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NATURAL RESOURCE AND ENVIRONMENTAL ECONOMICS (Econ 3012)



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Preface

This book is meant to students of economics who have already taken the prerequisite courses under the standard curriculum of the Department of Economics, Arba Minch University. It covers wider areas of natural resource and environmental concerns that serves as introductory lesson in this branch of economics. Even if it is a discipline that emerged very recently from the mainstream economics, environmental thinkers and practitioners have gone several miles ahead to make the world aware of the consequences of ignoring the environment in our day to day activities. As a result of persistent and hard work by these people, the world has now started to give attention about caring for the imperiled world and using the limited resources in an optimal way in almost all walks of life. This book will show you a snapshot of the wider and vast world of the field of natural resource and environmental economics.

CHAPTER ONE

1. INTRODUCTION

Course Contents:

Three major areas will be dealt

A brief history of the subject [Natural Resource and Environmental Economics] The linkages between the economy and the environment

Thinking about the future

Objectives:

Dear students, in this chapter we will be focusing on three major issues and after going through this chapter, students are expected to

Know how natural resource and environmental economics has emerged as discipline.

Clearly understand the interaction between human activities and nature (the environment).

Familiarize yourself with the two view points about the prospects of the world predicted based on the existing relationships of human beings and the environment.

1.1 A BRIEF HISTORY OF THE SUBJECT

We now briefly examine the development of Natural Resource and Environmental Economics from the time of the Industrial Revolution in Europe.

1.1.1 Classical Economics: The Contributors of Smith, Malthus, Ricardo and Mill to the Development of Natural Resource Economics

While the emergence of natural resource and environmental economics as a distinct sub-discipline has been a relatively recent event, concern with the substance of natural resources and environmental issues has much earlier antecedents. The label ‘classical’ identifies a number of economists writing in the eighteenth and nineteenth centuries, a period during which the industrial revolution was taking place (at least in much of Europe and North America) and agricultural productivity was growing rapidly. A recurring theme of political-economic debate concerned the appropriate institutional arrangements for the development of trade and growth.

These issues are central to the work of Adam Smith (1723-1790). Smith was the first writer to systematize the argument for the importance of markets in allocating resources, although his

emphasis was placed on what we would call on the dynamic effects of markets. His major work, *An Inquiry in to the Nature and Causes of the Wealth of Nations* (1776), contains the famous statement of the role of the ‘Invisible Hand’.

This belief in the efficacy of the market mechanism is a fundamental organizing principle of the policy prescriptions of modern economics, including resource and environmental economics, as will be seen in our account of it in the rest of the course.

A central interest of the classical economists was the question of what determined standards of living and economic growth. Natural resources were seen as important determinants of national wealth and its growth. Land (sometimes used to refer to natural resources in general) was viewed as limited in its availability. When to this were added the assumptions that land was a necessary input to production and that it exhibited diminishing returns, the early classical economists came to the conclusion that economic progress would be a transient feature of history. They saw the inevitability of an eventual stationary state, in which the prospects for the living standard of the majority of people were bleak.

This thesis is most strongly associated with Thomas Malthus (1766-1834), who argued it most forcefully in his *Essay on the principle of population* (1798), giving rise to the practice of describing those who now question the feasibility of continuing long-run economic growth as ‘neo-Malthusian’. For Malthus, a fixed land quantity, an assumed tendency for continual positive population growth, and diminishing returns in agriculture implied a tendency for output per capita to fall overtime. There was, according to Malthus, a long run tendency for the living standards of the mass of people to be driven down to a subsistence level. At the subsistence wage level, living standards would be such that the population could just reproduce itself, and the economy would attain a steady state with a constant population size and constant, subsistence-level, living standards.

This notion of a steady state was formalized and extended by David Ricardo (1772-1823), particularly in his *Principles of Political Economy and Taxation* (1817). Malthus’s assumption of a fixed stock of land was replaced by a conception in which land was available in parcels of varying quality. Agricultural output could be expanded by increasing the intensive margin (exploiting a given parcel of land more intensively) or by increasing the extensive margin (bringing previously uncultivated land in to productive use). However, in either case, returns to the land input were taken to be diminishing. Economic development then proceeds in such a way

that the ‘economic surplus’ is appropriated increasingly in the form of rent, the return to land, and development again converges toward a Malthusian stationery state.

In the writings of John Staurt Mill (1806-1873) (see in particular Mill (1857)) one finds a full statement of classical economics at its culmination. Mill’s work utilizes the idea of diminishing returns, but recognizes the countervailing influence of the growth of knowledge and technical progress in agriculture and in production more generally. Writing in Britain when output per person was apparently rising, not falling, he placed less emphasis on diminishing returns, reflecting the relaxation of the constraints of the extensive margin as colonial exploitation opened up new trenches of land, as fossil fuels were increasingly exploited, and as innovation rapidly increased agricultural productivity. The concept of a stationary state was not abandoned, but it was thought to be one in which a relatively high level of material prosperity would be attained.

Foreshadowing later developments in environmental economics, and the thinking of conversations, Mill adopted a broader view of the roles played by natural resources than his predecessors. In addition to agricultural and extractive uses of land, Mill saw it as a source of amenity values (such as the intrinsic beauty of countryside) that would become of increasing relative importance as material conditions improved.

1.1.2 Neoclassical Economics: Marginal Theory and Value

A series of major works published in the 1870s began the replacement of classical economics by what subsequently became known as ‘neoclassical economics’. One outcome of this was a change in the manner in which value was explained. Classical economics saw value as arising from the labor power embodied (directly and indirectly) in output, a view which found its fullest embodiment in the work of Karl Marx. Neoclassical economists explained value as being determined in exchange, so reflecting preferences and costs of production. The concepts of price and value ceased to be distinct. Moreover, previous notions of absolute scarcity and value were replaced by a concept of relative scarcity, with relative values (prices) determined by the forces of demand and supply. This change in emphasis paved the way for the development of welfare economics, to be discussed shortly.

At the methodological level, the technique of marginal analysis was adopted, allowing earlier notions of diminishing returns to be given a formal basis in terms of diminishing marginal

productivity in the context of an explicit production function. Jevons (1835-1882) and Menger (1840-1921) formalized the theory of consumer preferences in terms of demand and utility theory. The evolution of neoclassical economic analysis led to an emphasis on the structure of economic activity, and its allocative efficiency, rather than on the aggregate level of economic activity. Concern with the prospects for continuing economic growth receded, perhaps reflecting the apparent inevitability of growth in Western Europe at this time. Leon Walras (1834-1910) developed neoclassical General Equilibrium Theory, and in so doing provided a rigorous foundation for the concepts of efficiency and optimality that we employ extensively in this text. Alfred Marshall (1842-1924) (see *Principles of Economics*, 1890) was responsible for the elaboration of the partial equilibrium supply and demand based analysis of price determination so familiar to students of modern microeconomics. A substantial part of modern environmental economics continues to use these techniques as tools of exposition, as do we at many points throughout the course.

We remarked earlier that concern with the level (and the growth) of economic activity had been largely ignored in the period during which neoclassical economics was being developed. Economic depression in the industrialized economies in the inter-war years provided the backcloth against which John Maynard Keynes (1883-1946) developed his theory of income and output determination. The Keynesian agenda switched attention to aggregate supply and demand, and the reasons why market economies may fail to achieve aggregate levels of activity that involve the use of all of the available inputs to production. Keynes was concerned to explain, and produce remedies for, the problem of persistent high levels of unemployment, or recession.

This direction of development in the mainstream economics had little direct impact on the emergence of resource and environmental economics. However, Keynesian ‘macroeconomics’, as opposed to the microeconomics of neoclassical economics, was of indirect importance in stimulating a resurgence of interest in growth theory in the middle of the twentieth century, and the development of a neoclassical theory economic growth. What is noticeable in early neoclassical growth models is the absence of land, or any natural resources, from the production function used in such models. Classical limits-to-growth arguments, based on a fixed land input, did not have any place in early neoclassical growth modeling.

The introduction of natural resources in to neoclassical models of economic growth occurred in the 1970s, when some neoclassical economists first systematically investigated the efficient and

optimal depletion of resources. This body of work, and the developments that have followed from it, is natural resource economics.

1.1.2 Welfare Economics

The final development in mainstream economic theory that needs to be briefly addressed here is the development of a rigorous theory of welfare economics. Welfare economics attempts to provide a framework in which normative judgments can be made about alternative configuration of economic activity. In particular, it attempts to identify circumstances under which it can be claimed that one allocation of resources is better (in some sense) than another.

Not surprisingly, it turns out to be the case that such rankings are only possible if one is prepared to accept some ethical criterion. The most commonly used ethical criterion adopted by classical and neoclassical economists derives from the utilitarian moral philosophy, developed by David Hume, Jeremy Bentham and John Stuart Mill. Suffice to say now that utilitarianism has social welfare consisting of some weighted average of the total utility levels enjoyed by all individuals in the society.

Economists have attempted to find a method of ranking different states of the world which does not require the use of a social welfare function, and makes little use of ethical principles, but is nevertheless useful in making prescriptions about resource allocation. The notion of economic efficiency, also known as allocative efficiency or Pareto Optimality (because it was developed by Vilfredo Pareto (1897)) is what they have come up with. It can be shown that, given rather stringent conditions, an economy organized as a competitive market economy will attain a state of economic efficiency. This is the modern, and rigorous, version of Adam Smith's story about the benign influence of the invisible hand.

Where the conditions do not hold, markets do not attain efficiency in allocation, and a state of 'market failure' is said to exist. One manifestation of market failure is the phenomenon of 'externalities'. These are situations where, because of the structure of property rights, relationships between economic agents are not all mediated through markets.

The problem of pollution is a major concern of environmental economics. It first attracted the attention of economists as a particular example of the general class of externalities. Important early work in the analysis of externalities and market failure is to be found in Marshall (1890). The first systematic analysis of pollution as an externality is to be found in Pigou (1920).

However, environmental economics did not really ‘take off’ until the 1970s. The modern economic treatment of problems of environmental pollution is dealt in chapter 5.

Environmental economics is also concerned with the natural environment as a source of recreational and amenity services, which role for the environment can be analyzed using concepts and methods similar to those used in looking at pollution problems. Like pollution economics, it makes extensive use of the technique of cost-benefit analysis, which emerged in the 1950s and 1960s as a practical vehicle for applied welfare economics and policy advice.

The modern sub-disciplines of natural resource economics and environmental economics have largely distinct roots in the core of modern mainstream economics. The former emerged mainly out of neoclassical growth economics, the latter out of welfare economics and the study of market failure. Both can be said to effectively date from the early 1970s, though of course earlier contributions can be identified.

1.2 THE LINKAGES BETWEEN THE ECONOMY AND THE ENVIRONMENT

In economics the environment is viewed as a composite asset that provides a variety of services. It is a very special asset, since it provides the life support systems that sustain our very existence. As with other assets, we wish to prevent undue depreciation of the value of this asset so that it may continue to provide aesthetic and life-sustaining services.

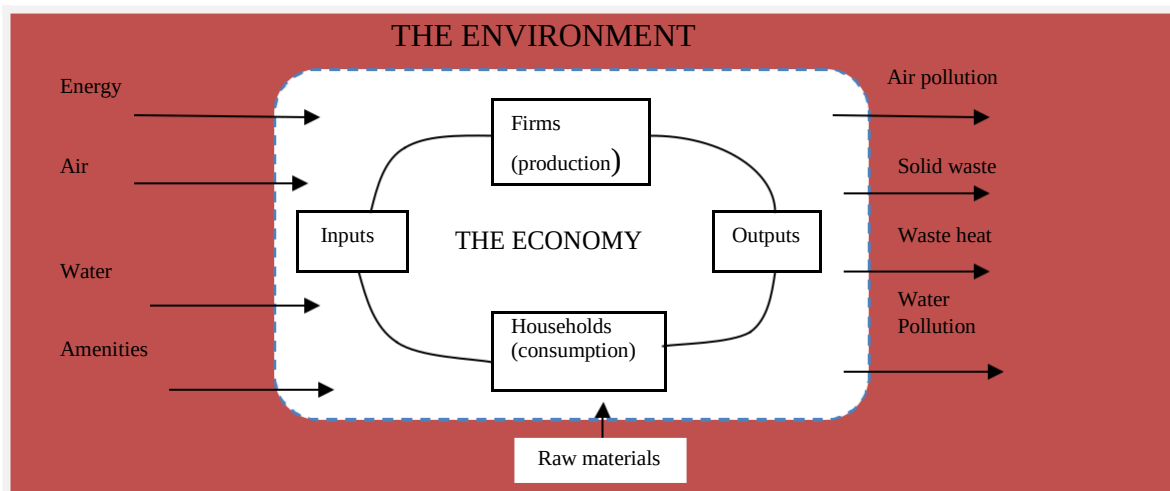
The environment provides the economy with raw materials, which are transformed in to consumer products by the production process, and energy, which fuels this transformation. Ultimately, these raw materials and energy return to the environment as waste products. (See Figure 1.1)

The environment also provides services directly to consumers. The air we breathe, the nourishment we receive from food and drink, and the protection we derive from shelter and clothing are all benefits we receive either directly or indirectly from the environment. In addition, anyone who has experienced the exhilaration of white-water canoeing, the total serenity of a wilderness trek, or the breathtaking beauty of a sunset will readily recognize that the environment provides us with a variety of amenities for which no substitute exists.

If the environment is defined broadly enough, the relationship between the environment and the economic system can be considered a *closed system*. For our purpose, a closed system is one in

which no inputs (energy, matter, and so on) are received from outside the system and no outputs are transferred outside the system. An *open system*, by contrast, is one in which the system imports or exports matter or energy.

Figure 1.1: The Economic System and the Environment



If we restrict our conception of the relationship in Figure 1.1 to our planet and the atmosphere around it, then clearly we don't have a closed system. We drive most of our energy from the sun, either directly or indirectly. We have also sent spaceships well beyond the boundaries of our atmosphere. Nonetheless, historically speaking, for material inputs and outputs (not including energy), this system can be treated as a closed system because the amount of exports (such as abandoned space vehicles) and imports (moon rocks, for example) are negligible. Whether the system remains closed depends on the degree to which space exploration opens up the rest of our solar system as a source of raw materials.

The treatment of our planet and its immediate environs as a closed system has an important implication which is summed up in the first law of thermodynamics—energy and matter cannot be created or destroyed. The law implies that the mass of materials flowing in to the economic system from the environment has to either accumulate in the economic system or return to the environment as waste. When accumulation stops, the mass of materials flowing in to the economic system is equal in magnitude to the mass of waste flowing to the environment.

Excessive wastes can, of course, depreciate the asset; when they exceed the absorptive capacity of nature, wastes reduce the services that the asset provides. Examples are easy to find: air pollution can cause respiratory problems; polluted drinking water can cause cancer; smog obliterates scenic vistas.

The relationship of people to the environment is also conditioned by another physical law, the second law of thermodynamics. Known popularly as the entropy law, this law states that the entropy increases. Entropy is the amount of energy not available for work. Applied to energy processes, this law implies that no conversion from one form of energy to another is completely efficient and that the consumption of energy is an irreversible process. Some energy is always lost during conversion, and the rest, once used, is no longer available for further work. The second law also implies that in the absence of new energy inputs, any closed system must eventually use up its energy. Since energy is necessary for life, life ceases when energy ceases.

We should remember that our planet is not even approximately a closed system with respect to energy; we gain energy from the sun. The entropy law does suggest, however, that this flow of solar energy establishes an upper limit of the flow of energy that can be sustained. Once the stocks of stored energy (such as fossil fuels and nuclear energy) are gone, the amount of energy available for useful work will be determined solely by this flow and by the amount that can be stored (dams, trees, and so on). Thus, over the very long run, the growth process will be limited by the availability of solar energy and our ability to put it to work.

1.3 THINKING ABOUT THE FUTURE

For several decades economists have been concerned with topics such as exhaustible resources and pollution, but during the last few decades the frequency of related books and articles have accelerated rapidly. Consequently, we have come to better understand the relationship between humanity and the environment and how that relationship affects, and is affected by, economic and political institutions.

In this regard, we will now consider two seemingly contrasting visions about the future of the relationship between the environment and humanity.

i) THE BASIC PESSIMIST MODEL

One end of the spectrum is defined by an ambitious study originally published in 1972 under the title *The Limits to Growth* and subsequently updated and revised in 1992 under the title *Beyond the Limits*. Based on a technique known as systems dynamics, developed by Professor Jay Forrester at Massachusetts Institute of Technology (MIT), a large scale computer model was constructed to simulate likely future outcomes of the world economy.

Conclusions of the Pessimist Model

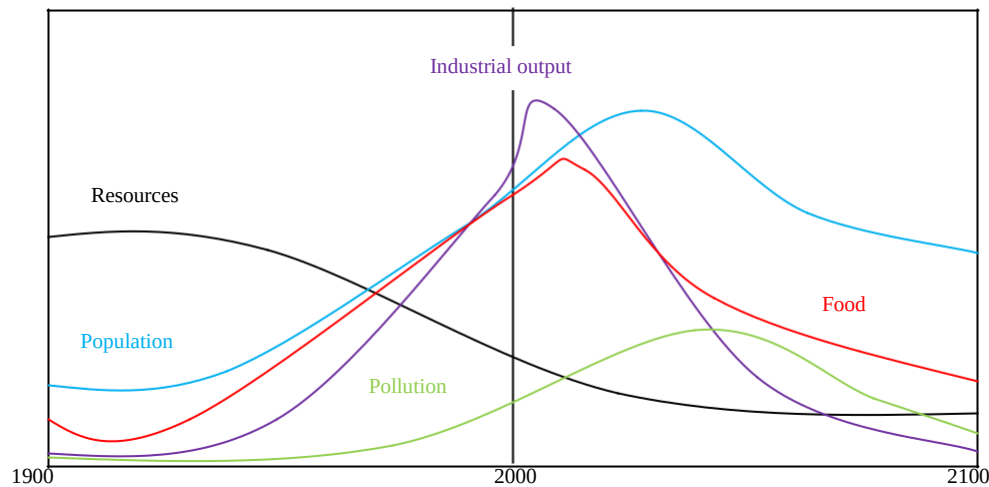
Three main conclusions were reached by this study.

- a) The first suggests that within a time span of less than 100 years with no major change in the physical, economic, or social relationships that have traditionally governed world development, society will run out of the nonrenewable resources on which the industrial base depends. When the resources have been depleted, a precipitous collapse of the economic system will result, manifested in massive unemployment, decreased food production, and a decline in population as death rate soars. There is no smooth transition, no gradual slowing down of activity; rather, the economic system consumes successively larger amounts of the depletable resources until they are gone. The characteristic behavior of the system is overshoot and collapse.
- b) The second conclusion of the study is that piecemeal approaches to solving the individual problems will not be successful. To demonstrate this point, the authors arbitrary double their estimates of the resource base and allow the model to trace out an alternative vision based on this new higher level of resources. In this alternative vision the collapse still occurs, but this time it is caused by excessive pollution generated by the increased pace of industrialization permitted by the greater availability of resources. The authors then suggest that if the depletable resource and pollution problems were somehow jointly solved, population would grow uncontrolled and the availability of food would become the binding constraint. In this model the removal of one limit merely causes the system to bump up subsequently in to another one, usually with more dire consequences.
- c) As its third and fourth conclusion, the study suggests that overshoot and collapse can be avoided only by an immediate limit on population and pollution, as well as a cessation of economic growth. The portrait painted shows only two possible outcomes: the terminator of growth by self-restraint ad conscious policy-an approach that avoids the collapse- or

the termination of growth by a collision with the natural limits, resulting in societal collapse. Thus, according to this study, one way or the other, growth will cease. The only issue is whether the conditions under which it will cease will be congenial or hostile.

Figure 1.2 Beyond the Limits Standard Run

State of the World



II) THE BASIC OPTIMIST MODEL

The second model starts with questioning the validity of the basic pessimist model; Is the portrait of the world economy presented by *Beyond the Limits* accurate?

Many think not. One of the most vocal critics is Julian Simon, a well-known population economist. His alternative vision, published under the title *The Unlimited Resource*, rejects the overshoot and collapse scenario in favor of a more optimistic vision.

The Nature of the Model

What concepts of how the world works underlie this optimistic vision? Simon's argument is founded on two main foundations. First, his reading of the evidence suggests that historically, human resourcefulness has always overcome both scarcities of resources and environmental problems associated with economic activity. Second, he finds no compelling reason why those trends cannot continue indefinitely in to the future.

To strengthen his argument, Simon offers several observations:

The amount of land being committed to agriculture is still increasing. Even where it is decreasing (the United States, for example) agricultural production has increased. Food production is therefore not likely to be a limit.

Contrary to popular belief, natural resources have not become more scarce overtime.

Apparent shortages are due more to (correctable!) problems with human behavior than to any physical lack of availability.

Population levels have declined as population and incomes have increased. Pollution is not the inevitable consequence of economic activity, but rather results from societal choices about how resources should be invested.

Conclusions of the Optimist Model

The Simon vision of the future concludes:

The standard of living has arisen along with the size of the world's population since the beginning of recorded time. And with increases in income and population have come less severe shortages, lower costs, and an increased availability of resources, including a clearer environment and greater access to natural recreation areas. And there is no convincing reason why these trends toward a better life, and toward lower prices for raw materials (including food and energy), should not continue indefinitely.

In summary,

In this chapter we have introduced two rather different world visions – one optimistic and one pessimistic. In part the differences between them depend on how human behavior is perceived. If intensifying pressure on the environment results in a behavioral response which intensifies the pressures, pessimism is justified. If, on the other hand, the human responses either currently are reducing those pressures or could be reformed so as to reduce those pressures, then optimism may be justified.

Summary

- ✚ The modern sub-disciplines of natural resource economics and environmental economics have largely distinct roots in the core of modern mainstream economics. The former emerged mainly out of neoclassical growth economics, the latter out of welfare economics and the study of market failure. Both can be said to effectively date from the early 1970s, though of course earlier contributions can be identified.
- ✚ Understanding the relationships between the environment and economic activity is crucial as its knowledge is a prerequisite for designing any policy that may have any direct or indirect impacts on these relationships.
- ✚ The economics approach views the environment as a composite asset, supplying a variety of services to humanity. The intensity and composition of those services depend on the actions of humans as constrained by physical laws, such as the first and second laws of thermodynamics.
- ✚ We have examined briefly two studies which provide different answer to the prospect of the world. The *Pessimistic* view is based upon the inevitability of exceeding the carrying capacity of the planet as the population and the level of economic activity grow. The *Optimistic* view sees initial scarcity triggering sufficiently powerful reductions in population growth and increases in technological progress that the future brings abundance, not deepening scarcity.

Problems

1. Critical evaluate why natural resource and environmental economics is ignored for long time and only emerged as a discipline recently.
2. Comment on the impacts of different projects in affecting the relationship between the environment and the economy by citing your own examples.
3. This chapter contains two views of the future. Since the validity of these views cannot completely be tested until the time period covered by the forecast has passed (so that predictions can be matched against actual events), how can we ever hope to establish whether one is a better view than the other? What criteria might be proposed for evaluating predictions?

CHAPTER II

ENVIRONMENT AND DEVELOPMENT: SOME ISSUES

Course Contents:

Dear students, this chapter has six major portions:

- Sustainable Development: Basic Concepts and Definitions
- Poverty and the Environment
- Population Growth and the Environment
- Economic Growth and the Environment
- National Accounting Practices and Macro-economic
- Performance Economy-Wide Policies and the Environment

Objectives

This chapter is designed to introduce students with vital developmental issues such as:

- Familiarizing students with what do we mean by ‘*sustainable development*’ and the various concepts associated with sustainability.
- Elaborating the interlinked relationships between poverty and the environment; and reasons behind these interconnections in some details.
- Assessing the views on the effects of population growth on the environment based on the theory of demographic transition.
- Describing the patterns of environmental degradations due to economic growth by substantiating with appropriate rationales.
- Elaborating the existing system of national accounts, its limitations and possible adjustments in measuring the macroeconomic performance of a nation.
- Introducing some economy wide policies giving special attention to their effects on the environment.

2.1 Sustainable Development: *Basic Concepts and Definitions*

For many years, it was thought that the eradication of poverty required well-designed development programs that were largely independent of considerations relating to the natural

environment. The goal of economic and political debate was to identify growth processes that could allow continually rising living standards. Economic development and ‘nature conservation’ were seen as quite distinct and separate problems. For some commentators, concern for the natural environment was a rather selfish form of self-indulgence on the part of the better-off.

Prospective have changed significantly since the 1970s. While the pursuit of economic growth and development continues, it is recognized that the maintenance of growth has an important environmental dimension. During the 1970s, a concern of sustainability began to appear on the international political agenda, most visibly in the proceedings of a series of international conferences. The common theme of these debates was the interrelationship between poverty, economic development and the state of the natural environment.

Perhaps the best-known statement of the sustainability problem derives from the 1987 report of the World Commission on Environment and Development (WCED), which set the agenda for much of the subsequent discussion of sustainability. The report that WCED produced in 1987 – *our common future* (WCED, 1987) – is often referred to as ‘the Brundtland report’ after the name of the WCED chairperson. It advanced, with great effect, the concept of ‘sustainable development’, which is now on political agendas, at least at the level of rhetoric, around the world. The Brundtland report was, in political terms, an outstanding and influential piece of work.

According to the Brundtland report, sustainable development is defined as follows:

“Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

It also states that far from requiring the cessation of economic growth, sustainable development recognizes that the problems of poverty and underdevelopment cannot be solved unless we have a new era of growth in which developing countries play a large role and reap large benefits.

Box 2.1: Sustainable, Sustained and Survival

Development The following notations are used: U_t = the utility level at time t

$\dot{U}_t$ = the rate of change of utility at time t

U_t^{MAX} = the maximum utility which can be held constant for ever from time t onwards, given production opportunities available at time t

U^{SURV} = the maximum utility level consistent with survival of the given population

Development is *sustainable* if $U_t \leq U_t^{MAX}$ always.

Development is *sustained* if $\dot{U}_t \geq 0$ always.

Development is *survival* if $U_t \geq U^{SURV}$ always.

If utility is a function of consumption alone, the usual consumption in inter-temporal economic analysis, then it is possible to replace the word ‘utility’ by ‘consumption’ in each of these criteria (and to change symbols from U to C commensurably) and thereby to define them in terms of consumption rather than utility. Doing this we obtain:

Development is *sustainable* if $C_t \leq C_t^{MAX}$ always.

Development is *sustained* if $\dot{C}_t \geq 0$ always.

Development is *survival* if $C_t \geq C^{SURV}$ always.

Note that the level of utility (or consumption) corresponding to survivability is taken to be constant overtime (hence C^{SURV} carries no time subscript). But C_t^{MAX} does (and must) include a time subscript. The highest level of constant, sustainable consumption an economy can obtain from any point of time onwards does depend on which point in time we consider. For example, at the end of a prolonged and major war, in which large stocks of resources have been consumed or irretrievably degraded, the maximum feasible level of sustainable consumption is likely to be smaller than it was before the war broke out.

2.1.1 Economic Concepts of Sustainability

A concern for sustainability derives from an ethical concern for future generations together with an appreciation of the facts which implies that such concern needs to be incorporated into current decision making – because, for example, of the use of non-renewable resources in production. If we did not care about future generations, then the use of non-renewable resources in production would not require any particular attention in current decision making. Equally, if nothing that we did now had any implications for future generations, then notwithstanding an ethical concern for them there would be no need to think about them in current planning and decision making.

Box 2.2: Six concepts of sustainability

1. A sustainable state is one in which utility (or consumption) is non-declining through time.
2. A sustainable state is one in which resources are managed so as to maintain production opportunities for the future.
3. A sustainable state is one in which the natural capital stock is non-declining through time.
4. A sustainable state is one in which resources are managed so as to maintain a sustainable yield of resource services.
5. A sustainable state is one which satisfies minimum conditions for ecosystem resilience through time.
6. Sustainable development as consensus-building and institutional development.

2.1.2 Weak and Strong Sustainability

In some economic contributions to the literature of sustainability a distinction is made between ‘*weak sustainability*’ and ‘*strong sustainability*’. In fact, the point being made concerns differing views about the conditions that need to be met for the realization of sustainability as constant consumption (or utility), rather than different conceptions or definitions of sustainability. ‘Weak’ is not a different kind of sustainability from ‘strong’. Proponents of both weak and strong sustainability take constant consumption (or utility) to be what sustainable is. They differ over what is necessary for its realization, and the difference is actually about substitution possibilities. As developed in the literature, the weak versus strong sustainability debate makes extensive use of the notion of ‘natural capital’, which we now explain. Production potential at any point in time

depends on the stock of productive assets available for use. This stock can be classified into human labor and all other productive resources. Now let us define the term ‘capital’ in a very broad sense, to include any economically useful stock, other than raw labor power. In this broad sense capital consists of:

- (a) *Natural Capital*: any naturally provided stock, such as aquifers and water systems, fertile land, crude oil and gas, forests, fisheries and other stocks of biomass, genetic material and earth’s atmosphere itself. We have previously discussed, in Chapter 1, the services that the natural environment provides to the economy. Talking of ‘natural capital’ is a way of referring to the collectivity of the environmental assets from which all such services flow.
- (b) *Physical Capital*: plant, equipment, buildings and other infrastructure, accumulated by devoting part of current production to capital investment.
- (c) *Human Capital*: stocks of learned skills embodied in particular individuals, which enhances the productive potential of those people.
- (d) *Intellectual Capital*: disembodied skills and knowledge. This comprises the stock of useful knowledge, which we might otherwise call the state of technology. These skills are disembodied in that they do not reside in particular individuals, but are part of the culture of society. They reside in books and other cultural constructs, and are transmitted and developed through time by social learning processes.

If human-made capital is defined to be the sum of physical, human and intellectual capital, then the total stock of capital can be seen as consisting of two parts: natural and human-made capital. The latter is sometimes referred to as reproducible capital.

This way of classifying production inputs leads to writing the economy’s production function in summary representative form as:

$$Q = Q(L, K_N, K_H)$$

Where L represents labor, K_N , natural capital and K_H human-made capital. Note that we have defined technology as part of K_H so that our formulation does not allow the function itself to change with changing technology. Within this framework, the difference between weak and strong sustainabilists turns on what they judge to be the extent of the substitution possibilities between K_N and K_H . Strong sustainabilists argue that there is not perfect substitutability between

the different types of capital assets while weak sustainabilists believe that there is a perfect substitution among capital assets of a nation.

The operational difference is that proponents of strong sustainability argue that sustainability requires that the level of K_N be non-declining, while proponents of weak sustainability argue that

it requires that it is the sum of K_N and K_H that must be non-declining. In brief, weak sustainability merely requires that the overall sum of different forms of capital assets of a nation must be non-declining (at least constant). That is, weak sustainability says that even if one form of capital assets decreases, it is not a problem if this decrease is compensated by the rise of the other form of capital assets of a nation. On the other hand, strong sustainability agrees that the overall sum of capital assets must be non-declining but there must be at least a certain threshold level of natural capital that must be non-declining as it can not be substituted by other forms of capital assets of a nation.

2.2 Poverty and the Environment

There is a strong relationship between poverty and the environment. In terms of causation, poverty leads to environmental degradation and environmental degradation worsen poverty by endangering the health and productivity of the poor. This implies that poverty leads to environmental degradation and in turn environmental degradation leads to poverty.

Poor people are forced to engage in number of activities like fetching water, fire wood collection, cattle grazing, etc. This causes environmental degradation

The environmental degradation can lower labor productivity of the poor. For example, fuel wood become scarce, and poor people spend more time collecting fuel wood consequently the poor earn lower income.

Box 2.3: Principal Health and Productivity Consequences of Environmental Problems

<i>Environmental problem</i>	<i>Effect on health</i>	<i>Effect on productivity</i>
<i>water pollution & water scarcity</i>	- deaths and illness, - poor household hygiene and - added health risks caused by water scarcity	- declining fisheries, - household time and municipal costs of providing safe water shortages
<i>Air pollution</i>	- premature deaths - childhood chronic coughing	- restriction on vehicle and industrial activity during critical episodes; - effect of acid rain on forests and water bodies
<i>Solid and hazardous wastes</i>	- disease spreads by rotting garbage and blocked drains	- pollution of ground water resources
<i>Deforestation</i>	- localized flooding leading to death and disease	- loss of sustainable logging potential of erosion prevention and carbon sequestration
<i>Solid degradation</i>	- reduce nutrition for poor farmers on depleted soils - greater susceptibility to drought	- field or land productivity loss
<i>loss of biodiversity</i>	- potential loss of new drugs	- reduction of ecosystem adaptation and loss of genetic resources
<i>Atmospheric changes</i>	- possible shift in vector born diseases - risks from domestic natural disaster	- regional change in agricultural productivity

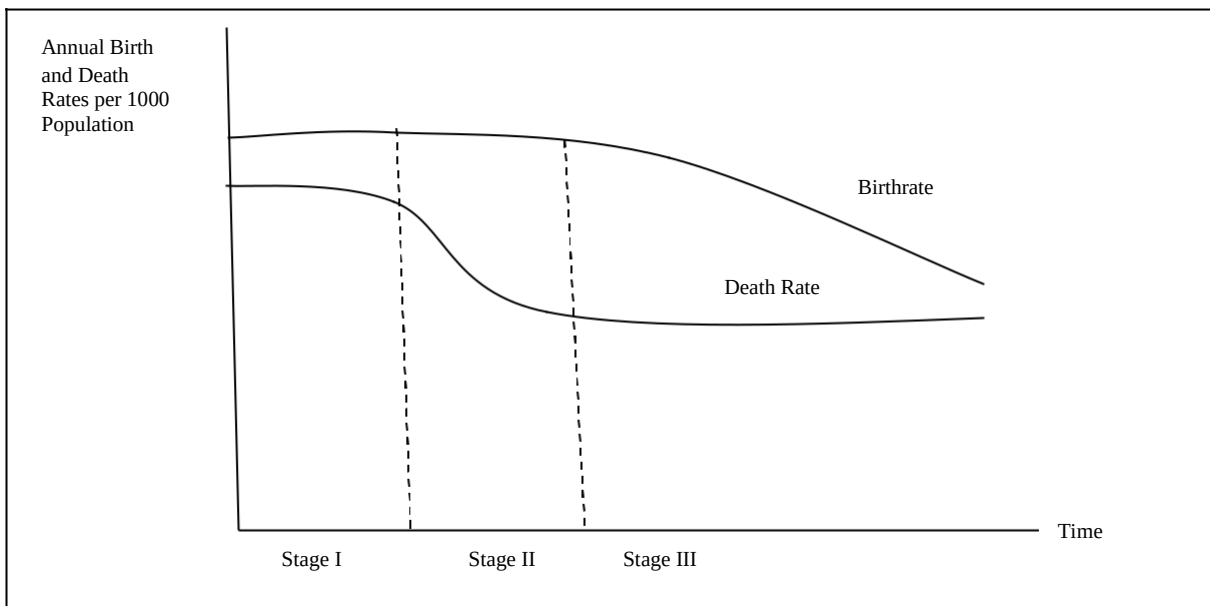
(Source: Mlier & Rauch cited in Teferi, 2007)

2.3 Population Growth and the Environment

Before discussing about the arguments on the possible effects of population growth on the environment, it is imperative to see what is known as the *theory of demographic transition*. This theory suggests that as nations develop, they eventually reach a point where birthrates fall. Most of the industrialized countries have passed through three stages of population growth as evidenced by this conceptual framework, the theory of demographic transition.

During stage I, the period immediately prior to industrialization, births are stable and slightly higher than death rates, ensuring population growth. During stage II, the period immediately following the initiation of industrialization, death rates fall dramatically with no accompanying change in birthrates. This decline in mortality results in a marked increase in life expectancy and a rise in the population growth rate. In Western Europe, stage II is estimated to have lasted somewhere around 50 years.

