Microeconomics and the Environment

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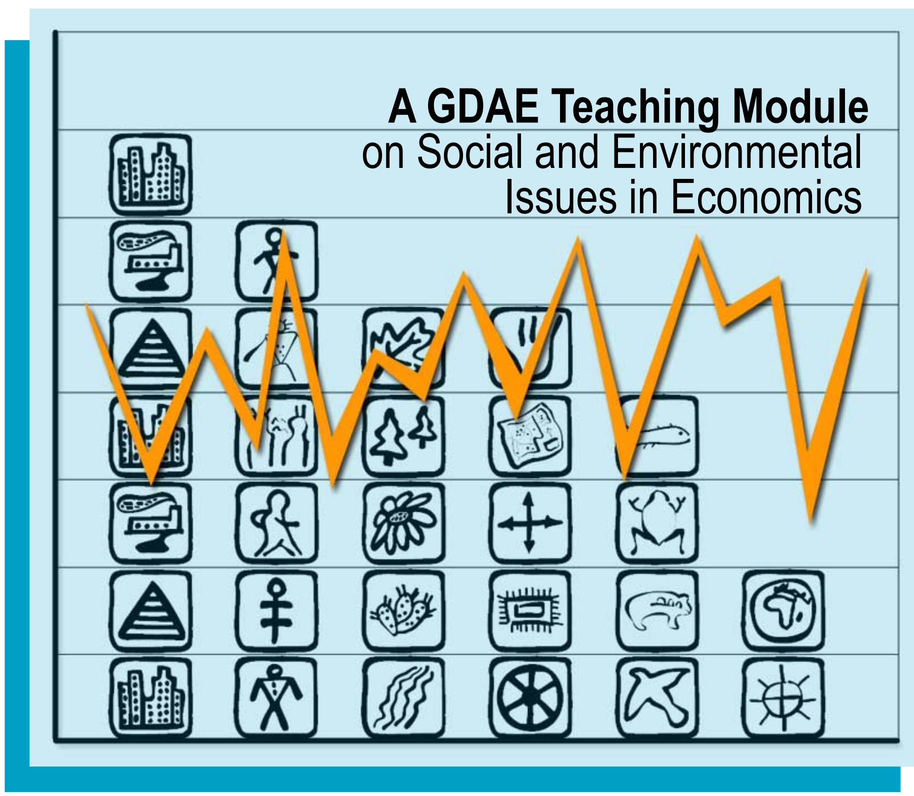

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1. THEORETICAL PERSPECTIVES ON THE ENVIRONMENT

The Two Paradigms of Economics and Ecology

There are many controversies over environmental issues. Should oil drilling be permitted in important wildlife habitat? Should air pollution regulations be tightened? Should we reduce our society's dependence on fossil fuels to prevent global climate change?

There are different approaches to addressing these important issues. The approach you consider appropriate depends on which **paradigm** you subscribe to. A paradigm is a vision of the world that corresponds to a certain set of values and principles. When dealing with the environment, two major paradigms exist:

- the **ecological paradigm,** based on the science of **ecology**, stresses the health and survival of **ecosystems**.
- the **economic paradigm** relies on **environmental economics** – the application of economic theory to environmental issues – and emphasizes maximizing the welfare of humans, even if this means harming the environment.

In some cases these two perspectives seem incompatible. But in other cases it may be possible to combine insights from the two different viewpoints. The field of **ecological economics** has emerged out of efforts to resolve the differences between the two paradigms. There may be bridges that can be built so that economics and ecology may have a constructive dialogue, leading to new insights on environmental issues and policies.

Ecosystems and economic systems

Ecosystems are natural systems composed of a diverse and complex set of plant and animal species in interaction with each other, as well as with physical systems including soils, minerals, fresh and salt water environments, and the atmosphere. Most natural systems are characterized by cycles, such as the water cycle, carbon cycle, nitrogen cycle, and others. It is through these cycles that natural systems maintain themselves over long periods of time.

Scales of ecosystems can vary from local to regional to global. A regional ecosystem like the ecosystem of the Rocky Mountains is a system of local ecosystems including valleys, plateaus, streams, and high altitude mountaintops. The **biosphere** as a whole represents the global ecosystem of planet Earth, regulating all the biological and geochemical cycles at the global scale.

Environmentalists, who advocate the vision embodied in the ecological paradigm, are interested in keeping in equilibrium the innumerable cycles of renewal, regeneration and reproduction that characterize all ecosystems. In this perspective, a crucial factor is the **resilience** of ecosystems -- their ability to return to equilibrium after having experienced shocks and disturbances.

Beyond a certain threshold of ecological irreversibility, the damage done to the regenerative functions of the ecosystem can be so great that the ecosystem may never recover from it. For example, rainforest ecosystems, which are extremely complex and host a great variety of species, are threatened by human activities including burning, logging, and clearing for agriculture. These activities can irreversibly destroy rainforest ecosystems, sometimes leaving the soil so depleted that it can support neither forest nor agriculture.

