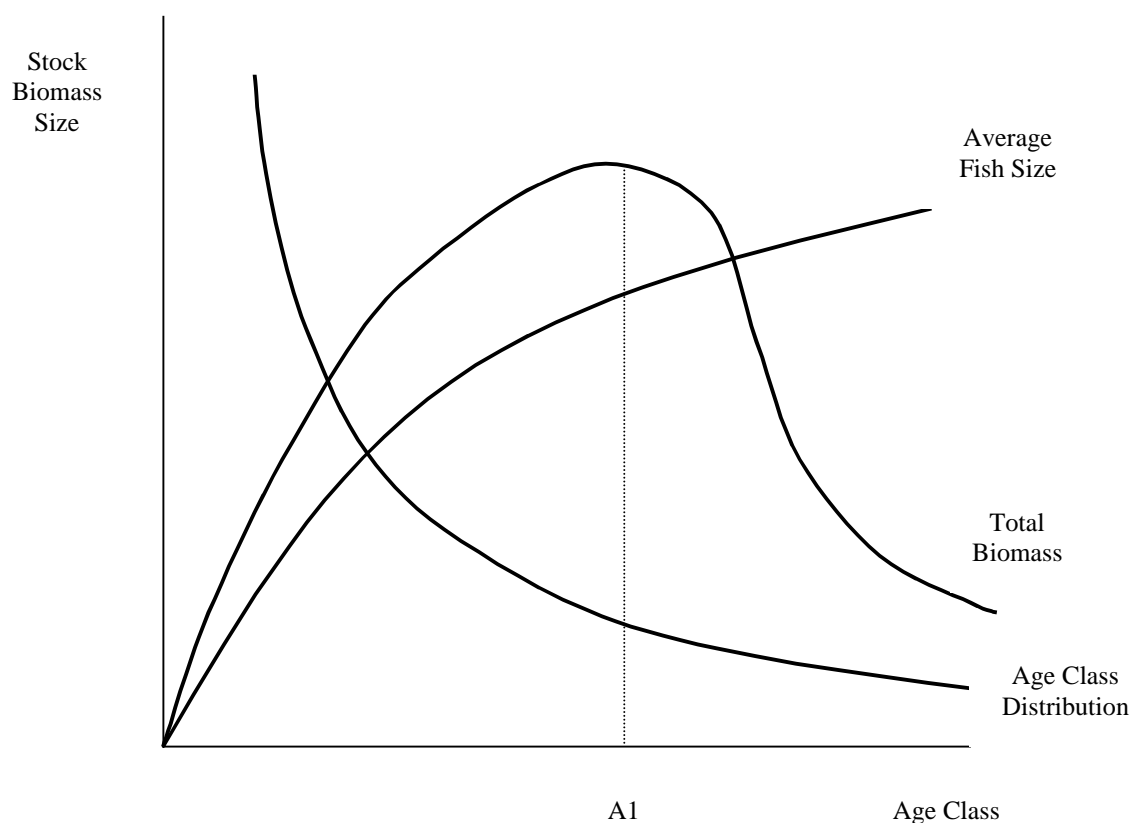
5.2.3 Renewable Resources with Common Property Rights -The Case of Fisheries

Fisheries have received extensive attention in recent years because of the collapse of many stocks around the world. The collapse of the cod fishery off Canada's Grand Banks and the stocks of Namibia are only two examples. Sharp declines in fish stocks off eastern Africa have also been noted. Unlike forest resources, fish are a fugitive resource. They migrate in and out of national fisheries management zones (200-mile limits) and are very difficult to monitor. Because fisheries are often harvested under common-property rights regimes, they require a different analysis.

a) Biological relationships and harvesting

In a fishery where no fishing occurs, the usual biological functions of age distribution, average size and total biomass are shown in Figure 5.3. The age distribution curve shows that the stock is comprised of large numbers of young fish and fewer older fish age classes. This is because over time, the mass of juvenile fish declines through mortality from disease and predators. The average fish size obviously increases as the fish move from one age class to the next older class. At some age class (A1 in Figure 5.3), the total biomass stock will be maximised when increases in average fish size offsets mortality losses in older age classes by the largest difference. Assuming it were possible to adjust fishing nets to catch only that age class, this would represent the maximum sustainable biological harvest (Howe 1979).