Figure 2.1: The Demographic Transition



Stage III, the period of demographic transition, involves large decline in the birthrate which exceed the continued declines in the death rate. Thus, the period of demographic transition involves further increases in life expectancy; but rather smaller population growth rates than characterized the second stage.

The theory of demographic transition is useful because it suggests that reductions in population growth might accompany rising standards of living, at least in the long run. However, it also leaves many questions unanswered. Will lower-income countries automatically experience demographic transition as living standards improve? Is industrialization or better designed agricultural production systems possible solutions to “the population problem?” Is population growth a threat to environmental amenities?

In regarding the last question, some people argue that population growth leads to environmental degradation. They suggest that more people would affect the environment at least in the following two ways:

- I. Population growth accelerates the demand for goods and services and this will eventually result in environmental degradation.
- II. The existence of more people would result in more waste- additional stress on assimilative capacity of the environment. Hence, there should be policies for reducing population growth rate. Some of the policies used to reduce population growth include family planning method, economic incentives and disincentives by government (for instance providing free education, house allowance, free food etc.), binding early marriages by law, and so forth.

On the other hand, some others argue that population growth leads to environmental degradation instead with population growth people may be forced to produce new technologies which is favorable for environmental replenishment. This is called Boserup hypothesis. They argue that the natural vegetation cover of the world increases in spite of population growth.

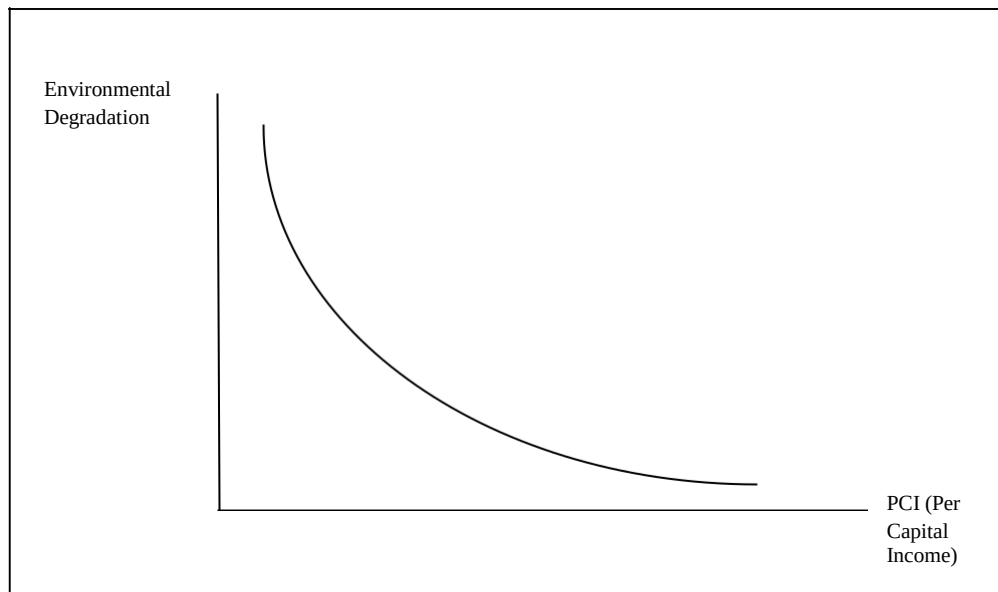
2.4 Economic Growth and the Environment

As stated earlier, environmental problems differ substantially between less and more developed countries. This is because most environmental problems tend to vary with economic growth. Does this mean that economic growth leads to environmental degradation?

Generally there are three patterns of relationship between economic growth and environmental degradation.

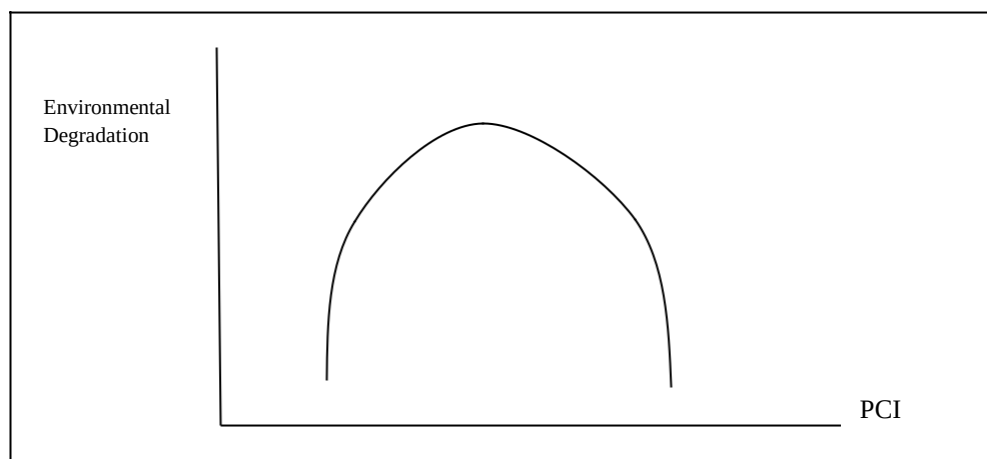
1. Some environmental problems decline as income rise

This is because increasing income provides the resources for public services such as urban sanitation, safe water, rural electricity, etc.



2. Some environmental problems initially worsen but then improve as income rise.

Example: Most forms of air and water pollution.



Rationale (the Conventional explanation)

At early stage of economic growth, people don't worry about the environmental problems; they worry about PCI growth. But when they grow more and more, they taste that pollution is the major problem. People look at environmental quality. As income rises, people attach high value to the environmental quality. They need clear air, water

etc. People, then start to take measure to reduce pollution as they grow more because they have the ability to do, they have more resources and afford to reduce environmental problems. As they use environmental policies, environmental degradation declines.

The tendency of many forms of environmental degradation to follow an "inverted U" when plotted against income has been christened the "Environmental Kuznet Curve." Environmental Kuznet Curve comes from Kuznet Curve, named after Simon Kuznet. Kuznet Curve shows the relation ship between per capita income and income inequality. At lower level of development income inequality is low; as economic growth increases it increases initially and then as countries grow more and more income inequality become low.

Box 2.4: The "Environmental Kuznet Curve"

We have seen that some environmental degradation increases first and then decreases with per capita income. Because this is reminiscent of Kuznet's conjecture for income inequality, this inverted U relationship has become known as the "*Environmental Kuznet curve*"

The cause of the upswing of the inverted U is simply that the greater out put per head generates more emissions, all else equal.

The cause of downswing is more controversial: the conventional explanation is that richer consumers demand higher environmental quality, richer governments are better able to enforce regulations that yield the higher environmental quality their constituents demand, and more technologically advanced producers are better able to control their emission

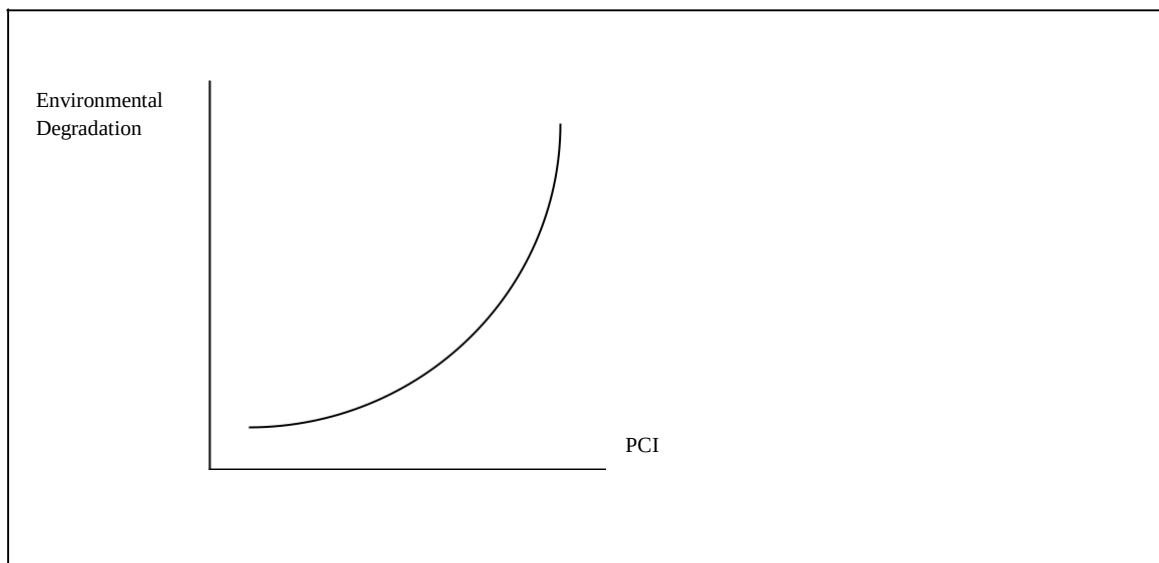
A more pessimistic explanation focuses on the composition of out put. Richer countries produce more service relative to manufactures, and with in manufacturing they tend to specialize in "cleaner" industries. Demand for the output of dirty industries is met by imports from poorer countries.

If this latter explanation is correct, then at the global level of income/economic growth of countries with per capita incomes above the 'turning point' of the inverted U for a certain form of environmental degradation does not improve environmental quality but instead redistributes degradation to poor countries. (Source: Teferi, 2007)

3. Some indicators of environmental stress worsen as income increase

These kinds of environmental problems have their own distinct nature in that they require very high abatement costs for emission reduction. Besides, the costs caused by such kinds of environmental problems are essentially borne by the society as a whole and not by the pollutant firm. Because of these reasons, polluters do not have incentive to reduce these types of environmental problems and as a result their will continually rise over time.

Example: Emissions of carbon and nitrogen oxides and municipal wastes are current examples.



The rationale behind this phenomenon is that due to income growth, people tend to use more canned products which affect the environment as the cans will be thrown away after consumption. In addition to this, income growth leads to a rise in the use of petroleum products which intensifies pollution coming from emission of carbon dioxide.

Box 2.5: Types (or forms) of Environmental Degradation

Environment refers to both the quality and quantity of natural resource. Environmental degradation has three aspects/dimensions: Quantity, Quality, Diversity/composition (species)

Hence environmental degradation is the deterioration of the environment in quality, quantity or diversity/composition.

1. Water related problems

- Water shortages*
- Water pollution & contamination*

2. Forest relate Problems

- Deforestation → ↓ in forest coverage*
- Degradation of forest → ↓ in forest productivity and loss of diversity*

3. Land related problems

- Sanitation → ↓ in salt content*
- Nutrient loss*
- Land scarcity*
- Overgrazing etc*

4. Fishery related problems

- Over fishing*
- Fish poisoning/contamination*
- Loss of fish species*

5. Urban related problems

- Congestion*
- Air , water and noise pollution*

NB. As quality problems are worsen quantity problems emerge.

(Source: Teferi, 2007)

2.5 National Accounting Practices and Macro-economic Performance

This deals with the issue of national income accounting to measure the macroeconomic performance of a nation. Traditionally, we employ GNP or GDP as indicators of macroeconomic performance of a country. This use of GNP (GDP) is often called UN system of National Accounts (SNA). This is the system of national accounting used by many countries.

Two major criticisms of SNA pointed out particularly by environmental economists and environmentalists are:

1. Aggregates such as GNP may be inadequate measures of economic activity when natural assets are ignored.
2. Services provided by the environment are not taken into account in the computation of measures like GNP.

These limitations call for adjustment of the entire system of national accounts for resource depletion and environmental degradation. Hence, the new SNA should inculcate environmental amenities which have been ignored by the current system of national accounts. Economists, therefore, have come with two approaches for adjusting the new SNA:

1. Physical Resource Accounting (PRA) approach

It tries to look at the effect of various economic activities on the environment in physical terms. This is making the adjustment in physical terms via the physical indicators. Examples of the physical indicators include

Deforestation:- measuring the volume of forest decline

⇒ by how much the forest decline per year.

Soil degradation:- measuring the amount of soil fertility decline

⇒ by how much does the soil quality go down? How many tones of soils are lost?

Water pollution:- measuring the volume/quality of water decline

⇒ what is happening to the total quantity and quality of water?

The challenge associated to this approach is that the calculation is not an easy task, it requires in put-out put calculation in physical terms. In this approach, as the name indicates, we are talking about changes in physical terms.

⇒ Basically, this is the work of natural scientists.

2. Monetary Accounting (MA):

This is particularly the interest of economists. In this case we try to attach monetary value to the change. Here, we will be able to come up with a single aggregate measure and we can tell what is happening to the economy. We convert the different measurement used in monetary value. This is not possible in the case of PRA. But, how do we attach monetary measure? Again we have two methods.

a) Environmentally Adjusted Domestic Product (EDP):

Net Domestic Product (NDP) is total income earned by the economy in any year less an allowance for the depreciation of man made capital.

$$NDP = GDP - D_{mc} \quad \text{where} \quad D_{mc} = \text{depreciation of manmade capital.}$$

Note that D_{mc} is subtracted because it is the used part of capital in production process (or it is a loss in the value of the asset). But it is not only the man made capital which is lost in the production process. In the production process we also lose natural resource capital. Hence, NDP is not the true measure of a country's economic activity and sustainable development. A country's economic activity and its sustainable development is obtained if the loss of natural resource capital is taken in to account. The measurement so obtained is called *Environmentally Adjusted Domestic Product (EDP)*. An environmentally adjusted measure of NDP (or EDP) would be a good measure of sustainable development when it fulfills the following three important requirements:

When all elements of NDP are correctly valued in terms of current economic situation.

When this is true in a fore ward looking sense too (prices reflect future scarcity).

When all depreciation of natural capital is similarly allowed for as well.

Consequently, we have $EDP = GDP - D_{mc} - D_{Nc}$

D_{Nc} = depreciation of natural capital which includes renewable, non renewable

= also includes loss of environmental quality.

EDP is the annual pay offs from the total (natural plus manmade) capital stock. EDP can rise through time if this total capital stock rises, and/or as technology improves. But if we fail to account for a loss of natural capital, our NDP measure exaggerates the real increase because that change in NDP may be at the expense of degrading the environment. Hence, in relative term, EDP better shows what is happening in the economy, and you may start taking measures. The main challenge to this adjustment is that practically measuring D_{Nc} is difficult.

D_{Nc}

Note: The adjustment of the entire system of national accounts for resource depletion and environmental degradation is known as “Green National Accounting”

b) Genuine savings (GeS):

As you may recall from your lessons in Macroeconomics, saving is an engine for economic growth. The transformation of savings into productive investments would result in economic growth of nations. From the experience of developed countries, it is evident that they had and still have a large amount of savings in their economy. However, developing countries have low level of saving which leads to low level of development. Besides, remember that it is net saving that really boosts the investment of a country and hence results in economic growth. Net saving is usually computed as:

$$Net\ Savings = Gross\ Savings - D_{mc}$$

The problem related to the above calculation is that it does not take in to account what happens to natural resource. It considers only the man made capital. Just as the entire system of national accounts can be adjusted for resource depilation and environmental degradation, so can the saving rates. This adjustment has become known as *Genuine Savings*. The concept of genuine savings is implied from the definition of weak sustainability. Genuine savings are savings adjusted not for depreciation of the man made

capital stock but also for depletion of natural resource and degradation of the environment

$$\text{Genuine Savings} = \text{Net savings} - D_{NC}.$$

Note: high dependency of natural resource results in lower GeS. Countries which depend on natural resource have lower GeS. Failure to account for depletion of natural resource results in wrong policy presentations.

2.6 Economy-Wide Policies and the Environment

The issue is the possible effects of policy measures on the environment. The question is what are the possible relations between the environment and policy? This question has become an important area of research. Several economists have tried to assess the possible impacts of economy-wide policies on the environment at depth. Let's briefly discuss them one by one:

1. **Trade Liberalization:** It is one important policy measure taken by countries particularly those making Structural Adjustment Program (SAP)¹. The basic idea here is the trade sector should have to work without any distortions. Reduction of tariff is one measure in trade liberalization. With reduction in tariff, the trade sector works better i.e. it operates more efficiently with lesser barriers. This implies that policy measures shouldn't be as such restrictive. From environmental point of view, although trade liberalization may not have direct importance, it indicates how the environment is affected. With trade liberalization, export would be promoted. When exported is promoted, the effect on the environment depends on the nature of commodities that the country is exporting. If the country relies on exports of primary commodities like agricultural production, timber and others, then people may destroy the environment in order to export more. But, this destruction process is affected by many factors like property rights.

¹ Structural adjustment programs address a well defined set of reform areas advocated by World Bank and International Monetary Fund (IMF). These will generally include establishing an appropriate macroeconomic framework for growth, introducing a set of supporting sectoral policies and investment efforts, and integrating the domestic economy into the world economy.

Regarding the industrial sector if tariff is reduced domestic industries would be less protected because with reduction of tariff foreign products will be largely released in to the economy. So, as a result of tariff reduction export is promoted and the industrial sector would be more efficient as a result of strong competition with foreign products. Hence, with the growth of the industrial production pollution may be promoted affecting the environment.

2. **Price Liberalization:** It refers to the removal of price control and subsidy in the economy by government. Both price controls and subsidies lead to distortion of the economy. When we implement price control, price will be artificially lower than the efficient level of price. Hence, price controls lead to inefficiency in the economy. According to SAP, countries need to remove price controls for the market to work properly. Subsidies also introduce distortions in the economy since prices will be far from the efficient level determined by the market so that firms fail to operate at efficient level.

In Ethiopia, both price control and most subsidies are now lifted out. The effect of this operation on the environment depends on the type of products. For example, during the Derg period there was strong price control. When the prices of products of poor farmers were significantly reduced, it leads to overutilization of the environment since farmers have a certain targeted income they must attain. If prices go up the farmers sell only small part of their output but if the prices are held lower the farmers are forced to sell more of their products to attain their targeted income. Also, subsidy has a similar effect as price control. To substantiate this statement with example, in Ethiopia, petroleum trading was under subsidy for several years before it was lifted. As a result of subsidy, the prices of the product went down and people relied more on petroleum as source of energy. The implication of this is that deforestation and other environmental damages would be reduced as a result of lower kerosene's price. On the other hand, the wide use of petroleum increases emission of carbon dioxide which increases global warming.

Some other people argue that it is possible to efficiently utilize both natural forests and petroleum without any subsidies. The existence of subsidy on fertilizers encourages farmers to use it more but recently that subsidy was removed and its price goes up. Other things held constant, there would be a fall in its consumption. But, fertilizer would be used efficiently, without recklessness and extravagancy, since farmers may not have the capacity much of it. The possible effect of this on the environment is with reduction in use of fertilizers imply a reduction in the use of other chemical fertilizers which reduces environmental hazards.

3. **Exchange Rate Reform:** this refers to the manipulation by government (particularly national bank) on the value of a country's currency vis-a-vis to foreign currencies. A typical example for this is a recent devaluation policy of Ethiopian government. The rationale of this move, according to government, is to improve our net-export balance in GDP² by encouraging exports and discouraging imports since now exporting and getting dollars become promising as the value of Birr decreases in relation to dollar. Now, if you get one dollar from export then it means you have around 11 Birr compared to only 2.07 Birr in the Derg fixed exchange rate regime. However, the effect of devaluation on the environment would depend on the type of export commodity. In typically developing countries like Ethiopia, where the exports are dominantly primary, devaluation policy lead to an increased export of products that come mainly from the environment, which leads to environmental hazards.

4. **Institutional Reforms**

Institutional reform is a general category comprising of four particular policy reforms:

- a) **Privatization:** refers to the transfer of ownership from the state to the private sector. One general argument is that if public organizations are privatized they would be more efficient because the private sector provides more incentives to

² As you may remember $GDP = C + I + G + NX$, where NX is net export, i.e., export minus import.

the workers. The impact of privatization on the environment depends on circumstances. For example, if public sectors are privatized, then private sectors will always focus on profitability than worrying on pollution as a result we would expect more pollution under private ownership than government ownership. In general, when private sector is very dominant there is less conservation of the environment. If an enterprise is owned by government we could expect externality to be reduced as government feels responsible and tries to internalize pollution externalities. However, in reality this may not happen in reality. For instance, in the former socialist countries of Western Europe the public sector was greatly polluting the environment. In short, the public sector is better than the private sector in causing externality on the environment.

- b) **Fiscal Reform**- changing the tax structure is one type of fiscal reforms. In some developing countries there is a reduction in tax to promote the agricultural sector but what happened is because the tax payment was significantly reduced and more people went out to agriculture by expanding farming grounds. Such expansion, however, leads to deforestation and other environmental hazards. Brazil is one best example in this regard.
- c) **Financial Liberalization**: it refers to a reform on interest rate. With financial liberalization, government may reduce interest rate and this could have an effect ultimately on the environment. One possible outcome with the reduction of interest rate is an increase in investment other things being constant. Such increase in investment would affect the environment depending on the investment area. It is straight forward for the reader to identify which investments have positive/negative impacts on the environment as such projects as tree planting, construction of industry, road and so on.
- d) **Land Reform**: this is a change in the ownership system of land. It has very important link with the environment because it takes the issue of property rights, land policy and the like.

For example: If we have a change in ownership of land from private to public sector. Then, if the farmers do not have private property right, the possible

effect would be misutilization of resources on the land. The farmers would also be discouraged to invest on the land since they are in suspicion of the ownership. Land reform is greatly linked with soil erosion, deforestation and other depletions on the topography of the land. Farmers construct protection of soil erosion belts only if they believe that they would work on their land for a fairly long period of time. This argument also applies for planting of perennial crops (crops that last for many farming seasons). If there is insecurity in the land tenure system, peasants tend to work short run activities on their land which may affect the environment negatively.

Box 2.6: Some Important Environmental Facts

- ♣ From the 19th c, world temperature ↑ by 0.4 to 0.8; rainfall decline by 20 to 40%
- ♣ One hectare forest absorbs 20% of carbon dioxide.
- ♣ 40% of the world's medicine is extracted from plants
- ♣ Brazil owns 65% of Amazon forest but 36% of total deforestation is also in Brazil.
- ♣ Congo has the largest forest coverage in Africa.

Ethiopian cases

- ♣ In early 19th c, 35% of the country is covered with dense forest. This amounts to 42 million hectares.
- ♣ In early 1950's only 16% of the land was covered by dense forest, which covers only about 19million hectares.
- ♣ Around 1980's the figure is reduced to 3.6%, i.e., only about 4 million hectares.
- ♣ As a result, Ethiopia loses 3.5 million tone of fertile land annually.

Causes of Deforestation

Major cause: high Population → demand of arable land as source of income.

↑population →demand of grazing land → deforestation

Others:

Ill managed grazing system

Lack of investment in this sector due to lack of market and attention

(Source: ETV, Nov. 2005 Cited in Teferi, 2007)

Summary

- ✚ Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
- ✚ There is a strong bi-directional causation between poverty and environmental degradation mainly because poor peoples are engaged in activities highly related to the environment and the intensification of environmental degradation further worsens the poverty level of the poor by lowering their productivity.
- ✚ It is important to remember the two views on the environment. The first group advocates that population growth has adverse effects on the environment as it induces more demand for goods and services coming directly and indirectly from nature; and increasing the accumulation of waste on the environment beyond its absorptive capacity.
- ✚ Some environmental problems decrease with a rise in per capital income (considering per capital income as a proxy for economic growth) and some other environmental problems rise at lower level of per capital income and decline gradually (thus having an inverted 'U' shape); and still some others decline as per capital income rises over time.
- ✚ The current system of antinational accounts (UN-SNA) has major limitations in measuring the macroeconomic performance of a nation especially because of ignoring the environment in its calculations. Hence two possible adjustments are forwarded: the physical resource accounting approach and the monetary accounting approach. While the latter is categorized in to two: environmentally adjusted domestic product and genuine savings.
- ✚ Governments employ some economy wide policies especially for development purposes, however, from environmental perspectives they have either favorable or adverse results depending on their specific instances.

Problems

1. The current system of national accounting system, as a measure of macroeconomic performance and sustainable development, is criticized for its limitation to reflect welfare only partially.
 - A. Discuss the two methods of adjusting the current system of national accounts under the monetary approach clearly.
 - B. When is an environmentally adjusted measure of NDP a good measure of sustainable development?
 - C. *“The concept of genuine savings is implied from the definition of weak sustainability”* comment.
2. Briefly explain the effects of the following economy wide policies on the environment;
 - i. Trade liberalization
 - ii. Institutional reforms
3. Clearly examine the bi-directional causations between poverty and environmental degradation by substantiating it with appropriate examples.
4. Distinguish the Kuznets curve from environmental Kuznets curve using relevant figures to help you answer the question.

CHAPTER THREE

3. EFFICIENCY AND THE ENVIRONMENT

Course Content:

This chapter has for main concerns:

- Normative Criteria for Decision-Making
- Static Efficiency
- Dynamic Efficiency
- Necessary Conditions for Economic Efficiency

Objectives:

Dear students, after going through the chapter you are expected to

Understand how benefits and costs are derived graphically and help us in decision making for net benefit maximization.

Differentiate the concepts of static and dynamic efficiency including their mathematical computations and especial features.

Know the four necessary conditions for economic efficiencies conceptually and graphically as well.

3.1 Normative Criteria for Decision-Making

If you were asked to evaluate the desirability of some proposed action, you would probably begin by attempting to identify both the gains from that action and the losses. If the gains exceed the losses, then it seems natural to support the action.

That simple framework provides the starting point for the economic approach. Economists suggest that actions have both benefits and costs. If the benefits exceed costs, then the action is desirable. On the other hand, if the cost exceed the benefits, then the action is not desirable.

We can formalize this in the following way. Let B be the benefits from a proposed action and C be the costs. Our decision rule would then be:

If $B > C$, then support the action. Otherwise, oppose the action.³

As long as B and C are positive an equivalent formulations would be:

If $B/C > 1$, support the action. Otherwise, oppose the action.

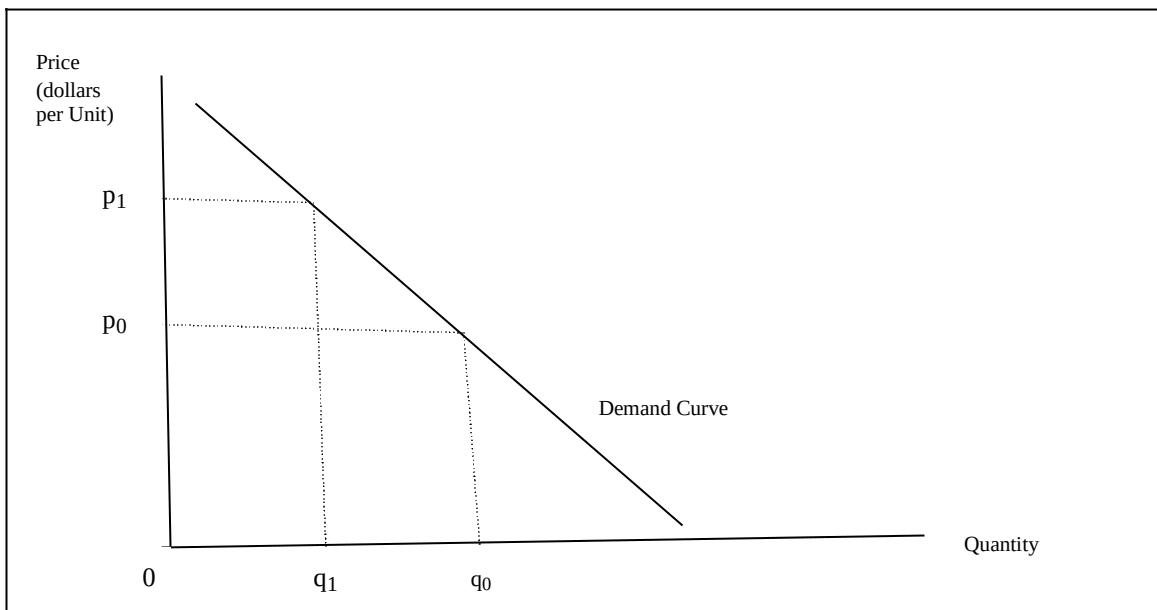
³ Actually if $B = C$, it wouldn't make any difference if the action occurs or not: the benefits and costs are a wash.

So far so good, but how do we measure benefits and costs? In economics the system of measurement is anthropocentric which simply means human-centered. All benefits and costs are valued in terms of their effects (broadly defined) on humanity. As shall be pointed out later, that does *not* imply (as it might first appear) that ecosystem effects are ignored unless they directly affect humans. The fact that large numbers of humans contribute voluntarily to organizations that are dedicated to environmental protection provides ample evidence that humans place a value on environmental preservation which goes well beyond any direct use they might make of it. Nonetheless, the notion that humans are doing the valuing is a controversial point.

Benefits can be derived from the demand curve for the good or service provided by the action. Demand curves measure the amount of a particular good people would be willing to purchase at various prices. In a typical situation, a person will purchase less of a commodity (or environmental service) the higher is its cost. In figure 2.2, when the price is p_0 , q_0 will be purchased, but if the price rises to p_1 , purchase will fall to q_1 .

The meaning of these demand curves can be illustrated with this hypothetical experiment; suppose you were asked: At a price of X dollars, how much commodity Y would you buy? Your answer could be recorded as a point on a diagram such as Figure 2.2. By repeating the question many times for different prices, we could trace out a locus of

Figure 3.1: The Individual Demand Curve



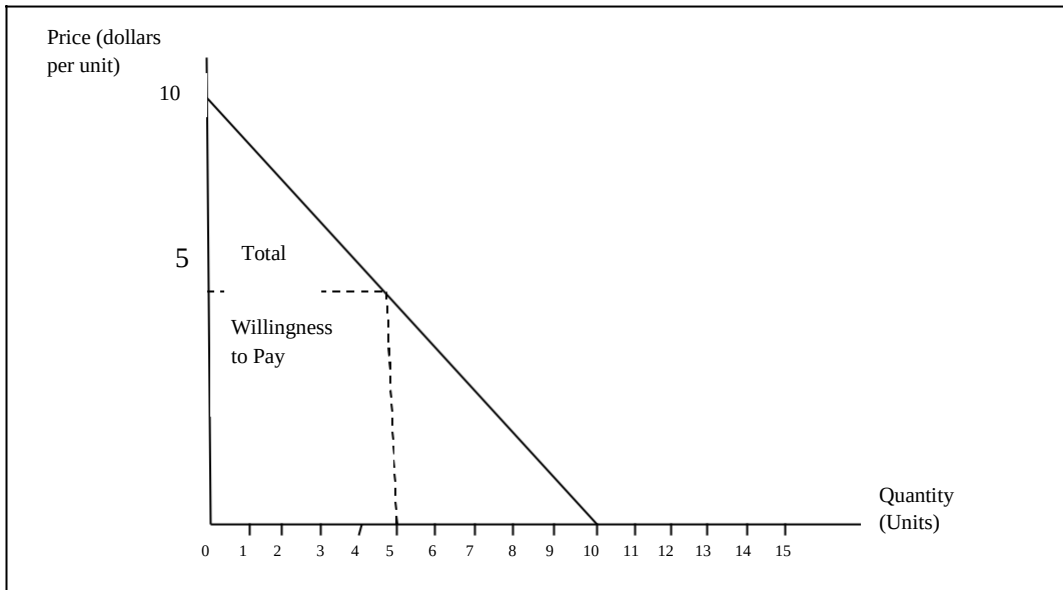
points. Connecting these points would yield an individual *demand curve*. Adding up all of the individual amounts demanded by all individuals at some stipulated price yields one point on the market demand curve. Connecting the points for various prices reveals the market demand curve.

For each quantity purchased, the corresponding point on the market demand curve represents the amount of money some person is willing to pay for the last unit of the good. The total willingness to pay for some quantity of this good - say, 3 units - is the sum of the willingness to pay for each of the three units. Thus the total willingness to pay for 3 units would be measured by the sum of the willingness to pay for the first, second, and third units, respectively. It is now a simple extension to determine that the total willingness to pay is the area under the continuous demand curve to the left of the allocation in question. For example, in Figure 2.3 the total willingness to pay for 5 units of the commodity is the shaded area.⁴ Total willingness to pay is the concepts we shall use to define total benefits. Thus total benefits are equal to the area under the market demand curve from the origin to the allocation of interest.

Measuring total costs on the same set of axes involves logic similar to measuring total benefits. It is important to stress that environmental services have costs even though they are produced with out any human input. All costs should be measured as opportunity costs.

For environmental services their opportunity cost is the net benefit forgone because the resource providing the service can no longer be used in their next most beneficial use. Resources are not free if they can be put to alternative uses. For example, suppose a particular stretch of river can be used for either for white-water canoeing or to generate

⁴ From simple geometry it can be noticed that for linear demand curves this area is the sum of the areas of the triangle on top plus the rectangle on the bottom. The area of a right angle triangle is $\frac{1}{2} \times \text{base} \times \text{height}$. Therefore, in our example this area is $\frac{1}{2} \times \$5 \times 5 = \$12.50$.

Figure 3.2: The Relationship of Demand to Willingness-to-Pay

electric power. Since the dam that generates the power would flood the rapids, the two uses are incompatible. The opportunity cost of producing power is the forgone net benefit that would have resulted from the white-water canoeing.

In graphing costs, we shall use the marginal opportunity cost curve to correspond to the marginal willingness to pay function used previously to graph benefits. The marginal opportunity cost curve defines the additional cost of producing the last unit. In purely competitive markets, the marginal opportunity cost curve is identical to the supply curve. Total cost is simply the sum of the marginal costs.⁵ The total cost of producing 3 units is equal to the cost of producing the first unit plus the cost of producing the second unit plus the cost of producing the third unit. As with total willingness to pay, the geometric representation of the sum of the individual elements of a continuous marginal cost curve is the area under the marginal cost curve, as illustrated in figure 2.4 by the shaded area FGJJK.

Since net benefit is defined as the excess of benefits over costs, it follows that net benefit is equal to that portion of the area under the demand curve which lies above the supply curve. Consider Figure 2.5, which combines the information in Figures 2.3 and 2.4.

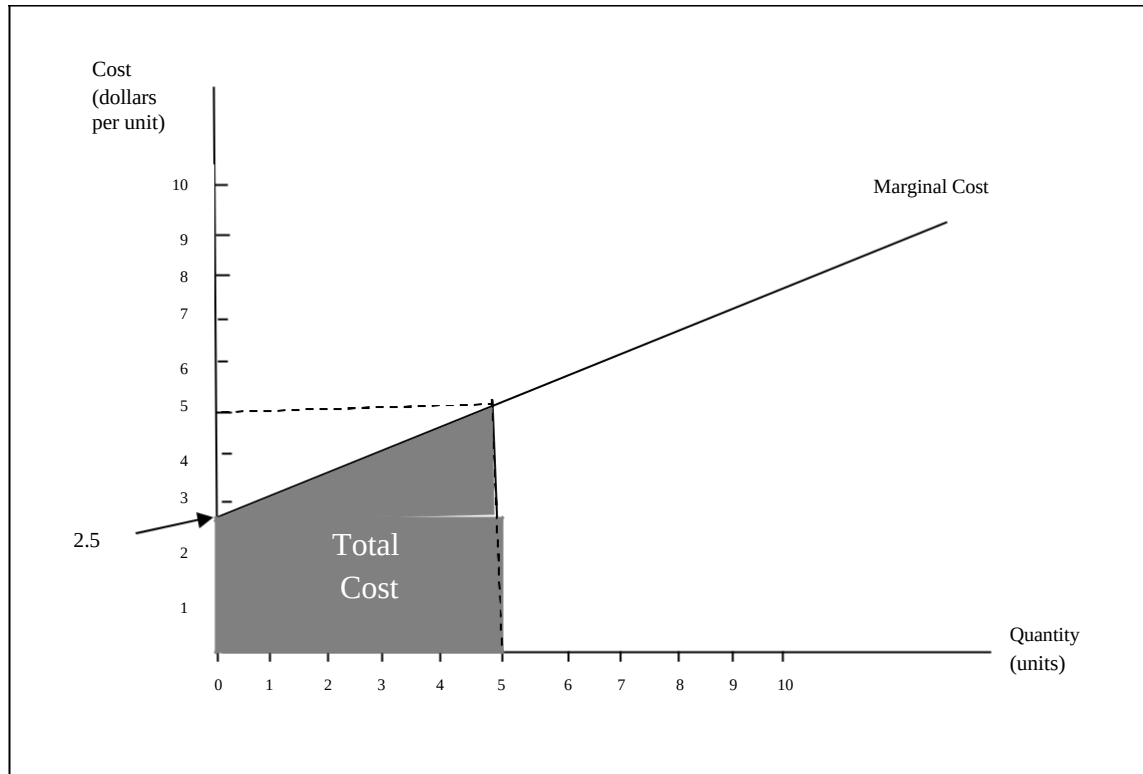
⁵ Strictly speaking, the sum of the marginal costs is equal to total variable cost. In the short run, this is smaller than total cost by the amount of the fixed cost. For our purposes this distinction is not important.