Economic values and environmental values

From the ecological perspective, a major goal is to make sure that ecosystems remain in a resilient state and do not suffer irreversible damage to their regenerative functions. The goal of environmental policy, in this view, should be maintaining the **sustainability** of ecosystems.

Economists, on the other hand, are concerned with the environment in so far as it affects the wellbeing of human societies. Whereas environmentalists are concerned about natural systems, economists are primarily interested in natural resources or natural services -- elements of physical and biological systems, which can be used for human benefit.

In this utilitarian perspective, the environment is taken into consideration only to the extent that it is useful to humans[1]. Standard economic analysis does not consider the environment to have an **intrinsic value**, a value in itself. In contrast, the ecological paradigm suggests that natural systems need to be protected for their own sake, independently of their use value to humans.

The economic paradigm focuses on the **efficiency** of the use of natural resources in the production process, as a measure of how well natural resources are used to satisfy human needs. The ecological paradigm places value on the long-term sustainability of natural systems. These different criteria imply different goals for economic activity. We will look first at the economic perspective, then compare it to the broader ecological view of a number of environmental issues.

Economic Analysis of the Environment

Economists have given increased attention to environmental issues during recent years, as it has become apparent that increased pollution and ecological degradation creates significant costs for human societies.

In economic theory, environmental issues are separated into two main categories:

1. The generation of wastes and pollutants as unwanted by-products of human activities
2. The management of natural resources, including **renewable** and **nonrenewable** resources.

[1] The utilitarian perspective, originated by Jeremy Bentham in the nineteenth century, is the source of the important concept of utility in economics. Economists use this concept to explain the value of goods and services or of resources. From this perspective, only things that are useful to humans can have utility, and therefore value.

When it comes to wastes and pollution, the key issue is how much should be permitted. Are current pollution levels too high … or too low? Ideally, we would all like pollution levels to be as low as possible, or eliminate pollution altogether. But in most cases, we have to consider the tradeoffs associated with lowering pollution levels. Economic analysis provides us with important insights on the "optimal" levels of pollution and the policies that can be instituted to reach these levels.

For natural resources, we need to determine which resources to use for different tasks. For example, to generate electricity should we rely on coal, natural gas, wind, or solar power? Fossil fuels are a non-renewable resource – how much should we use and how much should we leave for future generations? Again, economic analysis provides techniques which can help society answer these important questions.

Externalities and the "social optimum"

The concept of **externalities** is central to environmental economics. In economic terms, there is an externality when an activity creates spillovers on people who are not directly involved in the activity. For example, a firm which pollutes a river creates involuntary costs (a **negative externality**) for people who use the river for fishing, swimming, or for drinking water. Some of these costs might be measured in money terms – for example, the lost revenues of professional fishers. Some might be more difficult to measure but no less important – for example, health costs caused by toxins in the water or loss of enjoyment by those who can no longer swim in the polluted water.

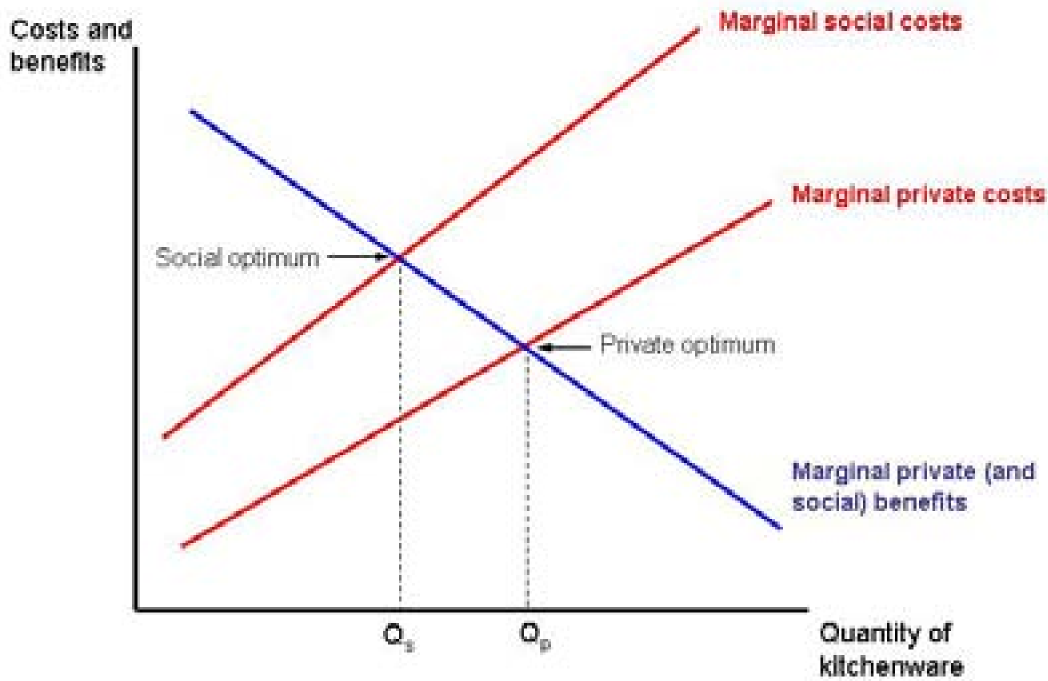
Some economic activities may bring benefits to people other than those involved in the activity. hese third parties benefit from what economists call **positive externalities**. An example of a positive externality is the case of bee-keeping. A honey-farmer raises bees for his own benefit – in order to sell the honey they produce. This is a private activity with private benefits and costs. However, bees contribute to the pollenization of flowers in the gardens and orchards of other people, who benefit freely from this positive externality. The owners of these gardens, harvesting flowers and fruits, receive an external benefit from the fact that their neighbor is a honey-farmer.

