Reading material for Second year economics students

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Chapter Four

Natural Resources

Objectives of the chapter

As it explained in the first chapter of this course, the findings of natural resource and environmental economists are used by governments and organizations to better understand how to efficiently use and sustain natural resources. The findings are used to gain insight into the following environmental areas:

- Extraction: the process of withdrawing resources from nature. Extractive industries are a basis for the primary sector of the economy. The extraction of natural resources substantially increases a country's wealth. Economists study extraction rates to make sure that resources are not depleted. Also, if resources are extracted too quickly, the sudden inflow of money can cause inflation.
- Depletion: the using up of natural resources, which is considered to be a global sustainable development issue. Many governments and organizations have become increasingly involved in preserving natural resources.
- Protection: the preservation of natural resources for the future. Protection policies state the necessary actions internationally, nationally, and individually that must take place to control natural resource depletion that is a result of human activity.
- Management: the use of natural resources taking into account economic, environmental, and social concerns. This process deals with managing natural resources such as land, water, soil, plants, and animals.

In this chapter the economic concept of natural resources, classification of natural resources, and the optimal depletion of different types of natural resources will be discussed. Hence, after the completion of this chapter, students able to:

- Understand and analyze the classification and optimal utilization of natural resources
- be aware of and explain the possible mechanisms that help in the conservation of natural environmental resources

4.1 Definition and Classification of Natural Resources

Natural resources are resources or any source of wealth that occurs naturally. Minerals, fossil fuels, timber, animal species, etc are all natural resources and are derived from the environment. Some of the resources are essential to survival, while others merely satisfy societal wants. Every man-made product in an economy is composed of natural resources. Natural resources can be classified in numerous ways that include source of origin, state of development, and renewability of the resources.

In terms of the source of origin, natural resources can be divided into the following types:

- Biotic: these resources come from living and organic material, such as forests and animals, and include materials that can be obtained them. Biotic natural resources also include fossil fuels such as coal and petroleum which are formed from organic matter that has decayed.
- Abiotic: these resources come from non-living and non-organic material. Examples of these resources include land, fresh water, air, and metals (gold, iron, copper, silver, etc.).

Natural resources can also be categorized based on their stage of development including:

- Potential resources: these are resources that exist in a region and may be used in the future. For example, petroleum in sedimentary rocks is a potential resource until it is actually drilled out of the rock and put to use.
- Actual resources: these are resources that have been surveyed, their quantity and quality has been determined, and they are currently being used. The development of actual resources is dependent on technology.
- Reserve resources: this is the part of an actual resource that can be developed profitably in the future use.
- Stock resources: these are resources that have been surveyed, but cannot be used due to lack of technology. An example of a stock resource is hydrogen.

Natural resources can also be classified based on their renewability:
Renewable natural resources: these are resources that can be replenished. They are also called as inexhaustible resources due to their high rate of regeneration relative to use/decay. Examples of renewable resources include solar energy, air and wind, living species (fish, forest, etc).

Renewable natural resources are available continuously and their quantity is not noticeably affected by human consumption. However, renewable resources do not have a rapid recovery rate and are susceptible to depletion if they are overused.

Non-renewable natural resources: these resources form extremely slow and do not naturally form in the environment. A resource is considered to be non-renewable when their rate of consumption exceeds the rate of recovery. These resources are also called as exhaustible resources as they are available in limited or finite quantity, i.e., rate of regeneration is insignificant compared to rate of use. Some examples of non-renewable natural resources are minerals and fossil fuels.

In this chapter, we will discuss the optimal depletion of natural resources based on the renewability characteristics of the natural resources. However, keep in your mind that, the distinction between Exhaustible and Inexhaustible resource is tricky. This is due to the fact that, exhaustible resources may not be exhausted or is impossible to exhaust, because;

- Deposits that are closer to surface (higher grade ores) – are extracted first (volume/quantity declines). So, costs of extraction increases over time that raises the market price which in turn leads to decrease in the extraction amount.
- At some price (chock price), substitutes become attractive; Examples, Coal is exhaustible; substitution by petroleum to some extent.
- New technology is invented to support extraction deep down from the surface

Inexhaustible resources – biological ones – can be totally depleted (exhausted). Stocks do not necessarily need to be reduced to zero for extinction to occur. Example,

- In hunting or harvesting of open-access resources, hunters or harvesters did not need to shoot or harvest the last one for extinction to occur
- There might be a loss in biodiversity as economic activity proceeds which may reduce the potential of renewable resources. Then, natural rate of decline outweigh the growth rate. Due to these two reasons, the Exhaustible resources cannot be exhausted; and the Inexhaustible resources sometimes can be exhausted.

4.2 Non-renewable resources

Non-renewable resources include fossil-fuel energy supplies – oil, gas and coal – and minerals – copper and nickel, for example. They are formed by geological processes over millions of years and so, in effect, exist as fixed stocks which, once extracted, cannot be renewed; that is, their growth (regeneration) rate is essentially zero. The question that of central importance is: what is the optimal extraction path over time for any particular non-renewable resource stock?

4.2.1 Theory of optimal depletion

In the static optimal depletion, Reserve-to-Use Ratio (RTUR) is frequently cited by press & government studies for the optimal deletion of non-renewable resources.

$$\text{RTUR} = \frac{\text{current reservation}}{\text{annual use}}$$

For example, if the current resource reserve is 25,000,000 ton and 500,000 ton is used annually, then;

$$\frac{\text{Current Reserves}}{\text{Annual Use}} = \frac{25{,}000{,}000 \text{ tones}}{500{,}000 \text{ tones}} \rightarrow \text{takes 50 years to deplete}$$

However, RTUR as the indicator of scarcity is incomplete. Because of crude estimate, it also ignores change in demand/use, ignores declining rate of use as price increases, and ignores newly discovered reserves or potential economic reserves as price increases

RTUR method has a number of limitations and cannot indicate the economically efficient rate of extraction. Year by year determination also cannot be efficient over time, because this year's extraction decision affects options & costs for future years. So, real economic response is the dynamically efficient rate of use. In a dynamic setting, the economically efficient allocation maximizes the Present Value of Net Benefits. At this allocation, PV (Marginal Net Benefits) are equal across time periods. Example, assume two-period Extraction of 20 Barrels of oil, and

$$\text{Demand}: MB = 8 - 0.4 * q$$

$$\text{Supply: } MC = \$2 / unit$$

$$\text{Stock of resource} = 20 \; units$$

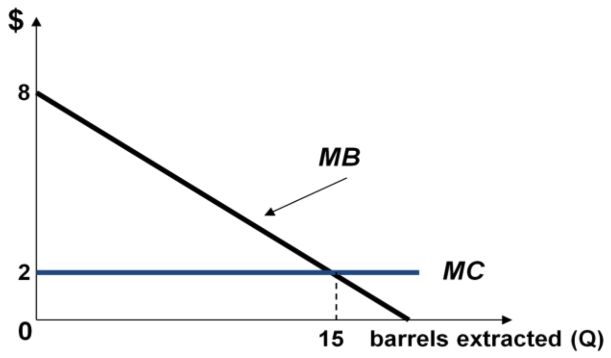
$$\text{Discount rate}: r = 0.10$$

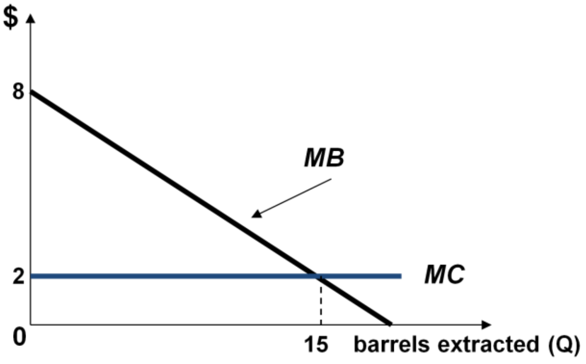
$$\text{PVNB} \equiv \text{present value of net benefits}$$

Problem with static efficiency and non-renewable resources

Under static allocation, suppose that the marginal benefit for oil (MB) = 8 – 0.4Q; this indicates the demand for the oil and is a demand function, and the marginal cost (MC) = $2 per barrel of oil. MC represents the supply of oil at price P. What level of oil Q should be extracted to maximizes the net benefit?

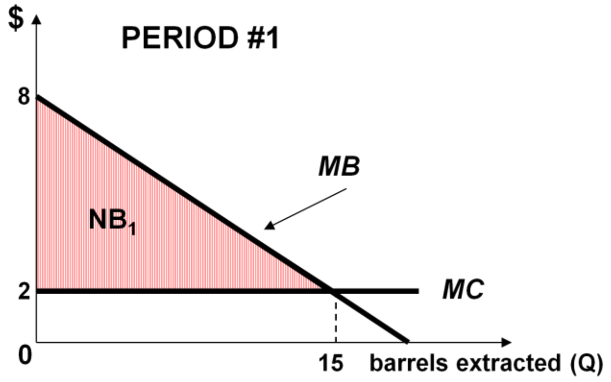
The net benefit is maximized at point where MB = MC. Hence, given the above example, 15 barrels of oil should be extracted in the first period to maximize the benefit. In the second period, the same amount will assumed to be extracted. So, the total extraction in our two period model will be 15 + 15 = 30 which is greater than the available stock of oil of 20 barrels.