Let's now use this apparatus to illustrate the use of the decision rules introduced earlier. Let's suppose for example that we are considering preserving a four-mile stretch of river and that the benefits and costs of that action are reflected in Figure 2.5. Should that stretch be preserved?

The analysis we have covered so far is very useful for thinking about actions where time is not an important factor. Yet many of the decisions made now have consequences which persist well into the future. Time is a factor. Exhaustible energy resources, once used, are gone. Biological renewable resources (such as fisheries or forests) can be overharvested, leaving smaller and possibly weaker populations for future generations. Persistent pollutants can accumulate overtime. How can we make choices when the benefits and costs may occur at different points in time?

Incorporating time into the analysis requires an extension of the concept we have already developed. This extension provides a way for thinking not only about the magnitude of benefits and costs, but also about timing. In order to incorporate timing, the decision rule must provide a way to compare the net benefit received in one period with the net benefit received in another. The concept that allows this comparison is called *present value*. Therefore, before introducing this expanded decision rule, we must define present value. Present value explicitly incorporates the time value of money. A dollar today invested at 10% interest yields \$1.10 a year from now (the return of the \$1 principal plus \$0.10 interest). The present value of \$1.10 received one year from now is, therefore, \$1 because, given \$1 now, you can turn it into \$1.10 a year from now by investing it at 10% interest. We can find the present value of any amount of money (X) received one year from now by computing $X/(1+r)$, where r is the appropriate interest rate (10% in our example).

Figure 3.3: The Relationship of Marginal Cost and Total Cost



What could your dollar earn in two years at r percent interest? Because of compound interest, the amount would be $\$1(1+r)(1+r) = \$1(1+r)^2$. It follows then that the present value of X received two years from now is $X/(1+r)^2$.

By now the pattern should be clear. The net present value of a one-time net benefit received n years from now is

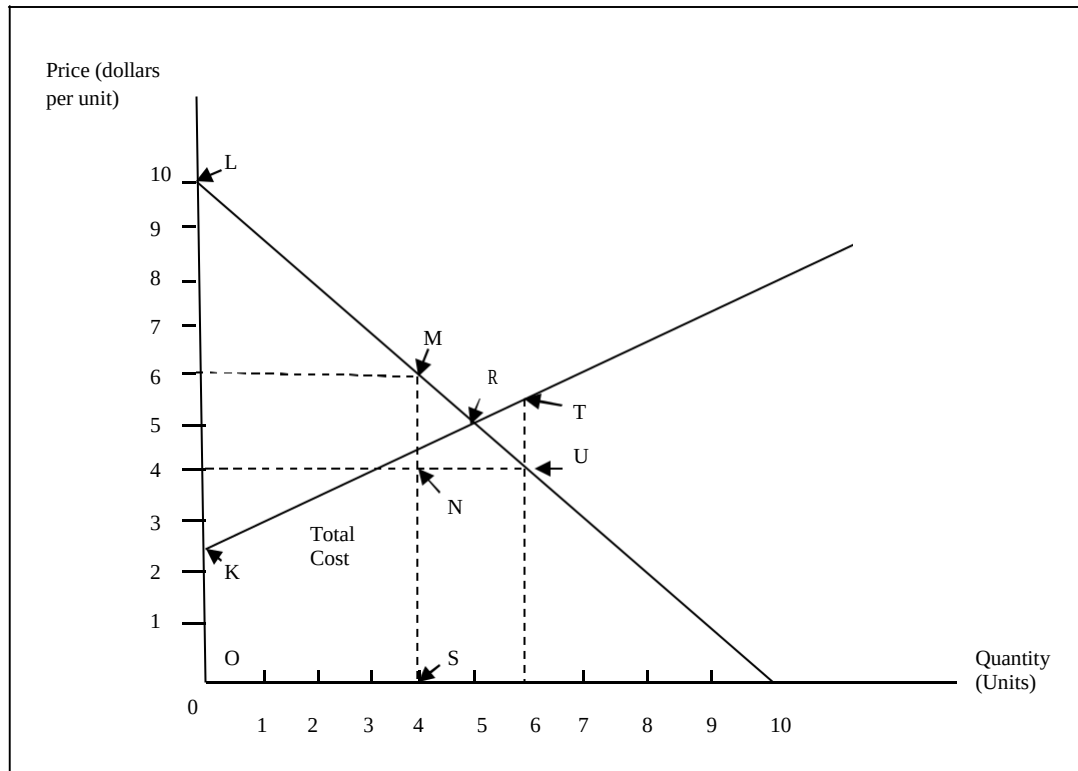
$$NPV[B_n] = \frac{B_n}{(1+r)^n}$$

The net present value of a stream of net benefits $\{B_0, \dots, B_n\}$ received over a period of n years is computed as

$$NPV[B_0, \dots, B_n] = \sum_{i=0}^n \frac{B_i}{(1+r)^i}$$

Where r is the appropriate interest rate and B_0 is the amount of net benefits received immediately. The process of calculating the present value is called *discounting*, and the rate r is referred to as the discount rate.⁶

Figure 3.4: The Derivation of Net Benefits



The number resulting from a present value calculation has a straightforward interpretation. Suppose you were investigating an allocation that would yield the following pattern of net benefits on the last day of each of the next five years: \$3000, \$5000, \$6000, \$10000, \$12000. If you use an interest rate of 6% ($r = 0.06$) and the above formula, you will discover that this stream has a present value of \$29,210.

What does that number mean? If you put \$29,210 in a savings account earning 6% interest rate and wrote yourself checks, respectively, for \$3000, \$5000, \$6000, \$10000, and \$12000 on the last day of each of the next five years, your last check would just restore the account to a zero balance. Thus, you should be indifferent about receiving \$29,210 now or in the specific five-year stream of benefits totaling \$36,000; given one,

⁶ The discount rate should equal the social opportunity cost of capital. See Mikesell (1977) for detailed examination of the reasons for this choice and its implications.

you can get the other. Hence, the method is called present value because it translates everything back to its current worth.

It is not possible to show how this analysis can be used to evaluate actions. First calculate the present value of net benefits from the action. If the present value is greater than zero, the action should be supported. Otherwise it should not.

3.2 Static Efficiency

The chief normative criterion for choosing among various allocations occurring at the same point in time is called *static efficiency*, or *merely efficiency*. An allocation of resources is said to satisfy the static efficiency criterion if the net benefit from the use of those resources is maximized by that allocation.

Let's show how this concept can be applied by returning to Figure 2.5. Previously we asked whether an action which preserved four miles of river was worth doing. The answer was yes because the net benefits from that action were positive.

Static efficiency, however, requires us to ask a rather different question; namely, what is the efficient number of miles to be preserved? We know from the definition that the efficient amount of preservation would maximize net benefits. Do four units maximize net benefits?

We can answer that question by establishing whether it is possible to increase the net benefit by preserving more or less of the river. If the net benefit can be increased by preserving more miles, clearly preserving four miles could not have maximized the net benefit and, therefore, could not have been efficient.

Consider what would happen if society were to choose to preserve five miles instead of four. What happens to the net benefit? It increases by area MNR. Since we can find another allocation with greater net benefit, four miles of preservation could not have been efficient. Are five? Yes. Let's see why.

We know that five miles of preservation convey more net benefits than four. If this allocation is efficient, then it must also be true that the net benefit is smaller for levels of preservation higher than five. Notice that the additional cost of preserving the sixth unit (the area under the marginal cost curve) is larger than the additional benefit received from

preserving it (the corresponding area under the demand curve). Therefore, the triangle RTU represents the reduction in net benefit that occurs if six miles are preserved rather than five.

Since the net benefit is reduced, both by preserving less than five and by preserving more than five, we conclude that five units is the preservation level that maximizes net benefit. Therefore, from our definition, preserving five miles constitutes an efficient allocation.⁷ One implication of this example is what we shall call the first equimarginal principle:

First Equimarginal Principle (the “Efficiency Equimarginal Principle”): Net benefits are maximized when the marginal benefits from an allocation equal the marginal costs.

This criterion helps to minimize wasted resources, but is it fair? The ethical basis for this criterion is derived from a concept called *pareto optimality*, named after the Italian-born Swiss economist Vilfredo Pareto, who first proposed it around the turn of the twentieth century.

Allocations are said to be Pareto optimal if no other feasible allocation could benefit some people without any deleterious effects on at least one other person.

Allocations that do not satisfy this definition are suboptimal. Suboptimal allocations can always be rearranged so that some people are better off and no one is hurt by the rearrangement. Therefore, the gainers could use a portion of their gains to compensate the losers sufficiently to ensure they were at least as well off as they were prior to the reallocation. Efficient allocations are pareto optimal. Since net benefits are maximized by an efficient allocation, it is not possible to increase the net benefit, there is no way the gainers could sufficiently compensate the losers; the gains to the gainers would necessarily be smaller than the losses to the losers.

⁷ The monetary worth of the net benefit is the sum of two right triangles, and it equals $(1/2)(\$5)(5) + (1/2)(\$2.50)(5)$ or \$18.75. Can you see why?

Inefficient allocations are judged inferior because they do not maximize the net benefit. By failing to maximize net benefit, they are forging an opportunity to make some people better off without harming others.

3.3 Dynamic Efficiency

The static efficiency criterion is very useful for comparing resource allocations when time is not an important factor. How can we make choices when the benefits and costs may occur at different points in time?

The traditional criterion used to find an optimal allocation when time is involved is called *dynamic efficiency*, a generalization of the static efficiency concepts already developed. In this generalization, the present-value criterion provides a way for comparing the net benefits received in one period with the net benefits received in another.

An allocation of resources across n time periods satisfies the dynamic efficiency criterion if it maximizes the present value of net benefits that could be received from all the possible ways of allocating those resources over the n periods.

3.3.1 The Simple Mathematics of Dynamic Efficiency

Assume that the demand curve for a depletable resource is linear and stable overtime.

Thus the inverse demand curve in year t can be written as:

$$P_t = a - bq_t \quad (1)$$

The total benefits from extracting an amount q_t in year t are then the integral of this function (the area under the inverse demand curve):

$$\begin{aligned} \text{Total Benefits} &= \int_0^{q_t} (a - bq) dq \\ &= aq_t - \frac{b}{2} q_t^2 \end{aligned} \quad (2)$$

Further assume that the marginal cost of extracting that resource is a constant c and therefore the total cost of extracting any amount q_t in year t can be given by

$$(\text{Total Cost})_t = cq_t \quad (3)$$

If the total available amount of this resource is Q , then the dynamic allocation of a resource over n years is the one which satisfies the maximization problem:

$$\max_q \sum_{i=1}^n \frac{a q_i - b q_i^2 / 2 - c q_i}{(1+r)^{i-1}} + \lambda [\bar{Q} - \sum_{i=1}^n q_i] \quad (4)$$

Assume that $\bar{Q}$ is less than would normally be demanded, the dynamic efficient allocation must satisfy

$$\frac{a - b q_i - c}{(1+r)^{i-1}} - \lambda = 0, \quad i = 1, \dots, n \quad (5)$$

$$\bar{Q} - \sum_{i=1}^n q_i = 0 \quad (6)$$

An implication is that $(P - MC)$ increases over time at rate r .

3.4 Necessary Conditions for Economic Efficiency

As we mentioned previously, an allocation of resource is said to be efficient if it is not possible to make one or more persons better off without making at least one other person worse off. Conversely, an allocation is inefficient if it is possible to improve someone's position without worsening the position of anyone else. A gain by one or more persons without anyone else suffering is known as a Pareto improvement. When all such gains have been made, the resulting allocation is sometimes referred to as Pareto optimal, or Pareto efficient. A state in which there is no possibility of Pareto improvements is sometimes referred to as being allocatively efficient, rather than just efficient, so as to differentiate the question of efficiency in allocation from the matter of technical efficiency in production.

Efficiency in allocation requires that three efficiency conditions are fulfilled – efficiency in consumption, efficiency in production, and product-mix efficiency.

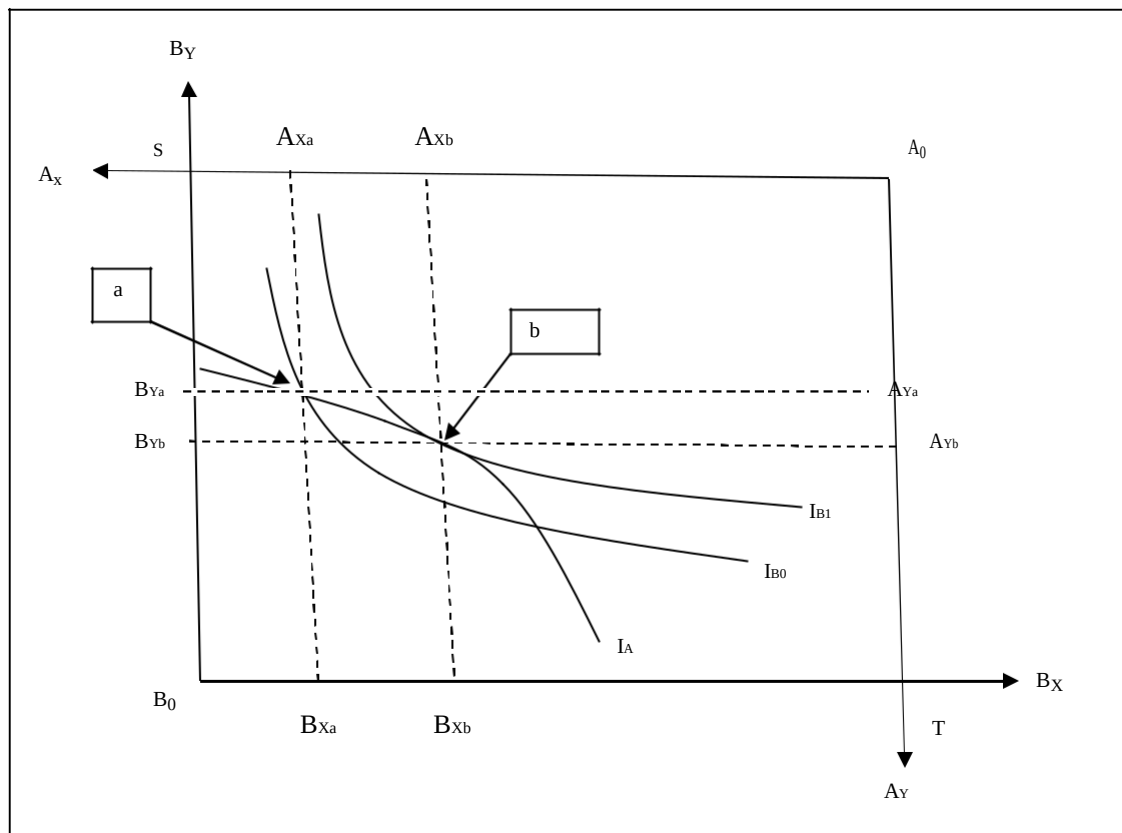
3.4.1 Efficiency in Consumption

Consumption efficiency requires that the marginal rates of utility substitution (MRUS) for the two individuals are equal:

$$MRUS^A = MRUS^B \quad (1)$$

If this condition were not satisfied, it would be possible to rearrange the allocation as between A and B of whatever is being produced so as to make one better off without making the other worse off.

Figure 3.5: Efficiency in Consumption



The figure above shows what is involved by considering possible allocations of fixed amounts of X and Y between A and B. The top right hand corner, labeled A_0 , refers to the situation where A gets nothing of the available X or Y, and B gets all of both commodities. The bottom left hand corner, B_0 , refers to the situation where B gets nothing and A gets everything. Starting from A_0 moving horizontally left measures A's consumption of X, and moving vertically downwards measures A's consumption of Y. As A's consumption of a commodity increases, so B's must decrease. Starting from B_0 moving horizontally right measures B's consumption of X, and moving vertically upwards measures B's consumption of Y. An allocation of X and Y as between A and B

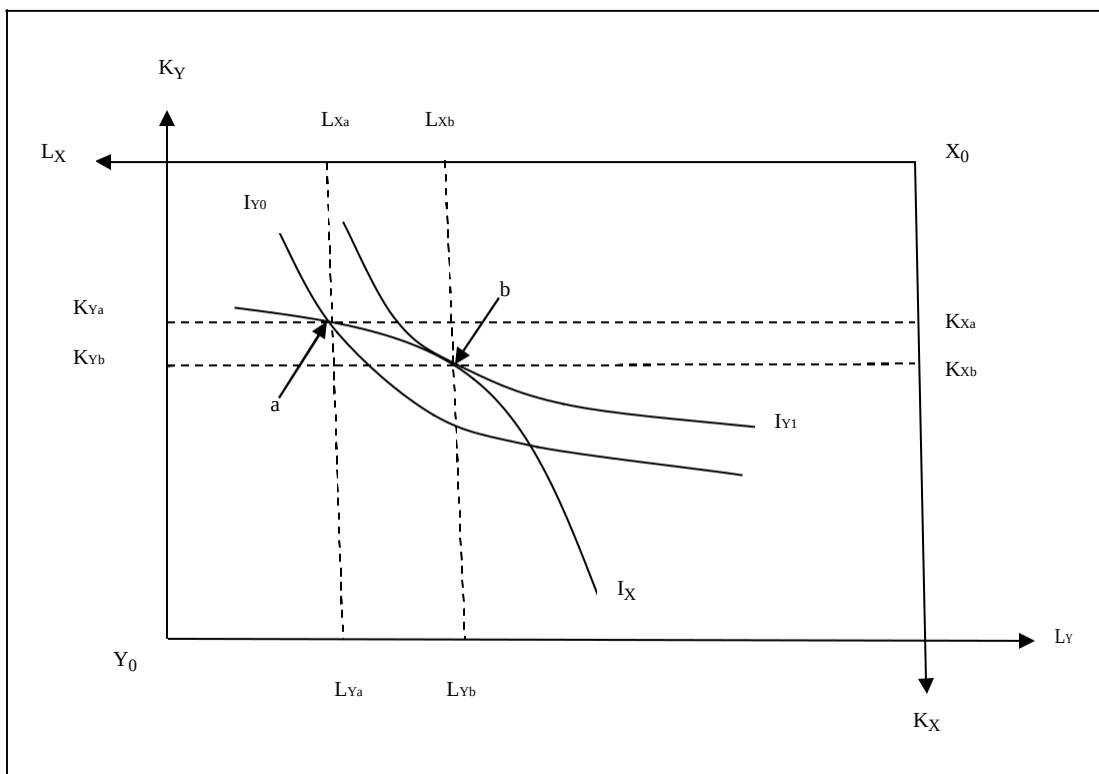
is uniquely identified by a point in the box SA_0TB_0 . At the point a , for example, A is consuming A_0A_{Xa} of X and A_0A_Y of Y , and B is consuming B_0B_{Xa} of X and B_0B_{Ya} of Y . The point a is shown as lying on I_A , which is an indifference curve for individual A . I_A may look odd for an indifference curve, but remember that it is drawn with reference to the origin for A which is the point A_0 . Also shown are two indifference curves for B , I_{B0} and I_{B1} . Consider a reallocation as between A and B . Starting from point a and moving along I_A , such that A is giving up X and gaining Y , while B is gaining X and giving up Y . Initially, this means increasing utility for B , movement onto a higher indifference curve, and constant utility for A . However, beyond point b any further such reallocation will involve decreasing utility for B . Point b identifies a situation where it is not possible to make individual B better off while maintaining A 's utility constant- it represents an efficient allocation of the given amounts of X and Y as between A and B . At b , the slopes of I_A and I_{B1} are equal – A and B have equal marginal rates of utility substitution.

3.4.2 Efficiency in Production

Turning now to the production side of the economy, recall that we are considering an economy with two inputs, L and K , which can be used [via the production functions of the equations $X = X(K^X, L^X)$ and $Y = Y(K^Y, L^Y)$] to produce the goods X and Y . Efficiency in Production requires that the marginal rate of technical substitution be the same in the production of both commodities. That is,

$$MRTS_X = MRTS_Y \quad (2)$$

If this condition were not satisfied, it would be possible to reallocate inputs to production so as to produce more of one of the commodities without producing less of the other. Figure 5.2 shows why this condition is necessary. It is constructed in a similar manner to Figure 5.1, but points in the box refer to allocations of capital and labor to the production of the two commodities rather than to allocations of the commodities between

Figure 3.6: Efficiency in Production


individuals. At X_0 no capital or labor is devoted to the production of commodity X – all of both resources is used in the production of Y. Moving horizontally to the left from X_0 measures increasing use of labor in the production of X, moving vertically down from X_0 measures increasing use of capital in the production of X. The corresponding variations in the use of inputs in the production of Y – any increase/decrease in use for X production must involve a decrease/decrease in use for Y production – are measured in the opposite directions starting from origin Y_0 .

I_x is an isoquant for the production of commodity X. consider movements along it the ‘southeast’ form point a, so that in the production of X capital is being substituted for labor, holding output constant. Correspondingly, given the full employment of the resources available to the economy, labor is being substituted for capital in the production of Y. I_{y0} and I_{y1} are isoquants for the production of Y. Moving along I_x from ‘a’ toward ‘b’ means moving onto a higher isoquant for Y – more Y is being produced with the production of X constant. Movement along I_x beyond point b will mean moving back to a lower isoquant for Y. The point b identifies the highest level of production Y that is

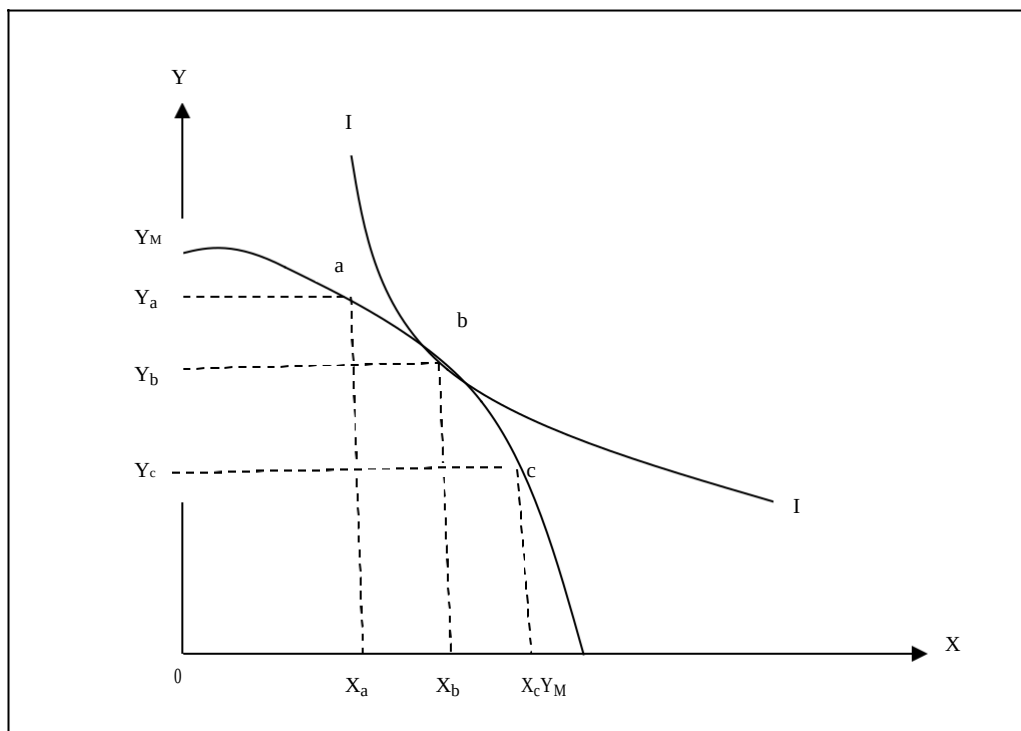
possible, given that the production of X is held at the level corresponding to I_x and that there are fixed amounts of capital and labor to be allocated as between production of the two commodities. At point b the slopes of the isoquants in each line of production are equal – the marginal rates of technical substitution are equal. If these rates are not equal, then clearly it would be possible to reallocate inputs as between the two lines of production so as to produce more of one commodity without producing any less of the other.

3.4.3 Product-mix Efficiency

The final condition necessary for economic efficiency is product-mix efficiency. This requires that

$$MRT_L = MRT_K = MRUS^A = MRUS^B \quad (3)$$

Figure 3.7: Product-mix Efficiency



This condition can be understood using Figure 5.3. Given that equation 1 (condition of consumption efficiency) holds, so that the two individuals have equal marginal rates of utility substitution, we can proceed as if they had the same utility functions, for which II in figure 5.1 is an indifference curve with slope $MRUS$. The individuals do not, of

course, actually have the same utility functions. But, given the equality of the MRUS, their indifference curves have the same slope at an allocation that satisfies the consumption efficiency condition, so we can simplify, without any real loss, by assuming the same utility functions and drawing a single indifference curve that refers to all consumers. Given that equation 2 (condition of production efficiency) holds, when we think about the rate at which the economy can trade off production of X for Y and vice versa, it does not matter whether the changed composition of consumption is realized by switching labor or capital between the two lines of production. Consequently, in Figure 5.3 we show a single production possibility frontier, $Y_M X_M$, showing the output combinations that the economy could produce using all of its available resources. The slope of $Y_M X_M$ is MRT.

In figure 5.3 the point 'a' must be on a lower indifference curve than II. Moving along $Y_M X_M$ from point 'a' toward 'b' must mean shifting to a point on a higher indifference curve. The same goes for movement along $Y_M X_M$ from 'c' toward 'b'. On the other hand, moving away from 'b', in the direction of either 'a' or 'c', must mean moving to a point on a lower indifference curve. We conclude that a point like 'b', where the slopes of the indifference curve and the production possibility frontier are equal, corresponds to a product mix – output levels for X and Y – such that the utility of the representative individual is maximized, given the resources available to the economy and the terms on which they can be used to produce commodities. We conclude, that is, that the equality of MRUS and MRT is necessary for efficiency in allocation. At a combination of X and Y where this condition does not hold, some adjustment in the levels of X and Y is possible which would make the representative individual better off.

An economy attains a fully-efficient static allocation of resources if the conditions given by equations 1, 2 and 3 are satisfied simultaneously. Moreover, it does not matter that we have been dealing with an economy with just two persons and two goods. The results readily generalize to economies with many inputs, many goods and many individuals. The only difference will be that the three efficiency conditions will have to hold for each possible pair wise comparison that one could make, so would be far more tedious to write out.

Summary

- ✚ In economics the system of measurement is anthropocentric which simply means human-centered. All benefits and costs are valued in terms of their effects (broadly defined) on humanity.
- ✚ An efficient local state is often called Pareto optimal. Allocations are said to be Pareto optimal if no other feasible allocation could benefit some people without any deleterious effects on at least one other person.
- ✚ A static efficient allocation is one that maximizes the net benefit overall possible uses of those resources. The dynamic efficiency criterion, which appropriate when time is an important consideration, is satisfied when the outcome maximizes the present value of net benefits from all possible uses of the resources.
- ✚ Efficiency in allocation requires that three efficiency conditions are fulfilled – efficiency in consumption, efficiency in production, and product-mix efficiency.

Problems

1. One convenient way to express the willingness-to-pay relationship between price and quantity is to use the inverse demand function. In an inverse demand function, the price consumers are willing to pay is expressed as a function of the quantity available for sale. Suppose the inverse demand function (expressed in dollars) for a product is $P = 80 - q$, and the marginal cost (in dollars) of producing it is $MC = 1q$, where P is the price of the product and q is the quantity demanded and/or supplied. (a) How much would be supplied in a static efficient allocation? (b) What would be the magnitude of the net benefits (in dollars)?
2. What is the concept that allows a way to compare the net benefit received in one period with the net benefit received in another period? Show the formula used for such purpose.
3. Efficiency in consumption is one the three necessary conditions for static efficiency. How does consumption efficiency happen? Use the appropriate graph to clarify your explanations.
4. Compare and contrast the following terms:
 - I. Efficiency locus and Contract curve
 - II. Indifference curve and Isoquant curve

CHAPTER FOUR

4. PROPERTY RIGHT, EXTERNALITY, MARKET FAILURE, AND THE ENVIRONMENT

Course Contents:

Dear students, in this chapter six major areas are dealt:

Property Rights

Producer's Surplus, Scarcity Rent, and Long-Run Competitive

Equilibrium Externalities as a Source of Market Failure

Improperly Designed Property Rights Systems

Divergence of Social and Private Discount Rates

Market Failures

Objectives

After going through this chapter, students are expected to

Identify the nature of relationships among property right systems with efficiency of market allocation.

Know the problems of improperly designed property right systems.

Clearly recognize the divergence of social and private discount rates.

Understand the sources of market failure and the methods used to remedy it.

4.1 Property Rights

4.1.1 Property Rights and Efficient Market Allocations

The manner in which producers and consumers use environmental resources depends on the property rights governing those resources. In economics, *property right* refers to a bundle of entitlements defining the owner's rights, privileges, and limitation for use of the resource. By examining such entitlements and how they affect human behavior, we will better understand how environmental problems arise from government and market allocations.

These property rights can be vested either with individuals, as in a capitalist economy, or with the state, as in a centrally planned specialist economy. It is not uncommon to hear that the source of environmental problems in a capitalist economy is the market system itself or, more specifically, the pursuit of profits. You may have heard this point of view

expressed as, “Corporation are more interested in profits than in the needs of the people.” Those who espouse this view look longingly at centrally planned economies as a means of avoiding environmental excess.

Simple answers rarely suffice for complex problems; environmental and natural resource problems are not an exception. Centrally planned economies, such as the former Soviet Union, have not historically avoided pollution excesses. On the other hand, the pursuit of profits is not inevitably inconsistent with fulfilling the needs of the people. Though the pursuit of profits may sometimes be inconsistent with fulfilling these needs, it is not always inconsistent. In fact, this pursuit is often the essential ingredient in meeting people’s needs. How can we tell when the pursuit of profits is consistent with societal objectives, such as efficiency, and when it is not?

4.1.2 Efficient Property Right Structures

Let’s begin by describing the structure of property rights that could produce efficient allocations in a well-functioning market economy. An efficient structure has three main characteristics:

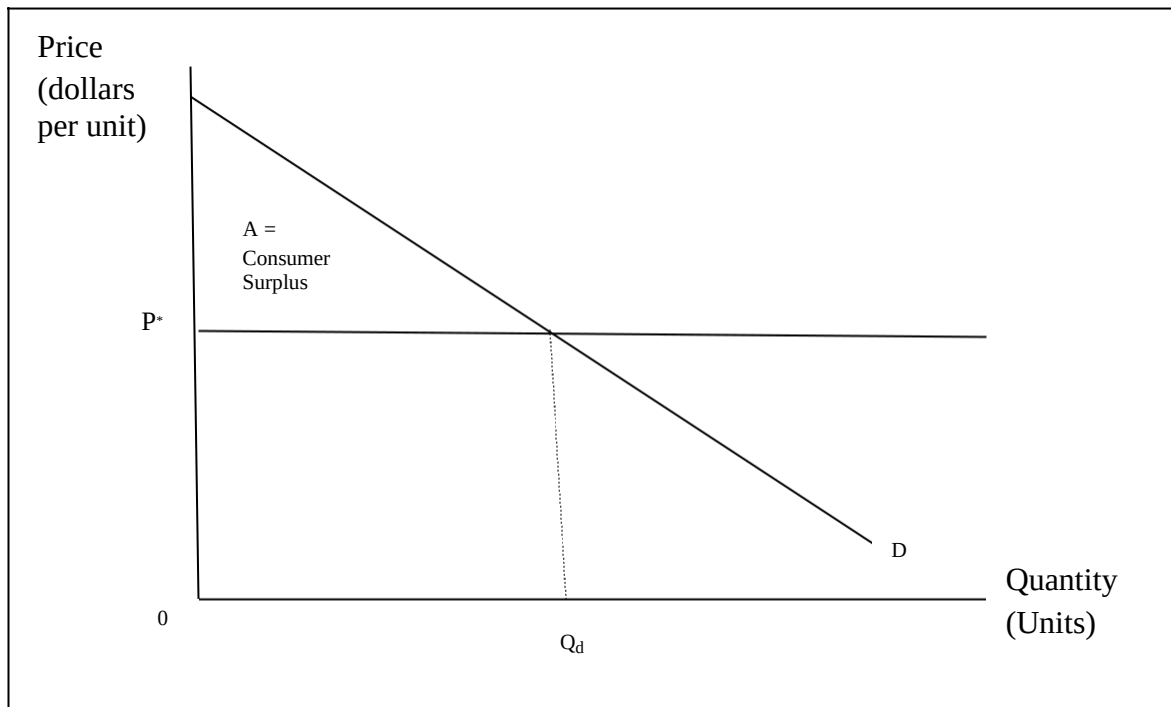
1. *Exclusivity* – All benefits and costs accrued as a result of owning and using the resources should accrue to the owner, and only to the owner, either directly or indirectly by sale to other.
2. *Transferability* – All property rights should be transferable from the owner to another in a voluntary exchange.
3. *Enforceability* – Property rights should be secured from involuntary seizure or encroachment by others.

An owner of a resource with a well-defined property right (one exhibiting these three characteristics) has a powerful incentive to use that resource efficiently because a decline in the value of that resource represents a personal loss. Farmers who own the land have an incentive to fertilize and irrigate it because the resulting increased production raises income level. Similarly, they have an incentive to rotate crops when that raises the productivity of their land.

When well defined property rights are exchanged, as in a market economy, this exchange facilitates efficiency. We can illustrate this point by examining the incentives consumers

and producers face when a well-defined system of property rights is in place. Because the seller has the right to prevent the consumer from consuming the product in the absence of payment, the consumer must pay to receive the product. Given a market price, the consumer decides how much to purchase by choosing that amount which maximizes his or her individual net benefit (see Figure 4.1).