In the presence of negative or positive externailities, unregulated private markets will fail to produce the optimal allocation of resources. We now consider the implications of negative and positive externalities in more detail.

The case of a negative externality

Figure 1 analyzes the case of an activity that creates a negative externality. Let's take the example of water pollution caused by a factory producing plastic kitchenware. The private costs are the firm's costs of production. The private benefits go to consumers of the firm's products, and to the producers as income[2]. The private optimum occurs when **marginal private costs** equal **marginal private benefits**, at a quantity produced and consumed equal to Q_p.

Figure 1: The Private Optimum and the Social Optimum with a Negative Externality



Under competitive conditions, the marginal private cost curve will be the **supply curve** and the marginal private benefit curve will be the **demand curve**. Thus in a market economy, under the conditions of perfect competition the **private optimum** will occur at the natural market equilibrium, balancing the costs of production with the benefits of consumption

In this example, however, there are other costs that are not included in the marginal private cost curve. There may be professional fishers downstream who are suffering financial losses due to water pollution. There are also losses to other people. Perhaps there used to be a beach downstream on the river with an ice cream shop that had to close because nobody is going swimming there anymore. People who used to use the beach are unhappy, and the owners of the shop have lost their incomes. If we can find a way of adding all these external costs to the private costs of production, we will have a measure of **marginal social costs**.

The **social optimum** is reached when marginal social costs equal **marginal social benefits**. Since there are no external social benefits in this example, total benefits are accurately

[2] In economic terminology, these benefits are referred to as **consumer surplus** and **producer surplus**.

captured by the marginal private benefit curve. In other words, the marginal private benefit curve is also the marginal social benefit curve. The intersection of marginal social costs and marginal private benefits gives us the **social optimum** at quantity Q_s, which is a lower level of production than the market equilibrium Q_p.

Let's consider this concept of the social optimum. Note that it represents a level of output at which there will be less pollution than the private optimum – but not zero pollution. In effect, it represents a compromise between society's desire for goods -- in this case plastic kitchenware – and society's desire for clean water. From the economist's point of view, a tradeoff exists between goods output and an unpolluted environment.

It will rarely be possible to produce goods with absolutely no pollution. Therefore we must decide how much pollution to tolerate if we wish to have the benefits of goods production. In doing so, we must in some way measure or estimate the social costs of pollution to balance against the social benefits of goods production.

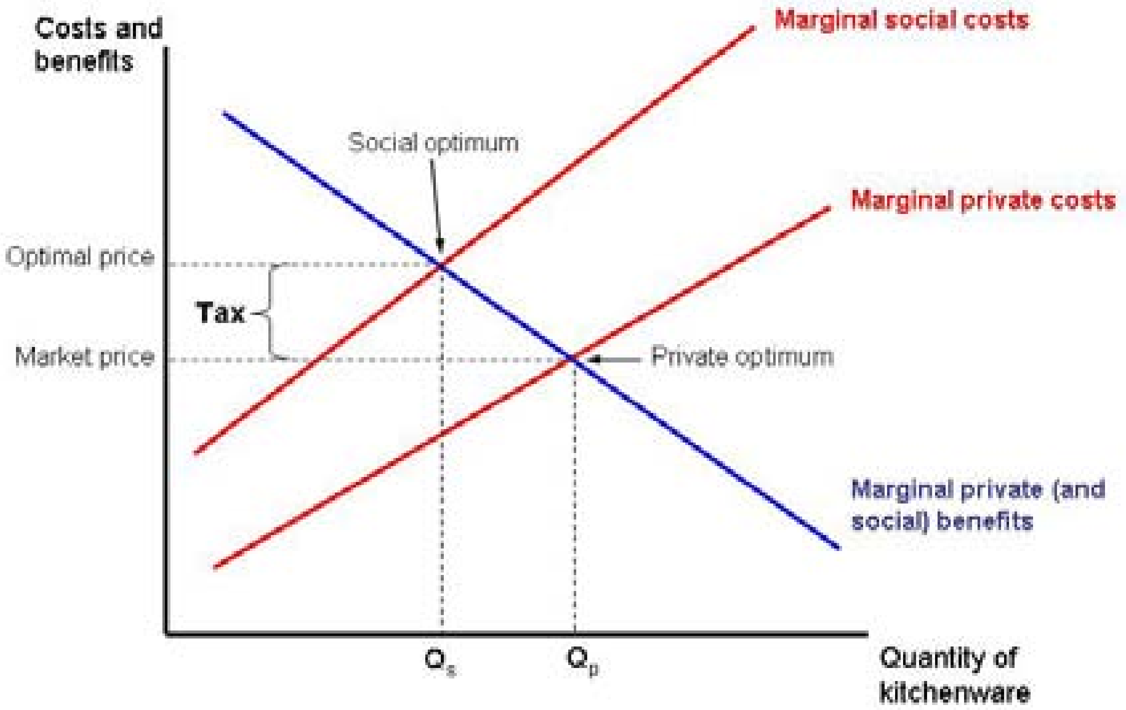
Economic policies to deal with externalities: a pollution tax