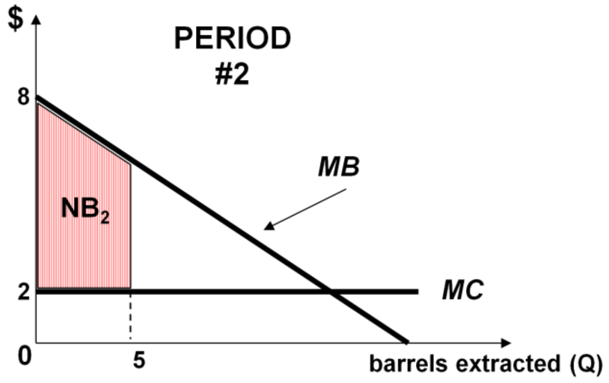




First Candidate for Two-period Consumption Allocation

Candidate 1: Extract 15 in period 1, and leave the remaining 5 for consumption in period 2.





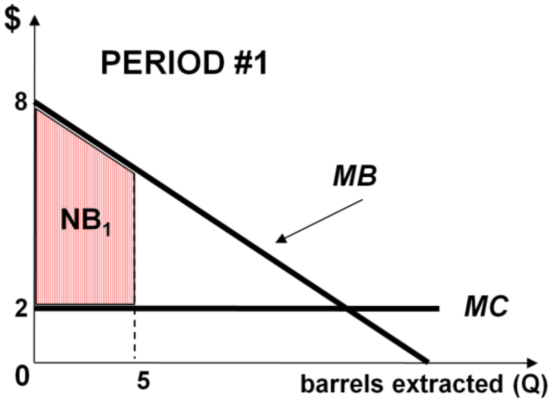
NB(shaded) = 45

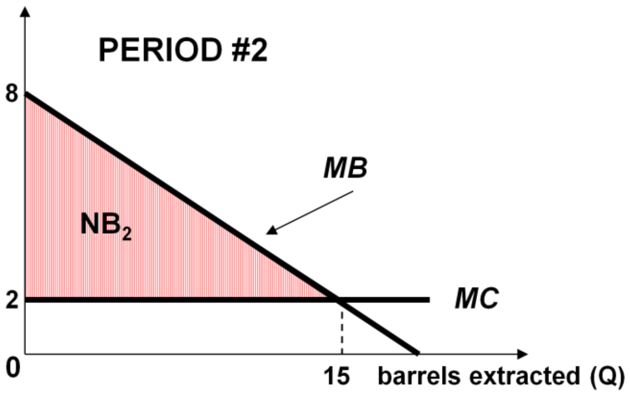
NB(shaded) = 25; discounted = 22.7

PVNB =45 + 25/(1+.10) = 45 + 22.7 = 67.7

Second Candidate for Two-period Consumption Allocation

Candidate 2: Extract 5 in period 1, and leave 15 for consumption in period 2





NB = 25

NB = 40.1

PVNB =25 + 45/(1+.10) = 25 + 40.1 = 65.1

In both cases however, Present Value of Net benefits is not maximized. So, the alternative solution is to use the Dynamic allocation Efficiency. In a dynamic setting, economically efficient allocation maximizes the present value of net benefits. PV(marginal net benefits) are equal across time periods.

Algebraic Solution to Dynamically Efficient Allocation in Two Periods

$$PV(MNB)_1 = PV(MNB)_2$$

$$PV(MB - MC)_1 = PV(MB - MC)_2$$

$$8 - 0.4 * q_1 - 2 = \frac{8 - 0.4 * q_2 - 2}{(1.10)^1}$$

$$q_1 + q_2 = 20 \quad so \quad q_2 = 20 - q_1$$

$$Substituting:$$

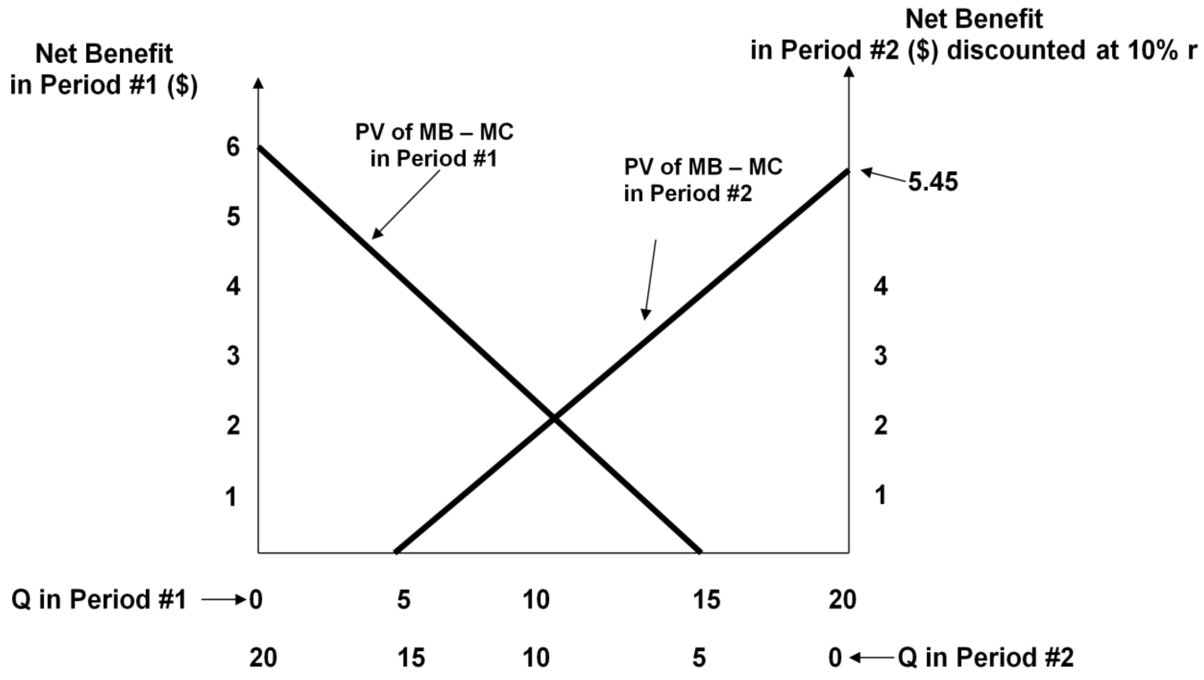
$$6 - 0.4 * q_1 = \frac{6 - 0.4 * (20 - q_1)}{(1.10)^1}$$

