ENVIRONMENTAL ECONOMICS CONT'D.

Fisheries

Marine fisheries of the world are in trouble. Depletion of once-productive fish stocks, a sporadic occurrence earlier in the twentieth century, has progressively become a common event. The declaration of 200 miles as fishing zones by most of the world's coastal nations in the 1970s, which was a reaction to over fishing by foreign fleets, has had limited success in terms of conservation. To name one example, the Northern cod fishery in the Western Atlantic collapsed in 1992, in spite of intense management activity by the Canadian government. The collapse caused by extreme over fishing has destroyed the economy of the Province of Newfoundland, throwing some 30,000 fishermen and plant workers on to the unemployment roster. Only limited signs of recovery of this historical fishery had appeared by 1999.

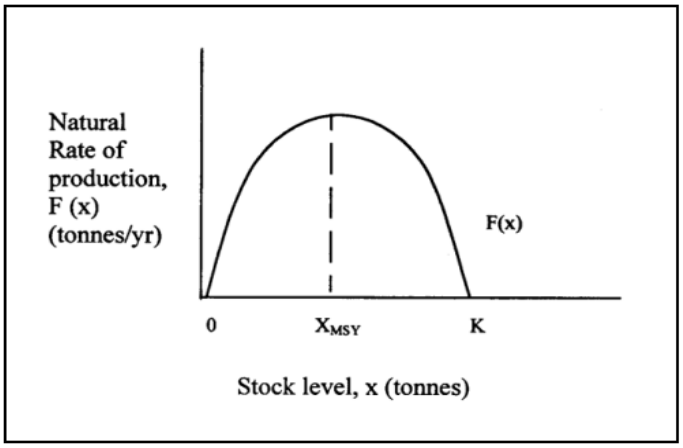
Fisheries as natural capital

Modern economic theory treats renewable resource stocks as forms of natural capital. To describe a generic model, let $x(t)$ denote the biomass of a given fish population at time t. When the biomass is x, the net rate of population growth equals $F(x)$. Harvesting at the rate h reduces the net population growth rate accordingly.

$$\frac{dx}{dt} = F(x) - h \qquad \textbf{Equation 10.1}$$

Here, the production of the natural capital, $F(x)$, is facilitated by the natural environment (driven ultimately by solar energy). Positive investment in natural capital occurs, if $h > F(x)$, whereas disinvestments occurs, if $h < F(x)$. Equilibrium at stock level is reached at $h = F(x)$. Figure 10.6 below illustrates this phenomenon:

Figure 10.6
Natural Capital: An Illustration



In the fishery model, it is assumed that F peaks at some value $x = x_{MSY}$ and then decreases to zero:

$$F(0) = 0,\ F(K) = 0,\ F''(x) < 0$$

$$\text{Max } F(x) = F(x_{MSY}) = h_{MSY} \qquad \textbf{Equation 10.2}$$

Here K is the environmental carrying capacity of the population; $x = K$ is a stable equilibrium (when $h = 0$) of the natural population. The harvest rate h_{MSY} given by the Equation 10.2 is the maximum sustainable yield (*MSY*) that can be harvested from the population. *MSY* has been the traditional management objective for most fisheries, but achieving this objective in a stable, efficient and equitable way has proved to be more difficult than anticipated due to various reasons.

Next, we introduce the quantity E, the fishing effort (e.g., the number of standardised fishing vessels in operation at time t), and assume that:

$$h = qEx \qquad \textbf{Equation 10.3}$$

Here q, the catchability coefficient, may in general depend on the current stock size x. For simplicity, however, we assume $q =$ *constant*. If c denotes the unit cost of effort, and p the landed price of fish, then the net flow of revenue (economic rent) equals:

$$R = pH - cE = (pqx - c)\,E \qquad \textbf{Equation 10.4}$$

On the basis of this simple model, we can discuss the concepts of bionomic equilibrium, depletion and optimal exploitation.