Figure 4.1: The Consumer's Choice

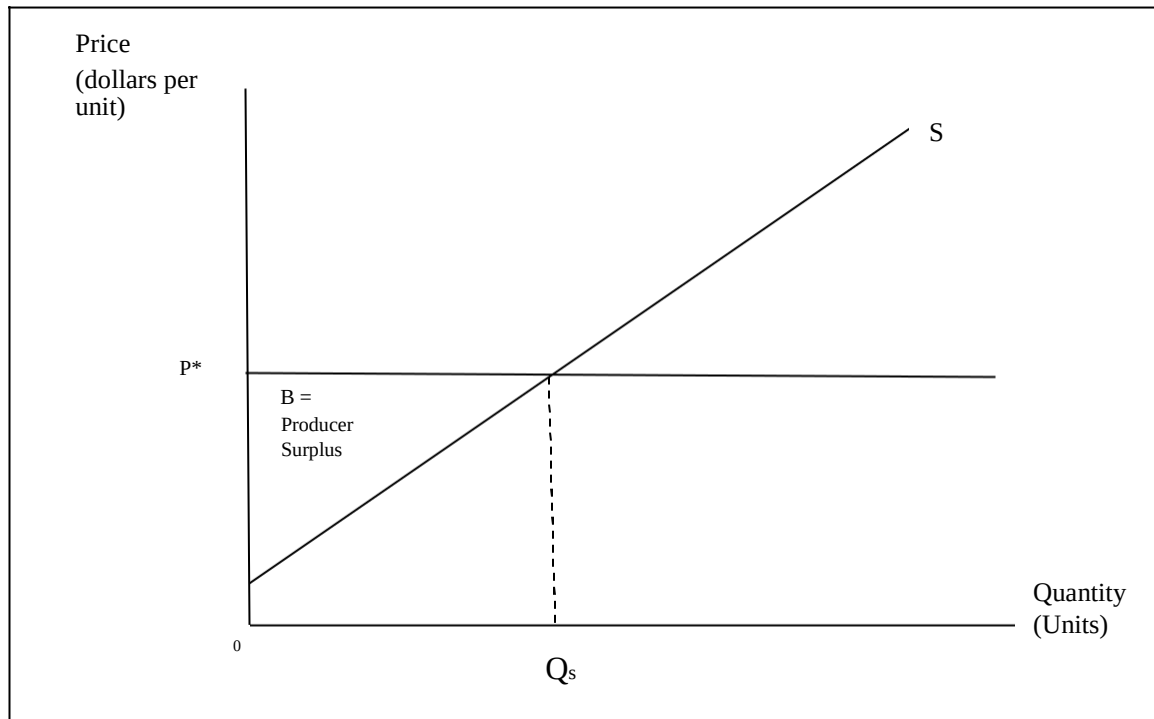


The consumer's net benefit is the area under the demand curve minus the area representing cost. The cost to the consumer is the area under the price line, since that area represents the expenditure on the commodity. Obviously, for a given price P^* , consumer net benefit is maximized by choosing to purchase Q_d units. Area A is then the geometric representation of the net benefit received, known as consumer surplus. It is the area under the demand curve that lies above the price, bounded from the left by the vertical axis and from the right by the quantity of good being considered.

The price level which producers and consumers face will adjust until supply equals demand, as depicted in Figure 4.3. Given that price, consumers maximize their supply, producers maximize their surplus, and the market clears.

Is allocation efficient? According to our definition of static efficiency from the previous chapter, it is clear the answer is yes. The net benefit is maximized by the market allocation and, as seen in figure 4.3, it is equal to the sum of consumer and producer surpluses. Thus, we have established a procedure for measuring net benefits, and a means of describing how the net benefits are distributed between consumers and producers.

Figure 4.2: The producer's Choice

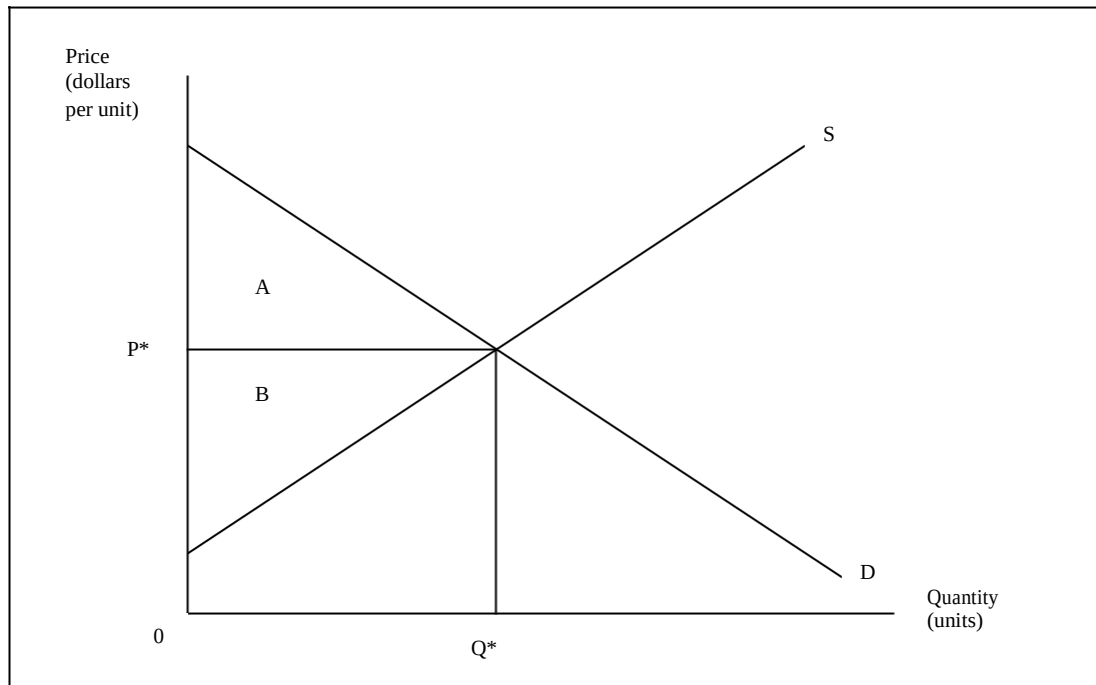


This distinction is crucially significant. Efficiency is not achieved because producers and consumers are seeking efficiency. They aren't! In a system with well-defined property rights and competitive markets in which to sell those rights, producers try to maximize their surplus and consumers try to maximize their surplus. The price system, then, induces those self-interested parties to make choices which are efficient from the point of view of society as a whole. It channels the energy motivated by self-interest into socially productive paths.

Though familiarity may have dulled our appreciation, it is noteworthy that a system designed to produce a harmonious and congenial outcome could function effectively

while allowing consumers and producers so much individual freedom in making choices. This is truly a remarkable accomplishment.

Figure 4.3: Market Equilibrium



4.2 Producer's Surplus, Scarcity Rent, and Long-Run Competitive Equilibrium

Since the area under the price line is total revenue, and the area under the marginal cost curve is total variable cost, producer's is related to profits. In the short run when some costs are fixed, producer's surplus is equal to profits plus fixed cost. In the long run when all costs are variable, producer's surplus is equal to profits plus rent, the return to scarce inputs owned by the producer. As long as new firms can enter into an industry where profits are earned without raising the profits of purchased inputs, long-run profits will equal zero and producer surplus will equal rent.

4.2.1 Scarcity Rent

Most natural resource industries, however, do give rise to rent and, therefore, producer's surplus is not eliminated by competition, even with free entry. This producer's surplus which persists in long-run equilibrium is called scarcity rent.

David Ricardo was the first economist to recognize the existence of scarcity rent. Ricardo suggested that the price of land was determined by the least fertile marginal unit of land. Since the price had to be sufficiently high to allow the poorer land to be brought into production, other, more fertile, land could be farmed at an economic profit. Competition could not erode that profit because the amount of land was limited and lower prices would serve only to reduce the supply of land below demand. The only way to expand production would be to bring additional, less-fertile, land (more costly to farm) into production; consequently, additional production does not lower price, as it does in a constant-cost industry. As we shall see, other circumstances also give rise to scarcity rent for natural resources.

4.3 Externalities as a Source of Market Failure

The Concept Introduced

Exclusivity is one of the chief characteristics of an efficient property rights structure. This characteristic is frequently violated in practice. One broad class of violations occurs when an agent making a decision does not bear all of the consequences of his or her action.

Suppose two firms are located by a river. The first produces steel, while the second, somewhat downstream, operates a resort hotel. Both use the river, though in different ways. The steel firm uses it as a receptacle for its waste, while the second uses it to attract customers seeking water recreation. If the two facilities have different owners, an efficient use of the water is not likely to result. Because the steel plant does not bear the cost of reduced business at the resort resulting from waste being dumped in to the river, it is not likely to be very sensitive to that cost in its decision making. As a result, it could be expected to dump too much waste in to the river, and an efficient allocation of the river would not be attained.

This situation is called an externality. An externality exists whenever the welfare of some agent, either a firm or household, depends not only on his or her activities, but also on

activities under the control of some other agent. In the example, the increased waste in the river imposed an external cost on the resort, a cost the steel firm could not be counted upon to consider appropriately in deciding the amount of waste to dump.

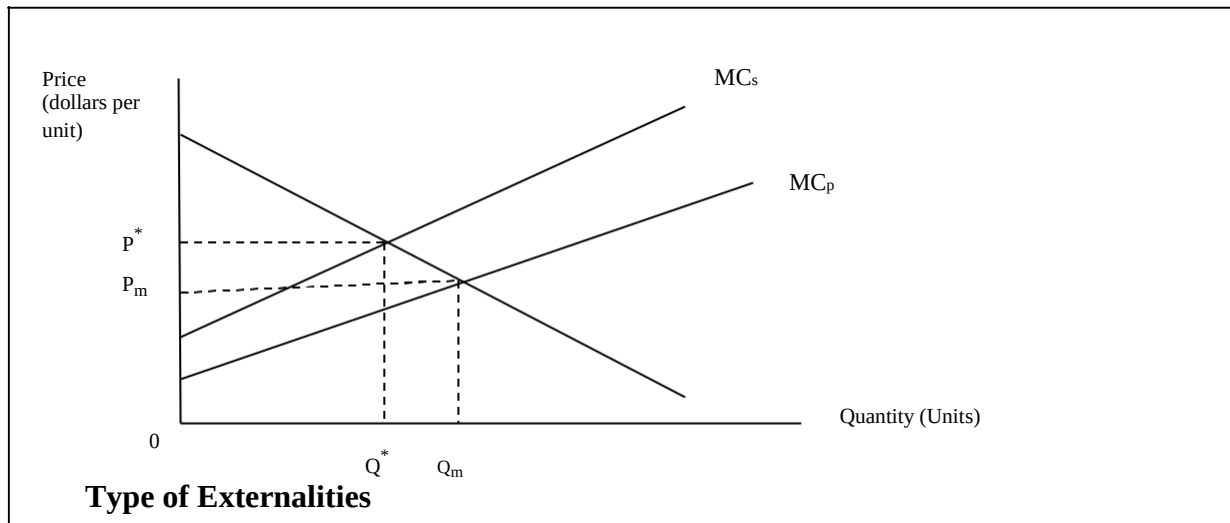
The effects of this external cost on the steel industry can be seen in Figure 4.4, which depicts the market for steel. Steel production inevitably involves producing pollution as well as steel. The demand for steel is shown by the demand curve D , and the private marginal cost of producing the steel (exclusive of pollution control and damage) is depicted as MC_p . Because society considers both the cost of pollution and the cost of producing the steel, the social marginal cost function (MC) includes both of these costs as well.

If the steel industry faced no outside control on its emission levels, it would seek to produce Q_m . That choice, in a competitive setting, would maximize its private producer surplus. But that is clearly not efficient, since the net benefit is maximized at Q^* not Q_m .

With the assistance of figure 4.4, we can draw a number of conclusions about market allocations of commodities causing pollution externalities:

1. The output of the commodity is too large.
2. Too much pollution is produced.
3. The prices of products responsible for pollution are too low.
4. As long as the costs are external, no incentives to search for ways to yield less pollution per unit of output are introduced by the market.
5. Recycling and reuse of the polluting substances are discouraged since release in to the environment is so inefficiently cheap.

The effects of a market imperfection for one commodity end up affecting the demands for raw materials, labor, and so on. The ultimate effects are felt through the entire economy.

Figure 4.4: The Market for Steel

External effects can be either positive or negative. Historically, the terms external diseconomy and external economy have been used to refer, respectively, to circumstances in which the affected party is damaged or benefited by the externality. Clearly, the water pollution example represents an external diseconomy. External economies are not hard to find, however. Private individuals who purchase a particularly scenic area provide an external economy to all who pass. Generally, when external economies are present, the market will undersupply the resources.

One other distinction is important. One class of externalities, known as *pecuniary externalities*, does not present the same kinds of problems as pollution does. Pecuniary externalities arise when the external effect is transmitted through altered prices. Suppose that a new firm moves into an area and drives up the rental price of land. That increase creates a negative effect on all those paying rent and, therefore, is an external diseconomy.

This pecuniary diseconomy, however, does not cause a market failure because the resulting higher rents are reflecting the scarcity of land. The land market provides a mechanism by which the parties can bid for land; the prices that result reflect the value of the land in its various use. Without pecuniary externalities, the price signals would fail to sustain an efficient allocation.

The pollution example is not a pecuniary externality because the effect is not transmitted through prices. In this example, prices do not adjust to reflect the increasing waste load. The scarcity of the water resource is not signaled to the steel firm. An essential feed back mechanism that is present for pecuniary externalities is not present for the pollution case.

The externalities concept is a broad one covering a multitude of sources of market failure. The next step is to investigate some specific circumstances which can give rise to externalities.

4.4 Improperly Designed Property Rights Systems

Other Property Rights Regime

Private property is, of course, not the only possible way of defining entitlements to resources use. Others possibilities include state-property regimes (where the government owns and controls the property), common-property regimes (where the property is jointly owned and managed by a specified group of co-owners) and *res nullius* regimes (in which no one owns or exercises control over the resources). All of these create rather different incentives for resource use.

State property regimes exist not only in former communist countries, but also to varying degrees in virtually all countries of the world. Parks and forests, for example, are frequently owned and managed by the government in capitalist as well as in socialist nations. Problems with both efficiency and sustainability can arise in state-property regimes when the incentives of bureaucrats who implement and/or make the rules for resource use diverge from collective interests.

Common property resources are those which are owned in common rather than privately. Entitlements to use common-property resources may be formal, protected by specific legal rules, or they may be informal, protected by tradition or custom. Common-property regimes exhibit varying degrees of efficiency and sustainability, depending on the rules which emerge from collective decision making. While some very successful examples of common-property regimes exist, unsuccessful examples are even more common.

One successful example of a common-property regime involves the system of allocating grazing rights in Switzerland. Though agricultural land is normally treated as private property in Switzerland, grazing rights on the Alpine meadows have been treated as common property for centuries. Overgrazing is protected by specific rules, enacted by an association of users, which limit the amount of livestock permitted on the meadow. The families included on the membership list of the association have been stable over time as rights and responsibilities have passed from generation to generation. This stability has apparently facilitated reciprocity and trust, thereby providing a foundation for continued compliance with the rules.

Unfortunately, that kind of stability may be the exception rather than the rule, particularly in the face of heavy population pressure. The more common situation can be illustrated by the experience of Mawelle, a small fishing village in Sri Lanka. Initially, a complicated but effective rotating system of fishing rights was devised by villagers to assure equitable access to the best spots and best times while protecting the fish stocks. Over time, population pressure and the infusion of outsiders both raised demand and undermined the collective cohesion sufficiently that the traditional rules became unenforceable, producing overexploitation of the resource and lower incomes for all the participants.

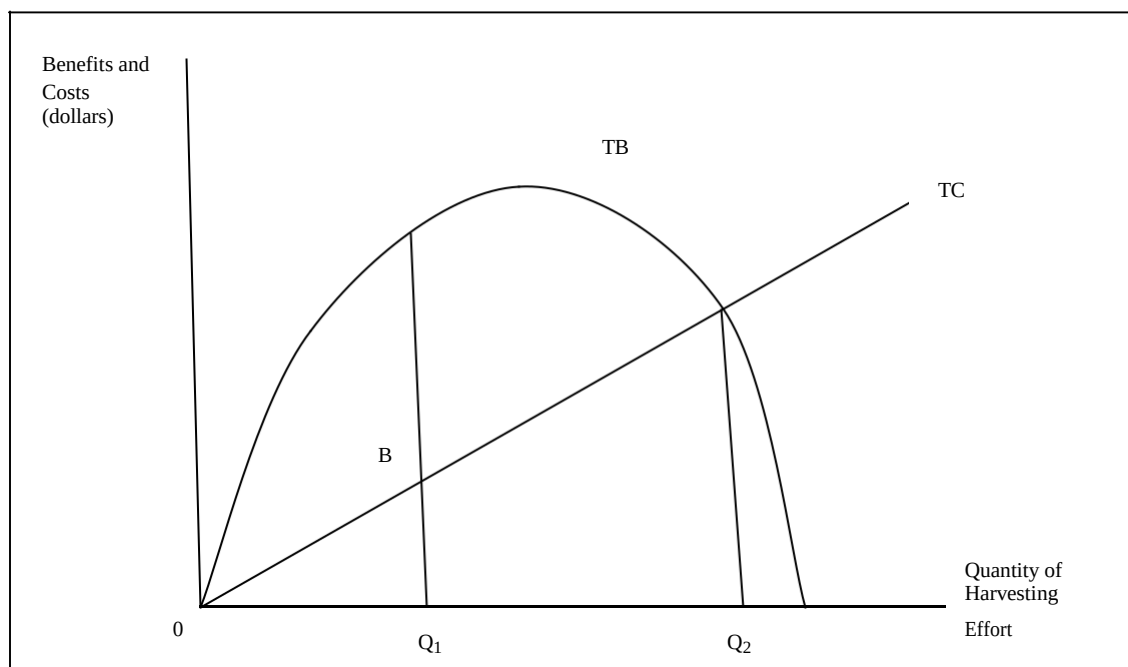
Res nullis property resources, the main focus of this section, can be exploited on a first-come, first-served basis, because no individual or group has the legal power to restrict access. *Open-access resources*, as we shall henceforth call them, have given rise to what has become known popularly as the “tragedy of the commons.”

The problems created by open-access resources can be illustrated by recalling the fate of the American bison. Bison are an example of “common pool” resources. Common-pool resources are characterized by non-exclusivity and divisibility. Non-exclusivity implies that they can be exploited by anyone while divisibility means that the capture of part of the resource by one group subtracts it from the amount available to the other groups. (Note the contrast between common-pool resources and public goods in the next section.) In the early history of the United States, bison were plentiful; unrestricted hunting access was not a problem. Frontier people who needed hides or meat could easily get whatever they needed; the aggressiveness of any one hunter did not affect the time and effort

expended by other hunters. In the absence of scarcity, efficiency was not threatened by open access.

As the years slipped by, however, the demand for bison increased and scarcity became a factor. As the number of hunters increased, eventually every additional unit of hunting activity increased the amount of time and effort required to produce a given yield of bison. In figure 4.5, we depict the social benefits and costs of bison hunting. Total benefits are calculated by multiplying, for each level of hunting activity, the (assumed constant) price of bison by the amount of harvested. The marginal benefit curve (not shown) is downward sloping because the greater the amount of hunting effort expended, the smaller the resulting population size. Smaller populations support smaller harvests per unit of effort expended.

Figure 4.5: Bison Harvesting



The efficient level of hunting activity in this model (Q_1) is the level where the net benefits are maximized. This allocation would yield society a scarcity rent equal to vertical distance AB.

With all hunters having completely unrestricted access to the bison, the resulting allocation would not be efficient. No individual hunter would have an incentive to protect scarcity rent by restricting hunting effort. Individual hunters, with out exclusive rights, would exploit the resource until their total benefit equaled total cost, implying a level of effort equal to Q_2 . Excessive exploitation of the heard occurs because individual hunters cannot appropriate the scarcity rent; therefore, they ignore it. One of the losses from further exploitation which could be avoided by exclusive owners – the opportunity cost of overexploitation – is not part of the decision-making process of open-access hunters.

Two characteristics of this formulation of the open-access allocation are worth noting: (1) In the presence of sufficient demand, unrestricted access will cause resources to be overexploited; (2) the scarcity rent is dissipated; no one appropriates the rent, so it is lost. Why does this happen? Unlimited access destroys the incentive to conserve. A hunter who can preclude others from hunting this stock has an incentive to keep the herd at an efficient level. This restraint results in lower costs in the form of less time and effort expended to produce a given yield of bison. On the other hand, a hunter exploiting an open-access resource would not have any incentive to conserve because the benefits derived from restraint would, to some extent, be captured by other hunters. Thus unrestricted access to resources promotes an inefficient allocation. As a result of excessive harvest and the loss of habitat as land was converted to farm and pasture, the Great Plains bison herds nearly became extinct (Lueck, 2002 cited in Tietenberg, 2003).

Public Goods

Public Goods, defined as those that exhibit both consumption indivisibilities and non-excludability, present a particularly complex category of environmental resources. *Nonexcludability* refers to a circumstance where, once the resources is provided, even those who fail to pay for it cannot be excluded from enjoying the benefits it confers. Consumption is said to be *indivisible* when one person's consumption of a good does not diminish the amount available for others. Several common environmental resources are public goods, including not only the "charming landscape" referred to by Emersson, but also clean air, clean water, and biological diversity.⁸

⁸ Notice that public "bads" such as dirty air and dirty water, are also possible.

Biological diversity includes two related concepts: (1) the amount of genetic variability among individuals within a single species, and (2) the number of species within a community of organisms. Genetic diversity, critical to species survival in the natural world, has also proved to be important in the development of new crops and livestock. It enhances the opportunities for cross-breeding and, thus, the development of superior strains. The availability of different strains was the key, for example, in developing a new, disease-resistant barley.

Because of the interdependence of species within ecological communities, any particular species may have a value to the community far beyond its intrinsic value. Certain species contribute balance and stability to their ecological communities by providing food sources or holding the population of the species in check.

The richness of diversity within and among species has provided new sources of food, energy, industrial chemicals, raw materials, and medicines. Yet there is considerable evidence that biological diversity is decreasing.

Can we rely on the private sector to produce the efficient amount of public goods such as biological diversity? Unfortunately, the answer is no! Suppose that in response to diminishing ecological diversity we decide to take up a collection to provide some means of preserving endangered species. Would the collection yield sufficient revenue to pay for an efficient level of ecological diversity? The general answer is no. Let's see why.

In figure 4.6, individual demand curves for preserving biodiversity have been presented for two consumers A and B. The market-demand curve is represented by the vertical summation of the two-individual demand curves. A vertical summation is necessary because everyone can simultaneously consume the same amount of biological diversity. We are therefore able to determine the market demand by finding the sum of the amounts of money they would be willing to pay for that level of diversity.

What is the efficient level of diversity? It can be determined by a direct application of our definition of efficiency. The efficient allocation maximizes net benefits. Net benefits, in turn, are represented geometrically by the portion of the area under the market demand curve that lies above the marginal-cost curve. The allocation that maximizes net benefits is Q^* , the allocation where the demand curve crosses the marginal cost curve.

Both consumers consume this amount. At this level of availability, the marginal net benefit to person B is OB where as the marginal net benefit to person A is OA. Adding these together produces OA + OB, society's marginal net benefit, which is equated to marginal cost.

Would a private market supply this amount? In general, the answer is that it would not.

The typical market will undersupply diversity.

One further insight can be gained from figure 4.6, and it is this insight that led to characterizing public-good problems as “complex” in the opening sentence of this section. The efficient market equilibrium for a public good requires different prices for each consumer. In figure 4.6, if consumer A is charged price $P_a(=OA)$, and consumer B is charged price $P_b(=OB)$, then both consumers will be satisfied with the efficient allocation (the efficient allocation would have maximized their net benefits given the prices).

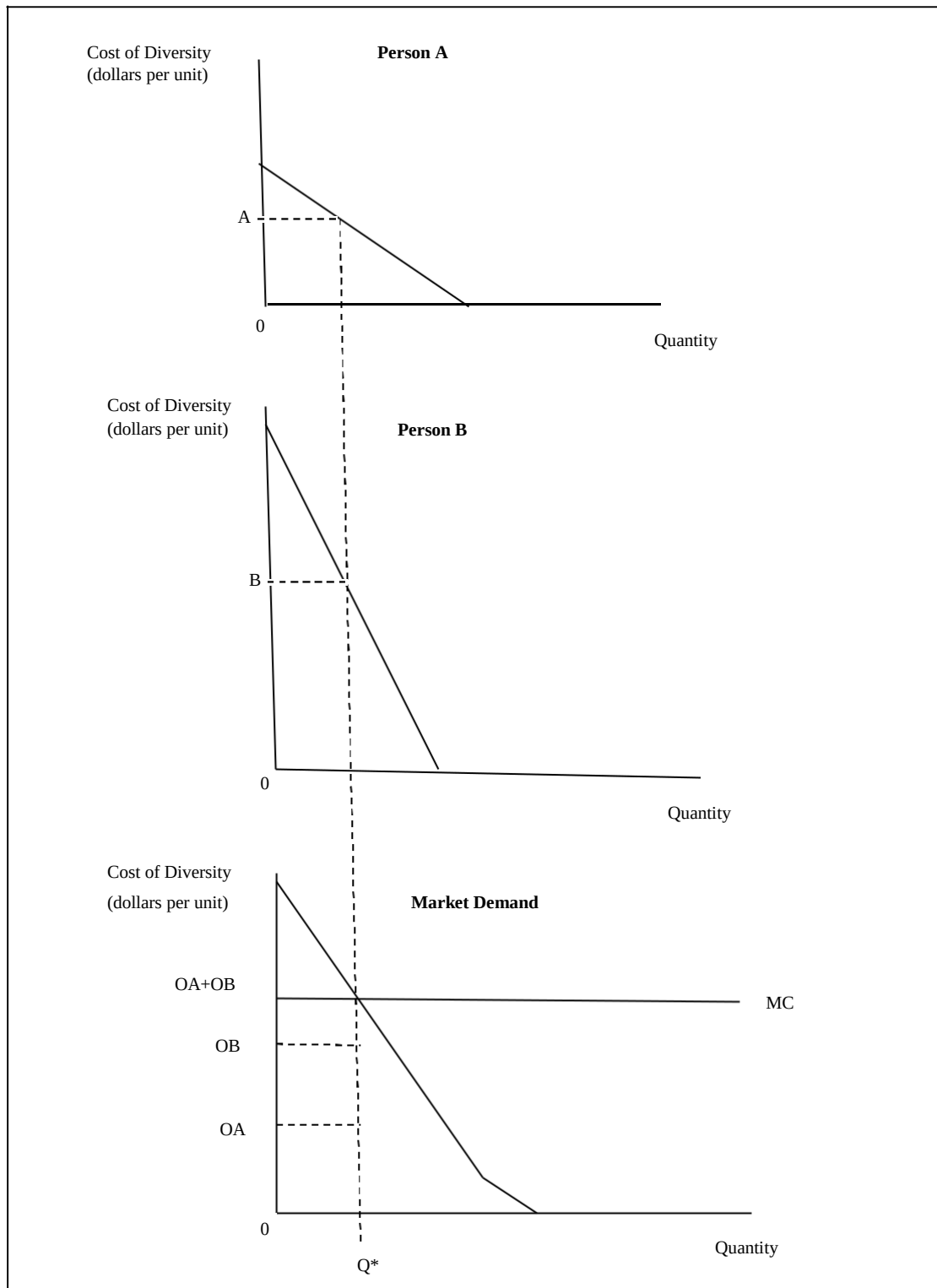
Furthermore, the revenue collected will be sufficient to finance the supply of the public good (because $F_a(Q^*) + F_b(Q^*) = MC(Q^*)$). Thus although an efficient pricing system

exists, it is very difficult to implement. The efficient pricing system requires charging a different price to each consumer; in the absence of excludability, consumers may not choose to reveal the strength of their preference for this commodity. Therefore, the producer could not possibly know what price to charge.

Inefficiency results because each person is able to become a free rider on the other's contribution. A *free rider* is someone who derives the benefits from a commodity without contributing to its supply. Because of the consumption indivisibility and non-excludability properties of the public good, consumers receive the benefits of any diversity purchased by other people. When this happens it tends to diminish incentives to contribute, and the contributions are not sufficiently large to finance the efficient amount of the public good; it would be undersupplied.

The privately supplied amount may not be zero. Some diversity would be privately supplied. Indeed, the privately supplied amount may be considerable.

Figure 4.6: Efficient Provision of Public Goods

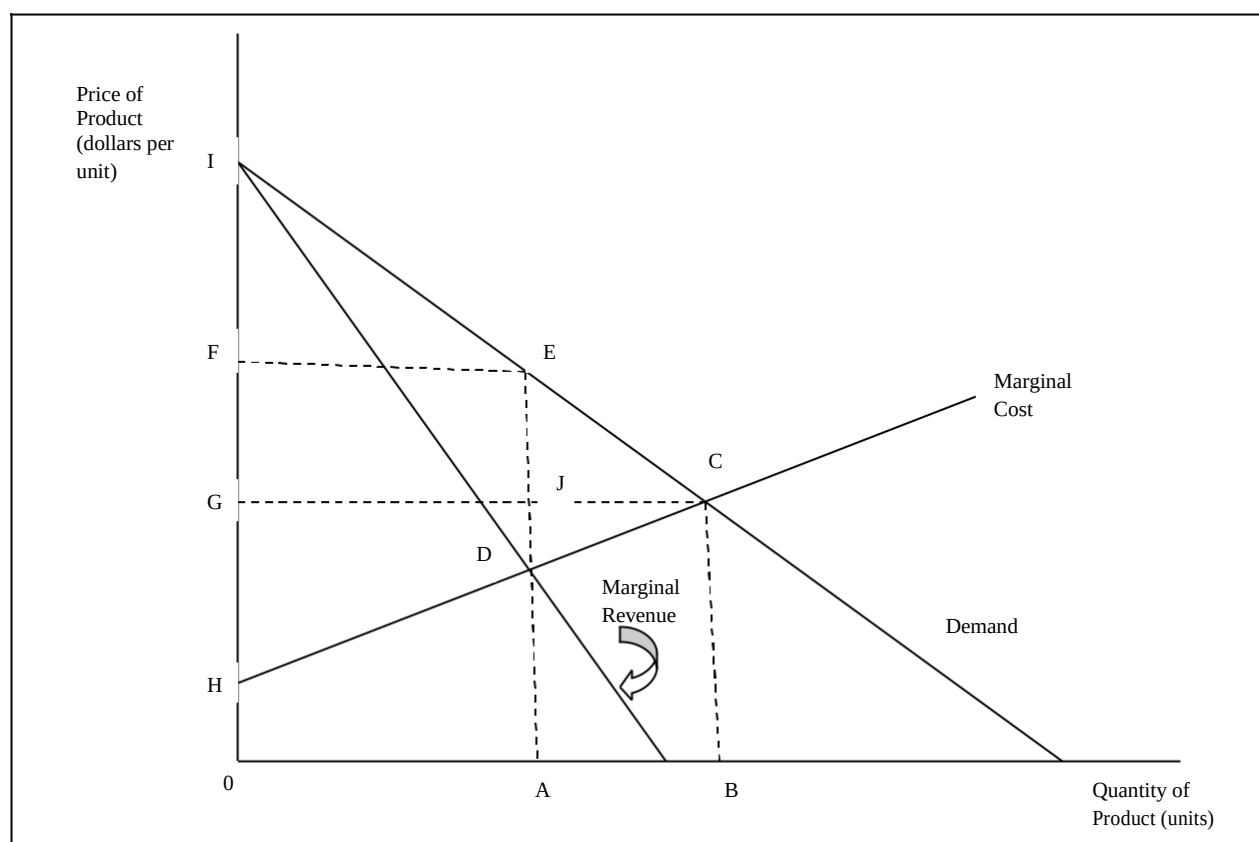


Imperfect Market Structures

Environmental problems also occur when one of the participants in an exchange of property rights is able to exercise an inordinate amount of power over the outcome. This can occur, for example, when a product is sold by a single seller, or *monopoly*.

It is easy to show that monopolies violate our definition of efficiency in the goods market (see Figure 4.7). According to our definition of static efficiency (chapter 2), the efficient allocation would result when OB is supplied. This would yield net benefits represented by triangle HIC. The monopoly, however, would produce and sell OA, where marginal revenue equals marginal cost, and would charge price OF. At this point, the producer's surplus albeit maximized, is clearly inefficient, because this choice causes society to lose net benefits equal to triangle EDC.⁹ Monopolies supply an inefficiently small amount of the good.

Figure 4.7: Monopoly and Inefficiency



⁹ Producers would lose area JDC compared to the efficient allocation, but they would gain area FEJG, which is much larger. Meanwhile, consumers would be worse off, because they lose the area FECJG. Of these, FEJG is merely a transfer to the monopoly, whereas EJC is a pure loss to society. The total pure loss (EDC) is called the *deadweight* loss.

Imperfect markets clearly play some role in environmental problems. For example, the major oil exporting countries have formed a cartel, resulting in higher-than-normal prices and lower-than-normal production. A *cartel* is a collusive agreement among producers to restrict production and raise prices. This collusive agreement allows the group to act as a monopolist. Note that the inefficiency in the goods market would be offset to some degree by the reduction in social costs caused by the lower levels of pollution resulting from the reduction in the combustion of oil.

4.5 Divergence of Social and Private Discount Rates

We conclude earlier that producers, in their attempt to maximize producer surplus, also maximize the present value of net benefits under the “right” conditions, such as the absence of externalities, the presence of properly defined property rights, and the presence of comparative markets within which the property rights can be exchanged.

Now let’s consider one more condition. If resources are to be allocated efficiently, firms must use the same rate to discount future net benefits as is appropriate for the society at large. If firms were to use a higher rate, they would extract and sell resources faster than would be efficient. Conversely, if firms were to use a lower-than appropriate discount rate, they would be excessively conservative.

Why might private and social rates differ? As stated in the previous chapter, the social discount rate is equal to the social opportunity cost of capital. This cost of capital can be separated into two components: risk free cost of capital and the risk premium. The *risk-free cost of capital* is the rate of return earned when there is absolutely no risk of earning more or less than the expected return. The *risk premium* is an additional cost of capital required to compensate the owners of this capital when the expected and actual returns may differ. Therefore, because of the risk premium, the cost of capital is higher in risky industries than in no-risk industries.

One difference between private and social discount rates may stem from a difference in social and private risk premiums. If the risk of certain private decisions is different from the risks faced by society as a whole, then the social and private risk premiums may differ. One obvious example is the risk caused by the government. If the firm is afraid its

assets will be taken over by government, it may choose a higher discount rate to make its profits before nationalization occurs. From the point of view of society – as represented by government – this is not a risk and, therefore, a lower discount rate is appropriate. When private rates exceed social rates, current production is higher than is desirable to maximize the net benefits to society. Energy production and forestry both have been subject to this source of inefficiency.

Though private and social discount rates do not always diverge, they may. When those circumstances arise, market decisions are not efficient.

4.6 Market Failures

Market failure is a situation that occurs when market prices fail to reflect the true social cost and benefits of resource use. Stated differently, market failure is a situation in which unregulated competitive market is inefficient because prices fail to provide proper signals to consumers and producers.

Competitive market fail for four basic reasons: market power, incomplete information, externality and public goods.

Market power: ability of a seller or a buyer to affect the price of good. Monopoly (market with only one seller) and monopsony (market with only one buyer) are the two forms of market power.

Incomplete information: consumers and producers may have incomplete information and may there after err in their consumption and production decision.

Externality: is when a consumption/production activity has an indirect effect on the other consumption/production activity that is not reflected directly in market prices.

Public goods: non exclusive or non rival good that can be made available cheaply but which once available is difficult to prevent others from consuming.

Here it is necessary to distinguish market failure from policy failures and institutional failures.

Policy failures occur when government intervention in the market system lead to economic inefficiency. Examples are subsidies, taxes, tariffs, quotas etc

These types of issues are dealt under SAP (structural adjustment program) and PAM (policy analysis matrices)

Institutional failures occur when government does not establish and enforce property rights even when it is technically possible to do so. Examples in natural resource management are inefficient taxation of economic rent from natural resources, low or zero stumpage fees etc.

4.6.1 Correcting Market Failure

The major problem in environmental economics are public good & externalities But is there any solution to these problems. Basically two solutions are proposed.

a. ***Redefining Property Right*** : One reason for inefficiency is improper definition of property right. Hence, we need to assign exclusive property right to the individuals. The individual will get a fee for the use of resource. The fee should be equal to the MC (= social marginal cost [SMC]) of using the resource. However, it should be noted that most common property resources are vast (or large) and single ownership may not be practical. Therefore, government regulation or ownership may be needed.

When assigning property right is not possible a government or community can invest on resource maintenance or it can restrict harvesting. e.g. by giving quotas, issuing license or imposing taxes.

b. ***Internalizing Externalities***: When there is an externality, for firm which causes the externality, the profit maximization conditions are not the same as the Pareto efficiency conditions. Therefore, the society must find a way of inducing their firm to accounting for the externality. Internalizing externalities may be defined as the process by which an externality is absorbed by the market system. This can be done by:

- i. Private transaction
- ii. Government instruments

i. Conditions required for internalizing externalities by private transactions

There must be technically feasible gains from internalizing externalities

There must be net gains from internalizing the externalities

⇒ transactions cost must be less than gains from internalizing externalities

There must be well defined property right

⇒ there should be no institutional barriers in
internalizing But the conditions are hardly achieved!

ii. Government instrument

There are two main types of government instruments for internalizing externalities,
namely

a. Regulatory instruments

E.g. air and water quality standards, permits and licenses, land water controls.