$$\Rightarrow q_1^* = 10.239, \quad q_2^* = 20 - q_1^* = 9.761$$

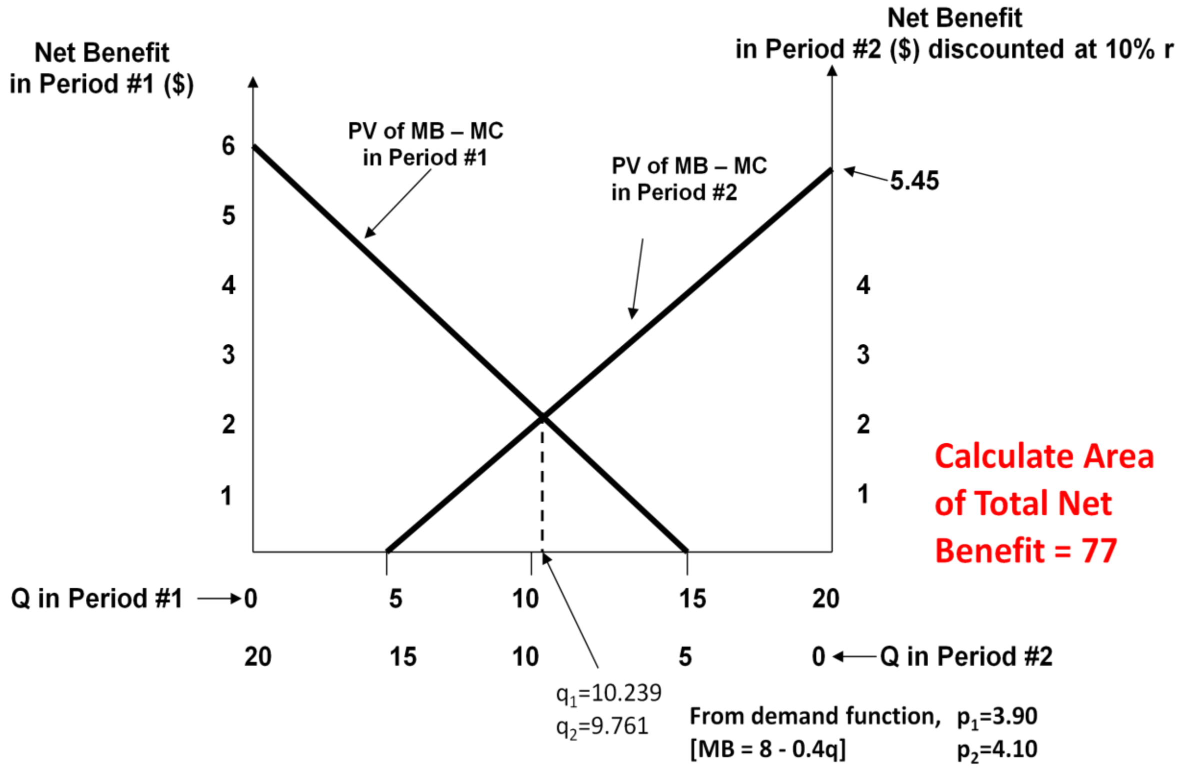
$$p_1 = 8 - (0.4 * 10.239) = \$3.90$$

$$p_2 = 8 - (0.4 * 9.761) = \$4.10$$

Non-renewable Resource Extraction: The Two-period Model



Dynamically Efficient Allocation in the Two-period Model



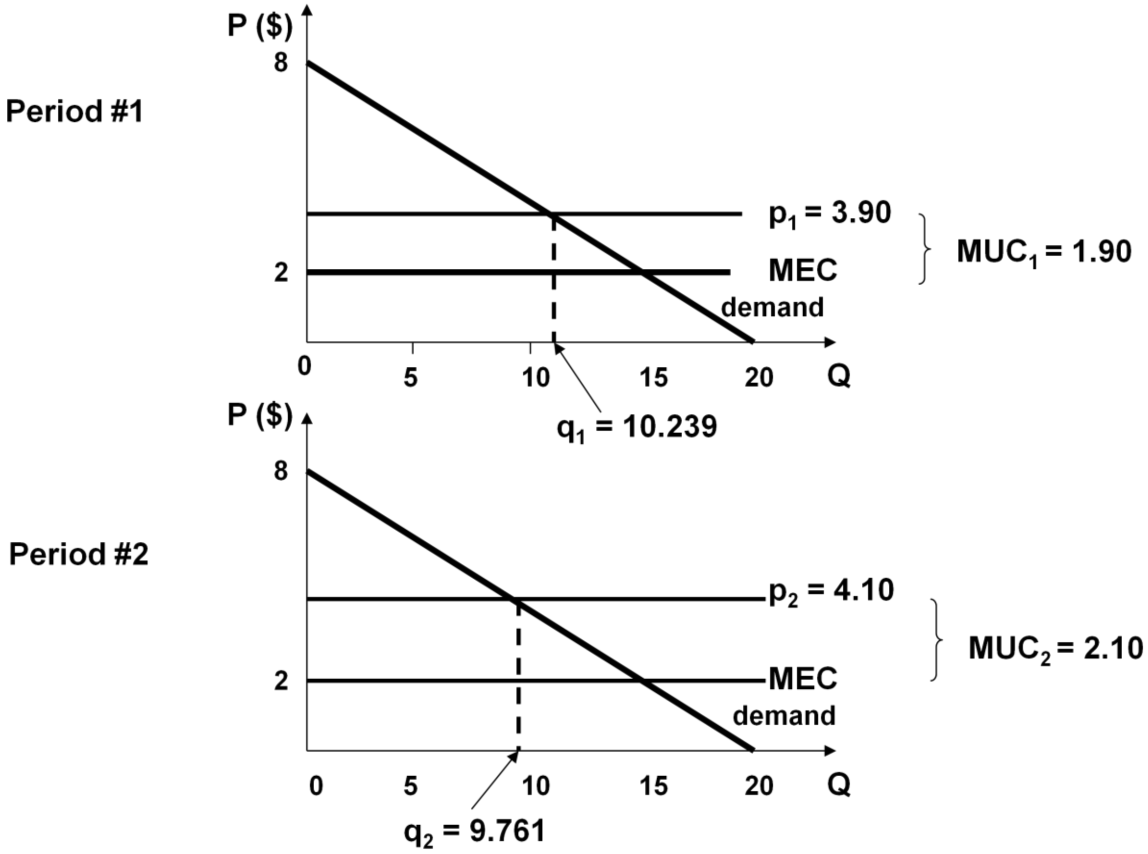
q_1=10.239
q_2=9.761

From demand function, **p_1=3.90**
[MB = 8 - 0.4q] **p_2=4.10**

Calculate Area of Total Net Benefit = 77

Dynamic Efficiency and Marginal User Costs (MUC)

MUC presents value of forgone consumption.



Scarcity and Marginal User Cost

Marginal User Cost (or Scarcity Rent) of current consumption is the opportunity cost of forgone consumption (the sacrifices of 15 - 10.239 = 4.7 units). For non-renewable resources, MUC = P – MEC. Thus, MUC for period 1 is \$3.9 – \$2 = \$1.9, and for period 2, MUC = \$4.1 – \$2 = \$2.1. This extra cost is a negative externality from the extraction of non-renewable resources. This cost must be internalized for market equilibrium allocation to be efficient.

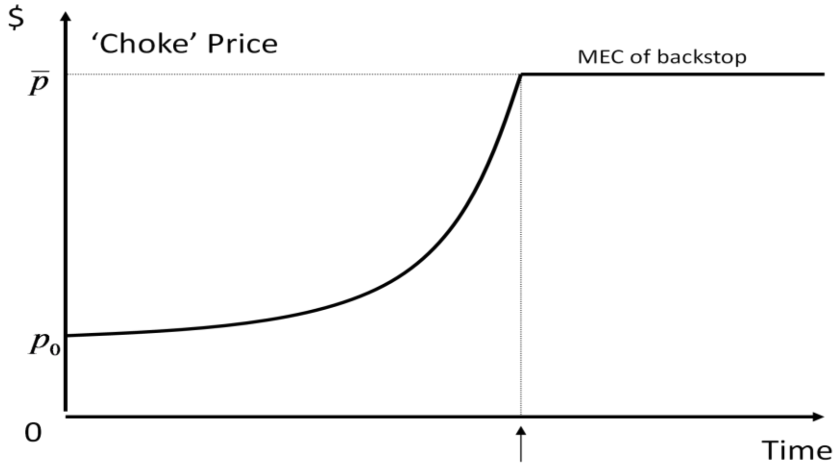
Generalizing from 2 Periods to N Periods

In the case of n-period, the exhaustion of the resource will occur at the point where;

MEC + MUC = reservation price or choke price

What does the choke price or reservation price represent?

Transition to a substitute resource/technology



Time at which **non-renewable resource is exhausted** and a **backstop is discovered** , thus **shifting to the backstop use so that price of the non-renewable resource tapers off**

What sets the chock price? A Transition to Other Non-Renewables

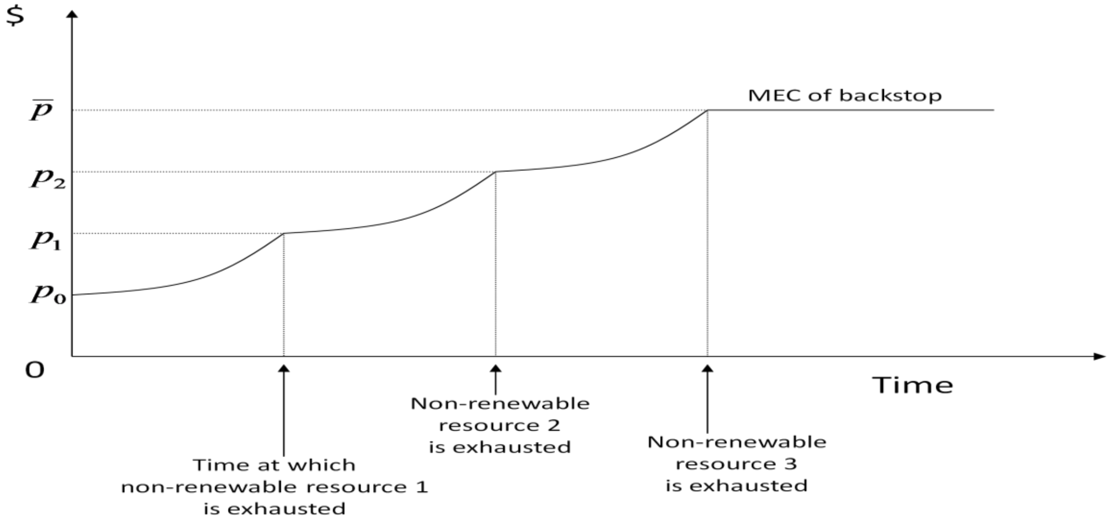
We can consider either:

- Same resource, but ores of different quality (coal with high or low energy content); or
- Different resources entirely (coal vs. oil)

Multiple transitions, based on incremental exhaustion of better resources (less costly)

- Society can think of backstop technology at end of process as well

Multiple non-renewable transitions, with backstop technology



Will the market achieve dynamic efficiency?

Holding the assumptions of perfectly competitive market many of which are met in the markets for non-renewable resources, market can lead to efficient resource allocation over time.

Under competitive market conditions, private owners of resources will consider scarcity, not simply their extraction costs, or they risk missing out on a capital gain. Hence, efficiency can be achieved.

However, there are conditions under which dynamically efficient extraction will not occur in our real world. These include;

- Incomplete markets
  - Asymmetric information
  - Externalities in production and/or consumption
  - If the resource is Public good
  - If the resource is open access/Tragedy of the commons/
    Under such conditions there is divergence between private and social discount rates that leads to inefficiency.
- Non-competitive market (monopoly)
  - For most reasonable demand functions, monopolist extracts more slowly, exhausts resource later (restrict supply) than competitive private owner.

4.2.2 Energy resources

Energy is one of our most critical resources; without it, life would cease. We derive energy from the food we eat. Through photosynthesis, the plants we consume — both directly and indirectly when we eat meat—depend on energy from the sun. The materials we use to build our houses and produce the goods we consume are extracted from the earth’s crust, and then transformed into finished products with expenditures of energy.

Currently, many industrialized countries depend on oil and natural gas for the majority of their energy needs. According to the International Energy Agency (IEA), these resources together supply 59 percent of all primary energy consumed world-wide. (Adding coal, another fossil fuel resource, increases the share to 86 percent of the total.) Fossil fuels are depletable, non-recyclable sources of energy. Crude oil proven reserves peaked during the 1970s and natural gas peaked in the 1980s in the United States and Europe, and since that time, the amount extracted has exceeded additions to reserves.

According to depletable resource models, oil and natural gas would be used until the marginal cost of further use exceeded the marginal cost of substitute resources—either more abundant depletable resources such as coal, or renewable sources such as solar energy.