Bionomic equilibrium

Bionomic equilibrium is the natural equilibrium point where the economic forces and the forces of biological productivity will be in balance. Consider an unregulated fishery exploited by numerous fishermen. If $pqx - c > 0$, that is, when:

$$x = x_{BE} = \frac{c}{pq} \qquad \textbf{Equation 10.5}$$

Equation 10.5 has several implications. Bionomic equilibrium depends on the cost/price (c/p) ratio: lower costs or higher prices lead to reduced biomass levels at equilibrium. Likewise, increased vessel efficiency, as reflected by increased catchability q, also reduces the bionomic equilibrium.. Sustainable yield equals $F(x_{BE})$. This will increase in the early development of the fishery, but will subsequently decline once x_{BE} falls below x_{MSY}. This latter situation, involving low fish stocks and low catches, characterises over fishing in the usual sense of the term. The model, thus, predicts that over-fishing is inevitable in an unregulated, open access fishery, provided that demand is highly relative to fishing costs. The history of countless fisheries supports this prediction.

Externalities

Over-fishing is sometimes attributed to externalities in the operation of individual firms/fishmonger competing in the fishery. In this context, externalities arise because each firm bases its decision solely on current returns to effort ($pqx-c$) and does not consider the effects of its catches on future stock levels. Additional short-term externalities may arise, if fishing vessels interfere with one another during search or capture activities. While such crowding externalities may influence the economic efficiency of fishing in important ways, they are probably less significant in terms of over fishing than the dynamic stock externality described above. Yet another form is the by-catch externalities, when firms seek a particular species (e.g., shrimp) or destroy other species (such as juvenile fish) that may also have value, either directly or as food for other targeted species.

Management techniques

Traditional management approaches concentrate on controlling annual catches. Typically, the management agency determines a total annual catch (TAC). The cumulative year's catch is tracked and the fishery closed once that TAC had been reached. Alternatively, the length of the fishing season may be determined in advance, based on an estimate of the fleet's capture efficiency. Assuming that TAC has been correctly calculated and that actual catches are quickly and accurately reported, this method has the potential for protecting vulnerable fish populations. However, there are usually unfortunate economic side effects.

The restricted seasonal opening forces the firms to compete vigorously for their share of the TAC and also motivates them to increase vessel capacity so as to maximise their catches. Eventually, there will be pressure on the management agency to increase the TAC (or retain the current TAC) even though this may destabilise the fishery and precipitate a collapse.

Most fish populations undergo environmentally induced fluctuations from which they usually recover under natural conditions. When an overcapitalised fishery is dependent on the stock, such a fluctuation may result in a population collapse, unless the management agency responds quickly by reducing the TAC.

To prevent over capacity, management agencies may be forced to regulate vessel size, appropriate horsepower and fishing gear. They may also limit the number of vessels licensed to participate in the fishery. Such regulations tend to interfere with market-based individual decisions and lead to an increasingly unwieldy management system.

An alternative approach, now being used with increasing frequency, employs individual's transferable quotas (ITQs). Each firm has a specified annual quota, which may be caught whenever and however it desires. Quota units may be bought from or sold to other fishers. The management authority, as usual, determines total quotas. Provided that illegal catches can be prevented, the ITQ approach has many advantages arising from decentralised decision-making and the elimination of competition among firms. Economic rents are preserved and distributed among quota owners.

Forestry

The proper economic management of forests is one of the classic problems in renewable resource economics. To maximise land value, one has to choose the harvest time optimally. It is obvious that, if prices, the interest rate and the biotechnology remain unchanged, then each rotation will be of the same length over an infinite time horizon.

The optimal cutting rule

Trees are biological resources in the same way as fish and crops, and the principles of forest management should, under well-defined property rights be analogous to what we have learnt in renewable resources (i.e., fishery). A fish stock should, in a steady state, be kept at a level where the yield from an extra unit added to the stock coincides with the real interest rate from an extra unit harvested and invested in a bank account.

This is a rule, which is analogous to the fundamental principle of profit maximisation in microeconomic theory: marginal revenue is equal to marginal cost. That is to say, the marginal cost (yearly) of keeping the fish in the fishing bank is the opportunity cost of not putting the market value of the fish in a bank. The marginal benefit (yearly) of an extra unit of the biomass is what it contributes to the stock over the period, and at, the optimal steady state, it coincides with the interest rate. This is steady state criterion for the economically optimal stock. To preserve the stock at a steady state level, we have to harvest the yearly yield generated at the steady state level of the stock.

What distinguished trees from fish is that, for the latter population, it is neither practically feasible nor theoretically necessary to distinguish between fish in different age classes. Instead, we adapt the fishing tackle to catch the more mature individuals. However, it is both practically and theoretically crucial to keep track of the age distribution on forestry. In this case, it turns out to be more practical to focus on non-stationary conditions and decide the conditions for the optimal time to harvest an even-aged stand.