They are also called *command-and-control* measures.

b. Economic instruments

E.g. Pigovian subsidies and taxes, tradable pollution rights, etc.

They are also called the *market based* instruments

Summary

How producers and consumers use the resources making up the environmental asset depends on the nature of the property rights governing resources use. When property right systems are exclusive, transferable, and enforceable, the owner of a resource has a powerful incentive to use the resource efficiently, since the failure to do so results in a personal loss.

The economic system will not always sustain efficient allocations, however. Specific circumstances which could lead to inefficient allocations include externalities, improperly defined property-right systems (such as common-pool resources and public goods), imperfect markets for the property rights to the resources (monopoly), and the divergence of social and private discount rates (under the threat of nationalization). When these circumstances arise market allocations do not maximize the present value of the net benefit.

The market equilibrium for goods and services establishes market clearing prices. When dealing with the environment, policy, institutional, and market failures result in excessive environmental damage or resource use, usually because prices (or policies) send the wrong signals. Correcting prices and/or policies for various types of failures is often beneficial to the environment because the corrections provide real scarcity signals that help in the correct allocation of resources. In cases of market failure, the perceived price does not reflect the real value of the resource (in either a positive or negative sense). The valuation of non-market goods and services is an important element in identifying, and correcting, market failures. Policy failures occur when policies encourage inappropriate behavior. Policy failures usually also result in market failures.

Problems

1. Suppose the state is trying to decide how many miles of a very scenic river it should preserve. There are 100 people in the community, each of whom has an identical inverse demand function given by $P = 10 - 1.0q$, where q is the number of miles preserved and P is the per mile price he or she is willing to pay for q miles of preserved river. (a) If the marginal cost of preservation is \$500 per mile, how many miles would be preserved in an efficient allocation? (b) How large are the net benefits?
2. Distinguish market failure from policy and institutional failures. What kind of remedy do you recommend for each of these forms of failures?
3. Clearly define the following terms:
 - i. Indivisibility
 - ii. Market power
 - iii. Pecuniary externalities

CHAPTER FIVE

5. OPTIMAL UTILIZATION OF NATURAL RESOURCES

Course Content:

Dear students, this chapter has four major portions:

Resource Taxonomy

Measuring Resource Scarcity

The Theory of Optimal Utilization of Non-Renewable Resources

The Theory of Optimal Utilization of Renewable Resources

Objectives:

This chapter is devoted to acquaint you with the following important issues:

Introducing the different categories and forms we use to classify resources based on their features.

Pointing out the criteria for an ideal scarcity indicator and discuss the possible measurements for scarcity.

Giving you a good treatment of the optimal utilization of non-renewable resources considering several scenarios.

Discussing the optimal utilization of renewable resources from biologist and economists view based on few examples of this class of resources.

5.1 Resource Taxonomy

Three separate concepts are used to classify the stock of depletable resources: (1) Current reserves, (2) Potential reserves, and (3) Resource endowment.

Current reserves are defined as known resources that can profitably be extracted at current prices. The magnitude of these current reserves can be expressed as a number.

Potential reserves, on the other hand, are mostly accurately defined as a function rather than a number. The amount of reserves potentially available depends upon the price people are willing to pay for those resources-the higher the price, the larger the potential reserves. Example: As the price per barrel increases, the amount of oil that can be economically recovered also increases.

Resource endowment represents the natural occurrence of resources in the earth's crust. Because prices have nothing to do with the size of the resource endowment, the latter is a geological rather than an economic concept. This concept is important because it represents an upper limit on the availability of terrestrial resources.

A *recyclable resource* is one that, although currently being used for some particular purpose, exists in a form allowing its mass to be recovered once that purpose is no longer necessary or desirable. For example: steel used for building body of an automobile can be recovered to be used for constructing house equipments once the automobile has already stopped functioning.

The current reserves of a depletable, recyclable resource can be augmented by economic replenishment as well as by recycling. Economic replenishment takes many forms, all sharing the characteristic that they turn previously unrecoverable resources in to recoverable ones. One obvious stimulant for this replenishment is price. As price rises, producers find it profitable to explore more widely, dig more deeply, use lower-concentration ores, and so on.

Higher prices also stimulate technological progress. Technological progress simply means advancement in the state of knowledge that allows us to do things we were not able to do before. Hence, it will enable us to recover more resources.

The other side of the coin for depletable, recyclable resources is that their potential reserves can be exhausted. The depletion rate is affected by the demand for and durability of products built with the resource and by the ability to reuse the products. Except where demand is totally price inelastic (i.e., insensitive to price), higher prices tend to reduce the quantity demanded. Durable products last longer, reducing the need for newer ones. Reusable products provide a substitute for new products.

5.2 Measuring Resource Scarcity

The first step in assessing the seriousness of resource scarcity is to select a means for detecting scarcity. While this may sound like a straightforward exercise, it is not. We begin by considering what properties the ideal indicators should have and the degree to which commonly used indicators live up to these standards.

5.2.1 Criteria for an Ideal Scarcity Indicator

An ideal indicator would have at least the three following properties:

1. *Foresight*: the ideal indicator should be forward-looking. It should anticipate scarcity and not merely record the scarcity once it has occurred. Thus, the ideal indicator should incorporate such things as future demand patterns, alternative sources of the resource, changes in extraction cost, and so on.
2. *Comparability*: the ideal indicator should allow direct comparisons to be made among resources for the purpose of identifying the most serious problems. This comparison should facilitate an assessment not only of the degree of scarcity, but also of its seriousness. Thus the indicator should be able to incorporate such differences as the importance of the resource and the availability of substitutes.
3. *Computability*: the ideal indicator should be readily calculated from reliable, published sources of information or should depend on information that could be readily collected.

5.2.2 Applying the Criteria

The major indicators of scarcity are dealt as follows:

1. *Reserve-to-use ratio*

This is a physical measurement for resource scarcity. It is conveniently calculated as stock (reserve of the resource) divided by consumption per a certain period of time and it is interpreted as the time limit the resource could serve until exhaustion. It tells us the time left for the resource to be extinct. Reserve-to-use ratio is forward looking, it allows comparisons to be made, and it is readily calculable.

2. *Real Resource Price*

Price is often used as an indicator for scarcity of resources. However, price of a resource is affected by several factors including inflation factor hence it is advisable to use real resource price (a nominal price deflated by inflation factor) instead of nominal price. With this framework, an increment in the real resource price of a resource would indicate a rise in the scarcity of the resource over time.

Price also reflects the effect of different variables on the resource such as the existence and status of substitutes and complements. Besides, it reflects the effect of technological progress on the valuation of the resource by the force of demand and supply.

Even if price is considered as one of the best measures for resource scarcity, it sometimes may not reflect the scarcity of the resource since is affected by government policies such as subsidies and price controls, which make prices of resources to be artificially low. Thus, price serves well as indicator of scarcity when there is no government intervention, that is, when we have competitive markets.

3. Marginal Extraction Cost (MEC)

It is the additional cost of extracting a unit of resource. As the resource becomes more and more scarce, we will expect MEC to increase because as we extract more and more of non renewable resource, we go deep to get some more resource which in turn increases cost of extraction.

4. Marginal Discovery Cost (MDC)

This refers to the marginal cost of discovering a new reserve for resources. The additional cost of discovering a resource is an indirect revelation for its scarcity. This is relatively a simpler indicator of scarcity since all what is required for its computation is merely to collect data on the discovery cost.

5. Marginal Scarcity Rent (MSR)

Marginal Scarcity Rent is computed as the difference between price and marginal extraction cost (MEC). It is often used as an indicator of scarcity because we have a price; what happens to price could be reflected and MEC could also tell us about scarcity of resource. We could expect MSR to increase as resource become more and more scarce. The problem with this method is that measurement of price is not easy.

5.3 The Theory of Optimal Depletion Non-Renewable Resources

If we are to judge the adequacy of market allocations, we must define what is meant by efficiency in relation to the management of depletable and renewable resource

allocations. Because allocation overtime is the crucial issue, dynamic efficiency becomes the core concept. As we noted in chapter 3, the dynamic efficiency criterion assumes that society's objective is to maximize the present value of net benefits coming from the resource. For a depletable, non-recyclable resource, this maximization requires a balancing of the current and subsequent uses of the resource. In order to review how the dynamic-efficiency criterion defines this balance, we shall elaborate on the very simple two-period model developed in chapter 3. We shall show how these earlier conclusions can be generalized to accommodate longer planning horizons and more complicated situations.

5.3.1 The Two-Period Model Revisited

In chapter 3 we defined a situation involving the allocation over two periods of a finite resource that could be extracted at a constant marginal cost. With a stable demand curve for the resource, an efficient allocation meant that more than half of the resource was allocated to the first period and less than half to the second period. This allocation was affected both by the marginal cost of extraction (MEC) and by the marginal user cost (MUC). Because of the fixed and finite supplies of depletable resources, production of a unit today precludes production of that unit tomorrow. Therefore, production decisions today must take forgone future net benefits into account. Marginal user cost is the opportunity cost measure that allows balancing to take place.

The marginal cost of extraction is assumed to be constant, but the current value of the marginal user cost rises over time. In summary, Our two-period example suggests that an efficient allocation of a finite resource with a constant marginal cost of extraction involves rising marginal user cost and falling quantities consumed.

5.3.2 The N-period Model Constant-Cost Case

We begin this generalization by retaining the constant marginal extraction cost assumption while extending the time horizon within which the resource is allocated. In the numerical example shown in Figure 7.2a and 7.2b, the demand curves and the marginal cost curve from the two-period case are retained. The only changes in this numerical example from the two-period case involve spreading the allocation over a large

number of years and an increase in the total recoverable supply from 20 to 40. (The mathematics behind this and subsequent examples is presented in the chapter appendix.) Figure 7.2a demonstrates how the efficient quantity extracted varies over time, while Figure 7.2b shows the behavior of the marginal user cost and the marginal cost of extraction. Total marginal cost refers to the sum of the two. The marginal cost of extraction is represented by the lower line, and the marginal user cost is depicted as the vertical distance between the marginal cost of extraction and the total marginal cost. To avoid confusion, note that the horizontal axis is defined in terms of time, not the more conventional designation, quantity.

Several trends are worth noting. First of all, in this case in the two-period model case, the efficient marginal user cost rises steadily in spite of the fact that the marginal cost of extraction remains constant. This rise in the efficient marginal user cost reflects increasing scarcity and the accompanying rise in the opportunity cost of current consumption.

In response to these rising costs overtime, the quantity extracted falls overtime until it finally goes to zero, which occurs precisely at the moment when the total marginal cost becomes \$8. At this point total marginal cost is equal to the highest price anyone is willing to pay, so demand and supply simultaneously equal zero. Thus, even in this difficult case involving no increase in the cost of extraction, an efficient allocation envisions a smooth transition to the exhaustion of a resource. The resource doesnot “suddenly” run out, although in this case it does run out.

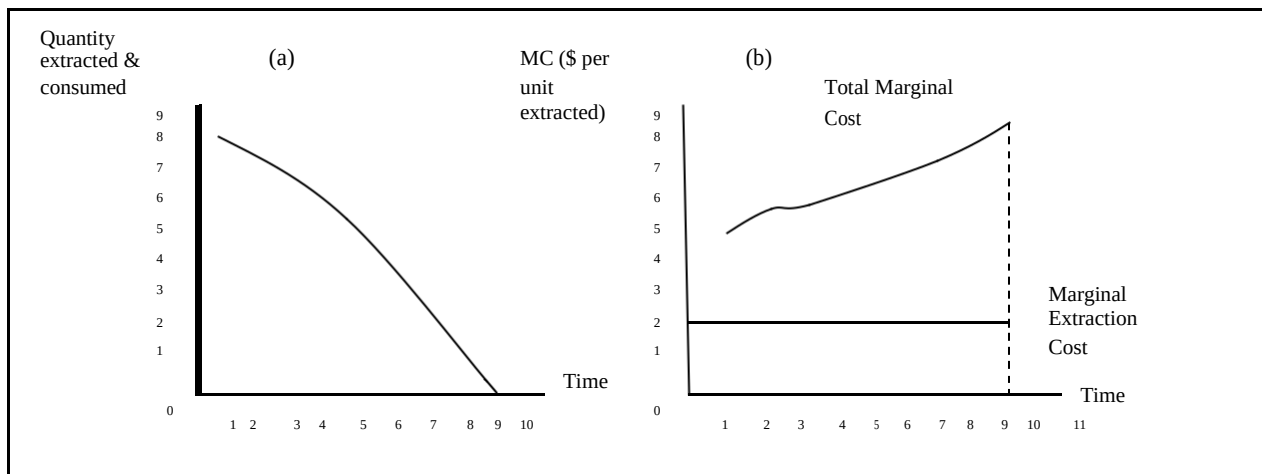
5.3.3 Transition to a Renewable Substitute

So far we have discussed the allocation of a depletable resource when no substitute is available to take its place. Suppose, however, we consider the nature of an efficient allocation when a substitute renewable resource is available at constant marginal cost.

Figure 5.1: Constant Marginal Cost of Extraction with no Substitute Resource

(a) *Constant marginal cost of extraction cost with no substitute resource: Quantity profile*

(b) *Constant marginal cost of extraction cost with no substitute resource: Marginal cost profile*



This case, for example, could describe the efficient allocation of oil or natural gas with a solar substitute or the efficient allocation of exhaustible ground water with a surface water substitute. How could we define an efficient allocation in this circumstance?

Since this problem is very similar to the one already discussed, we can use what we have already learned as a foundation for mastering this new situation. The depletable resource would be exhausted in this case, just as it was in the previous case, but that will be less of a problem, since we will merely switch to the renewable one at the appropriate time. For the purpose of our numerical example, assume the existence of a perfect substitute for the depletable resource which is infinitely available at a cost of \$6 per unit. The transition from the depletable resource to this renewable resource would ultimately transpire because its marginal cost (\$6) is less than the maximum willingness to pay (\$8). (Can you figure out what the efficient allocation would be if the marginal cost of this substitute resource was \$9 instead of \$6?)

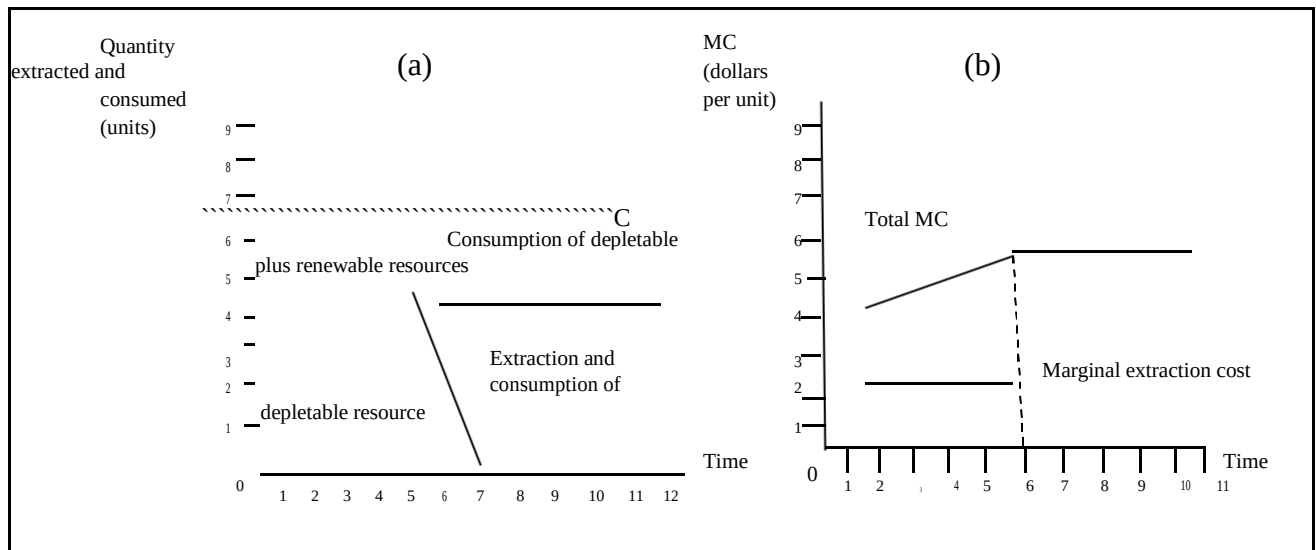
The total marginal cost for the depletable resource in the presence of a \$6 perfect substitute would never exceed \$6, because society could always use the renewable resource instead, whenever it was cheaper. Thus, while the maximum willingness to pay

(the *choke price*) sets the upper limit on total marginal cost when no substitute available, the marginal cost of extraction of the substitute sets the upper limit when one is available at a marginal cost lower than the choke price. The efficient path for this situation is give in Figures 7.3a and 7.3b.

In this efficient allocation, the transition is once again smooth. Quantity extracted is gradually reduced as the marginal user cost rises until the switch is made to the substitute. No abrupt change is evident in either marginal cost or quantity profiles.

Figure 5.2: Constant Marginal Extraction Cost with Substitute Resource

- (a) constant marginal extraction cost with substitute resource: Quantity profile
- (b) constant marginal extraction cost with substitute resource: Marginal cost profile



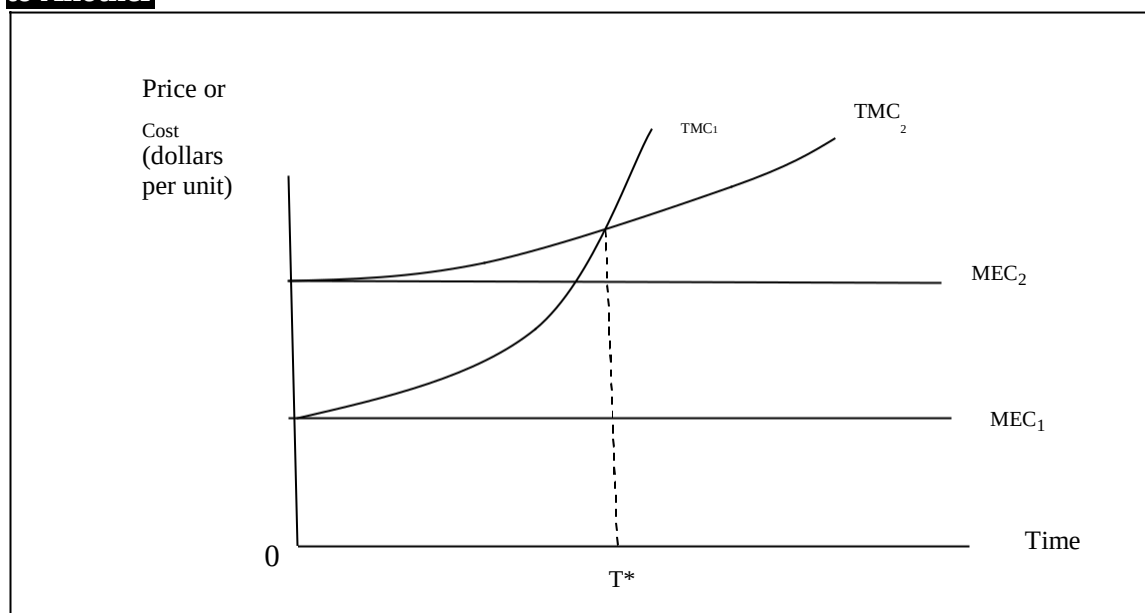
Because the renewable resource is available, more of the depletable resource would be extracted in the earlier periods than was the case in our previous numerical example without a renewable resource. As a result, the depletable resource would be exhausted sooner than it would have been without the renewable resource substitute. In this example the switch is made during the sixth period, whereas in the last example the last units were exhausted at the end of the eighth period.

At the transition point, called the switch point, consumption of the renewable resource begins. Prior to the switch point, only the depletable resource is consumed, while after the switch point only the renewable resource is consumed. This sequencing of

consumption pattern results from the cost patterns. Prior to the switch point, the depletable resource is cheaper. At the switch point, the marginal cost of the depletable resource (including MUC) rises to meet the marginal cost of the substitute, and the transaction occurs. Due to the availability of the substitute resource, consumption never drops below 5 units in any time period. This level is maintained because 5 is the amount which maximizes the net benefit when the marginal cost equals \$6 (the price of the substitute). (Convince yourself of the validity of this statement by substituting \$6 in to the willingness-to-pay function and solving for the quantity demanded.)

Though we shall not show the numerical example here, it is not difficult to see how an efficient allocation would be defined when the transition is from one constant marginal cost depletable resource to another depletable resource with a constant, but higher, marginal cost (see Figure below).

Figure 5.3: The Transition from One Constant-Cost Depletable Resource to Another



The total marginal cost of the first resource would rise overtime until it equaled that of the second resource at the time of transition. In the period of time prior to transition (T^*), only the cheapest resource would be consumed; all of it would have been consumed by T^* .

A close examination of the total marginal cost path reveals two interesting characteristics worthy of our attention. First, even in this case, the transition is a smooth one; total marginal cost never jumps to a higher level. Second, the rate of increase in total marginal cost slows down after the time of transition.

The first characteristic is easy to explain. The total marginal costs of the two resources have to be equal at the time of transition. If they weren't equal, the net benefit could be increased by switching to the lower-cost resource from the more expensive resource. Total marginal costs are not equal in the other periods. In the period before transition, the first resource is cheaper and therefore used exclusively, where as after transition the first resource is exhausted, leaving only the second resource.

The rate of increase in marginal cost is slower after transition simply because the component of total marginal cost that is growing (the marginal user cost) represents a smaller proportion of the total marginal cost of the second resource than of the first. The total marginal cost of each resource is determined by the marginal extraction cost plus the marginal user cost. In both cases the marginal user cost is increasing at rate r , and the marginal cost of extraction is constant. As seen in figure above, at the time of transition the MEC, which is constant, constitutes a much larger proportion of TMC for the second resource than for the first. Hence, total marginal cost rises more slowly for the second resource, at least initially.

5.3.4 Increasing Marginal Extraction Cost

We have now expanded our examination of the efficient allocation of depletable resources to include longer time horizons and the availability of other depletable or renewable resources which could serve as perfect substitutes. As part of our trek toward increasing realism, we will next consider a situation in which the marginal cost of extracting the depletable resource rises with the cumulative amount extracted. This is commonly the case, for example, with minerals, where the higher-grade ores are extracted first, followed by an increasing reliance on lower-grade ones.

Analytically, this case is handled in the same manner as the previous case except that the function describing the marginal cost of extraction is slightly more complicated. It increases with the cumulative amount extracted, i.e., the marginal cost of extraction at

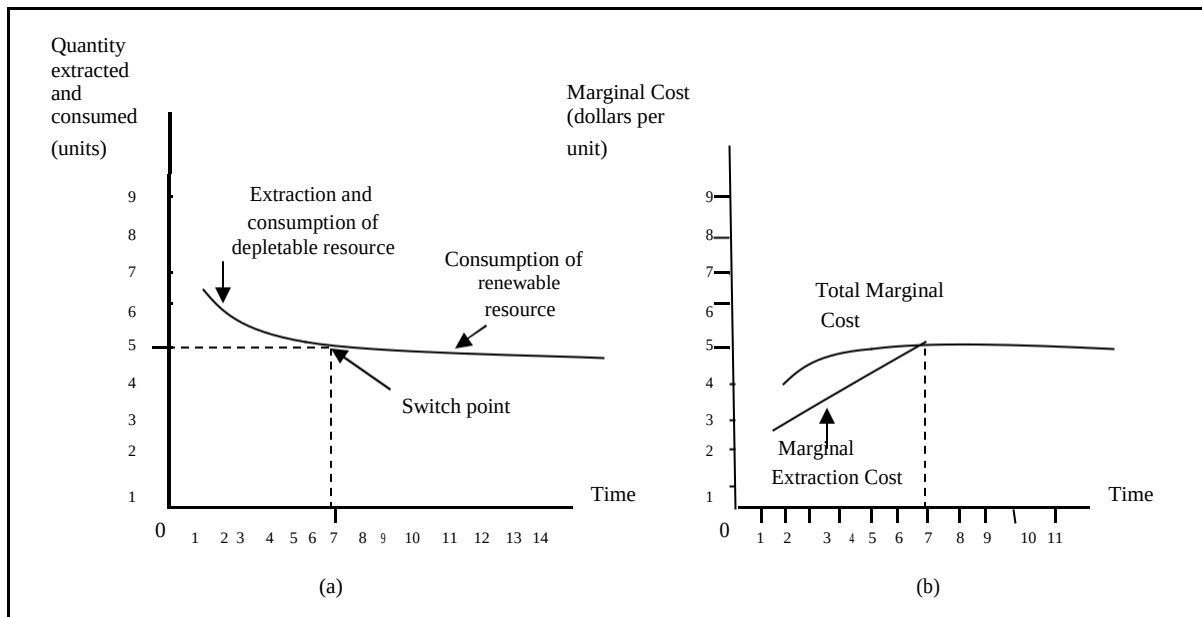
time t (MEC_t) = $\$2 + 0.1Q_t$, where Q_t is cumulative extraction to date. The dynamic efficient allocation of this resource is found by maximizing the present value of the net benefits using this modified cost of extracting function. The results of that maximization are portrayed in Figures 7.5a and 7.5b.

The most significant difference between this case and the others lies in the behavior of MUC. In the previous case we said that MUC rose over time at rate r . When the MEC increases with the cumulative amount extracted, marginal user cost declines overtime until, at the time of transition to the renewable resource, it goes to zero. Why is that?

Remember that MUC is an opportunity cost reflecting forgone future marginal net benefits. In contrast to the constant marginal cost case, in the increasing-cost case, every unit extracted raises the cost of extraction. Therefore, as the current marginal cost rises overtime, the sacrifice made by future generations (as an additional unit is consumed earlier) diminishes; the net benefit that would be received by a future generation if a unit of the resource were saved for them gets smaller and smaller as the marginal extraction cost of that resource gets larger and larger. By the last period the marginal extraction cost is so high that earlier consumption of one more unit imposes virtually no sacrifice at all. The opportunity cost of current extraction drops to zero, and total marginal cost equals the marginal extraction at the switch point.

Total marginal cost cannot be greater than the marginal cost of the substitute. Yet, in the increasing marginal extraction cost case, at the time of transition the MEC also must equal the marginal cost of the substitute. If that weren't true, it would imply that some of the resource which was available at a marginal cost lower than the substitute would not be used. This would clearly be inefficient, since net benefits could be increased by simply using less of the more expensive substitute. Hence, at the switch point, in the rising marginal cost case, the marginal extraction cost has to equal total marginal cost, implying a zero marginal user cost.

The increasing cost case differs from the constant cost case in another important way as well. In the constant cost case, the depletable resource reserve is completely exhausted. In the increasing cost case, however, the reserve is not exhausted; some is left in the ground because it is too expensive to take out.

Figure 5.4: Increasing Marginal Extraction Cost with Substitute Resource*(a) Increasing marginal extraction cost with substitute resource: Quantity profile.**(b) Increasing marginal extraction cost with substitute resource: marginal cost profile.*

Up to this point in our analysis, we have examined how an efficient allocation would be defined in a number of circumstances. First we examined a situation in which a finite amount of a resource was to be extracted at constant marginal cost. Despite the absence of increasing extraction cost, an efficient allocation involves a smooth transition to a substitute, when one is available, or to abstinence, when one is not. The complication of increasing marginal cost changes the time profile of the marginal user cost, but it does not alter the basic finding of declining consumption of depletable resources coupled with rising total marginal cost.

As a look at historical record reveals, the consumption patterns of most depletable resources have involved increases, not decreases, in consumption over time. Is this adequate evidence that the resources are not being allocated efficiently?

5.3.5 Exploration and Technological Progress

Using the historical patterns of increasing consumption to conclude that depletable resources are not being allocated efficiently would not represent a valid use of the theory of depletable resources. The models considered to this point have not yet included a consideration of the role of exploration for new resources or the role of technological progress, historically two significant factors in the determination of actual consumption paths.

The search for new resources is expensive. As easily discovered resources are exhausted, we must search in less rewarding environments, such as the bottom of the ocean or locations deep within the earth. This suggests the marginal cost of exploration, which is the marginal cost of finding additional units of the resource, should be expected to rise over time, just as the marginal cost of extraction does.

As the total marginal cost for a resource rises overtime, society should actively explore possible new sources of that resource. The higher the marginal cost of extraction for known resources is expected to rise, the larger is the potential increase in net benefits from exploration.

Some of this exploration would be successful; new sources of the resource would be discovered. If the marginal extraction cost of the newly discovered resources is low enough, these discoveries could lower, or at least retard, the increase in the total marginal cost of production. As a result, the new finds would tend to encourage more consumption. Compared to a situation with no exploration possible, the model with exploration would show a smaller and smaller decline in consumption, while the rise in total marginal cost would be dampened.

It is also not difficult to expand our concept of efficient resource allocations to include technological progress, the general term economists give to advances in the state of knowledge. In the present context, technological progress would be manifested as reductions in the cost of extraction. For a resource which can be extracted at constant marginal cost, a one-time breakthrough lowering the marginal cost of extraction would hasten the time of transition. Furthermore, for an increasing-cost resource, more of the

total available resource would be recovered in the presence of technological progress than would be recovered without it. (Why?)

The most pervasive effects of technological progress involve continuous downward shifts in the cost of extraction over some time period. The total marginal cost of the resource could actually fall over time if the cost-reducing nature of technological progress became so potent that, in spite of increasing reliance on inferior ore, of this resource, the fall in total marginal cost would be transitory, since ultimately it would have to rise, but, as we shall see in the next few chapters, this period of transition can last quite a long time.

5.4 The Theory Optimal Utilization of Renewable Resources

5.4.1 Storable, Renewable Resources: Forests

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.

Although the contributions that trees make to our everyday life are easy to overlook, even the most rudimentary calculations indicate their significance. Managing these forests is no easy task. In contrast to 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 replant. 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), establishing the proper balance requires some means of comparing the value of potentially conflicting uses. The efficiency criterion is one obvious method.

A glance at some of the vital signs of the forest resource does not inspire confidence that it is being managed either efficiently or sustainably. Deforestation is currently proceeding at an unprecedented rate. In 1992 the World Resources Institute (1992) [cited in Tietenberg (2003)] reported that 42 million acres of tropical forests, an area about the size of the state of Washington, are being destroyed each year as trees are cut for timber and

for clearing land for agriculture and development. This estimate, which was based upon remote-sensing data from satellites, was 50 percent higher than the previous global estimate prepared by the United Nations Food and Agricultural Organization in 1980.

Deforestation is a serious problem because it has intensified global warming, has decreased biodiversity, has caused agricultural productivity to decline, has increased soil erosion and desertification, and has precipitated the decline of traditional cultures of people indigenous to the forests. Instead of forests being used on a sustainable basis to provide for the needs of subsequent generations as well as current generations, the forests are being “crashed in.” According to a 1989 study for the International Tropical Timber Organization (cited in Titenberg 2003), a 69-member trade group based in Yokohama, Japan, less than 0.1% of tropical logging was done sustainably. *(In this context, sustainability refers to harvesting no more than would be replaced by growth; sustainable harvest would preserve the interests of future generations by assuring that the volume of remaining timber was not declining over time).* Currently forestry practices seem to violate both the sustainability and efficiency criteria. Why this occurring and what can be done about it?

In the remainder of this section we shall explore how economics can be combined with forest ecology to assist in efficiently managing this important resource. We begin by characterizing what is meant by an efficient allocation of the forest resource when the value of the harvested timber is the only concern. Starting simply, we first model the efficient decision to cut a single stand or cluster of trees with a common age by superimposing economic considerations on a biological model of tree growth. This model is then refined to demonstrate how the multiple values of the forest resource should influence the harvesting decision and how the problem is altered if planning takes place over an infinite horizon, with forests being harvested and replanted in a continual sequence. Turning to matters of institutional adequacy, we shall then examine the inefficiencies that have resulted or can be expected to result from both public and private management decisions and strategies for restoring efficiency.

Defining Efficient Management

Special Attributes of the Timber Resource

While timber shares many characteristics with other living resources, it also has some aspects that make it unique. Timber shares with many other animate resources the characteristic that it is both an output and a capital good. Trees, when harvested, provide a salable commodity; but left standing they are a capital good, providing for increased growth the following year. Each year, the forest manager must decide whether to harvest a particular stand of trees or to wait for the additional growth. In contrast to many other living resources, however, the time period between initial investment (planting) and recovery of that investment (harvesting) is especially long. Interval of 25 years or more are common in forestry, but not in many other industries. Finally, forestry is subject to an unusually large variety of externalities, which are associated with either the standing timber or the act of harvesting timber. These externalities not only make it difficult to define the efficient allocation, they play havoc with incentives, reducing the ability of institutions to manage efficiently.

The Biological Dimension

The growth is 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 4-inch top. For larger trees, the stump is 24 inches from the ground. Only standing trees are measured; those toppled by wind or age are not included. In this sense the volume is net rather than gross terms.

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 even reverses.

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 forests; 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 (see Figure 5.5) is based on the growth of a stand of Douglas fir trees in the Pacific Northwest.

Notice that the figure is consistent with the growth phases listed above, following an early period of limited growth in the middle ages, with growth ceasing after 13.5 years. When should this stand be harvested? Foresters have come up with a calculation called the mean annual increment (MAI) which provides the basis for a biological approach to answering this question. Developing this concept provides a useful contrast to the economic approach which is presented in subsequent sections.

The MAI is calculated by dividing the cumulative volume of the stand at the end of each decade by the cumulative number of years the stand has been growing up to that decade. For tree growth patterns like the ones represented by Figure 5.5, the MAI rises during the early ages and then falls during the later ages (see table 5.1, page 95).

According to the biological decision rule, the forest should be harvested at the age when the MAI is maximized. For our Douglas fir example, this occurs when the stand is 100 years old. Column 4 in Table 5.1 helps us to understand what is special about this age. Annual increment growth rises until the trees are about 70 years old, declining thereafter. The MAI rises for the first 100 years because the annual incremental growth is above the MAI during that period; it falls in the following years because the annual incremental growth is below the MAI.

The Economics of Forest Harvesting

To an economist, this biological criterion seems rather arbitrary; it fails to consider any of the factors such as the value of the timber, the timber value of money, or costs associated with planting and harvesting which would play a central role in an efficient harvesting decision. It is possible, however, to use the basic biological model of growth portrayed in Figure 5.5 as the basis for an economic model of the harvesting decision.