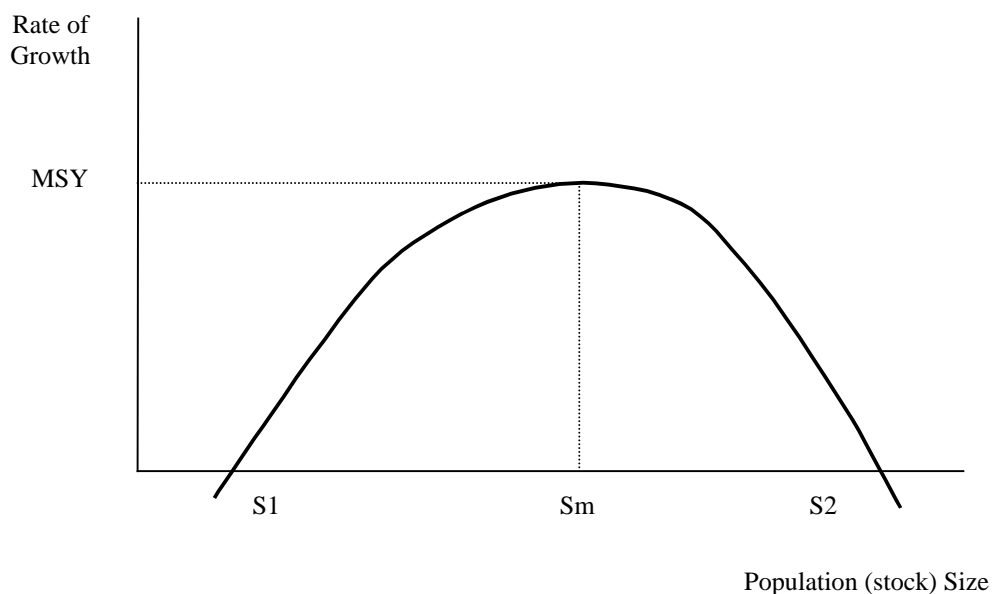
(1979); and Clark (1990).

Figure 5.3: Age class, biomass stock and average fish size

Shaefer (1957), proposed another biological model relating growth in fish stocks with the size of the fish stock (Figure 5.4). S_1 and S_2 represent equilibrium points where the rate of stock growth is zero. S_2 is a stable equilibrium point. It is also where fish stocks will gradually reach equilibrium with the natural environment. At this point, the aggregate annual stock growth would equal natural losses in the absence of external influences. The stock is at a maximum size but net growth is zero. Movement to the right of S_2 (an increase in stock from migration) would lead to overcrowding relative to food supplies and the stock would return to S_2 . A move to the left of S_2 , perhaps from disease, would reduce the stock relative to food supplies. Gradually, the stock would recover and return to equilibrium at S_2 . S_1 is an unstable equilibrium. In most cases, the stock size will gradually move to equilibrium at S_2 . However, if the population is reduced to the left of S_1 , the population will move to zero because of insufficient breeding stock. Extinction is the result. S_m is the point where the stock has the maximum natural growth rate, similar to the forestry MAI. Fisheries biologists would consider this point to represent the

maximum level of harvest, or maximum sustained yield (MSY). Again like the forestry case, this point does not include economic factors. A central question is whether S_m represents the economically optimum harvesting level.