An approach, which can be used to find the optimal economic decision, is to consider marginal revenue and marginal costs. The marginal revenue from preserving the stand intact, until the next period, is the growth of the biomass over the period, times the market price of timber. The opportunity cost of preserving the stand one more period is not only the interest on the revenue from selling the harvest, but also the interest on the value of the bare land. As indicated above, the latter component of the marginal cost of not harvesting the trees now surfaces, since one cannot start a new rotation without cutting down the standing trees. The marginal cost of keeping the stand intact can be decomposed into two components: the interest on the value of the standing trees and the interest on the value of the bare land.

We can sum up the discussion on the optimal rotation period under stationary external conditions such as constant prices, constant technology and a constant interest rate by the theorem proposed by Faustmann-Marshall-Pressler: a forest stand should be harvested when the change in its value with respect to time is equal to the interest on the value of the stand plus the interest on the value of the bare forest land.

Empirical studies of the timber market

The empirical studies extend the discussion of forest management by formally introducing the concept of timber supply. To start with, if all prices, including harvesting costs, are increased by the same percentage, the rotation period remains unchanged. The intuition is that both marginal revenue and marginal cost increase by the same percentage, and they are therefore, equalised at the original rotation period.

If only the prices for wood, but not the harvesting costs are increased, the revenues from waiting yet another year, as well as the opportunity cost of the standing trees (interest on the value of the stand), will increase. However, the opportunity cost of the bare land will increase by even more. The reason is that revenues are scaled up, while costs are kept constant. To compensate for the increased marginal cost, the rotation period is shortened to increase marginal growth, and indirectly, marginal revenue. The immediate effect of a shorter rotation period is that less wood will, in the long run, be supplied from the stand. However, forestry has become more profitable, and it is likely that more land will be transformed into forestland. The long-term effect on wood supply is, therefore, ambiguous.

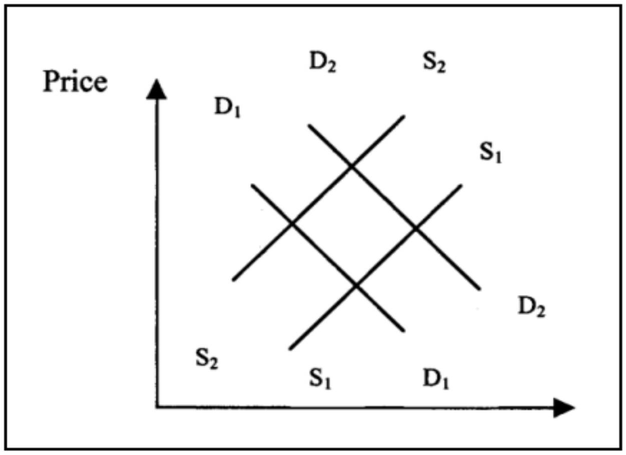
The demand for timber

The demand curve helps us to estimate both demand and supply curves from empirical data. The derivation of the demand curve can be dealt with very quickly. Timber and pulpwood are demanded as input in the forest industry. This means that we can use the theory of the firm and conclude that the input demand curve is downward sloping. We derive this result formally by a simple revealed-preference argument.

The timber market

Econometric analyses of the timber market require us to identify and estimate both the demand and supply curves, and identification is crucial. To identify the demand curve, we have to use the fact that the supply curve depends on entities such as felling costs, which do not affect the position of the demand curve. The principle is to use this shifter to cut out points along the fixed demand curve as illustrated in Figure 10.7 where an increase in felling costs shifts the supply curve from S_1S_1 to S_2S_2 along the demand curve D_1D_1:

The Supply-Demand Curve



Along the rationale established in Figure 10.6, we need a variable such as the price of lumber, which shifts the demand curve, to identify the latter.

Water use

Water resources serve multiple purposes in meeting human needs and their allocation has been a subject of dispute over centuries. Rapid population growth has resulted in increased water scarcity and interest in the pursuit of improved productivity in water resource management.

On the global level, irrigated agriculture is by far the largest consumer of water among the various users, and concern over improving water use efficiency in this sector has been widely reflected in the water economics literature. The emphasis in this Subsection is on water use in agriculture and its impact on the environment because much of the political debate in recent years has centred on use in this sector, and many of the conceptual and methodological issues that have been raised in addressing agricultural water issues apply in other sectors as well.