In this chapter we shall examine some of the major issues associated with the allocation of energy resources over time and explore how economic analysis can clarify our understanding of both the sources of the problems and their solutions.

Natural Gas: Price Controls

In the United States, during the winter of 1974 and early 1975, serious shortages of natural gas developed. Customers who had contracted for and were willing to pay for natural gas were unable to get as much as they wanted. The shortage (or curtailments, as the Federal Energy Regulatory Commission (FERC) calls them) amounted to two trillion cubic feet of natural gas in 1974–1975, which represented roughly 10 percent of the marketed production in 1975. In an efficient allocation, shortages of that magnitude would never have materialized. This happened due to the rapid raise in the demand for natural gas.

This situation resulted in seek for new sources of crude oil. This exploration activity uncovered large quantities of natural gas (known as associated gas), in addition to large quantities of crude oil, which was the object of the search. As natural gas was discovered, it replaced manufactured gas—and some coal—in the geographic areas where it was found. Then, as a geographically dispersed demand developed for this increasingly available gas, a long-distance system of gas pipelines was constructed. This situation also raises the depletion rate of those resources. Accordingly, governments started to regulate natural gas by setting price ceilings so as to limit level of extraction and consumption.

The ceiling would prevent prices from reaching their normal levels. Since price increases are the source of the incentive to conserve, the lower prices would cause more of the resource to be used in earlier years. Consumption levels in those years would be higher under price controls than without them. Effects on the supply side are also significant. Producers would produce the resource only when they could do so profitably. Once the marginal cost rose to meet the price ceiling, no more would be produced, in spite of the large demand for the resource at that price. Thus, as long as price controls were permanent, less of the resource would be produced with controls than without.

Oil: The Cartel Problem

Since we have considered similar effects on natural gas, we note merely that historically price controls have been responsible for much mischief in the oil market as well. A second source of misallocation in the oil market, however, deserves further consideration. Most of the world’s oil is produced by a cartel called the Organization of Petroleum Exporting Countries (OPEC). The members of this organization collude to exercise power over oil production and prices. Seller power over resources due to a lack of effective competition leads to an inefficient allocation. When sellers have market power, they can restrict supply and thus force prices higher than otherwise.

Though these conclusions were previously derived for nondepletable resources, they are valid for depletable resources as well. A monopolist can extract more scarcity rent from a depletable resource base than competitive suppliers simply by restricting supply. The monopolistic transition results in a slower rate of production and higher prices. The monopolistic transition to a substitute, therefore, occurs later than a competitive transition. It also reduces the net present value society receives from these resources.

The cartelization of the oil suppliers has apparently been very effective (Smith, 2005). Why? Are the conditions that make it profitable unique to oil, or could oil cartelization be the harbinger of a wave of natural resource cartels? To answer these questions, we must isolate those factors that make oil cartelization possible. Although many factors are involved, four stand out: (1) the price elasticity of demand for OPEC oil in both the long run and the short run; (2) the income elasticity of demand for oil; (3) the supply responsiveness of the oil producers who are not OPEC members; and (4) the compatibility of interests among members of OPEC.

Fossil Fuels: National Security and Climate Considerations

The Climate Dimension

All fossil fuels contain carbon. When these fuels are burned, unless the resulting carbon is captured, it is released into the atmosphere as carbon dioxide. As explained in more detail in Chapter 16, carbon dioxide is a greenhouse gas, which means that it is a contributor to what is known popularly as global warming, or more accurately (since the changes are more complex than simply universal warming) as climate change.

Climate considerations affect energy policy in two ways: (1) the level of energy consumption matters (as long as carbon-emitting sources are part of the mix) and (2) the mix of energy sources matters (since some emit more carbon than others). For example, among the fossil fuels, coal contains the most carbon per unit of energy produced and natural gas contains the least.

From an economic point of view, the problem with how the market makes energy choices is that in the absence of explicit regulation, emissions of carbon generally involve an externality to the energy user. Therefore, we would expect that market choices, which are based upon the relative private costs of using these fuels, would involve an inefficient bias toward fuels containing carbon, thereby jeopardizing the timing and smooth transition toward fuels that pose less of a climate change threat.

The National Security Dimension

Vulnerable strategic imports also have an added cost that is not reflected in the marketplace. National security is a classic public good. No individual importer correctly represents our collective national security interests in making a decision on how much to import. Hence, leaving the determination of the appropriate balance between imports and domestic production to the market generally results in an excessive dependence on imports due to both climate change and national security considerations. In the absence of any correction for national security and climate change considerations, the market would generally demand and receive inefficient level of the resource.

Unconventional Oil and Gas, Coal, and Nuclear Energy

While the industrialized world currently depends on conventional sources of oil and gas for most of our energy, over the long run, in terms of both climate change and national security issues, the obvious solution involves a transition to domestic renewable sources of energy that do not emit greenhouse gases. What role does that leave for the other depletable resources, namely unconventional oil and gas, coal, and uranium?

Although some observers believe the transition to renewable sources will proceed so rapidly that using these fuels will be unnecessary, many others believe that depletable transition fuels will probably play a significant role. Although other contenders do exist, the fuels receiving the most attention (and controversy) as transition fuels are unconventional sources of oil and gas, coal, and uranium. Coal, in particular, is abundantly available, and its use frees nations with coal from dependencies on foreign countries.

Unconventional Oil and Gas Sources

The term unconventional oil and gas refers to sources that are typically more difficult and expensive to extract than conventional sources. One unconventional source of both oil and natural gas is shale. The flow rate from shale is sufficiently low that oil or gas production in commercial quantities requires that the rock be fractured in order to extract the gas. While gas has been produced for years from shales with natural fractures, the shale gas boom in recent years has been due to a process known as “hydraulic fracturing” (or popularly as “fracking”). The oil can then flow more easily out of these fractures and tight pores. While some of these resources are quite large, they may also pose some difficult environmental and human health challenges. Emissions of air pollutants, including CO_2, are usually even greater for unconventional sources than they are for conventional sources.

Coal

Coal’s main drawback is its contribution to air pollution. High sulfur coal is potentially a large source of sulfur dioxide emissions, one of the chief culprits in the acid-rain problem. It is also a major source of particulate emissions and mercury as well as carbon dioxide, one of the greenhouse gases.

Capturing CO_2emissions from coal-fired plants before they are released into the environment and sequestering the CO_2 in underground geologic formations is now technologically feasible. Energy companies have extensive experience in injecting captured carbon dioxide into oil fields as one means to increase the pressure and, hence, increase the recovery rate from those fields. Whether this practice can be extended to saline aquifers and other geologic formations without leakage at reasonable cost is the subject of considerable current research.

Implementing these carbon capture and storage systems require modifications to existing power plant technologies, modifications that are quite expensive. In the absence of any policy controls on carbon emissions, the cost of these sequestration approaches would rule them out simply because the economic damages imposed by failing to control the gases are externalities. The existence of suitable technologies is not sufficient if the underlying economic forces prevent them from being adopted.

Uranium

Another potential transition fuel, uranium, used in nuclear electrical-generation stations, has its own limitations—abundance and safety. With respect to abundance, technology plays an important part. Resource availability is a problem with uranium as long as we depend on conventional reactors. However, if countries move to a new generation of breeder reactors, which can use a wider range of fuel, availability would cease to be an important issue. With respect to safety, two sources of concern stand out: (1) nuclear accidents, and (2) the storage of radioactive waste. Is the market able to make efficient decisions about the role of nuclear power in the energy mix? In both cases, the answer is no, given the current decision-making environment. Let’s consider these issues one by one.

Electricity

For a number of electric utilities, conservation has assumed an increasing role. To a major extent, conservation has already been stimulated by market forces. High oil and natural gas prices, coupled with the rapidly increasing cost of both nuclear and coal-fired generating stations, have reduced electrical demand significantly. Yet many regulatory authorities are coming to the conclusion that more conservation is needed.

Perhaps the most significant role for conservation is its ability to defer capacity expansion. Each new electrical generating plant tends to cost more than the last, and frequently the cost increase is substantial. When the new plants come on line, rate increases to finance the new plant are necessary. By reducing the demand for electricity, conservation delays the date when the new capacity is needed. Delays in the need to construct new plants translate into delays in rate increases as well.

Governments are reacting to this situation in a number of ways. One is to promote investments in conservation, rather than in new plants, when conservation is the cheaper alternative. Typical programs have established systems of rebates for residential customers to install conservation measures in their homes, provided free home weatherization to qualified low-income home owners, offered owners of multifamily residential buildings incentives for installing solar water heating systems, and provided subsidized energy audits to inform customers about money-saving conservation opportunities. Similar incentives have been provided to the commercial, agricultural, and industrial sectors.

The total amount of electric energy demanded in a given year is not the only concern. How that energy demand is spread out over the year is also a concern.

The capacity of the system must be high enough to satisfy the demand even during the periods when the energy demand is highest (called peak periods). During other periods, much of the capacity remains underutilized.

Energy Efficiency

As the world grapples with creating the right energy portfolio for the future, energy efficiency policy is playing an increasingly prominent role. In recent years the amount of both private and public money being dedicated to promoting energy efficiency has increased a great deal.

The role for energy efficiency in the broader mix of energy polices depends, of course, on how large the opportunity is. Estimating the remaining potential is not a precise science, but the conclusion that significant opportunities remain seems inescapable.

The existence of these opportunities can be thought of as a necessary, but not sufficient condition for government intervention. Depending upon the level of energy prices and the discount rate, the economic return on these investments may be too low to justify intervention. Additionally, policy intervention could, in principle, be so administratively costly as to outweigh any gains that would result.