Figure 5.5: Model of Tree Growth in a Stand of Douglas Fir

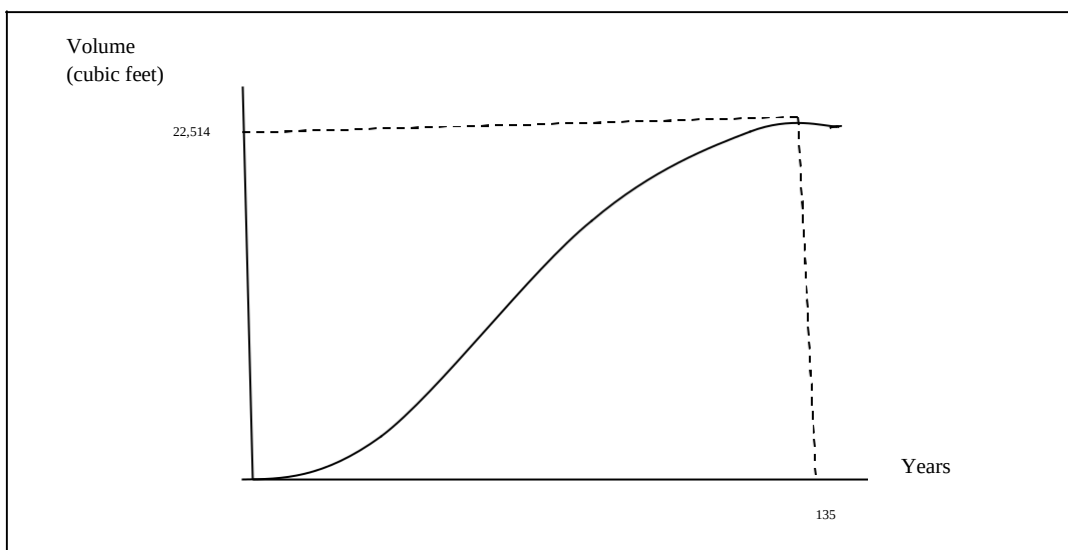


Table 5.1: The Biological Harvesting Decision: Douglas Fir

Age (years) (1)	Volume ^a (cubic feet) (2)	MAI ^b (cubic feet) (3)	Annual Increment Growth ^c (cubic feet) (4)
10	694	69.4	69.4
20	1912	95.6	121.8
30	3558	118.6	164.6
40	5536	138.4	197.8
50	7750	155.0	221.4
60	10104	168.0	235.4
70	12502	178.6	239.8
80	14848	185.6	234.6
90	17046	189.4	219.8
100	19000	190.0	195.4
110	20614	187.4	161.4
120	21792	181.6	117.8
130	22438	172.6	64.6
135	22514	166.8	11.6

^aCalculated from the equation used to produce figure 5.5.

^bColumn 2 divided by column 1.

^cChange over intervening period in column 2 divided by change in number of years in column 1.

From the definition of efficiency, the optimal time to harvest this stand would be that time which maximizes the present value of the net benefits from the wood. The size of the net benefits from the wood depends on whether the land will be perpetually committed to forestry or let to natural processes after harvest. For our first model, we will assume that the stand will be harvested once and the land will be left as is following the harvest. This model will serve to illustrate how the economic principles of forestry can be

applied to the simplest case, while providing the background necessary to move to more complicated and more realistic examples.

Two costs are presumed to be important in this decision-planting costs and harvesting costs. Apart from their magnitudes, these costs differ in one significant characteristic-the time at which they are borne. Planting costs are borne immediately, while harvesting costs are borne at the time of harvest. In a present-value calculation, harvesting costs are discounted (as is the value of the wood) because they are paid immediately. For the sake of our example, assume that planting this stand costs \$1000 and harvesting costs \$0.30 per cubic foot of wood harvested.

With these additions to the model, it is now possible to calculate the present value of net benefits that would be derived from harvesting this stand at various ages (see Table 5.2). The net benefits are calculated by subtracting the present value of costs from the value of the timber at that age. Three different discount rates are used to illustrate the influence of discounting on the harvesting decision. The undiscounted calculations ($r = 0.0$) simply indicate the actual values that would prevail at each age, while the positive discount rate takes the time value of money into account.

Table 5.2: Economic Harvesting Decision: Douglas Fir

Age (Years)	10	20	30	40	50	60	68	70	80	90	100	110	120	130	135
Volume (cubic feet)	694	1912	3558	5536	7750	10104	12023	12502	14848	17046	19000	20614	21792	22438	22514
Undiscounted ($r = 0.0$)															
Value of Timber (\$)	694	1912	3558	5536	7750	10104	12023	12502	14848	17046	19000	20614	21792	22438	22514
Cost (\$)	1208	1574	2067	2661	3325	4031	4607	4751	5454	6114	6700	7184	7538	7731	7754
Net Benefits (\$)	-514	338	1491	2875	4425	6073	7416	7751	9394	10932	12300	13430	14254	14707	14760
Discounted ($r=0.01$)															
Value of Timber (\$)	628	1567	2640	3718	4712	5562	6112	6230	6698	6961	7025	6899	6603	6155	5876
Cost (\$)	1118	1470	1792	2115	2414	2669	2833	2869	3009	3088	3107	3070	2981	2846	2763
Net Benefits (\$)	-560	97	848	1603	2299	2893	3278	3361	3689	3873	3917	3830	3622	3308	3113
Discounted ($r=0.02$)															
Value of Timber (\$)	567	1288	1964	2507	2879	3080	3128	3126	3046	2868	2623	2334	2024	1710	1449
Cost (\$)	1170	1386	1589	1752	1864	1924	1938	1938	1914	1860	1787	1700	1607	1513	1435
Net Benefits (\$)	-603	-98	375	755	1015	1156	1190	1188	1132	1008	836	634	417	197	14
Discounted ($r=0.04$)															
Value of Timber (\$)	469	873	1097	1153	1091	960	835	803	644	500	376	276	197	137	113
Cost (\$)	1141	1262	1329	1346	1327	1288	1251	1241	1193	1150	1113	1083	1059	1041	1034
Net Benefits (\$)	-672	-389	-232	-193	-237	-328	-415	-438	-549	-650	-737	-807	-862	-904	-921

Volume of timber from table 5.1

$$\text{Value of timber} = \text{price} * \text{volume} / (1+r)^t$$

$$\text{Cost} = \$1000 + \$0.30 * \text{volume} / (1+r)^t$$

$$\text{Net Benefits} = \text{Value of timber} - \text{Cost}$$

Some interesting conclusions can be gleaned from Table 5.2. First, discounting shortens the time until the stand is harvested. Whereas the maximum undiscounted net benefits occur at 135 years, when a discount rate of only 0.02 is used, the maximum occurs at 68 years, roughly half the time of the undiscounted case.

Second, changing the magnitude of the planting and harvesting costs does not change the optimal harvesting point. Notice that the maximum of the value of timber column and the net benefit column occur in precisely the same year for each of the discount rates. In other words, even if costs were zero, the harvesting decision would occur at the same point. Third, with high enough discount rates, replanting may not be sufficient. Note that with $r=0.04$, the present value of net benefits is uniformly negative due to the assumed \$1000 planting cost. Harvesting a naturally reseeded forest in this case would occur when the trees were about 40 years old, but the costs of replanting would exceed the benefits.

Higher discount rates imply shorter harvesting periods because they are less tolerant of the slow timber growth that occurs as the stand reaches maturity. The use of a positive discount rate implies a direct comparison between the increase in the value of the timber that occurs prior to harvesting and the increase in value that would occur if the forest

were harvested and the money from the sale invested at rate r . In the undiscounted case, the opportunity cost of capital is zero, so it pays to leave the money invested in trees as long as some growth rate declines sufficiently that more will be earned from financial investments.

The fact that neither harvesting nor planting costs affect the harvesting period results from the form of costs that we have used in the model. Because they are paid immediately, the present value of planting costs is equal to the actual expenditure; it does not vary with the age at which the stand is harvested. Essentially, a constant is being subtracted from the value of timber necessarily maximizes the difference between the present value of the timber and the (constant) present value of the planting cost.

This does not imply, however, that planting costs are irrelevant to the harvesting decision. If planting costs are sufficiently high, they can exceed the maximum value of the timber. In this case, the net benefits would be negative for all possible ages and it would not be efficient to plant this type of tree for commercial harvest.

Harvesting costs are a different matter. They differ from planting costs in two respects. Not only they are borne at the time of harvest, but total harvesting costs are also proportional to the amount of timber harvested (\$0.30 for each cubic foot). The present value of total harvesting costs changes with the harvesting period both because costs are discounted an amount determined by the harvesting date and because costs rise as the volume of wood to be harvested rises.

The impact of this type of cost on the harvesting decision can most easily be seen by realizing that the net benefits of a cubic foot of wood harvested at any given age is the price of that wood minus the marginal cost of harvesting that cubic foot, appropriately discounted. By assumption, the price and the marginal cost of a cubic foot of wood do not vary with age; they are constants. In the case of our numerical example, this constant net value before discounting is \$0.70 (the \$1.00 price minus the \$0.30 marginal harvest cost). If the marginal cost of harvesting were zero, this value would be \$1.00. Regardless what the marginal cost of harvesting is, this net value before discounting is a constant that is multiplied by the volume of timber at each age divided by $(1+r)^t$. Its role is merely to raise or lower the net benefits curve; it does not change its shape. Therefore net benefits will be maximized at the same age of the stand regardless of the value of the marginal

harvesting cost, as long as marginal harvesting cost is less than the price received; a rise in the marginal cost of harvesting will not affect the optimal age of harvest.

What would be the effect of a \$0.20 tax levied on each cubic foot of wood harvested in this simple model? Since this tax would raise the marginal cost of harvesting from \$0.30 per cubic foot to \$0.50 per cubic foot, it would have the same effect as a rise in harvesting cost; it would leave the optimal harvesting age unchanged.

The final conclusion that can be drawn from our numerical example relates to the decision to plant trees for subsequent harvest. When high discount rates combine with high replanting costs, planting trees for commercial harvest may not yield positive net benefits. For this specific set of circumstances, tree growth is simply too slow to justify the planting expense; profit-maximizing foresters would favor cutting down the forest without replanting it.

Sources of Inefficiency

The rather harmonious view of a regulated forest conveyed by these models contrasts rather sharply with the reality of rapid deforestation. Why are forests being harvested so rapidly, in apparent violation of both efficiency and sustainability criteria?

Global Inefficiencies

The first source of deforestation involves external costs that transcend national borders. Because the costs transcend national borders, it is unrealistic to expect national policy to solve the problem. Some international action would normally be necessary.

Biodiversity

Due to species extinction, the diversity of the forms of life that inhabit the planet is diminishing at an unprecedented rate. And the extinction of species is an irreversible process. Deforestation, particularly the destruction of the tropical rain forests, is a major source of species extinction because it destroys the most biological active habitats. In Particular, Amazonia has been characterized by Norman Myers (1984) cited in Titenberg (2003) as the “single richest region of the tropical biome.” The quantity of bird, fish,

plant, and insect life which are unique to that region is unmatched anywhere else on the planet.

One of tragic ironies of the situation is that these extinctions are occurring at precisely the moment in history when we would be most able to take advantage of the gene pool this biodiversity represents. Modern techniques now make it possible to transplant desirable genes from one species into another, creating species with new characteristics such as enhanced disease or pest resistance. But the gene pool must be diverse to serve as a source of donor genes. Tropical forests have already contributed genetic material to increase disease resistance of cash crops such as coffee and cocoa, and have been the source of some entirely new foods. Approximately one quarter of all prescription drugs have been derived from substances found in tropical plants. Future discoveries, however, are threatened by deforestation's deleterious on habitat.

Global Warming

Deforestation also contributes to global warming. Since trees absorb carbon dioxide, a major greenhouse gas, deforestation eliminates a potentially significant means of ameliorating the rise in carbon dioxide emissions. Furthermore, burning trees, an activity commonly associated with agricultural land clearing, adds carbon dioxide to the air, by liberating the carbon sequestered within the trees. Why is deforestation occurring so rapidly when the benefits conferred by a standing forest are so significant by virtually anyone's reckoning? The concept of externalities provides the key to resolving this paradox. Both the global warming and biodiversity benefits are largely external to the nation containing the forest, while the costs of preventing deforestation are largely internal. The loss of biodiversity precipitated by deforestation is perhaps most deeply felt by the industrialized world, not the countries that control the forests. Currently, the technologies to exploit the gene pool this diversity represents are in widest use in the industrialized countries. Similarly most of the damage from global warming would be felt outside the borders of the country being deforested. Yet stopping deforestation means giving up the jobs and income derived from harvesting the wood or harvesting the land made available by clearing the forests. It is therefore not surprising that the most vociferous opposition to the loss of biodiversity is mounted in the industrialized nations,

not the tropical forest nations. With global externalities we have not only a clear rationale for market failure, but also a clear rationale for why the governments involved can not be expected to solve the problem by themselves.

Poverty and Debt

Poverty and debt are also major sources of pressure on the forests. Peasants see unclaimed forest land as an opportunity to become landowners. Nations confronted with masses of peasants see unowned or publicly owned forests as a politically more viable source of land for the landless than taking it forcibly from the rich. With out land, peasants descend up on the urban areas in search of jobs in a large numbers than can be accommodated by urban labor markets. Politically explosive tensions, created and nourished by the resulting atmosphere of frustration and hopelessness, force governments to open up forested lands to the peasants or at least to look the other way as peasant stake their claim.

In eastern and southern Africa, positive feedback loops have created downward cycle in which poverty and deforestation reinforce each other. Most natural forests have long since been cut down for timber, fuel wood, and cleared land for agricultural purposes. As forests disappear, the rural poor divert more time toward locating fuel wood. When fuel wood is no longer available, animal waste is burned, thereby eliminating it as a source of fertilizer to nourish depleted soils. Fewer trees hasten soil erosion. Depleted soils lead to diminished nutrition, as does an inability to find or afford fuel wood or animal waste for cooking and for boiling unclean water. Lower nutrition saps energy, increase susceptibility to disease and reduces productivity. Survival strategies may necessarily sacrifices long-term goals simply toward off starvation or death; the forests are typically an early casualty.

Poverty at the national level takes the form of staggering levels of debt to service in comparison to the capacity to generate foreign exchange earnings. In periods of high real interest rates, servicing these debts commands most if not all foreign exchange earnings. Using these foreign exchange earnings to service the debt eliminates the possibility of using them to finance imports for sustainable activities to alleviate poverty.

The large debts owned by many developing countries also encourage these countries to overexploit their resources endowments to raise the necessary foreign exchange. Timber exports represent a case in point.

Perverse Incentives

Profit maximization does not produce efficient outcomes when the pattern of incentives facing decision makers is perverse. Forestry provides an unfortunately large number of situations where perverse incentives have produced very inefficient and unsustainable outcomes.

Privately owned forests are significant force all over the world, but in some countries, such as the United States, they are the dominant force. In the United States some 51% of forested land is privately owned. Some 10% of this forested land is owned by the forest industry, while the remaining privately owned 41% is held by farmers or other land owners (OECD 1991, 105). These later parcels tend to be small in size.

Can prescient private owners be counted up on to manage efficiently? For forests dedicated to timber harvesting, profit maximization can be compatible with efficient management. As long as social and private discount rates are the same and price expectations are accurate, the rotation which maximizes profits will also maximize net benefits. Both shorter-than-efficient rotations and longer-than-efficient rotations would result in lower benefits, so it is in the self-interest of the private owner to act efficiently.

5.4.2 Optimal Depletion of Fishery

Renewable resources are those for which the stock can be continually replenished. It is easy to think of renewable resources as perpetual. If this were automatically the case, we could merely assure ourselves that the market would ultimately make a smooth transition from depletable to renewable resources. But that is an overly view! Some renewable resources-living populations, such as plants and animals-are also exhaustible if not managed effectively. The growth or decline of these populations in general depends on the size of the population. If, through human activities, the population is drawn down beyond a critical threshold, the species can become extinct.

Extinction, though important, is not the only critical renewable resource management issue. If it were, public policy could concentrate on avoid extinction and not concern itself with any other outcome. Biological populations belong to a class of renewable resources we will call *interactive resources*, wherein the size of the resource stock (population) is determined jointly by biological considerations and by actions taken by society. The size of the population, in turn, determines the availability of the resources for the future. Thus humanity's actions determine the flow of these resources overtime. Since this flow is not purely a natural phenomenon, a second crucial dimension is the optimum rate of use interactive renewable resources? In the absence of outside influences, can the market be relied upon to achieve and sustain this rate?

In an often-cited book published during the early 1970s, Lester Brown (1974) caught the world's attention by reporting that the world's fish catch had started to decline, thus ushering in a new age of scarcity. Although this decline in total fish catch turned out to be temporary, during the 1970s the fish catch did not keep pace with population growth.

A more recent concern has been with the dramatic decline in the populations of several particularly valuable fish species. Total catch figures mask this problem because the declining catches of species such as cod, halibut, and haddock have been offset by corresponding increases in less familiar, and typically less valuable, species.

Understanding the sources of this decline is important not only because fish are an important source of protein, but also because the problems associated with efficiently managing fisheries provide a rich and varied introduction to the problems of managing a much broader class of biological common-property resources. To capitalize on both the transferability of insights derived from an analysis of fisheries and the wealth of analysis which already exists, we shall use the economics of fisheries management as a case study.

We begin by defining what is meant by an efficient allocation of the catch from a fishery; we can then examine how the market allocates this common-property resource and the past and potential roles for public policies in the quest for efficient and sustainable management.

Efficient Allocations

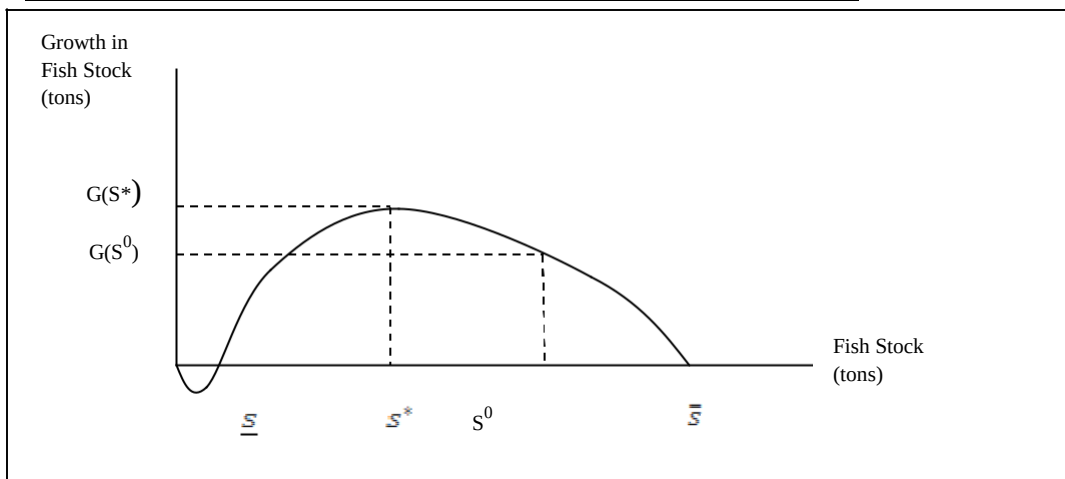
The Biological Dimension

Likely many other studies, our characterization of the fishery rests on a biological model originally proposed by Schaefer (1957). The Schaefer model posits a particular average relationship between the growth of the fish population and the size of the fish population. This is an average relationship in the sense that it abstracts from such influences as water temperature and the age structure of the population. The model therefore does not attempt to characterize the fishery on a day-to-day basis, but rather in terms of some long-term average in which these various random influences tend to counterbalance each other (see fig below).

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 ($\underline{S}$ to $\bar{S}$) where the population growth increases as the population increases and a range ($\bar{S}$ to $\bar{S}$) 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 $\bar{S}$) where the function intersects the horizontal axis and therefore growth in the stock is zero. $\bar{S}$ is known as the *natural equilibrium*, since this is population size which 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.

Figure 5.6 Relationship between the Fish Population and Growth



This natural equilibrium would persist because it is stable. A stable equilibrium is one in which movements away from this population level set forces in motion to restore it. If, for example, the stock temporarily exceeded $\bar{S}$, 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 $\bar{S}$.

This tendency for the population size to return to $\bar{S}$ works in the other direction as well. Suppose the population is temporarily reduced below $\bar{S}$. 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 $\bar{S}$ is reached again.

What about the other points on the curve? $\underline{S}$, 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 $\bar{S}$, this equilibrium is unstable. Population sizes to the right of $\underline{S}$ lead to positive growth and a movement along the curve to $\bar{S}$ 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 that population size which yields the maximum growth; hence the maximum sustainable yield is equal to this maximum growth and it represents the largest catch that can be perpetually sustained. If the catch is equal to the growth, the sustainable yield for any population size (between $\underline{S}$ and $\bar{S}$) can be determined by drawing a vertical line from the stock size of interest on the horizontal axis to the point where it intersects function, and drawing a horizontal line over to the vertical axis. The sustainable yield is the growth in the biomass field is the growth in the biomass defined by the intersection of this line with the vertical axis. Thus, in terms of Figure 5.6, $G(S^0)$ sustainable yield for population size S^0 . 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, if the population were drawn down to a level smaller than $\underline{S}$, to the extinction of the species.

Static Efficient Sustainable Yield

Is the maximum sustainable yield synonymous with efficiency? The answer is no. Efficiency, it may be remembered, 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 which, 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 extended is proportional to the size of fish population (the smaller the population, the fewer fish caught per unit of effort).

In any sustainable yield, catches, population, effort levels, and net benefits remain constant overtime. The static efficient sustainable yield allocation maximizes the constant net benefit.

In Figure below, the benefits (revenues) and costs are portrayed as a function of fishing effort and can be measured in vessel years, hours of fishing, or some other convenient metric. The shape of the revenue function is dictated by the shape of the function in Fig 5.6 above, since the price of fish is assumed constant. To avoid confusion, notice that

increasing fishing effort in Fig 5.6 would result in smaller population sizes and would be recorded as a movement from right to left. Because the variable on the horizontal axis in Fig 4.2 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 (E^m) where further effort reduces the sustainable catch and revenue for all years. That point, of course, corresponds to the maximum sustainable yield on Fig 4.1, which involves identical population and growth levels. Every effort level portrayed in Fig 4.2 corresponds to a population level in Fig 4.1.

The net benefit is presented in the diagram as the difference (vertical distance) between benefits (prices times the quantity caught) and costs (the constant MC of effort times the units of effort expended). The efficient level of effort is E^e , that point in Figure 5.7 where the vertical distance between benefits and costs is maximized.

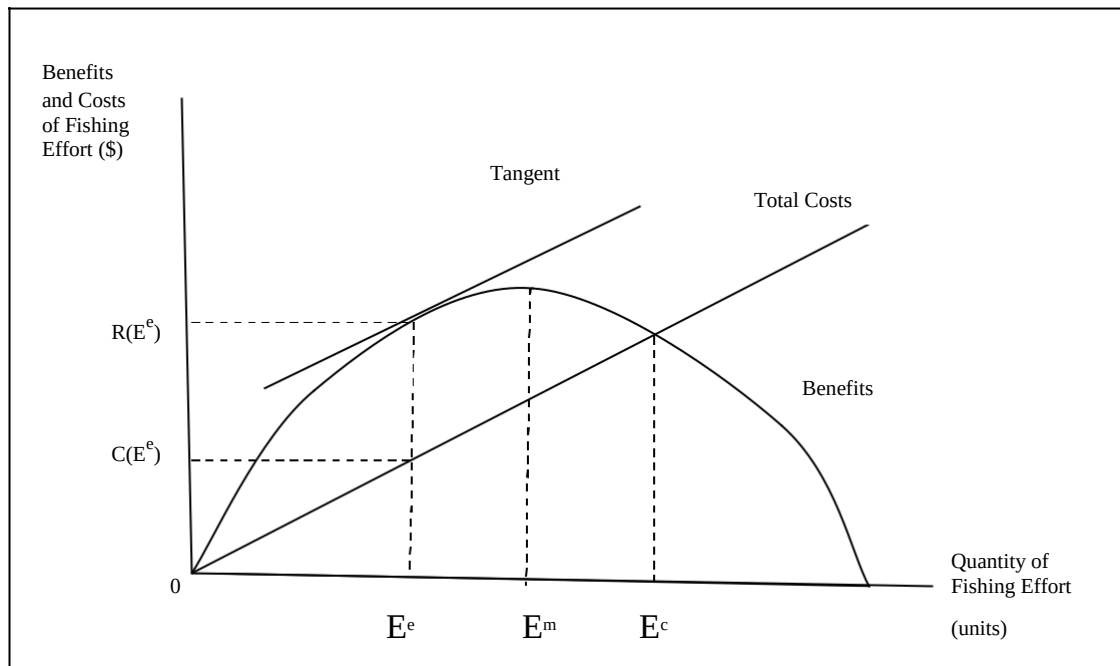
E^e is the efficient level of effort because it is where MB (which graphically is the slope of the total benefit curve) is equal to MC (the constant slope of the TC curve). Levels of effort higher than E^e are inefficient because the additional cost associated with them exceeds the value of the fish obtained. Can you see why lower levels of effort are 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 MSY would be efficient only if the MC of additional effort were zero. Can you see why? (Hint: What is the MB at the MSY?) Since this is not the case, the efficient level of effort is less than that necessary to harvest the MSY. Thus the static efficient level of effort leads to a larger fish population than the MSY level of effort.

To fix these concepts firmly in mind, consider what would happen to the static efficient sustainable yield if a technology change were to occur (for example, sonar detection) lowering MC of fishing. The lower MC would result in a rotation of the TC curve to the right. With this new cost structure the old level of effort is no longer efficient. The MC of fishing (slope of the TC curve) is now lower than the MB (slope of the TB curve). Since the MC is constant, the equality of MC and MB can result only from a decline in MBs. This implies an increase in effort. The new static efficient sustainable yield equilibrium

implies more effort, a lower population level, a larger catch, and a higher net benefit for the fishery.

Figure 5.7: Efficient Sustainable Yield for a Fishery



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 which maximizes the (identical) net benefit in every period. Any higher effort levels 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 mentioned, a new lower equilibrium level would be attained when the size of the catch once again equals the growth of population. Colin Clark (1976) [cited in Tietenberg, 2003] has shown mathematically that in terms of figure 5.7, as the discount rate is increased, the dynamic efficient level of effort is increased until, with an infinite discount rate, it becomes equal to E^C , the point at which the 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 E^C . We have seen that interdependent allocation 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. This implies: (1) the marginal cost of extraction equals the marginal willingness to pay, which equals the constant price, and (2) total benefits equal total costs.

This is not difficult to demonstrate mathematically. In our model, the yield (y) can be expressed as $y=qxe$, where q is the proportion of the population harvested with one unit of effort, x is the size of population and e is the level of effort. One of the conditions a dynamic efficient allocation has to satisfy with an infinite discount rate is $P=c/qx$, where p is the constant price, c is the constant marginal cost per unit of effort, and qx is the number of fish harvested per unit of effort. By multiplying both sides of this equation by y and collecting terms, we obtain $Py=ce$. The left-hand side is total benefits, while the right is total cost, implying net benefits are zero.

Earlier we demonstrated that the static efficient sustained yield implies a large fish population than the maximum sustained yield. Once discounting is introduced, it is inevitable that the dynamic efficient sustained yield would imply a smaller fish population than the static efficient sustained yield and it is impossible, though not inevitable, that the sustained catch would be smaller. Can you see why? In Figure 5.7 the sustained catch clearly is lower for an infinite discount rate.

The likelihood of the population being reduced below the level supplying the maximum sustainable yield depends on the discount rate. In general, the lower the extraction costs and the higher the discount rate, the more likely it is that the dynamic efficient level of effort will exceed the level of effort associated with the maximum sustainable yield. This is not difficult to see if we remember the limiting case discussed earlier. When the marginal extraction cost is zero, the static efficient sustainable yield and the maximum sustainable yield are equal.

Thus, with zero marginal extraction costs and a positive discount rate, the dynamic efficient level of effort necessarily exceeds the static level of effort and the level of effort associated with the maximum sustainable yield. Higher extraction costs reduce the static efficient sustainable yield but not the maximum sustainable yield. Higher extraction costs reduce the likelihood that discounting would cause the population to be drawn below the maximum sustainable yield level.

Would a dynamically efficient management scheme lead to extraction of fishery? As figure 5.7 shows, it would not be possible under the circumstances described here because E^c is the highest dynamically efficient level possible in this model, and that level falls well short of the level needed to drive the population to extinction. It is possible under other circumstances, however (Chang et al. 1981 cited in Tietenberg, 2003).

For extinction to occur under a dynamic management scheme, the benefit from extracting the very last unit would have to exceed the cost of extracting that unit (including the costs on future generations). As long as the population growth rate exceeds the discount rate, this will not be the case. If, however, the growth rate is lower than the discount rate, extinction can occur in an efficient management scheme if the costs of extracting the last unit are sufficiently low.

Why does the biomass rate of growth have anything to do with whether or not an efficient catch profile leads to extinction? Rates of growth determine the productivity of conservation efforts. With high rates of growth, future generations can be easily satisfied. On the other hand, when the rate of growth is very low, it takes a large sacrifice by current generations to produce more fish for future generations. In the limiting case, where the rate of growth is zero, we have a source with fixed supply and therefore no different from an exhaustible resource. Total depletion would occur whenever the price commanded by the resource is high enough to cover the marginal cost of extracting the last unit.

We have shown that the dynamic efficiency criterion is not automatically consistent with sustaining constant yields perpetually for an interactive renewable resource, since it is mathematically possible for an efficient allocation of a fishery lead to extinction of the resource. How likely are these criteria to conflict in practice?

Although the information is sketchy, most empirical studies suggest that because of the importance of extraction costs, the dynamically efficient catch rate is usually smaller than the maximum sustainable yield and extinction is rarely, if ever, efficient. The cost of catching the last few fish is usually well in excess of the price received from them. The two criteria are usually completely compatible, although we must bear in mind that they are not inevitably compatible.

Appropriability and Market Solutions

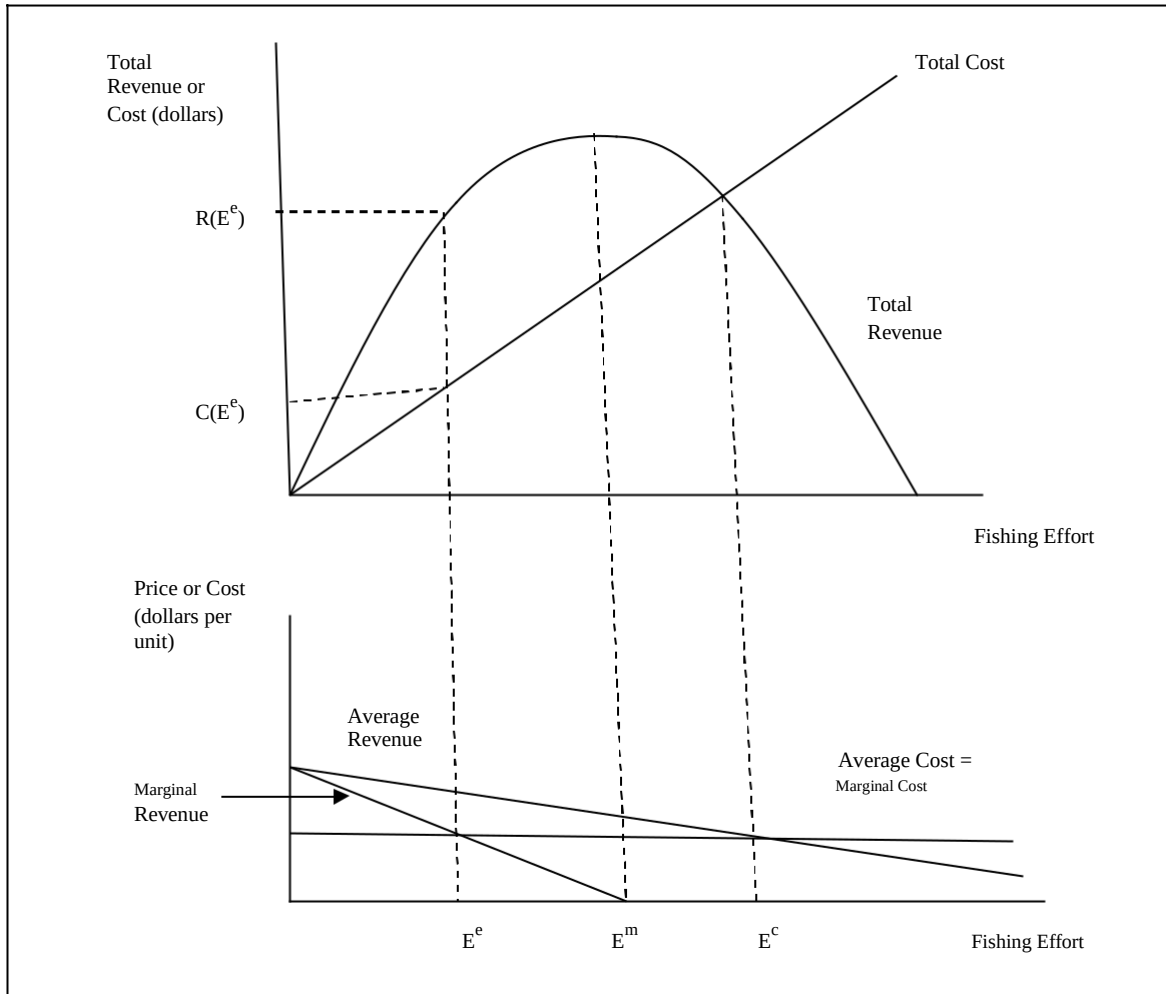
We have defined an efficient allocation of the fishery over time. The next step is to characterize the normal market allocation and to contrast these two allocations. Where they differ we can entertain the possibility of various public-policy corrective means.

Let's first consider the allocation resulting from a fishery managed by a competitive sole owner. A sole owner would have a well-defined property right to the fish. We can establish the behavior of a sole owner by elaborating on Figure 5.7, as is done in Figure 5.8. Notice that the two panels share a common horizontal axis which 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. Clearly this is effort level E^e , the static efficient sustainable yield. This will yield positive profits equal to the difference between $R(E^e)$ and $C(E^e)$.

Figure 5.8: Market Allocation in a Fishery



In ocean fisheries, however, sole owners are not normal. Ocean fisheries are typically free-access, common-property resources – no one exercises complete control over them. Since the property rights to the fishery are not conveyed to any single owner, no single fisherman can exclude others from exploiting the fishery. Sometimes common-property resources can coexist in the same market as private-property fisheries.

What problems arise when access to the fishery is completely unrestricted? Open-access resources create two kinds of externalities: a contemporaneous externality and an intergenerational externality. The contemporaneous externality, which is borne by the current generation, involves the over commitment of resources to fishing—too many fishermen, too much effort. As a result, current fishermen earn a substantially lower rate of return on their efforts. The intergenerational externality, borne by future generations, occurs because overfishing reduces the stock which, in turn, lowers future benefits from fishing.¹⁰

We can use figure 5.8 to see how these externalities arise. Once too many fishermen have unlimited access to the same common-property fishery, the property rights to the fish are no longer efficiently defined. At the efficient level, each boat would receive a profit equal to its share of the scarcity rent. This rent, however, serves as a stimulus for new fishermen to enter, drawing up costs and eliminating the rent. Open access results in overexploitation.

The sole owner chooses not to expend more effort than E^e because to do so would reduce the profits of the fishery, resulting in a personal loss to him. When access to the fishery is unrestricted, a decision to expend effort beyond E^e reduces profits to the fishery as a whole but not to that individual fisherman. Most of the decline in profits falls on the other fishermen.

In an open-access resource, the individual fisherman has an incentive to expend further effort until profits are zero. In Figure 5.8 that point is at effort level E^c , where average benefit and average cost are equal. It is now easy to see the contemporaneous externality—too much effort is being expended to catch too few fish, and the cost is substantially higher than it would be in an efficient allocation.

An intergenerational externality occurs because the size of the population is reduced, causing future profits to be lower than would otherwise be the case. As the existing

¹⁰ This will result in fewer fish for future generations as well as smaller profits if the resulting effort level exceeds that associated with the maximum sustainable yield. If the open access effort is lower than the maximum sustainable yield effort level (when extraction costs are very high), then reduction in stock would increase the growth in the stock, thus supplying more fish (albeit lower net benefits) to future generations.

population is overexploited, the open-access catch would initially be higher, but as growth rates are affected, the steady-state profit level, once attained, would be lower.

A resource owner with exclusive property rights balances the use value against the asset value. When access to the resource is unrestricted, exclusivity is lost. As a result, it is rational for a fisherman to ignore the asset value, since he or she can never appropriate it, and simply maximize the use value. In the process all the scarcity rent is dissipated. The allocation that results from allowing unrestricted access to the fishery is identical to that resulting from a dynamic efficient sustainable yield when an infinite discount rate is used. Open access resources do not automatically lead to a stock lower than that maximizing the sustained yield. We can draw a cost function with a slope sufficiently steep that it intersects the benefit curve at a point to the left of E^m . Nonetheless, it is not unusual for mature, open-access fisheries to be exploited well beyond the point of maximum sustainable yield.