Farm-level water allocation decisions

One of the most important issues facing policy makers is an assessment of the response of irrigated agriculture to increased water scarcity as reflected in increased water prices or reduced aggregate supplies of water. Evidence has shown that increases in water prices and reductions in water availability result in the adoption of water conservation technologies and the reduction of water use within existing practices, as well as changes in cropping patterns.

A key concept necessary for the analysis of farmers' water use patterns is that of effective water. The water that is actually utilised by the crop is effective water and is commonly measured by crop evapotranspiration coefficients (Stewart, et al., 1974, Grimm, et al., 1987). The total amount of water applied to the crop comes from several sources, including water applied for irrigation, rainwater and run off water that is drained from other fields. The residual quantity of applied water, which is not utilised by the crop becomes surface run off or percolates to groundwater.

The distinction between applied water and effective water gives rise to the concept of water efficiency. In cases, where the only source of water is applied water, water use efficiency is the ratio between effective and applied water. Water efficiency is highly dependent on the ability of the soil to store water, which can be utilised by the crop over time. Water efficiency is, typically, higher on heavy clay soils, which retain applied water, in comparison with sandy soils through which water passes rapidly. Climate and water quality also affect water efficiency. Through their effect on water efficiency, these factors influence irrigation technology choices. To illustrate how land quality and effective water influence farmer's choice of irrigation technology and water use, we turn to a simple model.

Suppose a farmer produces a crop with the following per acre production function:

$$y = f(e) \qquad \textbf{Equation 10.6}$$

Where y denotes output per acre and e is the effective water. The production function $f(*)$ has the regular properties of a neo-classical production function: $f(0) = 0, f'(*) > 0, f''(*) < 0$.

Let a_i denote applied water per acre under technology I, and α is the land quality index, assuming values from 0 to 1 from poor to good quality. For simplicity, assume two technologies: a traditional technology ($i = 0$) and a modern technology ($i = 1$). Modern irrigation technologies, which permit the application of small quantities of water over long periods of time, result in higher irrigation efficiencies, particularly on poor quality soils, which are incapable of retaining applied water. Thus, effective water under each irrigation type is a function of soil quality: $e = e_i(\alpha)$. Irrigation effectiveness is defined as:

$$h_i(\alpha) = e_i(\alpha)/a_i(\alpha) \qquad \textbf{Equation 10.7}$$

and

$$1 > h_1 > h_0 > 0$$

The cost per acre associated with each technology is k_i. This cost includes annualised repayment of investment costs and annual operating costs. The modern technology is assumed to be more capital-intensive, so that $k_1 > k_0$.

The modern technology will be selected in cases where the increased profits from higher yields or lower water costs offset the higher costs associated with the adoption of the technology. These results indicate that modern technology adoption will increase with increasing water or output prices. In addition, modern technology adoption is more likely to occur with poor land quality, due to the high price of effective water under the traditional technology, and the land augmenting qualities of the modern technology.

The economics of groundwater management

The optimal management of groundwater can be modelled as a non-renewable resource (e.g., desert regions with a closed aquifer) or as a renewable resource (i.e., when aquifers are recharged). The dynamics of optimal groundwater use depend on the price of energy, the interest rate, the efficiency of pumping and the hydrological characteristics of the system.

In the case of non-renewable groundwater with no technological change, the level of optimal pumping follows the standard hotelling rule. The rate of pumping declines over time with the interest rate, and the user cost of water (price minus extraction cost) rises. The introduction of technological changes, which increase water efficiency, leads to a reduction in extraction levels and extends the economic life of a finite aquifer. In contrast, improvements in pumping technology that reduce extraction costs actually tend to accelerate the pumping of aquifer.

In cases where groundwater aquifers can be recharged, the groundwater system may reach a steady state where pumping is equal to recharge. If the steady state level is below the initial stock of water, then a decline in pumping over time will occur, until the steady state is reached. In cases where groundwater aquifers have already been significantly depleted, an initial period when replenishment exceeds pumping levels will precede the attainment of the steady state.

Groundwater resources usually exhibit the characteristics of common property goods, where externalities arise because current water users do not take into account the impact of their pumping on future water users. Current pumping affects future water users primarily by lowering the depth of water, increasing pumping costs and by reducing the stock of water available for future pumping. In the absence of any common-pool management scheme, current users determine their water use levels by setting the value of the marginal product of water equal to their private pumping costs, rather than full social costs. Correct situations of over pumping may entail establishing a regional or local groundwater authority either by taxing pumping, or by establishing aggregate pumping levels and introducing a system of transferable permits for pumping rights within the system (Gisser, 1983). Enactment of these situations requires monitoring of groundwater by a water agency, which may not always be feasible.