The strongest case for government intervention flows from the existence of externalities. Markets are not likely to internalize these external costs on their own. The natural security and climate change externalities mentioned above, as well as other external co-benefits such as pollution-induced community health effects, certainly imply that the market undervalues investments in energy efficiency.

The analysis provided by economic research in this area, however, makes it clear that the case for policy intervention extends well beyond externalities. Internalizing externalities is a very important, but incomplete, policy response.

Consider just a few of the other foundations for policy intervention. Inadequately informed consumers can impede rational choice, as can a limited availability of capital (preventing paying more up front for the more energy-efficient choice even when the resulting energy savings would justify the additional expense in present value terms). Perverse incentives can also play a role as in the case of one who lives in a room (think dorm) or apartment where the amount of energy used is not billed directly, resulting in a marginal cost of additional energy use that is zero.

A rather large suite of policy options has been implemented to counteract these other sources of deficient levels of investment in energy efficiency. Some illustrations include the following:

- Certification programs such as Energy Star for appliances or LEED (Leadership in Energy and Environmental Design) standards for buildings attempt to provide credible information for consumers to make informed choices on energy efficiency options.
- Minimum efficiency standards (e.g., for appliances) prohibit the manufacture, sale, or importation of clearly inefficient appliances.
- An increased flow of public funds into the market for energy efficiency has led to an increase in the use of targeted investment subsidies. The most common historic source of funding in the electricity sector involved the use of a small mandatory per kilowatt-hour charge (typically called a “system benefit charge” or “public benefit charge”) attached to the distribution service bill.

The evidence suggests that none of these policies either by themselves or in concert are completely efficient, but that they have collectively represented a move toward a more efficient use of energy. Not only does the evidence seem to suggest that they have been effective in reducing wasteful energy demand, but also that the programs have been quite cost-effective, with program costs well below the cost of the alternative, namely generating the energy to satisfy that demand.

Another ways for energy efficiency include use of renewable source of energy like use of hydroelectric power, wind, photovoltaics (it involve the direct conversion of solar energy to electricity (as opposed to indirect conversions, such as when solar-heated steam is used to drive a turbine), active and passive solar energy, ocean tidal power, liquid biofuels, geothermal energy, and hydrogen which found abundantly in water, hydrocarbons that make up many of the fossil fuels, such as gasoline, natural gas, methanol, and propane.

4.2.3 Minerals

Once used, energy resources dissipate into heat energy. They cannot be recycled. Other resources, in contrast, retain their basic physical and chemical properties during use and under the proper conditions can be recycled or reused. They therefore represent a separate category for us to examine.

What is an efficient amount of recycling? Will the market automatically generate this amount in the absence of government intervention? How does the efficient allocation over time differ between recyclable and nonrecyclable resources? We begin our investigation by describing how an efficient market in recyclable, depletable resources would work.

An efficient economic system will orchestrate a balance between the consumption of newly mined and recycled materials, between disposing of used products and recycling, and between imports and domestic production.

Factors Mitigating Resource Scarcity

Recycling is promoted by resource scarcity, but resource scarcity is, in turn, affected by a number of other factors. Three alternatives have been particularly important: (1) exploration and discovery, (2) technological progress, and (3) substitution.

4.3 Renewable resources

As it explained earlier, renewable resources can be replenished in a short period of time, and include living species (animals, plants), water, solar, wind, etc. for renewable resources, rate of use relative to replenishment rate determines optimality (sustainability. We will discuss the optimal harvest of fish and forest under this sub topic.

4.3.1 Biological dimension of fisheries

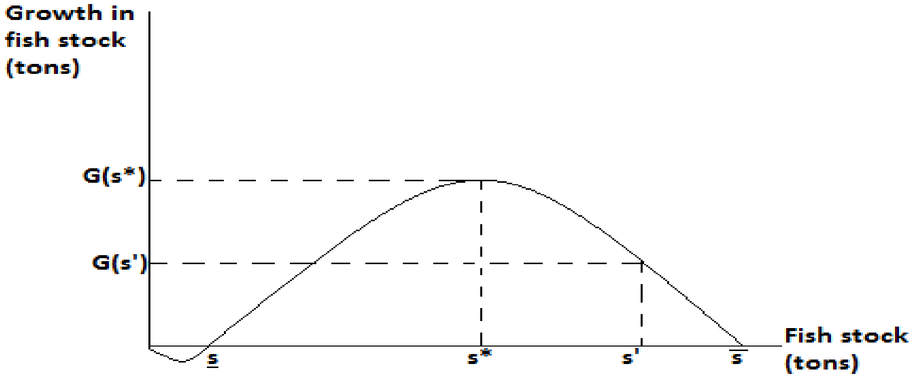
Modern fishing technology, increased demand for fish and open-access exploitation of fisheries resulting in many fish stocks to be at low levels. as a result, fish populations threatened to extinction. For example, global fish stocks that are in a state of decline have risen from 10% in 1975 to almost 41% in 2016. Hence, exploitation beyond Maximum Sustainable Yield (MSY) leads to declining populations.

The reproductive potential of a fish population is a function of the size of the fish population and characteristics of its habitat. Both the growth of the population and the population itself are measured in biomass units (weight in kg/tones). The following figure depicts a logistic growth function which illustrates the relationship between the fish population and the growth rate of the population.

The size of the population is represented on the horizontal axis and the growth of the population on the vertical axis. The graph suggests that there is a range of population sizes ($\underline{s}$ – s*) where population growth increases as the population increases and a range (s* - ŝ) where initial increases in population lead to eventual declines in growth. We can shed further light on this relationship by examining more closely the two points ($\underline{s}$ and ŝ) where the function intersects the horizontal axis and therefore growth in the stock is zero. ŝ known as the natural equilibrium or biological equilibrium, and called as the ***Carrying Capacity*** of the environment since this is population size that would persist in the absence of outside influences.

Reductions in the stock due to mortality or out-migration would be exactly offset by increases in the stock due to births, growth of the fish in the remaining stock, and in-migration.

This natural equilibrium would persist because it is stable. A stable equilibrium is one in which movements away from this population level set force in motion to restore it. If, for example, the stock temporarily exceeded, it would be exceeding the capacity of its habitat (called carrying capacity). As a result, mortality rates or out-migration would increase until the stock was once again within the confines of the carrying capacity of its habitat at ŝ.



Suppose the population is temporarily reduced below Ŝ. Because the stock is now smaller, growth would be positive and the size of the stock would increase. Over time, the fishery would move along the curve to the right until Ŝ is reached again.

Point $\underline{s}$ is known as the minimum viable population, represents the level of population below which growth in population is negative (deaths and out-migration exceed births and in-migration). In contrast to ŝ, this equilibrium is unstable. Population sizes to the right of $\underline{s}$ lead to positive growth and a movement along the curve to ŝ and away from $\underline{s}$. When the population moves to the left of $\underline{s}$, the population declines until it eventually becomes extinct. In this region, no forces act to return the population to a viable level.

A catch level is said to represent a sustainable yield whenever it equals the growth rate of the population, since it can be maintained forever. As long as the population size remains constant, the growth rate (and hence the catch) will remain constant as well.

S* is known in biology as the maximum sustainable yield population, defined as the population size that yields the maximum growth; hence, the maximum sustainable yield (catch) is equal to this maximum growth and it represents the largest catch that can be perpetually sustained. Since the catch is equal to the growth, the sustainable yield for any population size (between $\underline{s}$ and ŝ) can be determined by drawing a vertical line from the stock size of interest on the horizontal axis to the point at which it intersects the function, and drawing a horizontal line over to the vertical axis. The sustainable yield is the growth in the biomass defined by the intersection of this line with the vertical axis. Thus, G(S’) is the sustainable yield for population size S’. Since the catch is equal to the growth, population size (and next year’s growth) remains the same.

It should now be clear why G(S*) is the maximum sustainable yield. Larger catches would be possible in the short run, but these could not be sustained; they would lead to reduced population sizes and eventually the species will extinct if population drawn down to a level smaller than $\underline{s}$.

Static Efficient Sustainable Yield

However, the maximum sustainable yield is not the efficient yield. The answer is no. Recall that efficiency is associated with maximizing the net benefit from the use of the resource. If we are to define the efficient allocation, we must include the costs of harvesting as well as the benefits.

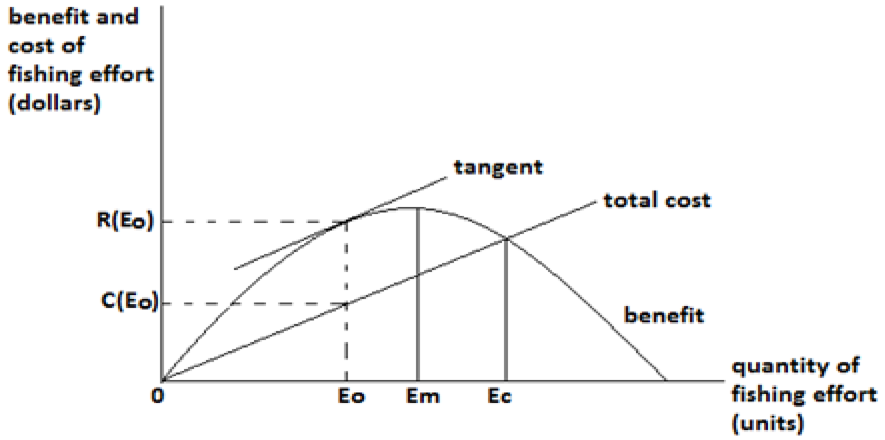
Let’s begin by defining the efficient sustainable yield without worrying about discounting. The static efficient sustainable yield is the catch level that, if maintained perpetually, would produce the largest annual net benefit. We shall refer to this as the static efficient sustainable yield to distinguish it from the dynamic efficient sustainable yield, which incorporates discounting. The initial use of this static concept enables us to fix the necessary relationships firmly in mind before dealing with the more difficult role discounting plays. Subsequently, we raise the question of whether or not efficiency always dictates the choice of a sustainable yield as opposed to a catch that changes over time.