The existence of externalities illustrate a case of **market failure**. Market failure occurs when the market process leads to a solution which is not socially optimal – and perhaps very far from optimal. In serious cases of pollution, for example when children's developing brains are damaged by lead poisoning from uncontrolled industrial emissions, it is clear that some policy is urgently needed to correct the market result. The solution which economic theory offers to bridge the gap between the private optimum and the social optimum is to "internalize" the externalities.

Suppose that a tax is imposed on the polluting firm in our example, based on the amount of pollution it emits. The social cost of pollution now becomes a private cost – a dollar amount that the firm will have to pay for each unit of pollution. The object of this tax is not just to penalize the firm. It is to send an economic message: firms that create less pollution will pay less tax. This creates an incentive for the firm to control its pollution.

Figure 2 shows how such a **pollution tax** works in the market. It creates a new market equilibrium at which less of the polluting good is produced. At the same time, it raises the market price of the good. The external cost is thus internalized by making both buyers and sellers aware of the cost to third parties of creating pollution. Consumers will tend to buy less of the pollution-creating good (because it costs more) and producers will tend to produce less of it (because including the tax it is now less profitable).

Figure 2: The Impact of a Pollution Tax



Of course, it may be possible to find ways to produce kitchenware that involve less pollution. Types of kitchenware that can be produced with less pollution will be taxed less heavily, encouraging both producers and consumers to favor them. In that case the social optimum will be achieved not by cutting back production, but by shifting to different kinds of production. The tax provides the necessary incentive for this socially beneficial economic shift.

The British economist Arthur Pigou was the first economist to propose this solution in order to "internalize" the total costs of an activity into the market. A tax of this type is therefore sometimes referred to as a **Pigovian tax**. From a theoretical point of view, the Pigovian tax is a fine solution to the problem of externalities. There is just one problem – how do we know how much the tax should be?

In our example, the tax should reflect the true social costs of water pollution. But these costs can be complex. Some costs might be relatively easily to measure – for example, the lost revenues of commercial fisheries. But how about health costs? Recreational costs? And how about another type of costs which we have not mentioned – the **ecological costs** of damage to non-commercial fish and other species in the river? If we are not sure that we know the dollar value of these costs, we cannot be confident that the tax policy will really lead to a socially optimal solution.

A different economic policy approach – tradable pollution permits

It is possible to design a market-oriented pollution control policy that avoids the problem of having to measure the dollar value of environmental costs. In the **tradable pollution permit** approach, policy-makers decide first on the level of pollution reduction that is needed. A certain quantity of pollution permits is issued. These permits may be distributed to existing firms, or may be sold at auction to firms that are producing the goods responsible for the pollution.

This system is designed to reach the same overall level of pollution as a traditional system of **regulation** but at a lower economic cost. In a regulation system, every company has to comply with environmental regulation even if it costs one firm twice as much as another to do so. Under the trading system, a firm could even choose to increase its level of pollution as long as it is able to purchase credits from another firm. Producers whose technical processes are cleaner than others - and therefore who do not need many permits to pollute - can sell permits on the market to more polluting industries, allowing them to postpone costly controls until new technologies become available.

Under this system, the price of a pollution permit will be determined by market supply and demand, not by the government. Over time, it is possible to tighten pollution standards by reducing the number of available permits. Over time, the price of permits may increase (if fewer permits are available) or decrease (as improved technology makes it easier to cut emissions).