In many cases, the management of groundwater can be improved by removing policies which encourage over pumping, particularly the subsidisation of electricity. Electricity is the major cost component in operating irrigation pumps. Lower electricity rates decrease the cost of pumping and increase the depth to which it is profitable for farmers to pump. This is a major cause of over pumping and the depletion of groundwater aquifers. Frequently, ground and surface water systems can be managed conjunctively, where the optimal management of the system depends on the stocks and flows of the two water sources over time. Surface water canals have been established in many regions to compensate or augment depleted groundwater aquifers. In other situations, groundwater reservoirs have been established as buffer stock to supplement the use of surface water supplies in times of low supply.

Agriculture

Environmental externalities from agricultural activities, both past and present, are pervasive. Since Neolithic times, humans have been converting forests, wetlands and prairies into crop and grazing lands. These activities have shaped the rural landscape and the hydrology and ecology of agriculture as a bio-economic activity. Thus, agriculture is both a source and receptor of environmental externalities.

Contemporary evaluations of the environmental impacts of agriculture are both positive and negative. For example, the loss of biodiversity that occurred with the expansion of the agricultural frontier and human settlement in developing countries is viewed as an irreversible loss of natural capital. Yet, it is land drainage that has been an important factor in eliminating malaria in Europe and North America. In addition, agricultural land is an important habitat for many remaining wildlife species. Also, rural and urban populations often value agricultural landscape as open space.

Traditionally, agricultural policies attempt, with varying degrees of success, to achieve objectives related to farm income, agricultural prices and agricultural trade (Gardner, 1990; Johnson, 1991). Agricultural externalities, although influenced by the scale, location and methods of agricultural production, are at best a secondary consideration. Agricultural policy is concerned with encouraging the supply of positive agricultural externalities, and reducing the generation of negative externalities (Ervin and Graffy, 1996).

Negative environmental externalities

As is the case in any economic enterprise, energy and materials enter the farms as purchased inputs and environmental flows (e.g., rainfall, sun, etc.) and are removed as commodities and outflows to the environment. Moreover, while soils represent a stock of productive services, they can also be a flow of pollutants in so far as wind (air) and water carry eroded soils to off-farm locations, where they can cause significant environmental harm. Environmental outflows are in part the result of purposeful waste disposal activities such as burning fields to remove stubble or dumping unused pesticides in streams. However, natural processes such as run-off and volatilisation of nitrogen are important forces in the formation and fate of agricultural residues. Let us elaborate on this further.

Run off from agricultural lands carry fertilisers, pesticides, livestock wastes, salts, pathogens and eroded soils into streams, lakes, estuaries and coastal waters. Many recent environmental assessments identify agricultural run-off as a major cause of surface-water quality problems in developed countries. Although the current knowledge of the state of groundwater is limited, there is evidence of groundwater contamination by agricultural chemicals around the world. Nitrates and pesticides that percolate into groundwater used to supply drinking water are of particular concern. The overall state of knowledge about chronic human health effects of pesticides is quite limited, but concern has been raised about the consequences of low exposures over long periods of time.

Economic costs from agricultural water pollution include reduced productivity of sports and commercial fisheries, in-stream recreational losses, increased cost of water treatment for industrial and domestic uses, costs of illness and death when contaminated waters are consumed, material damages and adverse impacts on the diversity and functioning of ecosystems. Although real or perceived human health rights often command the most attention, the costs associated with damages to the ecosystem and non-living systems are probably much larger.

Apart from reaching surface-water or groundwater supplies, excess nitrogen in the soil can be lost to the atmosphere through denitrification and volatilisation. Volatilised forms of nitrogen such as ammonia, nitrous oxide and nitrogen dioxide can contribute to acidification of the atmosphere and, in turn acid rain.

Agriculture, a source of several pollutants, is a contributor to greenhouse gas emissions. It is estimated that it accounts for one fifth of global emissions. The conversion of tropical forests to agricultural land, which releases carbon that had been sequestered in these forests, has perhaps garnered the most attention. Fossil fuels consumed in the process of using farm machinery and in the process of manufacturing fertilisers are other, albeit minor, sources of greenhouse gas emissions from agriculture.