We condition our analysis on three assumptions that simplify the analysis without sacrificing too much realism: (1) the price of fish is constant and does not depend on the amount sold; (2) the marginal cost of a unit of fishing effort is constant; and (3) the amount of fish caught per unit of effort expended is proportional to the size of fish population (the smaller the population, the fewer fish caught per unit of effort).

In any sustainable yield, annual catches, population, effort levels, and net benefits, by definition, remain constant over time. The static efficient sustainable yield allocation maximizes the constant annual net benefit.

The benefits (revenues) and costs are portrayed as a function of fishing effort which can be measured in vessel years, hours of fishing, or some other convenient metric. The maximum population size (involving zero effort) is equal to the carrying capacity, while the minimum population size is zero. Because the variable on the horizontal axis is effort, and not population, an increase in fishing effort is recorded as a movement from left to right.

As sustained levels of effort are increased, eventually a point is reached (Em) at which further effort reduces the sustainable catch and revenue for all years. That point, of course, corresponds to the maximum sustainable yield on the above figure (S*), meaning that both points reflect the same population and growth levels. Every effort level portrayed in the following figure corresponds to a specific population level in the above figure.



Efficient sustainable yield for fishery

The net benefit is presented in the diagram as the difference (vertical distance) between benefits (prices times the quantity caught) and costs (the constant marginal cost of effort times the units of effort expended). The efficient level of effort is Eo, that point in the above figure at which the vertical distance between benefits and costs is maximized. Eo is the efficient level of effort because it is where marginal benefit (which graphically is the slope of the total benefit curve) is equal to marginal cost (the constant slope of the total cost curve). Levels of effort higher than Eo are inefficient because the additional cost associated with them exceeds the value of the fish obtained. Can you see why lower levels of effort are also inefficient?

Now we are armed with sufficient information to determine whether or not the maximum sustainable yield is efficient. The answer is clearly no. The maximum sustainable yield would be efficient only if the marginal cost of additional effort were zero. Can you see why? (Hint: What is the marginal benefit at the maximum sustainable yield?) Since at Em the marginal benefit is lower than marginal cost, the efficient level of effort is less than that necessary to harvest the maximum sustainable yield. Thus, the static efficient level of effort leads to a larger fish population, but a lower annual catch than the maximum sustainable yield level of effort.

Dynamic Efficient Sustainable Yield

The static efficient sustainable yield turns out to be the special case of the dynamic efficient sustained yield where the discount rate is zero. It is not difficult to understand why; the static efficient sustained yield is the allocation that maximizes the (identical) net benefit in every period. Any effort levels higher than this would yield temporarily larger catches (and net benefit), but this would be more than offset by a reduced net benefit in the future as the stock reached its new lower level. Thus, the undiscounted net benefits would be reduced.

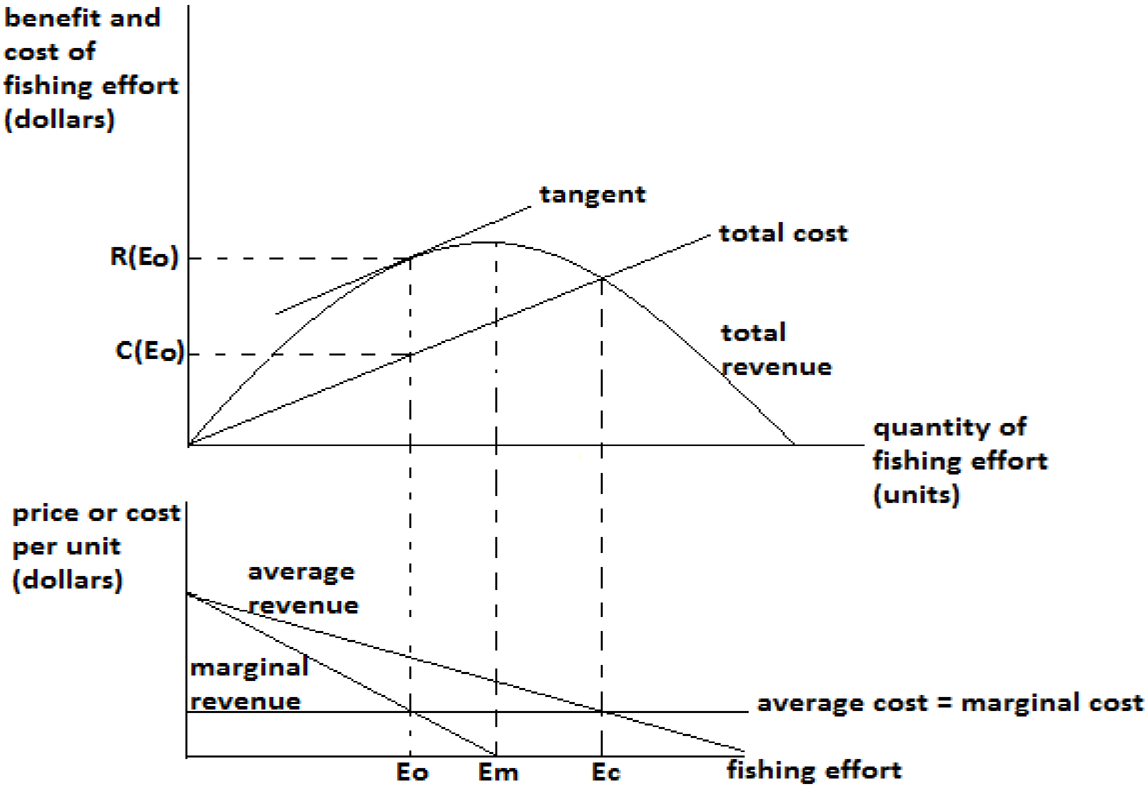
The effect of a positive discount rate for the management of a fishery is similar to its influence on the allocation of depletable resources—the higher the discount rate, the higher the cost (in terms of forgone current income) to the resource owner of maintaining any given resource stock. When positive discount rates are introduced, the efficient level of effort would be increased beyond that suggested by the static efficient sustained yield with a corresponding decrease in the equilibrium population level.

The increase in the yearly effort beyond the efficient sustained yield level would initially result in an increased net benefit from the increased catch. (Remember that the amount of fish caught per unit effort expended is proportional to the size of the population.) However, since this catch exceeds the sustained yield for that population size, the population of fish would be reduced and future population and catch levels would be lower. Eventually, as that level of effort is maintained, a new, lower equilibrium level would be attained when the size of the catch once again equals the growth of the population. Colin Clark (1976) has shown mathematically that in terms of Figure 13.2, as the discount rate is increased, the dynamic efficient level of effort is increased until it would become equal to Ec, the point at which net benefits go to zero.

It is easy to see why the use of an infinite discount rate to define the dynamic efficient sustained yield results in allocation Ec. We have seen that temporally interdependent allocations over time give rise to a marginal user cost measuring the opportunity cost of increasing current effort. This opportunity cost reflects the forgone future net benefits when more resources are extracted in the present. For efficient interdependent allocations, the marginal willingness to pay is equal to the marginal user cost plus the marginal cost of extraction. With an infinite discount rate, this marginal user cost is zero, because no value is received from future allocations. (Do you see why?) This implies that (1) the marginal cost of extraction equals the marginal willingness to pay, which equals the constant price, and (2) total benefits equal total costs.

In the following figure note that the two panels share a common horizontal axis that allows us to examine the effect of various fishing effort levels on both graphs. A sole owner would want to maximize his or her profits. Ignoring discounting for the moment, the owner can increase profits by increasing fishing effort until marginal revenue equals marginal cost. Gordon suggests that Net Economic Yield (economic rent) be maximized (identified by MR = MC) so as to Maximize Social Benefits. This occurs at effort level Eo which is the static efficient sustainable yield, and yields positive profits equal to the difference between R(Eo) and C(Eo).

In ocean fisheries however, sole owners are unlikely. Ocean fisheries are typically open-access resources – no one exercises complete control over them and no fisherman can exclude others from exploiting since property rights to the fishery are not conveyed to any single owner,



Market allocation in a fishery

Overexploitation and Open Access

Social efficiency requires MC = MR. However, in open access each fisher compares average catch and associated revenue with the value of the highest alternative to fishing. Let say, the highest alternative available is $50 per day (opportunity cost of fishing). Given this, fisher will compare average catch (Average Product) multiplied by Price against the $50. Then the greater number of fishers in the fishery than would be if the decision to enter was based on a comparison of AR, rather than MR.