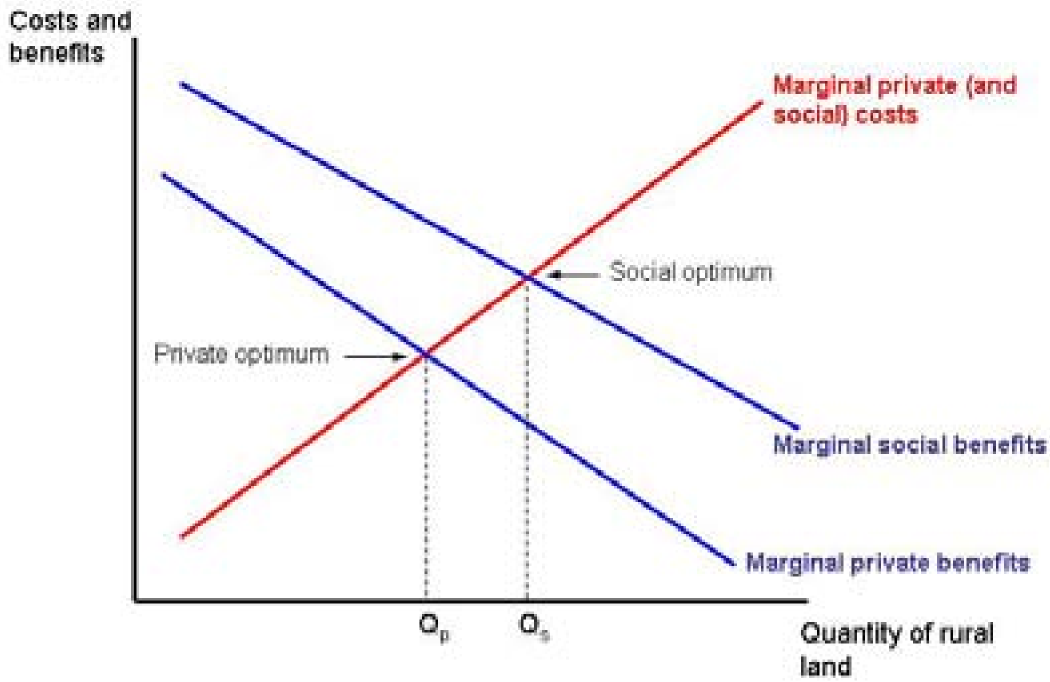
Economic policy for positive externalities

Just as it is in society's interest to internalize the social costs of pollution, it is also socially beneficial to internalize the social benefits of activities that generate positive externalities. For example, many suburban and rural towns have instituted open land preservation programs. Using tax incentives or public purchases they seek to maintain or increase the amount of open and rural land. Why do they do this?

A private landowner may have his/her own reasons for keeping land open or using it as farmland. But there are significant third-party benefits from such uses. Others who live in the town enjoy the sight of natural areas and farmland close to their homes. A beautiful setting may significantly increase surrounding property values while an industrial or residential development nearby would lower them. The external benefits are not limited to residents of the town. Passers-by, hikers, bicyclists, and out-of-state tourists may all draw satisfaction – utility, to use the economic theory term – from the pleasant scenery.

An economic analysis of the situation is shown in Figure 3. Marginal social benefits are higher than marginal private benefits because they include gains to neighbors and passers-by as well as to private land-owners. At the social optimum, there is a higher quantity of open and rural land than at the private market equilibrium.