Summary

The efficient allocation of depletable and renewable resources depends on the circumstances. When the resource can be extracted at a constant marginal cost, the efficient quantity of the depletable resource extracted declines overtime. If no substitute is available, the quantity declines smoothly to zero. If a renewable constant cost substitute is available, the quantity of the depletable resource extracted will decline smoothly to the quantity available from the renewable resource. In both cases, all of the available depletable resource would be eventually used up and marginal user cost would rise over time, reaching a maximum when the last unit of depletable resource was extracted.

The efficient allocation of an increasing marginal user cost resource is similar in that the quantity extracted declines over time, but differs with respect to the behavior of marginal user cost and the cumulative amount extracted. Whereas marginal user cost typically rises over time when the marginal cost of extraction is constant, it declines over time when the marginal cost of extraction rises. Furthermore, in the constant-cost case the cumulative amount extracted is equal to the available supply; in the increasing cost case it is less.

Introducing technological progress and exploration activity into the model tends to delay the transition to renewable resources. Exploration expands the size of current reserves, while technological progress keeps marginal extraction cost from rising as much as it otherwise would. If these effects are sufficiently potent, marginal cost would actually decline from some period of time, causing the quantity extracted to rise.

Forests represent an example of storable, renewable resource. Typically tree stands go through three distinct growth phases – slow growth in volume in the early stage, followed by rapid growth in the middle years and slower growth as the stand reaches full maturity. The owner who harvests the timber receives the income from its sale, but the owner who delays harvest will receive additional growth. The amount of growth depends on the part of the growth cycle the stand is in. From an economic point of view, the efficient time to harvest a stand of timber is when the present value of net benefits is maximized. The present value of net benefits is maximized when the marginal gain from delaying the harvest one more year is equal to the marginal cost of the delay.

Unrestricted access to commercially valuable species will generally result in over-exploitation. This overexploitation, in turn, results in overcapitalization, depressed incomes of fishermen, and depleted fish stocks. Even extinction of the species is possible, particularly for fisheries characterized by particularly low extraction costs. When extraction costs are higher, extinction is unlikely, even with unrestricted access.

Problems

1. 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 which is compatible with the efficient sustainable yield?
2. Suppose you are given that Aluminum has a constant marginal cost of extraction (MEC) over time. And, after five years of continuous extraction, there happened a transfer to another depletable resource with a constant but a higher MEC.
 - a. Draw the Marginal cost profile of the resource utilization and transfer Path of the resources.
 - b. Do you think that there is a difference in the steepness of Marginal cost curves of the two resources? If yes, reason out?
 - c. Is the transfer continuous or is there a jump?
 - d. Do you think the Aluminum reserve would exhaust at the time of transfer? Justify your response.

CHAPTER SIX

6. ECONOMICS OF POLLUTION CONTROL: AN

OVERVIEW Course Content:

Dear students, this chapter has the following major sections for discussion:

Pollutant Taxonomy

Defining the Efficient Allocation of Pollution

Market Allocation of Pollution

Efficient Policy Responses

Cost-Effective Policies for Uniformly Mixed Fund Pollutants

Trans-Boundary Environmental Problems and Policy Issues

Objectives

After going through this chapter, students are expected to:

Know the different taxonomy of pollutants depending on their few specific features.

Deficiencies of pollution allocation by the market system and a need for government's role.

Identify the efficient allocation of pollution reductions among sources of emissions.

Understand the policy approach to controlling the flow of these waste products by developing a general framework for analyzing pollution control.

6.1 Pollutant Taxonomy

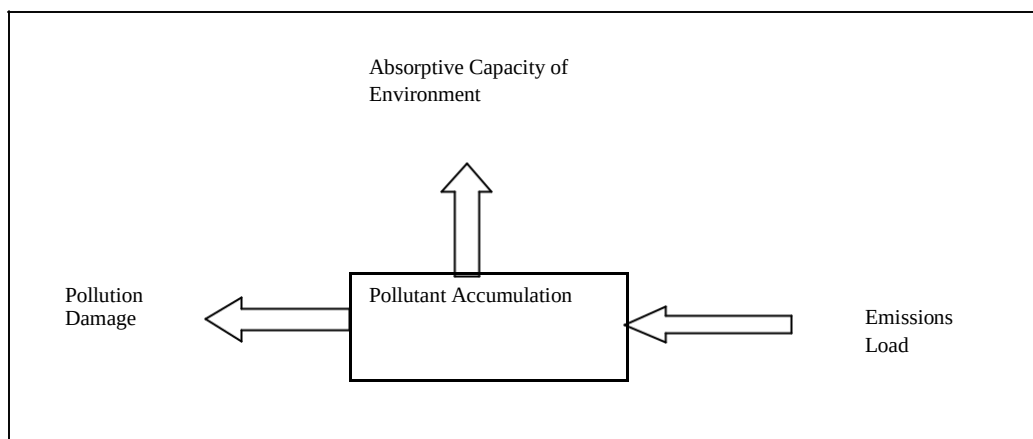
The amount of waste products emitted determines the load upon the environment. The damage done by this load depends on the capacity of the environment to assimilate the waste products (see Figure 6.1). We call this ability of the environment to absorb pollutants its absorptive capacity. If the emissions load exceeds the absorptive capacity, then the pollutant accumulates in the environment.

Pollutants for which the environment has little or no absorptive capacity are called *stock pollutants*. Stock pollutants accumulate over time as emissions enter the environment. Examples of stock pollutants include non-biodegradable bottles tossed by the road side;

heavy metals, such as lead, which accumulate in the soils near the emission source; and persistent synthetic chemicals such as dioxin and PCBs (polychlorinated biphenyls). Pollutants for which the environment has some absorptive capacity are called *fund pollutants*. For these pollutants, as long as the emission rate does not exceed the absorptive capacity of the environment, the pollutants do not accumulate. Examples of fund pollutants are easy to find. Many organic pollutants injected in to an oxygen-rich stream will be transformed by the resident bacteria into less harmful inorganic matter. Carbon dioxide is absorbed by plant life and the oceans.

The point is not that the mass is destroyed; the law of conservation of mass suggests this can not be the case. Rather, when fund pollutants are injected into the air or water, they may be transformed in to substances that are not considered harmful to people or to the ecological system or they may be diluted or dispersed that the resulting concentrations are not harmful.

Figure 6.1: Relationship between Emissions and Pollution Damage



Pollutants can also be classified by their *zone of influence*, defined both horizontally and vertically. The horizontal dimension deals with the domain over which damage from an emitted pollutant is experienced. The damage caused by *local* pollutants is experienced near the source of emission, while the damage from *regional* pollutants is experienced at greater distances from the source of emission. The local and regional categories are not mutually exclusive; it is possible for a pollutant to be both. Sulfur oxides and nitrogen oxides, for example, are both local and regional pollutants.

The vertical zone of influence describes whether the damage is caused mainly by ground-level concentrations of an air pollutant or by concentrations in the upper atmosphere. When the damage caused by a pollutant is determined mainly by concentrations of the pollutant near the earth's surface, it is called a *surface pollutant*. When its damage is related more to its concentration in the upper atmosphere, the substance is called *global pollutant*.

Water pollutants are obviously surface pollutants, but air pollutants can be surface pollutants, global pollutants, or both. One common global pollutant, carbon dioxide injected in to the atmosphere as a product of fossil-fuel combustion, has been implicated in raising world temperatures via the “greenhouse effect.” In addition, chlorofluorocarbon emissions play a role in the distraction of the ozone layer, which protects the earth's surface from harmful solar radiations. As we shall see, the appropriate policy responses for global and surface pollutants are quite different.

This taxonomy will prove useful in designing policy responses to these various types of pollution problems. Each type of pollutant requires a unique policy response. The failure to recognize these distinctions leads to counterproductive policy.

6.2 Defining the Efficient Allocation of Pollution

Pollutants are the residuals of production and consumption. These residuals must eventually be returned to the environment in one form or another. Since their presence in the environment may depreciate the service flows received, an efficient allocation of resources must take this cost into account. What is meant by the efficient allocation of pollution depends on the nature of the pollutant. Stock pollutants

The efficient allocation of a stock pollutant must take into account the fact that the pollutant accumulates in the environment over time and that the damage caused by its presence increases and persists as the pollutant accumulates. By their very nature, stock pollutants created interdependency between the present and the future, since the damage imposed in the future depends on current actions.

It is not hard to establish what is meant by an efficient allocation in these circumstances. Suppose, for example, that we consider the allocation of a commodity which we refer to

as X . Suppose further that the production of X involves the generation of a proportional amount of a stock pollutant. The amount of this pollution can be reduced, but that takes resources away from the production of X . The damage caused by the presence of this pollutant in the environment is further assumed to be proportional to the size of the accumulated stock. As long as the stock of pollutants remains in the environment, the damage persists.

The efficient allocation, by definition, is the one which maximizes the present value of the net benefit. In this case the net benefit at any point in time t is equal to the benefit received from the consumption of X minus the cost of damage caused by the presence of the stock pollutant in the environment.

This damage is a cost that society must bear, and in terms of its effect on the efficient allocation, this cost is not unlike that of extracting minerals or fuels. While for minerals the extraction cost rises with the cumulative amount of the depletable resource extracted, the damage cost associated with a stock pollutant rises with the cumulative amount deposited in the environment. The accretion of the stock pollutant is proportional to the product of X and this pollution cost as exists between the extraction cost and the production of a mineral. They both rise over time with the cumulative amount produced. The one major difference is that the extraction cost is borne only at the time of extraction, while damage is borne as long as the stock pollutant exists in the environment.

We can exploit this similarity to infer the efficient allocation of a stock pollutant from our knowledge of the efficient allocation of a depletable resource with rising extraction cost. As discussed in chapter 4, when extraction cost rises, the efficient quantity of a depletable resource extracted and consumed declines over time.

Exactly the same pattern would emerge for a commodity which is produced jointly with a stock pollutant. The efficient quantity of X (and therefore, the addition to the accumulation of this pollutant in the environment) would decline over time as the marginal cost of the damage rises. The price of X would rise over time, reflecting the rising social cost of production. To cope with the increasing marginal damage, the amount of resources committed to controlling the pollutant would increase over time. Ultimately, a steady state would be reached where additions to the amount of the pollutant in the environment would cease and the size of the stock would stabilize. At this

point all further emission of the pollutant created by the production of X would be controlled (through recycling). The price of X and the quantity consumed would remain constant. The damage caused by the stock pollutant would persist.

As with the case with rising extraction cost, technological progress could modify this efficient allocation. Specifically, technological progress could reduce the amount of pollutant generated per unit of X produced; it could create ways to recycle the stock pollutant rather than injecting it into the environment; it could develop ways of rendering the pollutant less harmful. All of these responses would lower the marginal damage cost associated with a given level of production of X. Therefore, more of X could be produced with technological progress than without it.

Stock pollutants are, in a sense, the other side of the intergenerational equity coin from depletable resources. With depletable resources it is possible for current generations to create a burden for future generations by using up resources, thereby diminishing the remaining endowment. Stock pollutants can create a burden for future generations by passing on a damage cost which persists well after the benefits received from incurring that damage cost have been forgotten. Though neither of these situations automatically violates our sustainability criterion, they clearly require further scrutiny.

Fund Pollutants

To the extent that the emission of fund pollutants exceeds the assimilative capacity of the environment, they accumulate and share some of the characteristics of stock pollutants. When the emission rate is low enough, however, the discharges can be assimilated by the environment, with the result that the link between present emissions and future damage may be broken.

When this happens, current emissions cause current damage and future emission cause future damage, but the level of future damage is independent of current emissions. This independence of allocations among time periods allows us to explore the efficient allocation of fund pollutants using the concept of static, rather than dynamic, efficiency. Because the static concept is simpler, this affords us the opportunity to incorporate more dimensions of the problem without unnecessarily complicating the analysis.

The normal starting point for the analysis would be to maximize the net benefit from the waste flows. However, pollution is more easily understood if we deal with an equivalent formulation involving the minimization of two rather different types of costs: damage cost and control or avoidance costs.

To examine the efficient allocation graphically, we need to know something about how control costs vary with the degree of control and how the damages vary with the amount of pollution emitted. Though our knowledge in these areas is far from complete, economists generally agree on the shape of these relationships.

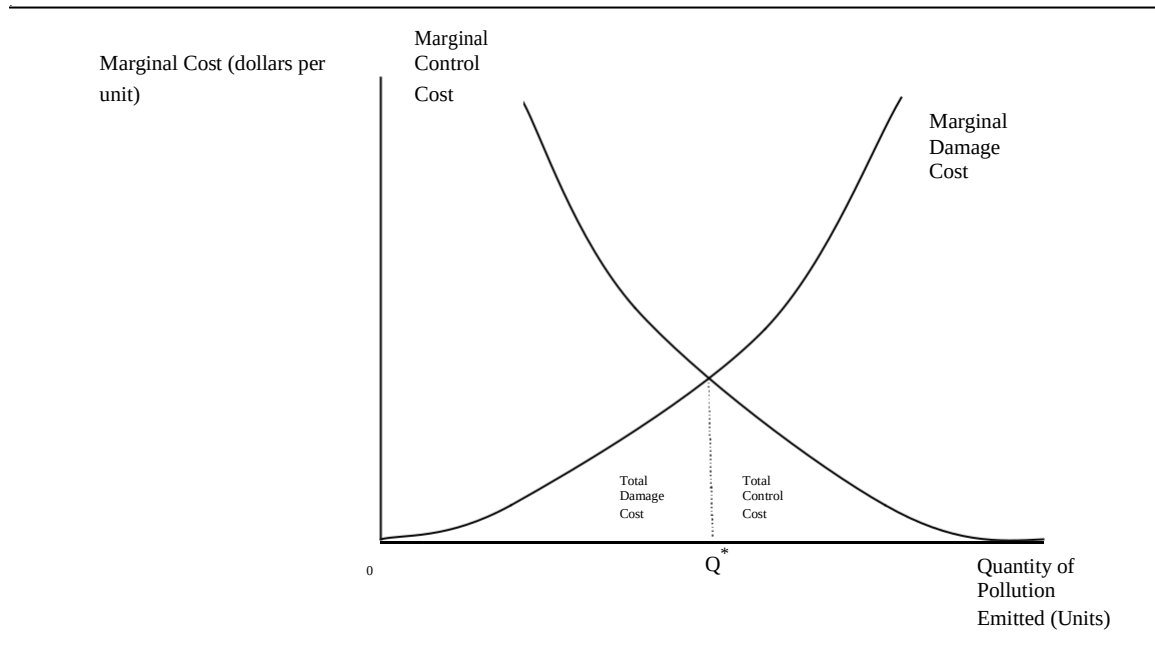
Generally the marginal damage caused by a unit of pollution increases with the amount emitted. When small amounts of the pollutant are emitted, the marginal damage is quite small. However, when large amounts are emitted, the marginal unit can cause significantly more damage. It is not hard to understand why. Small amounts of pollution are easily diluted in the environment; the body can tolerate small quantities of substances. However, as the amount in the atmosphere increases, dilution is less effective and the body is less tolerant.

Marginal control cost commonly increase with the amount controlled. For example, suppose a source of pollution tries to cut down on its particulate emissions by purchasing an electrostatic precipitator which captures 80% of the particulates as they flow past in the stack. If the source wants further control, it can purchase another precipitator and place it in the stack above the first one. This second precipitator captures 80% of the remaining 20%, or 16% of the uncontrolled emissions. Thus, the first precipitator would achieve an 80% reduction from uncontrolled emission, while the second precipitator, which costs the same as the first, would achieve only a further 16% reduction. Obviously each unit of emission reduction costs more for the second precipitator than for the first.

In figure 6.2 we use these two pieces of information on shapes of the relevant curves to derive the efficient allocation. A moment from right to left refers to greater control and less pollution emitted. The efficient allocation is represented by Q^* , the point at which the

damage caused by the marginal unit of pollution is exactly equal to the marginal cost of avoiding it.¹¹

Figure 6.2: Efficient Allocation of A Fund Pollutant



Greater degrees of control (point to the left of Q^*) are inefficient because the further increase in avoidance costs would exceed the reduction in damages. Hence total costs would rise. Similarly, levels of control lower than Q^* would result in a lower cost of control but the increase in damage costs would be even larger, yielding an increase in total cost. Either increasing or decreasing the amount of controlled causes an increase in total cost. Hence Q^* must be efficient.

The diagram suggests that, under the conditions presented, the optimal level of pollution is not zero. If you find this disturbing, remember that we confront this principle everyday. Take the damage caused by automobile accidents, for example. Obviously, a considerable amount of damage is caused by automobile accidents. Yet we do not reduce that damage to zero because the cost of doing so would be too high.

¹¹ At this point we can see why this formulation is equivalent to the net benefit formulation. Since the benefit is damage reduction, another way of stating this proposition is that marginal benefit must equal marginal cost. That is, of course, the familiar proposition derived by maximizing net benefits.

The point is *not* that we do not know how to stop automobile accidents. All we would have to do is eliminate automobiles! Rather, the point is that since we value the benefits of automobiles, we take steps to reduce accidents (using speed limits) only to the extent that the costs of accident reduction are commensurate with the damage reduction achieved. The efficient level of automobile accidents is not zero.

The second point to be made is that in some circumstances the optimal level of pollution *may* be zero, or close to it. This situation occurs when the damage caused by even the first unit of pollution is so severe that it is higher than the marginal cost of controlling the last unit of pollution. This would be reflected in figure 6.2 as a leftward shift of the damage cost curve of sufficient magnitude that its intersection with the vertical axis would lie above the point where the marginal cost curve intersects the vertical axis. This circumstance seems to characterize the treatment of highly dangerous radioactive pollutants such as plutonium.

Additional insights are easily derived from our characterization of the efficient allocation. For example, it should be clear from figure 6.2 that the optimal level of pollution generally is not the same for all parts of the country. Areas which have higher population levels or are particularly sensitive to pollution should have lower levels, while areas which have lower population levels are less sensitive should have more.

Examples of ecological sensitivity are not hard to find. For instance, some areas are less sensitive to acid rain than others because the local geological strata neutralize moderate amounts of the acid. Thus, the marginal damage caused by a unit of acid rain is lower in those fortunate regions than in other less tolerant. It can also be argued that pollutants affecting visibility are more damaging in national parks and other areas where visibility is an important part of the aesthetic experience than in other more industrial areas.

6.3 Market Allocation of Pollution

Since air and water are treated in our legal system as common-property resources, at this point in this book, it should surprise no one that the market misallocates them. Our general conclusion that common-property resources are overexploited certainly applies here. Air and water resources have been overexploited as waste repositories. However,

this conclusion only scratches the surface; much more can be learned about market allocations of pollutions.

When firms create products, rarely does the process of converting the raw material in to outputs use 100% of the mass. Some of the mass, called a residual, is left over. If the residual is valuable, it is simply reused. However, if it is not valuable, the firm has an incentive to deal with it in the cheapest manner possible.

The typical firm has several alternatives. It can control the amount of the residual by using inputs more completely so that less is leftover. It can also produce less output, so that smaller amounts of the residual are generated. Recycling the residual is sometimes a viable option, as is removing the most damaging components of the waste stream and disposing of the rest.

Because damage costs are externalities but controlled costs are not, what is cheapest for the firm is not always cheapest for society as a whole. When pollutants are injected in to water courses or the atmosphere, they cause damages to hose firms and consumers downstream or downwind of the source. These costs are not borne by the emitting sources and hence not considered by it, although they certainly are borne by society at large.¹² As with other services which are systematically undervalued, the disposal of wastes into the air or water becomes inefficiently attractive. Inefficient pollution control choices lead to further inefficiencies in product and input markets.

In the case of stock pollutants, the problem is particularly severe. Uncontrolled markets would lead to an excessive production of X, too few resources committed to pollution control, and an inefficiently large amount of the stock pollutant in the environment. Thus the burden on future generations caused by the presence of this pollutant would be inefficiently large.

There are important differences between the inefficiencies associated with pollution control and the previously discussed inefficiencies associated with the extraction or production of minerals, energy, and food. For private-property resources, the market forces provide automatic signals of impending scarcity. These forces may be understated (as when the vulnerability of imports is ignored), but they operate in the correct direction.

¹² Actually the source certainly considers some of the costs, if only to avoid adverse public relations. The point, however, is that this consideration is likely to be incomplete; the source is unlikely to internalize all of the damage cost.

Even when some resources are treated as free-access common property (fisheries), the possibility for a private-property alternative (fish farming) is enhanced. When private-property and free-access common-property resources sell in the same market, the private-property owner tends to ameliorate the excesses of those who exploit common properties. Efficient firms are rewarded with high profits.

With pollution, no comparable automatic amelioration mechanism is evident.¹³ Because this cost is borne partially by innocent victims rather than producers, it does not find its way into product prices. Firms which attempt unilaterally to control their pollution are placed at a competitive disadvantage; due to the added expense, their costs of production are higher than those of their less conscientious competitors. Not only does the unimpeded market fail to generate the efficient level of pollution control, it penalizes those firms which might attempt to control an efficient amount. Hence, the case for some sort of government intervention is particularly strong for pollution control.

6.4 Efficient Policy Responses

Our use of the efficiency criterion has helped in demonstrating why markets fail to produce an efficient level of pollution control and in tracing out the effects of this less-than-optimal degree of control on the markets for related commodities. It can also be used to define efficient policy responses. Efficiency is achieved when the marginal cost of control is equal to the marginal damage caused by the pollution for each emitter. One way to achieve this equilibrium would be to impose a legal limit on the amount of pollution allowed by each emitter. One way to achieve this equilibrium would be to impose a legal limit on the amount of pollution allowed by each emitter. If the limit were chosen precisely at the level of pollution where marginal control cost equals marginal damage (Q^* in Figure 6.2), efficiency would have been achieved.

An alternative approach would be to internalize the marginal damage caused by each unit of emissions by means of a tax or charge on each unit of emissions. either this per-unit charge could increase with the level of pollution (following the marginal damage curve for each succeeding unit of emission) or the tax rate could be constant as long as the rate

¹³ Affected parties do have an incentive to negotiate among themselves, a topic covered in chapter 4. As pointed at there, however, that approach works well only in cases where the number of affected parties is small.

were equal to the marginal social damage at the point where the marginal social damage and marginal control costs cross (see Figure 6.2). Since the emitter is paying the marginal social damage when confronted by these fees, pollution costs would be internalized. The efficient choice would also be the cost-minimizing choice for the emitter.¹⁴

However, while the efficient levels of these policy instruments can be easily defined in principle, they are very difficult to implement in practice. To implement either of these policy instruments, we must know the level of pollution at which the two marginal cost curves cross for every emitter. That is a tall order, one that imposes unrealistically high information burden on control authorities. Control authorities typically have very poor information on control costs and little reliable information on marginal damage functions. How can environmental authorities allocate pollution control responsibility in a reasonable manner when the information burdens are apparently so unrealistically large? One approach, the choice of several countries including the United States, is to select specific legal levels of pollution based on some other criterion such as providing adequate margins of safety for human or ecological health. Once these thresholds have been established by whatever means, only half of the problem has been resolved. The other half deals with deciding how to allocate the responsibility for meeting predetermined pollution levels among the large numbers of emitters.

This is precisely where the cost-effectiveness criterion comes in. once the objective is stated in terms of meeting the predetermined pollution levels at minimum cost; it is possible to derive the conditions that any cost-effective allocation of the responsibility must satisfy. These conditions can then be used as a basis for choosing among various kinds of policy instruments which impose more reasonable information burdens on control authorities.

6.5 Cost-Effective Policies for Uniformly Mixed Fund Pollutants

6.5.1 Defining A Cost-Effective Allocation

We begin our analysis with uniformly mixed fund pollutants, which analytically are the easier to deal with. The damage caused by these pollutants depends on the amount

¹⁴ Another policy choice is to remove the people from the polluted area. This strategy is often used for heavily contaminated toxic waste sites.

entering the atmosphere. In contrast to non-uniformly mixed pollutants, the damage caused by uniformly mixed pollutants is relatively insensitive to where the emissions are injected into the atmosphere. Thus the policy can focus simply on controlling the total weight of emissions in a manner that minimizes the cost of control. What can we say about the cost-effective allocation of control responsibility for uniformly mixed fund pollutants?

Consider a simple example. Assume that there are two emission sources currently emitting a total 30 units of emissions. Assume further that the control authority determines that the environment can assimilated 15 units, so that a reduction of 15 units is necessary. How should this 15-unit reduction be allocated between the two sources in order to minimize the total cost of the reduction?

With the aid of Figure 6.3 below, we can demonstrate the answer. The figure is drawn by measuring the marginal cost of control for the first source from the left-hand axis (MC_1) and the marginal cost of control for the second source from the right-hand axis (MC_2).

Notice that the total of 15 units reduction is achieved for every point on this graph; each point represents some different combination of reduction by the two sources. Drawn in this manner, the diagram represents all possible allocations of the 15-unit reduction between the two sources. The left-hand axis, for example, represents an allocation of the entire reduction to the second source, while the right-hand axis represents a situation in which the first source bears the entire responsibility. All points in between represent different degrees of shared responsibility. What allocation minimizes the cost of control? In the cost-effective allocation, the first source cleans up 10 units, while the second source cleans up 5 units. The total variable cost of control for this particular assignment of the responsibility for the reduction is represented by area A plus area B. Area A is the cost of control for the first resource; area B the cost of control for the second. Any other allocation would result in a higher total control cost. (Convince yourself that this is true.)

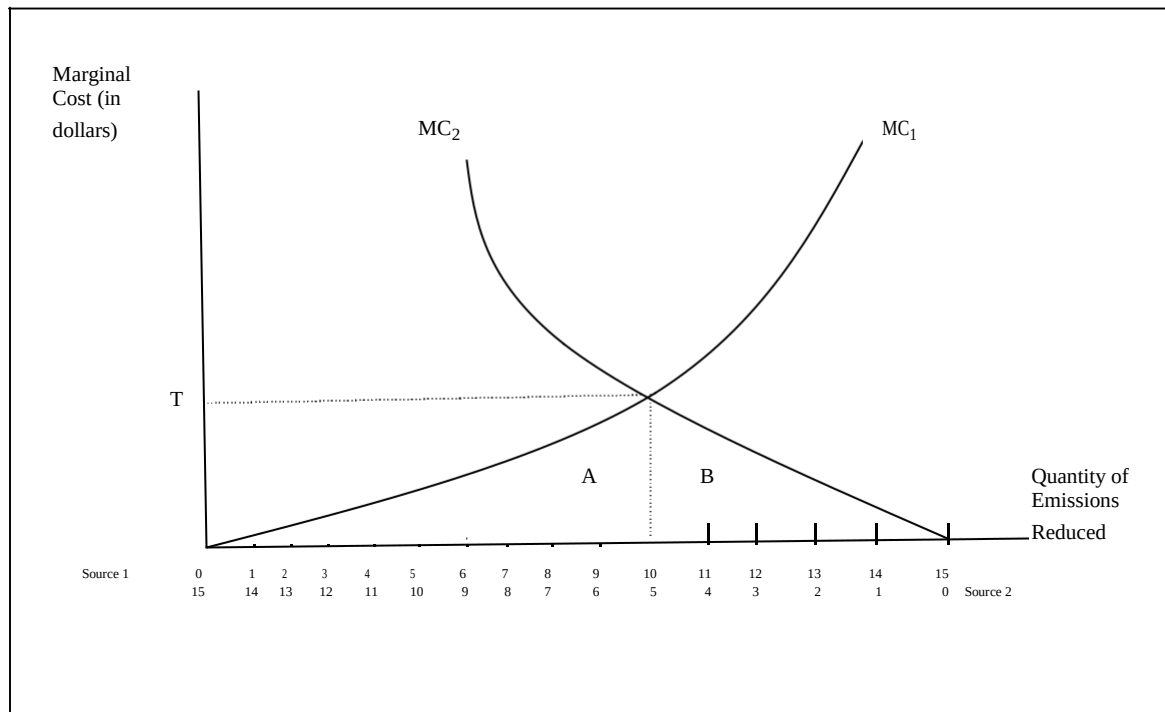
Figure 6.3: Cost-Effective Allocation of A Uniformly Mixed Pollutant

Figure 6.3 also demonstrates the Cost-Effectiveness Equimarginal principal introduced in chapter 3. The cost of achieving a given reduction in emissions will be minimized if and only if the marginal costs of control are equalized for all emitters.¹⁵ This is demonstrated by the fact that the marginal cost curves cross at the cost-effective allocation.

6.5.2 Cost-Effective Pollution Control Policies

This proposition can be used as a basis for choosing among the various policy instruments which the control authority might use to achieve this allocation. Sources have a large menu of options for controlling the amount of pollution they inject in to the environment. The cheapest method of control will differ widely not only among industries but also among plants in the same industry. The selection of the cheapest method requires detailed information on the possible control techniques and their associated costs.

¹⁵ This statement is true when marginal cost increases with the amount of emissions reduced (see Figure 6.3). Suppose that for some pollutants the marginal cost were to decrease with the amount of emissions reduced. What would be the cost-effective allocation in the admittedly unusual situation?

Generally, plant managers are able to acquire this information for their plants when it is in their interest to do so. However, the government authorities responsible for meeting pollution targets are not likely to have this information. Since the degree to which these plants would be regulated depends on cost information, it is unrealistic to expect these plant managers to transfer unbiased information to the government. Plant managers would have a strong incentive to overstate control costs in hopes of reducing their ultimate burden.

This situation poses a difficult dilemma for control authorities. The cost of incorrectly assigning the control responsibility among various polluters is likely to be large. Yet the control authorities do not have the information at their disposal to make a correct allocation. Those who have the information-the plant managers-are not inclined to share it. Can the cost-effective allocation be found? The answer depends on the approach taken by the control authority.

a) Emission Standards

We start our investigation of this question by supposing that the control authority pursues a traditional legal approach by imposing a separate emission standard on each source. In the economics literature this approach is referred to as the “command-and-control” approach. An emission standard is a legal limit on the amount of the pollutant an individual source is allowed to emit. In our example it is clear that the two standards should add up to the allowable 15 units, but it is not clear how, in the absence of information on control costs, these 15 units are to be allocated between the two sources. The easiest method of resolving this dilemma-and the one chosen in the earliest days of pollution control-would be simply to allocate each source and equal reduction. As is clear from Figure 6.3, this strategy would not be cost-effective. While the first source would have lower costs, this cost reduction would be substantially smaller than the increase faced by the second source. Compared to a cost-effective allocation, total costs would increase if both sources were forced to clean up the same amount.

When emission standards are used, there is no reason to believe that the authority will assign the responsibility for emission reduction in a cost-minimizing way. This is probably not surprising. Who would have believed otherwise?

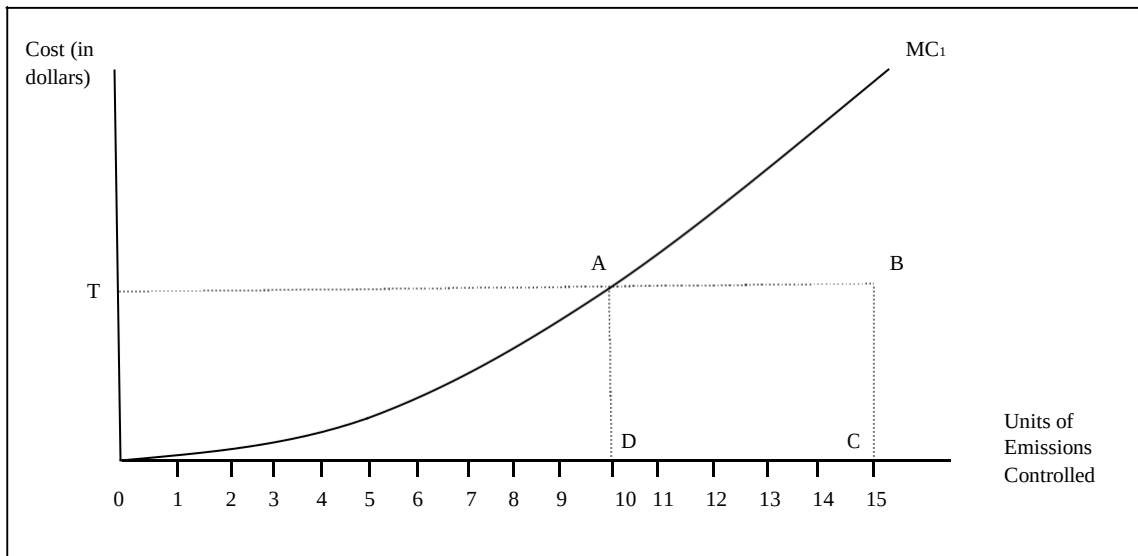
Surprisingly enough, however, some policy instruments do allow the authority to allocate the emission reduction in a cost-effective manner even when it has no information on the magnitude of control costs. These policy approaches rely on economic incentives to produce the desired outcome. The two most common approaches are known as emission charges and transferable emission permits.

b) Emission Charge

An emission charge is a fee, collected by the government, levied on each unit of pollutant emitted into the air or water. The total payment any source would make to the government could be found by multiplying the fee times the amount of pollution emitted. Emission charges reduce pollution because pollution costs the firm money. To save money, the source seeks way to reduce its pollution.

How much pollution control would the firm choose to purchase? A profit-maximizing firm would control, rather than emit, pollution whenever it proved cheaper to do so. We can illustrate the firm's decision with Figure 6.4. The level of uncontrolled emission is 15 units and the emission charge is T . Thus, if the firm were to decide against controlling any emissions, it would have to pay T times 15, represented by area OTBC.

Is this the best the firm can do? Obviously not, since it can control some pollution at a lower cost than paying the emission charge. It would pay the firm to reduce emissions until the marginal cost of reduction is equal to the emission charge. The firm would minimize its cost by choosing to clean up 10 units of pollution and emitting 5 units. At this allocation the firm would pay control costs equal to area OAD and total emission charge payments equal to area ABCD for a total cost of OABC. This is clearly less than OTBC, the amount the firm would pay if it chose not to clean up any pollution.

Figure 6.4: Cost-Minimizing Control of Pollution with an Emission Charge

Let's carry this one step further. Suppose that we levied the same emission charge on both sources discussed in Figure 6.3. Each source would then control its emissions until its marginal control cost equaled the emission charge. (Faced with an emission charge T , the second source would clean up 5 units.) Since they both face the same emission charge, they will independently choose levels of control consistent with equal marginal control costs. This is precisely the condition that yields a cost-minimizing allocation.

This is a remarkable finding. We have shown that as long as the control authority imposes the same emission charge on all sources, the resulting reduction allocation automatically minimizes the costs of control. This is true in spite of the fact that the control authority may not have any knowledge of control costs.

However, we have not yet dealt with the issue of how the appropriate level of the emission charge is determined. Each level of a charge will result in some level of emission reduction. Furthermore, the responsibility for meeting that reduction will be allocated in a manner that minimizes control costs. How high should the charge be set to ensure that the resulting emission reduction is the desired level of emission reduction?