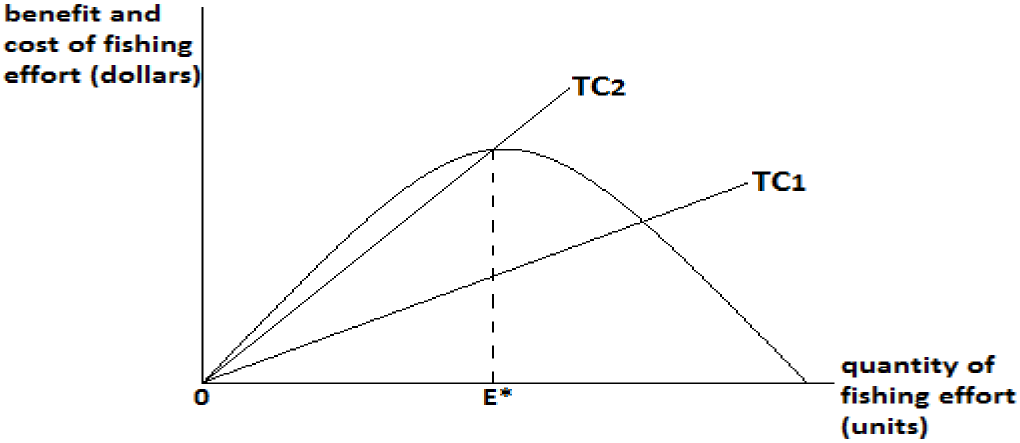
Open-access resources generally violate the efficiency criterion and may violate the sustainability criteria, and leads to loss in welfare associated with too much effort being employed in the fishery (Ec). If these criteria are to be fulfilled, some restructuring of the decision-making environment is necessary. The efficient solutions are;

- Efficient solutions (policies)
    - Privatize fishery - hard to do, not popular
    - Tax on effort - would work, but not done much
    - Raise real cost of fishing - common, but not efficient,
        - Gear restrictions
        - Shorten fishing season
        - Close certain fisheries
    - End up using more resources to catch same number of fish, and aquaculture (the controlled raising and harvesting of fish).

- ***Gear restriction*** (smaller search equipment, and slower movement)
    - Regulation: it is ***legal to harvest but designed to leave a portion of the fish stock in the water*** to provide a sufficient ***breeding stock to ensure future populations***

- ***Fishing season*** is closed for a ***certain period on an annual basis***, generally during spawning season (***biological analysis*** of breeding behavior)
- Regulations to ***protect fish stocks which are congregate*** and ***vulnerable*** to ***overharvesting***
- ***Limits on how many fish may be captured*** in a ***given time period*** (weight caught, number of fish, or volume of catch)
- ***Limiting catch quota*** (for individuals, businesses)
- ***Limited entry:*** system to direct effort
    - fixed number of boats to operate in the fishery
- ***Economic exclusion zone*** – geographical limit based on water rights

The following figure illustrates the effect of increase in cost of fishing. TC1 reflects the total cost in an unregulated fishery and the total cost after these policies were imposed (TC2). Increase in cost reduces the level of extraction. The net benefit received from an efficient policy is shown graphically as the vertical distance between total cost and total benefit. After the policy, however, the net benefit was reduced to zero; the net benefit (represented by vertical distance) was lost to society.



Effects of regulation

Other Issues in Fishery Management

The following are some problems of fishery management other than overexploitation.

- **Non-discriminatory** fishing
- **Destruction of habitat** (fish ecosystem) through fishing and non-fishing activities;
- **Pollution** of fishery habitat;
- **Recreational fisheries** (open-access exploitation)
- **Conflicts** between user groups
- **Poor international cooperation** concerning the harvesting of migratory species

4.3.2 Forest resources

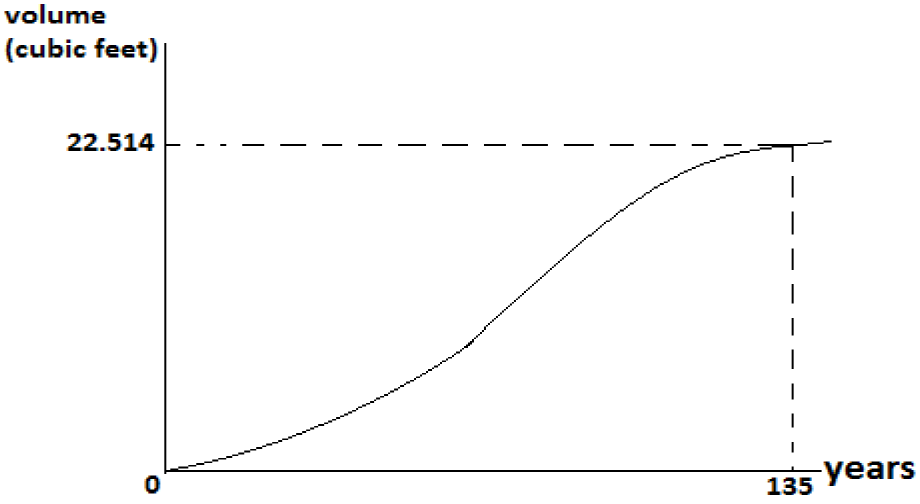
Forest is a renewable resource that lies on both natural regeneration and replanting by forest managers to produce new generation of trees. Forests provide a variety of products and services. The raw materials for housing and wood products are extracted from the forest. In many parts of the world, wood is an important fuel. Paper products are derived from wood fiber. Trees cleanse the air by absorbing carbon dioxide and adding oxygen. Forests provide shelter and sanctuary for wildlife and they play an important role in maintaining the watersheds that supply much of our drinking water. In general forests help our environment to functioning well.

Managing these forests is no easy task. In contrast to crops such as cereal grains, which are planted and harvested on an annual cycle, trees mature very slowly. The manager must decide not only how to maximize yields on a given amount of land but also when to harvest and whether to replant. In addition, a delicate balance must be established among the various possible uses of forests. Since harvesting the resource diminishes other values (such as protecting the aesthetic value of forested vistas or providing habitat for shade-loving species), establishing the proper balance requires some means of comparing the value of potentially conflicting uses. The efficiency criterion is one obvious method.

Tree growth is conventionally measured on a volume basis, typically cubic feet, on a particular site. This measurement is taken of the stems, exclusive of bark and limbs, between the stump and a four-inch top. Based on this measurement of volume, the data reveal that tree stands go through distinct growth phases. Initially, when the trees are very young, growth is rather slow in volume terms, though the tree may experience a considerable increase in height. A period of sustained, rapid growth follows, with volume increasing considerably. Finally, slower growth sets in as the stand fully matures, until growth stops or decline sets in.

The actual growth of a stand of trees depends on many factors, including the weather, the fertility of the soil, susceptibility to insects or disease, the type of tree, the amount of care devoted to the trees, and vulnerability to forest fire or air pollution. Thus, tree growth can vary considerably from stand to stand. Some of these growth-enhancing or growth-retarding factors are under the influence of foresters; others are not.

Abstracting from these differences, it is possible to develop a hypothetical but realistic biological model of the growth of a stand of trees. Our model, as shown in Figure 12.1 is based on the growth of a stand of Douglas fir trees in the Pacific Northwest.2 Notice that the figure is consistent with the growth phases listed above, following an early period of limited growth in its middle ages, with growth ceasing after 135 years.



Model of Tree Growth in a Stand of Douglas Fir.

Optimal harvesting level of forest

There are two options for the optimal harvesting of forest namely, harvest where MAI is maximized, and harvest where volume /total yield/ is maximized.

Using Mean Annual Increment

MAI = V(t)/t where V(t)/t is the average growth per year a tree

Biologists argue that forest should be harvested at the age when MAI reaches its maximum, and the average growth per year a tree or stand of trees has exhibited/experienced to a specified age.

$$MAI = \frac{\text{commulative volume of the stand } [V(t)]}{\text{commulative years the stand has been grown } [t]}$$

Consider the following table.

Age (years) [1]	**Volume (Cubic meter) [2]**	**MAI [3=2/1]**
1	694	694
2	1,912	956
3	3,558	1,186
4	5,536	1,384
5	7,750	1,550
6	10,104	1,684
7	12,502	1,786
8	14,848	1,856
9	17,046	1,894
10	***19,000***	***1,900***
11	20,614	1,874
12	21,792	1,815
13	***22,438***	***1,726***

Harvesting when ***volume /total yield/ is maximized***

From the above table MAI is maximized when the tree stands 10 yrs (Biological optimum) by using the first option. Every 10 yrs, we obtain 19,000 cubic meter timber Using the second option, maximum volume occurs when the tree stands 13 years. Every 13 years, we obtain 22,438 cubic meter timber.

Cutting Options	**Age of tree cutting**	**Timber volume**	**MAI**
Maximum volume	13	22,438	1,726
Maximum MAI	10	19,000	1,900

The Economics of Forest Harvesting

The above harvesting period neglects costs of harvesting and planting, and time value and the value (price) of the timber Planting costs are borne immediately, and harvesting costs and revenue received born far in the future.

- harvesting costs and revenues are discounted
- planting costs are not discounted because they are paid immediately

In Economist, then, harvesting period is the time at which Net Benefit is Maximized. That is:

Net benefit (NB) = Total benefit (TB) – Total cost (TC)

Net benefit (NB) = Price*volume of the tree – (planting cost + harvesting cost)

To calculate the net benefit, we assume some assumptions. These assumptions include;

- Price of timber is constant over the year at p per cubic meter
- Land is bare to begin with – there are no trees on it at age 0
- Planting cost occurs when the stand is established & is equal to D
- Harvesting cost is constant at C per cubic meter
- We harvest all of the timber from a stand of trees of uniform age and growth characteristics, and
- The interest rate is r

The optimal age of harvesting a forest in a single rotation at any time t is given as follows

- TR= P*V(t) where V(t) is timber volume in cubic meter at time t

$PV(TR) = (P * V(t))/(1+r)^t$

Total harvest cost $(THC) = C * V(t)$

$PV(THC) = (C * V(t)) / (1+r)^t$

Planting cost = PC =D

$NPV = PV(TR) – PV(THC) – PC$

$$=P*V(t)/(1+r)^t – (C*V(t)/(1+r)^t – D$$

$$= (P – C)*V(t) / (1+r)^t – D$$

Conclusion: the efficient age of harvest is the one that maximizes this expression

Sources of inefficient forest management include Global inefficiency, Open access resource, Incomplete markets, and Poverty and debt.