Figure 5.4: The stock-growth relation - fisheries



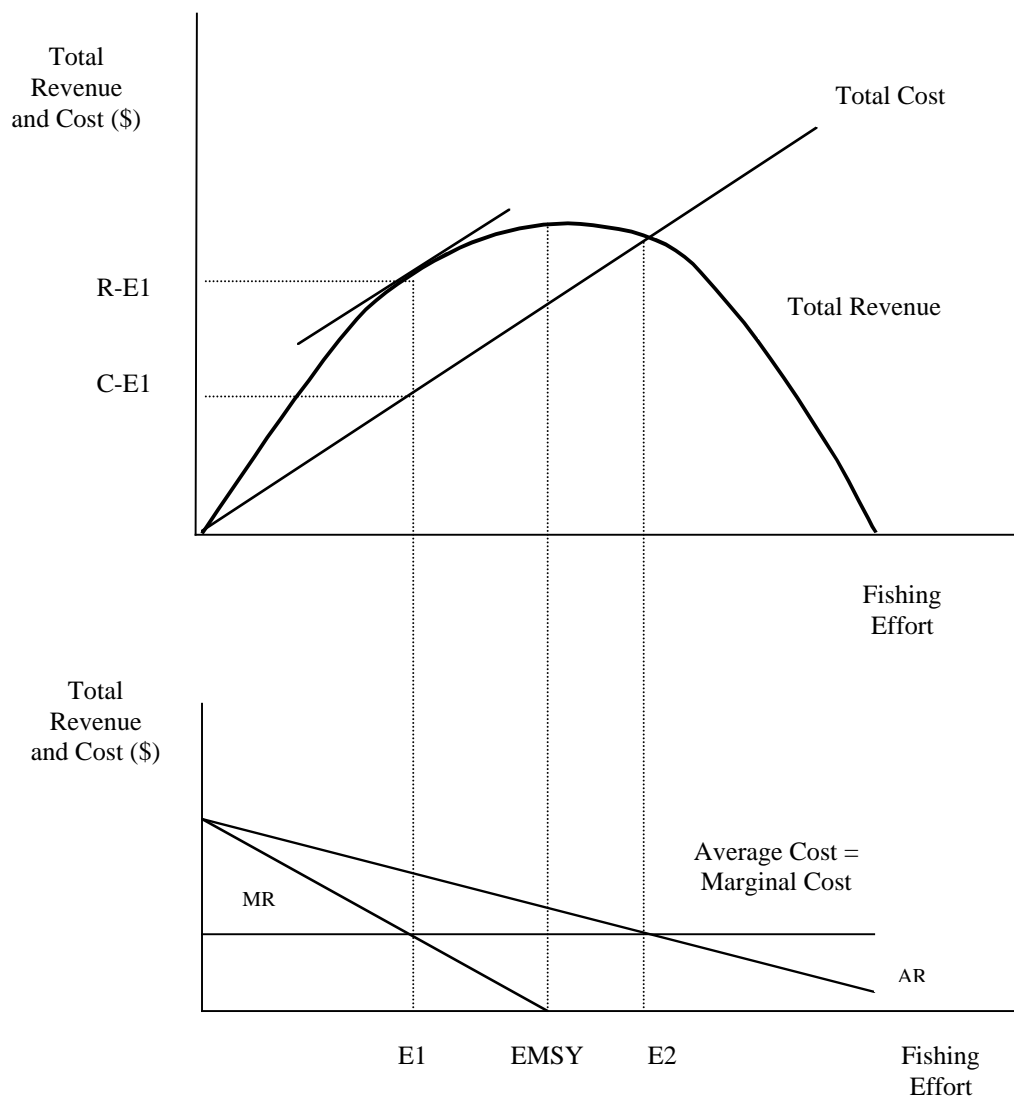
b) Economic aspects of fisheries

An efficient harvesting point is where net benefits are maximised. For fisheries managers, the central economic question tends to focus on selecting the optimum level of fishing effort relative to maintaining stocks at some sustainable level. A basic economic model assumes constant fish prices, constant marginal cost of a unit of fishing effort, and that the amount of fish caught per unit of effort is proportional to the stock size. Thus, as stock size increases, the fish catch per unit of effort will also increase. Figure 5.5 represents an efficient sustainable yield. The upper chart links fishing effort with fishing costs and revenues. A 45-degree line originating from the lower left corner represents costs. The total cost function is a straight line because of the assumption of constant marginal costs. Revenues are simply price times catch volume. Therefore, the revenue curve has the same shape as the curve in Figure 5.4 since fish prices are assumed to be constant. The slope of the revenue curve reflects marginal revenue. An increase in fishing effort is represented by a movement from left to right in Figure 5.5. As fishing effort is increased from the left axis on the upper chart, a point is reached where additional effort will reduce the

sustainable harvest and revenue. This point, E-MSY is the same maximum sustained yield as in Figure 5.4. Net benefits are represented by the difference between total revenues and total costs. Maximum net benefits occurs where the vertical distance between total costs and a tangent along the revenue curve is greatest, in other words where marginal cost equals marginal revenue. This is point E1.

Clearly, the economically efficient harvesting level (E1) is well below the biological maximum sustained yield (EMSY). In a static economic model, a zero discount rate is assumed and the efficient harvest level is point E1. However, in a dynamic model with positive discount rates, gradually increasing the discount rate will tend to expand the efficient level of effort to the right. At an infinite discount rate, the equilibrium position will be E2.