Figure 3: A Positive Externality

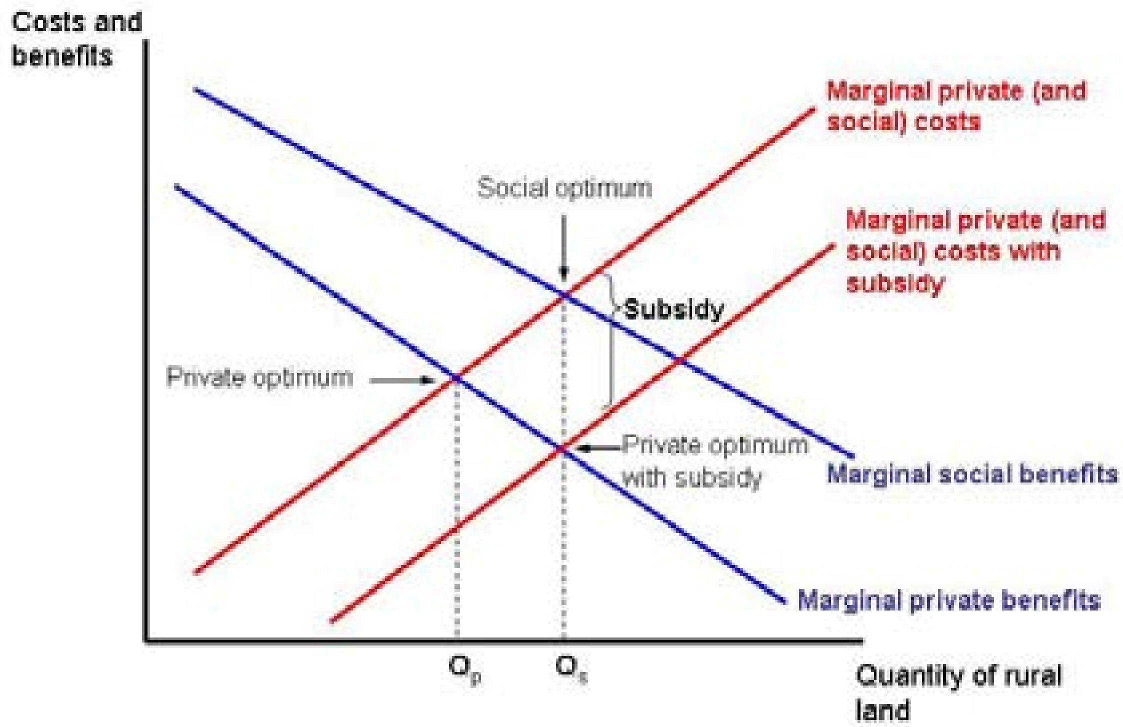


How can we increase the quantity of open land supplied? From an economic point of view, one policy that could achieve the social optimum would be a **subsidy** to encourage the provision of open land. It is in the social interest to encourage landowners, through tax rebates or purchase of development rights[3], to keep land in an undisturbed state.

By lowering the costs (through tax rebate) or offering a payment (through purchase of development rights), public authorities encourage landowners to maintain open and rural land (Figure 4). The effect is exactly parallel to the use of a tax to discourage economic activities which create negative externalities -- except that in this case we want to encourage economic uses of land which have socially beneficial side-effects.

[3] In development rights purchase programs, a town or state buys the rights to development on private land. The landowner retains ownership of the land, but cannot use it for industrial or residential development.

Figure 4: A Subsidy for Open and Rural Land Use



Cost-Benefit Analysis

One of the advantages of using environmental policy tools which work through market mechanisms -- like taxes, subsidies, and transferable permits -- is that the final decisions on resource use and goods production are left up to firms and individuals. The government acts to modify market outcomes, but not to determine the exact result. But in some cases governments must make specific decisions which have both economic and environmental implications. In such cases, cost-benefit analysis (CBA)[4] is a tool used by decision makers to balance the positive and negative consequences of a proposed action.

Take the example of a proposed government project: the construction of a large dam. The project will have some major economic benefits: hydroelectric power, a stable water supply for irrigation, and flood control. But it will also have negative impacts. Farmland and wildlife habitat will be flooded, some communities will have to relocate, and some fish species may become extinct. There may be new recreational opportunities created for lake boating and fishing, but there will be a loss of scenic whitewater rafting and hiking.

[4] The terms "cost-benefit analysis" and "benefit-cost analysis" are both used, and have the same meaning. "Cost-benefit analysis" is more common and will be used here.

How can we evaluate whether to build the dam or not? Some costs and benefits are relatively easy to assess. We can probably get good estimates of the construction costs of the dam, and of the value of hydroelectric power and irrigation water, for example. But how can we put a dollar value on the social and ecological losses that will result?

Different kinds of value

Economists use various techniques to estimate different kinds of values. The most obvious kind of value is **use value –** the values placed on a resource by those who directly use it. In this example, the value of farmland used for raising crops is a direct use value, which can be measured by its market price. Certainly farmers whose farms are submerged by the dam waters will suffer losses at least equal to the value of their farms. These should be included in our estimates of costs associated with dam construction. The impacts of the dam on other users are also important, such as the loss of whitewater rafting or hiking opportunities. These use values are more difficult to measure because information from markets is not readily available in dollar terms.

In addition to use values, there are three important kinds of **non-use values**. One of these is **option value**. If we decide to go ahead and build the dam, the farms and forests which are flooded will be lost forever -- the decision is irreversible. On the other hand, if we decide not to build the dam today, we could still decide to build it ten or twenty years from now. Thus we can preserve the **option** of building, or of not building, the dam by simply doing nothing.

Option values are important because economies change over time, and so do the values of different goods, services, and environmental assets. Farmland or undeveloped natural areas might become much more valuable in future; on the other hand, the need for hydroelectric power or irrigation water might become much greater. In either case, the decision on the dam could be made with better information at a later date[5].

Another non-use value is **existence value**. Consider the fish species that might be made extinct by building the dam. Even if these species have no commercial value, many people might feel that they should be preserved. Some might feel that other species have their own rights to exist, independent of human valuations. Other might argue that the existence of many different species means that we ourselves live in a richer world -- richer in a spiritual rather than a monetary sense. Thus we might seek to preserve other species for our own sense of well-being, even if those species are never of economic use to humans.

It is also important to consider the value of leaving an undamaged world to future generations, something which economists identify as **bequest value**. Clearly existence, option, and bequest values will be difficult to put in monetary terms -- but may nonetheless be very important. Economists use a technique called **contingent valuation** to measure non-use values.

[5] If we take this logic to its extreme, of course, we would never do anything -- which is why option values have to be weighed against other values.

This is essentially a survey technique, in which people are asked how much they would be willing to pay to preserve rafting or hiking opportunities. The resulting estimate of **willingness-to-pay** can be included in a cost-benefit analysis -- although its reliability is debatable[6].