Without knowing the cost of control, the control authority cannot establish the correct tax rate on the first try. It is possible, however, to develop an iterative, trial-and-error process to find the appropriate charge rate. This process is initiated by choosing an arbitrary

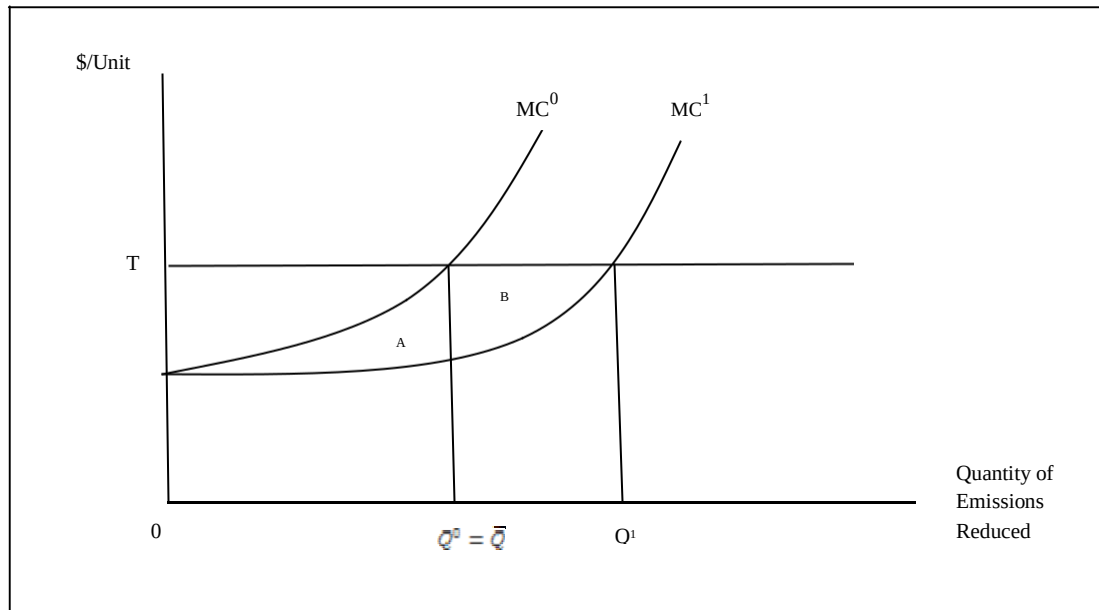
charge rate and observing the amount of reduction that occurs when that charge is imposed. If the observed reduction is larger than desired, it means the charge should be lowered; if the reduction is smaller, the charge should be raised. The new reduction which results from the adjusted charge can then be observed and compared with the desired reduction. Further adjustments in the charge can be made as needed. This process can be repeated until the actual and desired reductions are equal. At that point the correct emission charge would have been found.

The charge system not only causes sources to choose a cost-effective allocation of the control responsibility, it also stimulates the development of newer, cheaper means of controlling emissions, as well as promoting technological progress. This is illustrated in Figure 6.5.

The reason for this is rather straightforward. Control authorities base the emission standards on specific technologies. As new technologies are discovered by the control authority, the standards are tightened. These stricter standards force firms to bear higher costs. Therefore, with emissions standards, firms have an incentive to hide technological changes from the control authority.

With an emissions charge system, the firm saves money by adopting cheaper new technologies. As long as the firm can reduce its pollution at a marginal cost lower than T , it pays to adopt the new technology. In Figure 6.5 the firm saves A and B by adopting the new technology and voluntarily increases its emissions reduction from Q^0 to Q^1 .

With an emission charge, the minimum cost allocation of meeting a predetermined emission reduction can be found by a control authority even when it has no information on control costs. An emission charge also stimulates technological advances in emission reduction. Unfortunately, the process of finding the appropriate rate takes some experimenting. During the trial-and-error period of finding the appropriate rate, sources would be faced with a volatile emission charge. Changing emission charges would make planning for the future difficult. Investments that would make sense under a high emission charge might not make sense when it falls. From either a policy-maker's or business manager's perspective, this process leaves much to be desired.

Figure 6.5: Cost Savings from Technological Change: Charges Versus Standards

c) Transferable Emission Permits

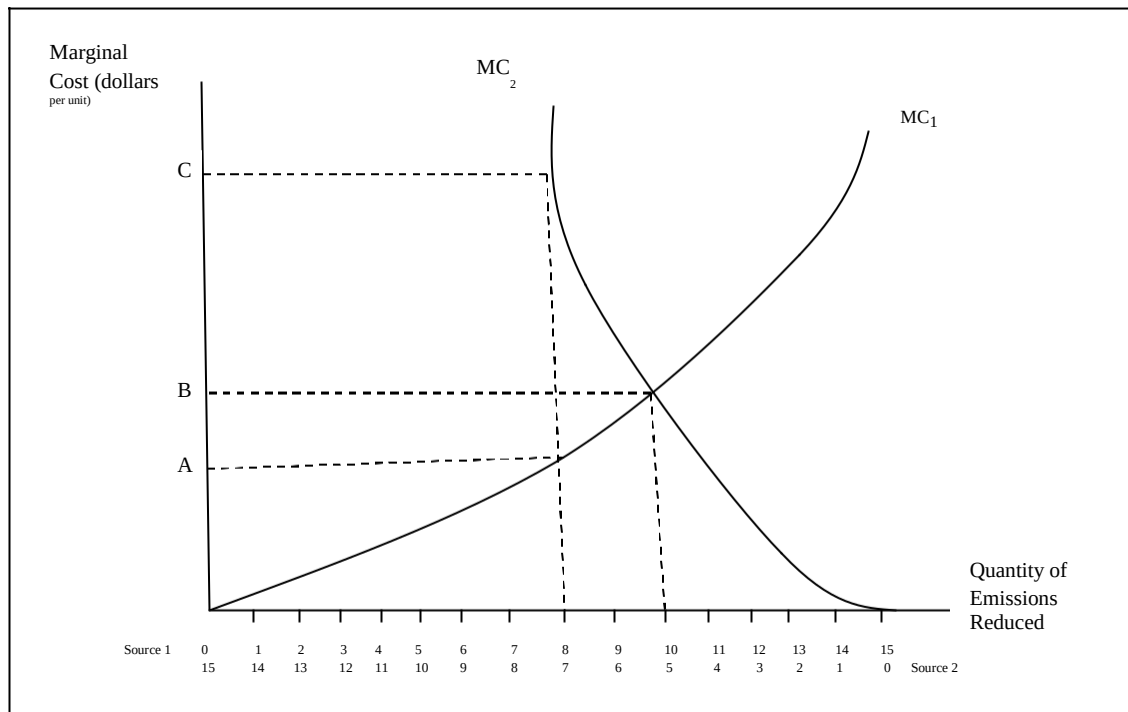
It is possible for the control authority to find the cost-minimizing allocation without going through a trial-and-error process? It is possible if a *transferable emission permit system* is used to control pollution. Under this system, all sources are required to have permits to emit. Each permit specifies exactly how much the firm is allowed to emit. The permits are freely transferable; they can be bought and sold. The control authority issues exactly the number of permits needed to produce the desired emission level. Any emissions by a source in excess of those allowed by its permit would cause the source to face severe monetary sanctions.

Why this system automatically leads to a cost-effective allocation can be seen in Figure 6.6, which treats the same set of circumstances as Figure 6.3. Suppose that somehow the first source found itself with 7 permits. Since it has 15 units of uncontrolled emissions, this would mean it must control 8 units. Similarly, suppose that the second source has the remaining 8 permits, meaning that it would have to clean up 7 units. Notice that both firms have an incentive to trade. The marginal cost of control for the second source (C) is substantially higher than that for the first (A). The second source could lower its cost if it could buy a permit from the first source at a price lower than C. The first source,

meanwhile, would be better off if it could sell a permit for a price higher than A. Since C is greater than A, grounds for trade certainly exist.

A transfer of permits would take place until the first source had only 5 permits left (and is controlling 10 units), while the second source had 10 permits (and was controlling 5 units). At this point, the permit price would equal B, since that is the marginal value of

Figure 6.6: Cost-Effectiveness And The Emission Permit System



the permit to both sources, and neither source would have any incentive to trade further.

The Permit market would be in equilibrium.

Notice that the market equilibrium for an emission-permit system is the cost-effective allocation! Simply by issuing the appropriate number of permits (15) and letting the market to do the rest, the control authority can achieve a cost-effective allocation without having even the slightest knowledge about control costs. This system allows the government to meet its policy objective while allowing greater flexibility in how that objective is met.

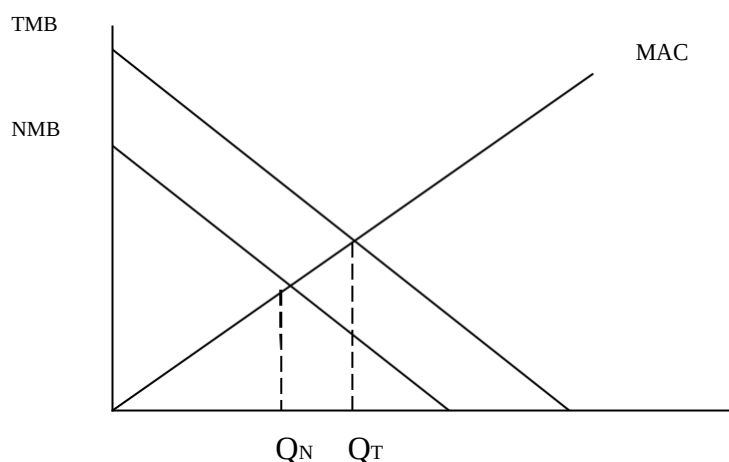
The incentives created by this system ensure that sources use this flexibility to achieve the objective at the lowest possible cost. As we shall see in the next two chapters, this

remarkable property has been responsible for the prominence of this type of approach in current attempts to reform the regulatory process.

6.6 Trans-boundary Environmental Problems And Policy Issues

When we were discussing about environmental policies earlier, we were talking about national environmental policies. There are also international problems that require the concern of few or all countries in the world. These are global warming, depletion of ozone layer, lose of global biodiversity, international waters, acid rain e.t.c. In such kind of problems, the kind of policy a country follows is not the same as we have discussed earlier because there is a question of efficiency that will be created due to the discrepancy of marginal net benefit of pollution reduction nationally and globally.

Figure 6.7: International Efficient Level of Emission Reduction



NMB: National Marginal Benefit of Emission Reduction

TMB: Total (global) Marginal Benefit of Emission Reduction.

The reason for the difference in efficiency of reduction of emission is the NMB for reducing emissions is less than the TMB. As far as the country is concerned, it prefers at a point where $NMB=MAC$, i.e., at Q_N . But, internationally Q_T is the efficient level. Hence, it calls for collaboration and mutual understanding among countries to reach at the internationally efficient level of emission reduction, Q_T .

Summary

In this chapter we developed the conceptual framework needed to evaluate current approaches to pollution control policy. We have seen that there are many different types of pollutants, and different policy approaches are appropriate for each one.

Stock pollutants pose the most serious inter-temporal problems. The efficient production of a commodity that generates a stock pollutant could be expected to decline over time. Eventually, a point would be reached when all of the pollutant would be recycled. After this point the amount of the pollutant in the environment would not increase. The amount already accumulated, however, would continue to cause damage perpetually unless some natural process could reduce the amount of the pollutant over time.

The efficient amount of a fund pollutant was defined as the amount which minimizes the sum of damage and control costs. Using this definition, we were able to derive two propositions of interest: (1) the efficient level of pollution would vary from region to region; and (2) the efficient level of pollution would not generally be zero (especially for less dangerous pollutants since zero pollution means no production and consumption), although in some particular circumstances (such dangerous pollutants as nuclear waste leakage) it might.

Since pollution is a classic externality, markets will generally produce more than the efficient amount of both fund and stock pollutants. For both pollutants this will imply higher than efficient damages and lower than efficient control costs. For stock pollutants an excessive amount of pollution would accumulate in the environment, imposing a detrimental externality on future generations as well as on current generations.

The market would not provide any automatic ameliorating response to the accumulation of pollution as it would in the case of natural resource scarcity. Firms attempting to unilaterally control their pollution are placed at a competitive disadvantage. Hence, the case for some sort of government intervention is particularly strong for pollution control. While policy instrument could in principle be defined to achieve an efficient level of pollution for every emitter, in practice it is very difficult because the amount of information required by the control authorities is unrealistically high.

Cost effectiveness analysis provides a way out of this dilemma. In the case of uniform mixed-fund pollutants, uniform emission charges or an emission-permit system could be used to attain the cost effective allocation even when the control authority has no information whatsoever on either control costs or damage costs. Uniform emission standards would not, except by coincidence, be cost-effective. In addition, either permits or charges would stimulate more technological progress in pollution control than would emission standards.

Some pollutants have an international nature and hence the efforts of individual countries may not be effective. In that regard, the cooperation and mutual understanding among nations to come to the efficient level of emission reductions is vital.

Problems

1. Two firms can control emissions at the following marginal costs: $MC_1 = \$200q_1$, $MC_2 = \$100q_2$, where q_1 and q_2 are, respectively, the amount of emissions reduced by the first and second firms. Assume that with no control at all, each firm would be emitting 20 units of emissions or a total of 40 units for both firms. Compute the cost effective allocation of control responsibility if a total reduction of 21 units of emissions is necessary.
2. Compare and contrast emission standards, emission charges and transferable emission permits as policies for ensuring efficient level of emissions by government.
3. For pollutants having international nature, what do you think should be the specific roles and responsibilities of developing and developed economies to attain the efficient level of emissions reduction?

CHAPTER SEVEN

7 VALUATION OF ENVIRONMENTAL AMENITIES

Course Content:

Dear Students, this chapter focuses on the following three major areas:

Dimensions of Value

Valuation Methods

Environmental Analysis

Objectives

After a thorough reading of this chapter you are expected to

Understand the rationale behind for evaluating environmental amenities synchronizing it with market failure for pricing environmental goods and services.

Identify the different dimensions of value and their respective definitions and contributions in understanding valuation of the environment.

Appreciate the most widely used environmental valuation techniques and their conceptual and methodological similarities and differences.

Be acquainted with major environmental appraisal methods used in the contemporary world.

7.1 Introduction

This chapter is about the ways in which economists attach values to the unpriced services provided by the natural environment. ‘*Environmental Valuation*’ is a very active and rapidly expanding field. It is also somewhat controversial. Many non-economists regard putting prices on environmental services as totally misconceived, if not wicked. While most economists accept the desirability of environmental valuation, there is disagreement over the prospects for actually doing it in a satisfactory way.

The original, and still the principal, motivation for environmental valuation was to enable environmental impacts to be included in cost-benefit analysis. Impacts can be favorable or unfavorable. Taking the latter first, suppose that there is proposed some development – a mine or a tourist resort – in a wilderness area. The argument for valuing the services provided by the wilderness area, which would be reduced, and perhaps totally lost, if the

development goes ahead, is that only then can they be compared with the standard costs and benefits of the project so that a proper decision on it can be made.

7.2 Dimensions of Value

Once we agree that valuation is important, then we have to see the dimensions of values. First, we divide the total economic value (TEV) into $TEV = \text{Use Value (UV)} + \text{Non-Use Value (NUV)}$

Use Value- is the value that we attach for a good because we use it currently or we expect to use it in the future.

Non-Use Value- is the value that we attach to a resource even if we don't use them. $\text{Use Value} = \text{Direct Use Value} + \text{Indirect Use Value} + \text{Option Value}$

As the name indicates, direct use value is a value that arises from direct use of a resource where as indirect use value is a value that you get it indirectly.

Option Value: It is a value you attach to a resource expecting to use it in the future. So, it is attached to future benefits. E.g. National Park: Since you may have a plan to visit in the future, you may oppose the destruction of National park and pay some money for the conservation of it.

Example: Forest

The direct use value of a forest is the money you collect by selling trees. Forests can have other benefits. For instance, they conserve soil. This is an indirect value. Biodiversity can be a type of an indirect value you get from forests. Two Types of Non-Use Value

- i. Bequest Value
- ii. Existence Value

i. Bequest Value

You may want resources to be reserved for future generations and this value is called Bequest value since you are paying for its conservation to the future generations

ii. Existence value

It is a value that people attach because resources exist even if they do not use it. This is mostly found in developed countries. They pay, for instance, for African Elephants so that they are reserved.

In practice, it is a difficult task to calculate the value of resources. The value of a resource you may be calculating is the total value from different perspectives like direct values, indirect values e.t.c.

7.3 Valuation Methods

i) The Contingent Valuation Method (CVM)

The CVM works by directly soliciting (asking) from a sample of consumers their willingness to pay (WTP), or willingness to accept (WTA) for a change in the level of environmental service flows in a carefully structured hypothetical market.

Basically, it is a survey method. You have to prepare a questionnaire to ask respondents the amount of their WTP or WTA. You ask people how much they are willing to pay for a certain resource (state (quality) of environmental change). And, if the question is WTA, you ask how much compensation the respondent accept for a certain project to be established in her/his plot. In WTP, we take the maximum value and in WTA the minimum value of the sample.

Contingent valuation method (CVM) is a questionnaire based valuation technique whereby willingness to pay (WTP) or willingness to accept (WTA) are directly obtained from the respondents with respect to a specific good. As such the technique is applicable in all circumstances. CVM has mainly been used with respect to non-marketed goods and in particular for environmental goods/ resources. In this context a hypothetical market for a non-marketed good is defined and the respondent is requested to specify their WTP's (or WTA's). In the following we will focus on CVM in relation to eliciting monetary values for environmental goods rather than non-marketed goods in general. For example, a CVM study could examine the ex-ante value obtained from a project reducing air pollution for a specific area; the respondents in such a study would be asked how much they would be willing to pay for the reduction in air pollution.

A CVM study involves interviews with the participants which can be undertaken as face-to-face, mail or telephone based. The typical CVM study starts with informing the

participants about the environmental resource in focus (e.g. air quality) along with information about the proposed change in the environmental resource and the procedure to be used to finance the proposed change in the environmental resource. This information is provided in order to familiarize the respondents about the change to be evaluated such that the possibility for valid and reliable answers is enhanced. On the basis of this information the respondents are asked about willingness to pay. Usually, a series of follow-up questions are included in order to confirm the given WTP (or WTA) as well as provision of socioeconomic background information (gender, age, employment, income). This background information can be utilized to examine their relationship to WTP, e.g. the extent to which willingness to pay depends on income could be tested.

The question concerning the willingness to pay can be structured in different ways, where the main forms include:-

- open ended;
- dichotomous choice;
- bidding games;
- payment card based forms.

Open ended based WTP would be formulated as what is the maximum you would be willing to pay for [the specified change in the environmental good]? . Dichotomous choice formats involve two questions, where the first one concerns whether or not there is a willingness to pay for a specified change in the environmental good. This question should be answered with a yes or no, if yes then a question is asked concerning whether the WTP is equal to a specified amount. For bidding games the participants are asked whether they are willing to pay a specified amount. If yes, then another question is asked about willingness to pay a specified amount higher than the previous amount. This process continues until a no answer is obtained. Participants in payment card based forms of CVM are shown a card on which a range of payments is illustrated. The participants should then identify the payment on the card which corresponds to their willingness to pay. Obviously, other methods exist which can be used to elicit WTP, e.g. as combination of the above discussed main forms.

The CVM is extremely flexible and can be used to value most any environmental asset. Further, CVM and other non-market methods are required accurately to capture non-use values. This is a significant point in a world comprised of ecosystems under great stress from human impacts, where increasing attention is being given to non-use values. For example, the Warrawong Earth Sanctuary in southern Australia has been purchasing and restoring swamps in southern Australia for as little as 40 cents an acre. This large land mass is today referred to as the "Little Jurassic Park," because it supports a wide range of plant and animal species. Each year, tens of thousands of visitors pass through the sanctuary. The question faced by social scientists, which can be somewhat addressed through non-market environmental valuation methods, is how to place a value on such an environmental resource (Arrow and others, 1993).

The primary disadvantage of CVM is that it may not yield accurate results due to biases that may be introduced in the survey or through respondents' behavior. These biases include *strategic bias*, where the respondent's belief that his answers may be used to affect government policy leads him to intentionally understate or overstate his willingness to pay to achieve the desired policy result. The payment vehicle cited in the questionnaire may also result in bias due to an aversion to certain taxes or fees. The availability of information or misperceptions concerning environmental quality can also result in bias. To minimize bias, analysts must be extremely careful in how they design surveys and conduct interviews. An extensive body of economic literature addresses the sources of inaccuracy in CV studies and the development of methods to deal with specific issues of survey design and implementation. A primary source of information is the *Report of the NOAA Panel on Contingent Valuation*, a document detailing the findings of a blue ribbon panel convened by the National Oceanic and Atmospheric Administration (NOAA), and chaired by two Nobel Laureates, which examined the drawbacks to CVM, investigated key issues surrounding the design of CV surveys, and presents guidelines for completing CV studies (Arrow and others, 1993).

Contingent valuation studies are focused on valuing specific changes in environmental conditions, such as those related to a coastal restoration project. Thus, individuals who are surveyed in CV studies are typically presented with a specific program or action and asked to value it in its entirety.

ii) The Hedonic Pricing Method (HPM)

The **hedonic pricing method** of environmental valuation uses surrogate markets for placing a value on environmental quality. The real estate market is the most commonly used surrogate in hedonic pricing of environmental values. Air, water, and noise pollution have a direct impact on property values. By comparing properties with otherwise similar characteristics or by examining the price of a property over time as environmental conditions change and correcting for all non-environmental factors, information in the housing market can be used to estimate people's willingness to pay for environmental quality.

HPM seeks to find a relationship between the levels of environmental services and the prices of marketed goods.

Price of house = $f(\text{structural characteristics of a house, neighbor characteristics, environmental quality, e.t.c.})$

Where, structural characteristics include number of rooms, existence of bathrooms, e.t.c; and neighborhood characteristics comprises of features such as the existence of clinic near to it, police station, school e.t.c.

Using such relationship you can come up with the indirect measurement for the benefit of improvements in environmental quality.

Other beings constant, in a city the price of house in a polluted and non-polluted area is different. So, if this is the case you can come up with the benefit of improvement in environmental quality (Q).

So, you compute $\frac{P}{Q}$ to get the change in the price of house because of environmental quality.

The contingent method is conducted in many developing countries like Ethiopia. But, the hedonic pricing method typically employed in developed countries because of lack of data but it is employed in few developing countries.

iii) The Travel Cost Method

The **travel cost** method is employed to measure the value of a recreational site by surveying travelers on the economic costs they incur (e.g., time and out-of-pocket travel

expenses) when visiting the site from some distance away. These expenditures are considered an indicator of society's willingness to pay for access to the recreational benefits provided by the site.

To better understand the travel cost method, consider the case of coastal pollution resulting in closure of a recreational beach. To estimate the associated lost value of recreational benefits, the first step of a travel cost analysis would be to survey individuals about the number of trips and expenses incurred during each trip to the beach. The second step is to examine the relationship between the expense incurred and the total number of trips taken (Table 7.1). Thus, the travel cost method enables the analyst to develop an implicit demand curve for the recreational benefits offered by the site per person, which can then be multiplied by the number of people in each cost category (generally judged by estimating costs associated with various distances from the site). In turn, the demand curve can be used to measure consumer surplus and monetize the direct, use value of the site.

Table 7.1 Trip Expense and Number of Trips to a Recreation Beach

Trip Expense	Number of Trips
<\$20	100
\$20-\$40	45
\$40-\$60	32
\$60-\$80	17
\$80-\$100	9
>\$100	4

(Source: Arrow and others, 1993)

The travel cost method can be used to measure not only the elimination of a site but also the impact of access restrictions and changes in environmental quality. The travel cost method, however, is limited in application and captures only direct recreational benefits and only when there are measurable travel costs to examine. Finally, the travel cost

method does not measure non-use and intrinsic values or other sources of value, such as commercial values.

It is typically used to estimate the values of sites typically used estimate the values of sites typically national parks. In this method, the costs consuming the services of the environmental asset are used as a proxy for price; that is why it is called the travel cost method. It is also a method based on survey (you prepare a questionnaire for tourists who visit the area and relate it to the different characteristics of tourists). So, the method is to relate the site of the place and the cost of travel.

Number of visits a person make to a certain site = $f(\text{travel cost of the site})$ i.e. $\text{Visits} = f(\text{travel cost})$

iv) The Production Function Approach

As the name indicates, this method uses estimation of production function to calculate the estimates of values of agricultural products.

$Y = f(L, K, \text{soil fertility e.t.c.})$

It helps to see by how much output changes to a change in the factors. Example: Soil fertility reduction.

If we represent soil fertility by Q , then the measure of MP is $\frac{y}{Q}$ is the change in output due to a change in soil fertility.

We can also consider other factors e.g. water availability.

$P_y \frac{Y}{Q}$ gives you the value of output you lost because of the change in environmental quality.

The production function can be broadened to include other factors like air quality on the health of people e.t.c in addition to agricultural and industrial output factors.

7.4 Environment Analysis

Investment is a vehicle for economic growth. Because of this, governments always strive to attract investors to put in money in their land. However, investments have either positive/negative effects on the environment. Hence, policy-makers have to consider the tradeoffs between economic growth and the environment in their decision for project

appraisal. In the mainstream economics in general and in environmental economics in particular, we do have three methods to do environmental analysis.

i) **Cost-Benefit Analysis**

By ‘*cost-benefit analysis*’ we mean the social appraisal of investment projects. Here, ‘*social*’ signifies that the appraisal is being conducted according to criteria derived from welfare economics, rather than according to commercial criteria. Cost-benefit analysis, that is, attempts to appraise investment projects in ways that correct for market failure. If there were no market failure, social and commercial criteria would coincide. An ‘investment projects’ is something that involves a current commitment with consequences stretching over future time. It need not, that is, be an ‘investment’ in the sense of the accumulation of capital, though, of course, it may be and frequently is. As generally used, the term ‘cost-benefit analysis’ would also embrace, for example, the appraisal of the adoption now of a government policy intended to have future effects.

Cost-benefit analysis relates to the environment in two main ways. First, many projects intended to yield benefits in the form of the provision of goods and services have environmental impacts – consider damming a river in a wilderness area to generate electricity. To the extent that such impacts are externalities there is market failure and they do not show up in private, commercial, appraisals. The costs of such projects are understated in ordinary financial appraisals. Second, there are projects the main purpose of which is to have beneficial environmental impacts – consider the construction of a sewage treatment plant. Here also the impacts typically involve external effects, and so would not appear in an ordinary financial appraisal.

In all cases, the basic strategy of cost-benefit analysis is the same. It is to attach monetary values to the environmental impacts, desired and undesired, so that they are considered along with, and in the same way as, the ordinary inputs (labor, capital, raw materials) to and outputs (goods and/or services) from the project. Algebraically, cost-benefit analysis is calculated as

$$NPV = \sum_{t=0}^T \frac{NB_t}{(1+r)^t} - \sum_{t=0}^T \frac{C_t}{(1+r)^t}$$

Where, NB_t = is net benefit of the project at time t

B_t = is benefit of the project at time t

C_t = is cost of the project at time t

and that the project should go ahead if $NPV > 0$.

The relevance of this analysis for environmental economics is if, for instance, you have a certain project, it makes sense to maximize NPV but projects often do the analysis without considering environmental factors (benefit or cost to the environment). E.g. If a factory pollutes the environment then this cost has to be added to cost of the project. So, this is the relevance of cost-benefit analysis to environmental economics issues i.e. you can incorporate environmental issues in it.

- ii) **Cost Effectiveness Analysis:** It is difficult to measure benefits so the option is to measure only costs and try to select the one with less cost. In short, cost minimization when you don't have to (difficult to) compute benefits.

What can be done to guide policy when the requisite valuation for benefit-cost analysis is either unavailable or not sufficiently reliable? Without a good measure of benefits, making an efficient choice is no longer possible.

In such cases it frequently is possible, however, to set a policy target on some other basis other than a strict comparison of benefits and costs. One example is pollution control. What level of pollution should be established as the maximum acceptable level? In many countries, studies of the effects of a particular pollutant on human health have been used as the basis for establishing that pollutant's maximum acceptable concentration. Researchers attempt to find a threshold level below which no damage seems to occur. That threshold is then further lowered to provide a margin of safety and that becomes the pollution target.

Cost-effectiveness analysis frequently involves an optimization procedure. An optimization procedure, in this context, is merely a systematic method for finding the lowest cost means of accomplishing the objective. This procedure does not, in general, produce an efficient allocation because the predetermined objective may not be efficient. All efficient policies are cost-effective, but not all cost-effective policies are efficient.

In our pollution control example, cost-effectiveness can be used to find the least cost means of meeting a particular standard and its associated cost. Using this cost as a bench mark, we can estimate how much costs could be expected to increase from this minimum level if policies which are not cost-effective are implemented.

iii) Environmental Impact Assessment/Analysis (EIA)

What can be done when the information needed to perform a benefit-cost analysis or a cost-effectiveness analysis is not available? The analytical technique designed to deal with this problem is called environmental impact analysis. An environmental impact analysis attempts to quantify the consequences of various actions on the environment.

In contrast to cost-benefit analysis, EIA makes no attempt to convert all these consequences into a one-dimensional measure, such as dollars, to ensure comparability. In contrast to cost-effectiveness analysis, environmental impact analysis does not necessarily attempt to optimize. Environmental impact analysis places a large amount of relatively undigested information at the disposal of the policy maker. It is up to the policy-maker to assess the importance of the various consequences on the environment and act accordingly. Hence, policy makers evaluate the different impacts of a project on the environment.

Example: A project to cut trees- the impact may increase soil degradation. This analysis is inter-disciplinary; it has to be done by different disciplines. This needs a lot of scientific information and it is done by natural scientists.

Summary

Valuation of environmental amenities is a prerequisite for the optimal depletion of resources. Since market fails in pricing the precious asset, the environment, using the usual market mechanisms of demand and supply interactions, it is vital for economists to seek alternative ways of valuing environmental goods and services to keep it from human beings' massive destructions. Thus, in this chapter, you have come across some of the techniques used for such purposes and it is left for you to make contrasts and comparisons among these methods; and especially appreciate the applications of each method to value distinct environmental goods and services.

Besides, it is the aim of this chapter to make students to consider project appraisal techniques they have seen in some other courses and evaluate their limitations especially in incorporating environmental amenities in their computations.

Problems

1. The contingent valuation Method (CVM) is a popular valuation method especially in developing countries. How does the CVM work to elicit the valuation of environmental amenities, which has been literally ignored by the market system? Provide your own instance of a CVM scenario.
2. Evaluate the three types of environmental analysis techniques based on their applicability to different types of projects and their limitations.
3. Suppose we have house A near the airport and another house B far from the airport.
 - (a) Which one the two houses should have higher valuation (price) keeping all other features of the house constant?
 - (b) Which type of valuation technique is applicable for this particular example?

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ARBA MINCH UNIVERSITY FACULTY OF BUSINESS AND ECONOMICS
DEPARTMENT OF ECONOMICS

A Worksheet on Natural Resource and Environmental Economics
[Econ-351] for Distance Learners

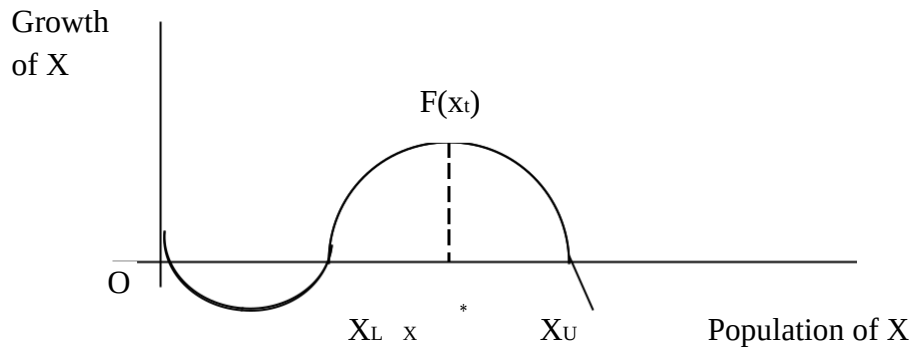
Instructions:

1. Write your name, ID No. and section on each page of the work book.
2. Attempt all the questions.
3. Neatness and Clarity have their own rewards.

Part I: Answer each of the questions accordingly.

1. _____ measure the amount of a particular good people would be willing to purchase at various prices.
A. Cost curves B. Supply curves C. Demand curves D. Marginal Revenue curves E. None
2. One of the following is not true
A. In economics, all benefits and cost are valued only in terms of their effect on humanity.
B. For each quantity purchased, the corresponding point on the market demand curve represents the amount of money some person is willing to pay for the last unit of the good.
C. In purely competitive markets, the opportunity cost curve is identical to the supply curve.
D. Dynamic efficiency is the maximization of net benefits overtime.
E. None
4. Which of the following is not true about renewable resources
A. It should exhibit economically significant rates of regeneration
B. Their rate of regeneration should be seen in short period of time.
C. Natural replenishment augments the flow of renewable resources at a negligible rate.
D. None
5. One is different from the other
A. Loss of Biodiversity B. Acid rain C. Global warming D. Non-biodegradable bottles E. None
7. All except one affect the depletion rate of non-renewable resources A. Recycling B. Durability C. Demand D. None
8. What do we mean by 'computability' as a criterion for an ideal scarcity indicator?
A. The indicator should enable us to see the balance of the resource.
B. The indicator should enable us to see the seriousness of the resource
C. The indicator should enable us to compare availability of resource with its Substitute
D. All

Question 9-12 are based on the graph below:



9. In the above graph, X_U is a point where
 - A. The growth rate of population X is maximum
 - B. There is stable equilibrium in the presence of human action
 - C. There is maximum sustainable yield
 - D. A and B
 - E. None
10. In the above graph, the growth rate of population x is negative
 - A. Between 0 and X_L inclusive
 - B. Between X_L and X_U inclusive
 - C. For the population of $X > X_L$
 - D. A&C
 - E. Only C
 - F. None
11. Point X_L in the above diagram is
 - A. The minimum viable population
 - B. A point where growth rate is zero
 - C. An unstable equilibrium
 - D. B and C
 - E. None
12. The graph for the growth rate of Population is
 - A. Strictly concave
 - B. Strictly convex
 - C. Initially convex and then concave
 - D. Initially concave and then convex
13. Which of the following properties do satisfy the Marginal Damage Cost curve of nuclear radiation?
 - A. The curve is a flatter one
 - B. The slope of the curve is a large number
 - C. The slope of the curve is a small number
 - D. The curve is a steeper one
 - E. B&C
 - F. B&D
14. Government levies tax for pollution reduction at a point where
 - A. The $MDC = MAC$
 - B. The $MAC_1 = MAC_2$, for two firms
 - C. $MDC=0$
 - D. $MAC=0$
15. All except one is true
 - A. The efficient level of emission reduction is lower for a nation than the globe
 - B. Environment performance bond has its own advantage for promoting investment
 - C. Governments allocate emission reduction among industries based on their Marginal Damage Costs
 - D. A & C
 - E. B and C

Part II: Fill in the Blank Spaces

16. _____ is the concept that allows a way to compare the net benefit received in one period with the net benefit received in another period.
17. _____ is a criterion for an ideal scarcity indicator that enables us to see the balance of the resource.
18. _____ measures the opportunity of producing an extra unit of the resource against the future generation.
19. _____ is a policy which government requires firms to pay some money as a form of environmental cost (collateral) and it will be returned back to the firm if the project does not cause any environmental degradation.
20. _____ is a method that seeks to find a relationship between the levels of environmental services and the prices of marketed goods.

Part III: Essay Type

1. One of the policy instruments in which government employs for pollution reduction is emission charge.
 - A. What is the base for government to determine the level of emission charges?
 - B. Briefly discuss the limitation of emission charges.
 - C. Elaborate on how governments do to eliminate this problem.
2. Suppose you are given that Aluminium has a constant marginal cost of extraction (MEC) over time. And, after five years of continuous extraction, there happened a transfer to another depletable resource with a constant but a higher MEC.
 - A. Draw the Marginal cost profile of the resource utilization and transfer Path of the resources.
 - B. Do you think that there is a difference in the steepness of Marginal cost curves of the two resources? If yes, reason out?
 - C. Is the transfer continuous or is there a jump?
 - D. Do you think the Aluminium reserve would exhaust at the time of transfer? Justify your response.
3. Discuss clearly about Contingent Valuation Method (CVM). Give one instance of yours where CVM is applicable.
4. Graphically depict the optimal depletion of a Fishery from the point of view of Biologists and Economists. Explain the points that make the two views distinct one from another by defining the major features in each model.
5. (a) Define non-renewable resources by specifying their identifying characteristics.
(b) What are the main factors influencing the rate of depletion of non-renewable resources?
(c) What differentiates the optimal depletion of non-renewable resources from renewable resources?