Figure 5.5: Optimal fishing level, costs and revenues



The lower chart in Figure 5.5 illustrates the impact of property rights. Position E1 reflects a situation of efficient property rights. Property owners would behave rationally and maximise their net returns where marginal cost and marginal revenue are equated. In reality however, many fisheries are open access, common property situations. Each individual in the fishery has an incentive to increase their catch because reductions in profit are spread over the entire industry. Individuals will continue to increase their catch until average cost equals average revenue (E2). At this point, all excess rents are dissipated. This is the same position as with an infinite discount rate. Efficiency and sustainability criteria are not addressed in a common property resource situation.

c) Management issues

As with open access forests, fisheries without efficient property rights usually are unsustainable. Public policy to address this failure can take many forms. One approach is to promote aquaculture farms for appropriate species. While recognising that aquaculture can bring its own environmental problems, it does reflect one option for reducing fishing stress on certain species. Another approach is to raise the cost of fishing, thus rotating the total cost function in Figure 5.5 towards the vertical axis. This would reduce the optimal fishing effort to a lower level. Fishing costs to the private sector have often been increased by governments through regulations over fishing equipment (boat or net size), location (closing some areas), and shortening the season allowed for fishing. Most of these regulations are focused on maintaining the biological MSY rather than on maximising net benefits and accordingly, they often are not as successful as desired.

More effective results have tended to follow a direct tax on fishing effort. However, perhaps the most successful results globally have occurred through the introduction of individual transferable quotas (ITQs). Typically, quotas are established that entitle the holder to a specific catch of fish. The quotas are transferable and thus can be bought and sold. The aggregate of all quotas equals the most efficient catch level. The initial quotas can be dispersed to existing fishermen or auctioned in some way. Existing quotas can also be bought back by government to reduce the number of boats (and hence total fishing effort) in the fishery.

5.3 ECONOMICS OF NON-RENEWABLE RESOURCES

5.3.1 Basic Depletion Model

Non-renewable resources have unique characteristics that differentiate them from renewable resources when constructing an economic model of optimal depletion. First, economic reserves are relatively fixed in the absence of new technology. Second, the total identified resources are finite. Unlike forests, total stocks cannot be augmented by human intervention. Third, depletion of one unit today means one less unit available in the future, thus current production decisions must account for foregone production and resulting benefits in the future. This is the concept of marginal user cost or opportunity cost. Marginal user cost is the present value of these foregone opportunities (Pearce and Turner 1990). Total costs equal the extraction costs plus marginal user costs. A more precise measure of cost would include external or environmental costs (Pearce and Markandya 1989). In this case, total opportunity cost = marginal extraction cost + marginal user cost + marginal environmental cost.

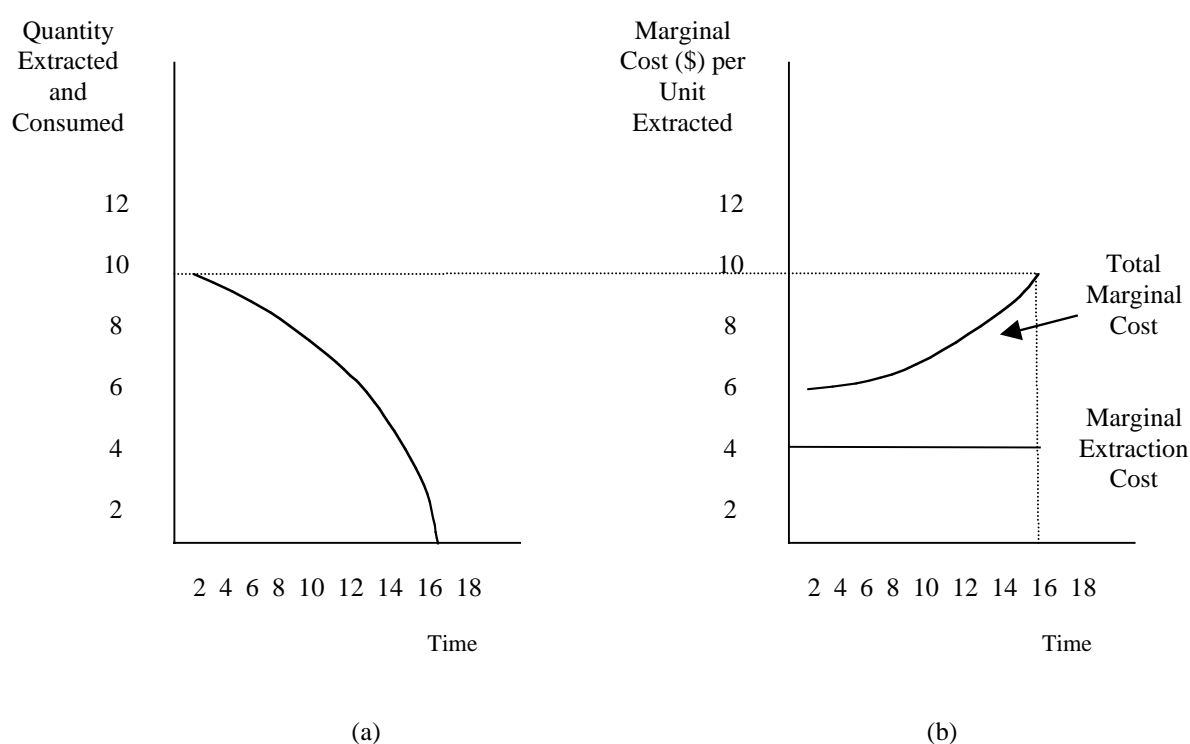
Initially, assume that the marginal extraction cost is constant. With a stable demand curve and constant marginal extraction costs, marginal user costs will increase over time, reflecting increasing scarcity. The rate of increase in the current value of the marginal user cost will equal the discount rate⁷. In an efficient allocation of depletable resources, the equality of the discount rate and marginal user cost maintains a balance between current and future production. Higher discount rates tend to result in more rapid exhaustion of the resource. Increasing extraction costs also produce the same result.