Suppose that we can succeed in measuring all the costs and benefits associated with dam construction. If the benefits outweigh the costs, should we then proceed with dam construction? Not necessarily. We should also consider the **benefit/cost ratio**, obtained by dividing total benefits by total costs. Suppose that this ratio is only slightly larger than one (i.e. benefits exceed costs, but only slightly). Then it may well be that some other project will offer a better benefit/cost ratio. For example, a series of small dams rather than one large one might offer us the same hydropower and irrigation benefits, while avoiding the social and ecological damage.

Economists generally feel that cost-benefit analysis is a useful tool. Critics of cost-benefit analysis point to the many difficulties involved in obtaining reliable estimates, and the fact that some things, like spiritual value or the value of community, are essentially impossible to estimate in dollar terms. It seems that we should use cost-benefit analysis with caution -- as we will see when we consider the issue of global climate change later in the module.

Public Goods and Common Property Resources

When we think of markets, we usually think of typical examples of goods and services: markets for apples, CDs, computers, cars, or perhaps markets for factor services such as labor and capital. In these markets firms and individuals exchange goods and services for money payments. All these goods and services, although very different in nature, share two essential properties. First, their use is typically limited to one user. If I eat an apple, there is nothing left for someone else; while I am using my computer, no one else can check out the web on it; if I rent a car, it is not available for anyone else to rent while I am driving it.

Goods whose use is limited to one user at a time are called **rival**. For most goods, it is usually easy to identify a legal owner or renter who is entitled to use or consume them. These goods are called **excludable**. The right to use or consume the good can be refused to others. A good that is both rival and excludable is called a **private good**.

Are all goods rival and excludable? What about going to a concert? There are one thousand other listeners like myself and we all enjoy the same good at the same moment. The fact that I am listening certainly doesn't prevent anyone else in the concert hall from listening as well. Here is a good (music in a concert hall) which is non-rival. Of course, I did have to pay for a ticket to enter the hall. The concert is therefore an excludable but **non-rival** good. This type of goods, which require an "access-right" to be enjoyed, but can be consumed jointly by all

[6] Sometimes economists try to estimate **willingness-to-accept** rather than willingness to pay. In the dam example, people might be asked how large a payment would adequately compensate them for the loss of hiking and rafting opportunities. Willingness-to-accept estimates are often much higher in dollar value than willingness-to-pay estimates for the same items, which leads some critics to question the reliability of the contingent valuation approach.

the authorized users, are sometimes called **club goods** (in a club, the “access-right” is the membership, which allows the members to enjoy all the club’s facilities in common).

What kind of good is an apartment shared by roommates? Each room is the “private property” of each roommate, therefore rival and excludable (a private good), but the common parts like the kitchen the bathroom and the living room are shared. They are in joint, or **non-excludable**, use among the roommates. However, these common areas may be rival: if my roommate uses the bathroom, I cannot use it at the same time[7]. We have here a case where the common parts of the apartment are rival and non-excludable. Goods that are both rival and non-excludable are called **common property resources**.

Are there goods that are both non-rival and non-excludable? Think of the ocean, the mountains: can’t you go sailing or hiking without preventing anyone from doing the same? And who could forbid you to go there and enjoy yourself if you wanted to? These natural goods are accessible to everyone in joint use (non-excludable) and use by one person does not prevent others from using them as well (non-rival). Goods that are both non-rival and non-excludable are called **public goods**.

However, the property of non-rivalry can disappear if too many users are involved in the process of jointly using a resource or amenity. On a beautiful summer day mountains and public beaches are often crowded, which may make them significantly less enjoyable. A quiet canoe trip down a river may be ruined by the presence of many noisy powerboats. The limit to non-rivalry is reached when the level of density or concentration of users is such that everyone is disturbing everyone else. This is called the **congestion threshold**.

The four types of goods or amenities, according to their property of rivalry/non-rivalry and excludability/non-excludability are represented in Table 1.

Table 1: The Four Types of Goods

	Non-excludable	**Excludable**
Non-rival	Public goods	Club goods
Rival	Common property resources	Private goods

Source: Adapted from V. & E. Ostrom, 1977.

There is a connection here with our earlier analysis of externalities. The issue of “rivalry” between users of a common property resource is nothing but an example of negative externalities between them. If my action disturbs someone else – and at the same time his disturbs me – we both create negative externalities for each other. The problem of congestion is an illustration of a situation where all users impose negative externalities on everyone else: my presence in the crowd or the traffic jam contributes to the problem.

[7] Some parts of the apartment, such as kitchen and dining room, may or may not be rival depending on circumstances. My roommates and I may choose to cook and eat together (non-rival), but if I want to cook a large meal and invite other friends over, this may conflict with my roommates’ ability to use the kitchen and dining room (rival).

Some public goods, on the other hand, represent strong cases of positive externalities. A public park in the middle of a city is a good example. Individuals do not have to pay to enter the park, but all benefit from the relief it offers from traffic and concrete. You don't even have to enter the park to enjoy it – just walking past is more pleasant than walking down a treeless street. All who live nearby also enjoy the view of the park.