Sustainable Forestry

We have examined three types of decisions by landowners—the harvesting decision, the replanting decision, and the conversion decision—that affect the rate of deforestation. In all three cases, profit-maximizing decisions may not be efficient and these inefficiencies tend to create a bias toward higher rates of deforestation. These cases present both a challenge and an opportunity. The current level of deforestation is the challenge. The opportunity arises from the realization that correcting these inefficiencies can promote both efficiency and sustainability.

Does the restoration of efficiency guarantee sustainable outcomes? Let’s suppose that we apply the environmental sustainability definition to forestry. By this definition, sustainable forestry can be realized only when the forests are sufficiently protected that harvests can be maintained perpetually. Also, sustainable forestry would require harvests to be limited to the growth of the forest, leaving the volume of wood unaffected (or non-decreasing) over time.

Efficiency is not necessarily compatible with this definition of sustainable forestry. Maximizing the present value involves an implicit comparison between the increases in value from delaying harvest (largely because of the growth in volume) and the increase in value from harvesting the timber and investing the earnings (largely a function of r, the interest rate earned on invested savings). With slow-growing species, the growth rate in volume is small. Choosing the harvest age that maximizes the present value of net benefits in slow-growing forests may well involve harvest volumes higher than the net growth of the forest.

The search for sustainable forestry practices that are also economically sustain-able has led to a consideration of new models of forestry. One involves a focus on planting rapidly growing tree species in plantations. Rapidly growing species raise the economic attractiveness of replanting because the invested funds are tied up for a shorter time. Species raised in plantations can be harvested and replanted at a low cost. Forest plantations have been established for such varied purposes as supplying fuel wood in developing countries and supplying pulp for paper mills in both the industrialized and developing countries. Plantation forestry is controversial, however. Not only do plantation forests typically involve a single species of tree, which results in a poor wildlife habitat, they also tend to require large inputs of fertilizer and pesticides.

In some parts of the world, the natural resilience of the forest ecosystem is sufficiently high that sustainability is ultimately achieved, despite decades of earlier unsustainable levels of harvest. In the United States, for example, sometime during the 1940s, the net growth of the nation’s timberlands exceeded timber removals. Subsequent surveys have confirmed that net growth has continued to exceed harvests, in spite of a rather large and growing demand for timber. The total volume of forest biomass in the United States has been growing since at least World War II; for the country as a whole, harvests during that period have been sustainable, although the harvests of some specific species in some specific areas have not.

Public Policy

One public policy approach involves restoring efficient incentives. The following examples flow naturally from the previous discussion:

- Concessionaires should pay the full cost for their rights to harvest publicly controlled lands, including compensating for damage to the forests surrounding the trees of interest.
- The magnitude of land transferred to squatters should not be a multiple of the amount of cleared forest.
- The rights of indigenous peoples should be respected.

Another approach involves enlisting the power of consumers in the cause of sustainable forestry. The process typically involves the establishment of standards for sustainable forestry, employing independent certifiers to verify compliance with these standards, and allowing certified suppliers to display a label designating compliance.

For this system to work well, several preconditions need to be met. The certification process must be reliable and consumers must trust it. Additionally, consumers must be sufficiently concerned about sustainable forestry to pay a price premium (over prices for otherwise-comparable, but uncertified, products) that is large enough to make certification an attractive option for forestry companies. This means that the revenue should be sufficient to at least cover the higher costs associated with producing certified wood. Nothing guarantees that these conditions would be met in general.

Most of these changes could be implemented by individual nations to protect their own forests. And to do so would be in their interests. By definition, inefficient practices cost more than the benefits received. The move to a more efficient set of policies would necessarily generate more net benefits, which could be shared in ways that build political support for the change. But, what about the global inefficiencies that transcend national boundaries? How can they be resolved?

Several economic strategies exist. They share the characteristic that they all involve compensating the nations conferring external benefits so as to encourage conservation actions consistent with global efficiency.

Debt-Nature Swaps

One strategy involves reducing the pressure on the forests caused by the international debt owed by many developing countries. Private banks, the holders of much of the debt, are not typically motivated by a desire to protect biodiversity. Nonetheless, it is possible to find some common ground for negotiating strategies to reduce the debt. Banks realize that in some cases complete repayment of the loans is probably impossible. Rather than completely write off the loans, an action that not only causes harm to the income statement but also creates adverse incentives for repayment of future loans, they are willing to consider alternative strategies.

One of the more innovative policies that explore common ground in international arrangements has become known as the debt-nature swap. It is innovative in two senses: (1) the uniqueness of the policy instrument, and (2) the direct involvement of nongovernmental organizations (NGOs) in implementing the policy. A debt–nature swap involves the purchase at a discounted value in the secondary debt market of a developing country debt, usually by a non-governmental environmental organization. The new holder of the debt offers to cancel the debt in return for an environmentally related action on the part of the debtor nation.

Extractive Reserves

One strategy designed to protect the indigenous people of the forest as well as to prevent deforestation involves the establishment of extractive reserves. These areas would be reserved for the indigenous people to engage in the traditional hunting-gathering activities.

Conservation Easements and Land Trusts

One private approach to internalizing the forestry benefits that may normally be externalized in deciding how the resource is to be used involves conservation easements. Conservation easements provide a means for amenity values to be explicitly considered in forestry decisions. In the right circumstances, they can facilitate efficient preservation of those values.

The World Heritage Convention

The World Heritage Convention came into being in 1972 with the primary mission of identifying and preserving the cultural and natural heritage of outstanding sites throughout the world, and ensuring their protection through international cooperation. Currently, some 178 countries have ratified the convention.

Ratifying nations have the opportunity to have their natural properties of outstanding universal value added to the World Heritage List. The motivation for taking this step is to gain international recognition for this site, using the prestige that comes from this designation to raise awareness for heritage preservation and the likelihood that the site can be preserved. A ratifying nation may receive both financial assistance and expert advice from the World Heritage Committee as support for promotional activities for the preservation of its properties as well as for developing educational materials.

Royalty Payments

One potential source of revenue for biodiversity preservation involves taking advantage of the extremely high degree of interest by the pharmaceutical industry in searching for new drugs derived from these biologically diverse pools of flora and fauna. Establishing the principle that nations containing these biologically rich resources within their borders would be entitled to a stipulated royalty on all products developed from genes obtained from these preserves provides both an incentive to preserve the resources and some revenue to accomplish the preservation.

Nations harboring rich, biological preserves have begun to realize their value and to extract some of that value from the pharmaceutical industry. The revenue is in part used for inventorying and learning more about the resource as well as preserving it. For example, in 1996, Medichem Research, an Illinois-based pharmaceutical company, entered into a joint venture with the Sarawak government.

The organization created by this joint venture has the right to file exclusive patents on two compounds that offer some promise as cancer treatments. The agreement specified a 50–50 split from royalties once the drug is marketed.

Carbon Sequestration Credits

To the extent that landowners do not receive all the benefits of landownership, they may discount or ignore the benefits that accrue to others. Carbon sequestration credits are an attempt to rectify one such imbalance. Is this an efficient remedy?

Debt-nature swaps, extractive reserves, royalty payments, carbon sequestration credits, and conservation easements all involve recognition of the fact that resolving the global externalities component of deforestation requires a rather different approach from resolving the other aspects of the deforestation problem. In general, this approach involves financial transfers from the industrialized nations to the tropical nations, transfers that are constructed so as to incorporate global interests into decisions about the future of tropical forests.

Recognizing the limited availability of international aid for the preservation of biodiversity habitat, nations have begun to tap other revenue sources. Tourist revenues have become an increasingly popular source, particularly where the tourism is specifically linked to the resources that are targeted for preservation. Rather than mixing these revenues with other public funds, nations are earmarking them for preservation.

Exercises

1. Discuss the optimal depletion or the optimal use of nonrenewable and renewable resources. Illustrate your discussions with appropriate diagrams. What are the sources and remedies of inefficiency in the allocation of these resources?
2. Forests in most countries are owned either by the state or by the community. Discuss the pros and cons of this situation in relative to privatization of forests.
3. When the government allows private firms to extract minerals offshore or on public lands, two common means of sharing in the profits are bonus bidding and production royalties. The former awards the right to extract to the highest bidder, while the second charges a per-ton

royalty on each ton extracted. Bonus bids involve a single, up-front payment, while royalties are paid as long as minerals are being extracted.

A. If the two approaches are designed to yield the same amount of revenue, will they have the same effect on the allocation of the mine over time? Why or why not?
B. Would either or both be consistent with an efficient allocation? Why or why not?
C. Suppose the size of the mineral deposit and the future path of prices are unknown. How do these two approaches allocate the risk between the mining company and the government?

4. Is the establishment of the 200-mile limit a sufficient form of government intervention to ensure that the tragedy of the commons does not occur for fisheries within the 200-mile limit? Why or why not?

5. Assume that the relationship between the growth of a fish population and the population size can be expressed as $g = 4P - 0.1P^2$, where g is the growth in tons and P is the size of the population (in thousands of tons). Given a price of \$100 a ton, the marginal benefit of smaller population sizes (and hence larger catches) can be computed as $20P - 400$.

A. Compute the population size that is compatible with the maximum sustainable yield. What would be the size of the annual catch if the population were to be sustained at this level?
B. If the marginal cost of additional catches (expressed in terms of the population size) is $MC = 2(160 - P)$, what is the population size that is compatible with the efficient sustainable yield?