5.3.2 Optimal Depletion – Finite Stocks And No Substitutes

Figure 5.6 represents a case of finite stocks, no substitutes and constant marginal extraction costs. Environmental costs are ignored. Chart (a) illustrates the efficient pattern of depletion over time. After 16 years, the stock has been depleted. Chart (b) shows a constant marginal

extraction cost of \$4 per unit. Total marginal cost, comprising of marginal extraction costs and marginal user costs, rises from about \$6 to \$10 over the lifespan of the deposit. This reflects increasing scarcity of the resource over time and the associated increase in marginal user cost of current extraction. In response to rising costs (chart b), quantity extracted falls over time until reaching zero, which occurs at the same point when total marginal cost reaches \$10 per unit. That also matches the highest willingness to pay from chart (a). At this point, demand and supply equal zero.

Figure 5.6: Quantity profile (a) and cost functions (b), no substitutes

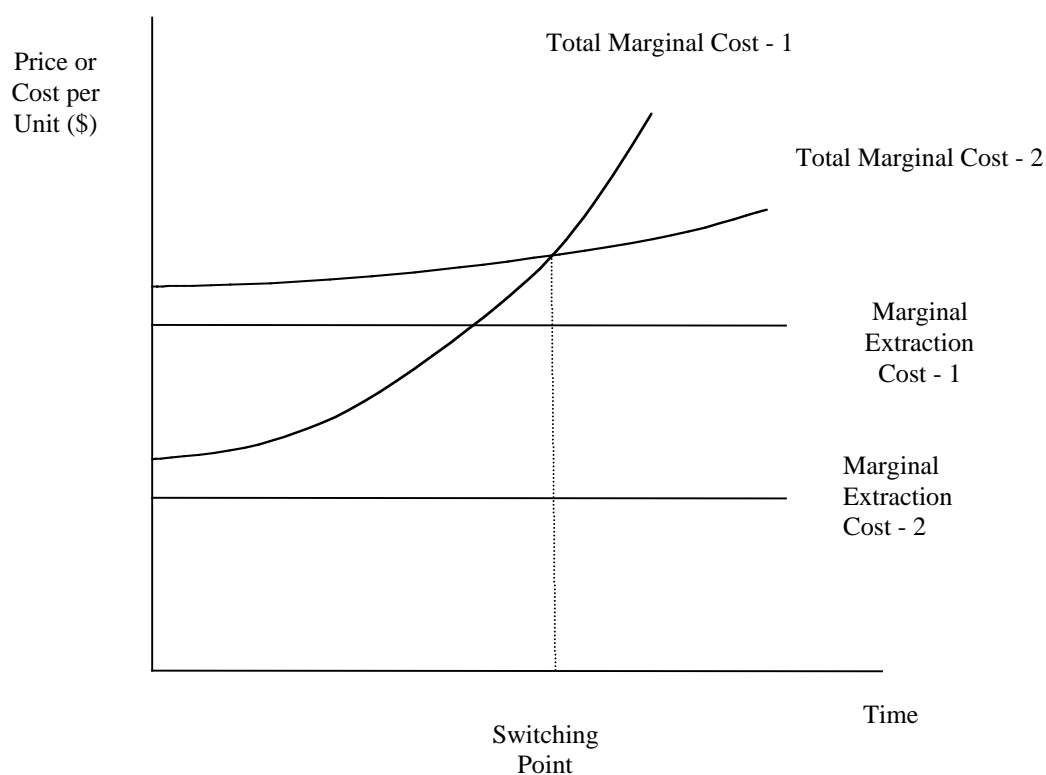


⁷ This is the basic condition for optimal depletion of *in situ* non-renewable resources first postulated by Hotelling (1931). The “Hotelling” rule is still an important concept in resource economics although it does omit stock effects (physical effects on future conditions of the stocks caused by current depletion) and environmental costs.

5.3.3 Optimal Depletion – Finite Stocks and a Switch to more Expensive Sources

The case of a finite stock of non-renewable resources is not always reality. Producers often switch to lower-grade and higher-cost resources as better quality and more accessible resources are mined. In this case, the producer is shifting to a resource with a higher constant marginal extraction cost (Figure 5.7). The switching point is when the total marginal cost curves intersect. Prior to the switching point, only resource 1 is used because it has a lower total marginal cost per unit, comprised of the marginal extraction cost (constant) and the marginal user cost. Because of the rising marginal user cost, resource 1 is now more expensive, even though it has a lower marginal extraction cost. This example illustrates the importance of accounting for user (or opportunity) costs in resource economics.

Figure 5.7: Shifting to higher extraction cost non-renewable resources



5.3.4 Management Issues

Policy-makers often believe that producers of non-renewable resources will want to extract the resource as fast as possible. In reality, if producers hold well-defined property rights to the resource, they will recognise that the resource has two values, first when mined and sold, and second, as an asset in the ground. If the resource price is rising, the asset value will also increase. A profit-maximising producer will try and balance these two values.

On the government side, price controls are often used in some countries to keep consumer prices lower than what an efficient market would allow, particularly for energy. Price controls tend to increase resource exploitation because the future asset value is constrained. Price controls can also reduce the incentive for exploration and technology development of substitute (renewable resources) and more efficient mining technology. Environmental costs of non-renewable resource extraction should be internalised back to the producer where possible. Various economic instruments are available (see module 7) that can provide incentives for producers to reduce environmental impacts.

5.4 MEASURES OF RESOURCE SCARCITY

5.4.1 Physical Measures of Scarcity

Two physical measures of scarcity are commonly used in assessing future availability of non-renewable resources, static reserve index, and exponential index.

a) Static reserve index

The static reserve index (or reserve-to-use ratio) is simply the current reserves of a particular non-renewable resource divided by the rate of current consumption. This measure indicates the number of years remaining before the resource is depleted. While simple to understand, the static reserve index focuses only on non-renewable resources, it fails to account for price/cost changes shifting more resources into the current reserve category, and does not make allowances

for improved technology. It also assumes static rates of depletion. This index often portrays an overly pessimistic outlook.

b) Exponential index

The exponential index is more sophisticated by providing for an average percentage change in resource consumption over time to match forecast economic growth. The index is calculated as:

$$\frac{\ln(r \times s) + 1}{r}$$

where: ln = natural log

r = average annual % growth in resource consumption

s = static index (years)

Other than this feature, the exponential index shares the same problems as the static reserve index of not accounting for economic and technological influences on stocks and depletion rates.

5.4.2 Economic Measures of Scarcity

Four main economic measures of scarcity are used to assess future resource availability, resource price trends, scarcity rents, marginal extraction costs and marginal discovery costs.

a) Resource price trends

Resource price trends are based on the theory that efficient resource prices will reflect factors such as rising demand and higher prices, changes in extraction costs, and augmenting stocks through substitution. Trends in resource prices, adjusted for inflation, should therefore indicate growing or declining scarcity. As a resource stock becomes scarce relative to demand, the expected response is an increase in price. Where markets are efficient, this indicator is effective and can be applied to both renewable and non-renewable resources. However, one of the problems with this approach is that many natural resources are plagued by imperfect market

prices, or no market price at all. Also, market prices do not reflect externalities that have not been internalised.

b) Scarcity rent

Scarcity rent is based on the concept of user cost, which is the present value of all foregone uses from the current extraction of a resource (Howe 1979). The scarcity rent is the user cost of a marginal unit of resources being extracted at a particular point in time. It is forward-looking by accounting for future changes in demand, prices, costs, and technology. Under well-informed and competitive market conditions, scarcity rent will equal the user cost and market price of the currently marginal resources in situ. Like resource price, the scarcity rent can be estimated for renewable and non-renewable resources.

Where natural resource stocks are large relative to current and future demand, scarcity rents would not increase and in fact could be zero if changes in technology led to decreasing extraction costs. This could be the case of a frontier economy, for example in Canada in the 1800s where forests were virtually infinite relative to current and forecast demand. An alternative case is with a finite stock such as rare minerals and rising extraction costs. As the stocks become depleted relative to demand, extraction costs will increase and at the same time, the market price of the commodity will rise. Scarcity rents will usually increase over time, signalling reduced resource availability.

Deriving scarcity rents is difficult in practice and requires substantial information. In some cases such as common property resources, scarcity rents are zero at all times. Interpreting scarcity rents is also tricky because of the influence of costs. If demand for the resource is highly price elastic, then increasing production costs relative to price will gradually squeeze rents to zero. This would signal no increase in scarcity.

A simple approach to estimating scarcity rent is taking the resource market price net of all factor-input costs. It represents the net income or rent accruing to the resource owner. It is intuitive that as a natural resource becomes scarce, its rental value per unit will increase. However, there are many difficulties with this approach. The rent may in fact reflect a “Ricardian rent”, which is an

excess of rent value over scarcity rents due to short-term market constraints on supply, differentials between resource quality, etc. Also, precise information on resource rents and royalties for minerals or forests is often not published. Some governments simply will not release these data. Estimating rents indirectly requires cost information, which is usually not available from the private sector.

c) Marginal extraction costs

Marginal extraction (or unit) costs are a fairly effective indicator of scarcity. If economic reserves of depletable resources were becoming scarce, firms would have to seek out more costly stocks to meet a given level of demand. This would result in higher marginal extraction costs as an indicator of scarcity. The benefit of this indicator is that it avoids the problems of linking changing prices and costs. This indicator can be applied to renewable and non-renewable resources, including common property resources. One problem however, is that the indicator only reflects current cost and pricing conditions. It does not reflect future changes in demand or extraction costs. Also, unit costs are difficult to derive in practice because private sector costs will not usually be freely available. Barnett and Morse (1963) derived a method of estimating unit costs based on marginal labour and capital costs. Simply, if increased labour and capital are required per unit of extracted resource over time, it signals growing scarcity. Conversely, if these inputs are declining for every unit of resource extracted over time, the index reflects new, lower cost resources being discovered or technology being developed to offset the effect of inferior grades or higher cost resources being tapped.

d) Marginal discovery costs

As natural resources become scarcer, it is logical to assume that the marginal cost of locating new stocks in more remote areas will increase. As an example, exploring for oil in the seabed will be more expensive than shallow fields on land. Producers will explore lower-cost sites first. These then form the current reserves exploited and as extraction costs rise, exploration shifts to less accessible regions. Where marginal discovery costs can be observed, they can form a proxy for marginal scarcity rent.

e) Using economic measures of scarcity

All four economic indicators have strengths and weaknesses. Using only one indicator can often lead to a wrong conclusion about resource scarcity. Trends in real prices are effective where markets are efficient for the resources in question. Scarcity rents can be used where information is available to derive estimates. Commercial forests are a common case because rents can often be indirectly estimated. Where scarcity rents cannot be derived, marginal discovery costs may be used as a proxy. Unit costs are often used for common property resources. The best approach is to use as many indicators as possible.

5.4.3 Are Resources Becoming Scarce?

For more than 150 years, academics have argued over the scarcity of natural resources and the long-term supply of these resources relative to forecast demand, particularly with assumptions of increasing global population. Concern over natural resource limits was popularised by Thomas Malthus in the early 1800s. Malthus proposed a pessimistic view that absolute physical limits on the availability of natural resources, especially land, would restrict human development. At the same time, David Ricardo suggested an opposing and more optimistic view. He proposed that rising extraction costs and prices would stimulate increased exploration and technology to ameliorate physical resource scarcity.

This debate continues. The 1972 study by Meadows et al, “Limits to Growth” and its updated version in 1992, “Beyond the Limits”, provide a good example of a pessimistic model. These studies have three general conclusions, based largely on static and exponential scarcity indices. First, society will run out of non-renewable resources within 100 years assuming no major changes in the traditional physical, economic and social relationships governing the world. Second, a piecemeal approach to solving these problems will fail. Third, resource depletion and collapse of ecosystems can only be avoided by an immediate limit on population and pollution. The 1992 study concluded that many of the resource limits identified in 1972 had already been exceeded, for example by the collapse of some fish stocks, the high level of deforestation and soil erosion in many countries, and increased pollution in many large cities. While putting

forward a pessimistic view, the authors indicated that a collapse is avoidable by making the right choices now.

Barnett and Morse's (1963) seminal work titled *Scarcity and Growth: the Economics of Natural Resource Availability* examined unit cost and real resource price trends for a wide range of commodities in agriculture, mineral and forestry from 1870 to 1957. The study was focused on the United States. With the exception of forestry, the authors found no empirical evidence of rising resource scarcity. The authors concluded that improved technology, substitution, and increased exploration mitigated resource scarcity.

Johnson, Bell and Barnett (1980) updated the 1963 study and found that the trend of increasing scarcity in forestry was reversed from 1958 to 1980. All agricultural and mineral products from the 1963 study continued to exhibit declining unit extraction costs to 1972. Since 1962, only the unit costs for fishing increased over time. The optimistic view of Barnett and Morse was challenged however, in more recent studies using more sophisticated methods based on price trends (Smith 1980; Slade 1982).

The optimistic view is shared by Simon (1984) under the title *The Ultimate Resource*. Simon concludes that the general standard of living has risen along with an increasing world population. Resource availability has been increasing as impending scarcity causes higher prices, thereby stimulating expanded exploration, and investment in technology to find substitutes or methods of recycling. Simon provides data to illustrate that global food production is increasing, natural resources are not becoming scarcer, and pollution levels are declining as incomes increase in most countries. The most recent optimistic view is held by Lomborg (2001) in, which he states that the resource base is actually growing.

Balancing these opposing views of resource scarcity and inferring a future direction depends largely on human behaviour (Tietenberg 2000). Optimism is warranted where the human (and political) response to increased environmental pressure is to seek positive change. On the other hand, if the human response is to intensify environmental pressure, then a more pessimistic outlook may be justified. Environmental issues such as global warming, declining biodiversity,

agro-chemical pollution may signal that markets and economics cannot prevent degradation. At the same time, these problems may be due to market and policy failure sending the wrong signals to producers and consumers. Regardless, more sustainable use of natural resources often requires economic solutions that are unpalatable to politicians who may have a very short time horizon.

5.5 SUMMARY

Renewable and non-renewable natural resources play a central role in economic and social development in eastern and southern Africa. Renewable resources naturally regenerate within a reasonable time and the stock can be augmented through human intervention. With sound management, including efficient property rights, renewable resource stocks and subsequent flows of benefits can be maintained in perpetuity. Non-renewable (or depletable) resource stocks cannot be augmented through human intervention. The total stock is relatively fixed and is split between economic and sub-economic reserves based on market prices and extraction costs. Factors influencing the stock classification and depletion rates include prices, extraction costs and technology. Also, as exploration technology improves (often spurred by rising resource prices), new stocks may be discovered and will add to either economic or sub-economic stocks. In addition, the availability of substitutes and potential for re-use and recycling are important factors.

With renewable resources such as forests and fish, biological and economic harvesting criteria are quite different. Biological criteria are based on concepts of maximum sustained yield, which is the annual harvest of the maximum annual net stock growth. Economic criteria account for costs and revenues. Generally, with forests, the economic harvesting period is shorter than the biological period. Increasing the discount rate also tends to shorten the harvest timing. With fisheries, the optimal level of effort is often less than that associated with the MSY, however the choice of discount rate can move the optimal harvest in either direction. The efficiency of property rights is critical in determining the optimal harvest level in fisheries. With all renewable

resources, efficient property rights are critical for producers to manage the resource stock optimally.

With non-renewable resources, the relationship between marginal extraction cost, marginal user cost (opportunity cost to future generations of using the resource now), and product price determines the depletion rate. Where marginal extraction costs are constant, the marginal user cost will rise at a rate equal to the discount rate. Management issues focus on providing efficient property rights and pricing regimes. Price controls by governments often result in increased resource extraction.

Two physical and four economic indicators have been developed to help determine whether or not natural resources are becoming scarce. Physical indicators tend to provide overly pessimistic forecasts because they do not account for changing prices, technology and substitutes. Economic indicators are preferred. Most forecasts using economic indicators appear to suggest that natural resource scarcity is not as serious as some people would postulate. Most studies, however, are for the United States or more general global outlooks. There is a need to initiate similar studies in this region to understand trends in resource use and scarcity.

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