It would be possible to divide the public park up into building lots and construct businesses or residences instead – but who would favor that? Private benefits would be created for the new owners of these buildings, but the great public benefits of the park would be lost, degrading the quality of life for the whole city.

The concepts of public good and common property resource are extremely useful when dealing with environmental goods and amenities. Oceans, the atmosphere, and many natural ecosystems like tropical rainforests and mountains are sometimes referred to as **open access**, meaning that they are available for anyone to use (non-excludable). To a certain extent they are limitless and can be considered as public goods. However many of the resources they contain are finite, degradable or depletable, which means that the economic analysis of common property resources will apply to them.

All the living species found in terrestrial or marine ecosystems are potentially depletable if the rate of extraction is higher than their natural rate of renewal. This means that there is always a threshold of extraction beyond which the resource is over-harvested, over-fished, or over-hunted, leading to its depletion. This is a particular case of the congestion threshold. Below this threshold, the resource seems abundant. Once the threshold is reached, the resource starts declining. Then all the users become competitors for this scarcer and scarcer resource, until it finally disappears.

Even the atmosphere can be overused. The release of pollutants beyond a certain level can significantly modify natural cycles. Chlorofluorocarbons (CFCs) which destroy the stratospheric ozone layer are an illustration, as well as greenhouse gases, which contribute to global climate change. Below the threshold, the atmosphere is taken for granted -- as a pure public good available to all -- whereas in fact the atmosphere, like other natural systems, is vulnerable to overuse. Overuse of non-excludable or open access resources is a phenomenon that has been called the **tragedy of the commons** (see Box 1).

The origin of the tragedy comes from a **paradox of aggregation**: if everyone tries to obtain more for themselves, this behavior results in less for everyone. The pursuit of personal interest leads each individual user to take as much as possible of the resource, which increases the overall level of extraction of the resource and drives it irremediably to its destruction – and to the ruin of all the users.

Box 1: The Tragedy of the Commons

The tragedy of the commons develops in this way. Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. Such an arrangement may work reasonably satisfactorily for centuries because tribal wars, poaching, and disease keep the numbers of both man and beast well below the carrying capacity of the land. Finally, however, comes the day of reckoning -- the day when the long-desired goal of social stability becomes a reality. At this point, the inherent logic of the commons remorselessly generates tragedy.

As a rational being, each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, "What is the utility to me of adding one more animal to my herd?" This utility has one negative and one positive component. The positive component is a function of the increment of one animal. Since the herdsman receives all the proceeds from the sale of the additional animal, the positive utility is nearly +1. The negative component is a function of the additional overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all the herdsmen, the negative utility for any particular decision-making herdsman is only a fraction of –1.

Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another…. But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit – in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all.

Source: Garrett Hardin, "The Tragedy of the Commons," Science 162 (1968).

Successful local management, communal fisheries, grazing land, forests, irrigation systems have often proved that the tragedy of the commons is not inevitable. However, when rules governing access to the commons cannot be enforced or are not strong enough to prevent **free-riders** (either outsiders or insiders) from using the resource without authorization, degradation and perhaps complete destruction of the resource is likely to follow.

When the scope of a resource is regional or even global (oceans and the atmosphere are often called **global commons**), enforcement of rules of access must be decided at the international level, to prevent the damages associated with open access.

In the next sections we will examine several environmental issues involving externalities, common property resources and public goods. We will also extend the analysis of environmental issues to the industrial system as a whole, and consider possible policy solutions for the sustainable management of resources and the environment.

2. THE GLOBAL CLIMATE CHANGE ISSUE: ANALYSIS AND POLICY

In recent years there has been growing concern over the issue of global climate change[8] (see Box 2). From the point of view of economic analysis, **greenhouse gases** emissions resulting from economic activity create negative externalities and lead to the overuse of a common property resource.

The atmosphere is a global commons into which individuals and firms can release pollution in the shape of gases and particulates. The release of pollution creates a "public bad" born by everyone -- a negative externality with a wide impact. In many countries, environmental protection laws limit the release of **local and regional air pollutants**. In economic terminology, the negative externalities associated with local and regional pollutants have to some degree been internalized.

But in the case of carbon dioxide, the major greenhouse gas, few controls exist since it has no short-term damaging effects at ground level. As carbon dioxide and other greenhouse gases accumulate in the atmosphere, significant effects on world weather will result, although there are many differences of opinion about the probable scale and timing of these effects.

If indeed the effects of climate change are likely to be severe, it would be in the interest of everyone to lower their emissions for the common good. But where no agreement or rules on emissions exist, it is not in the interest of any individual firm, city, or nation act to reduce emissions. Only a strong international agreement binding nations to act for the common good could prevent the tragedy from occurring. Since CO_2 and other greenhouse gases continuously accumulate in the atmosphere, stabilizing or "freezing" emissions will not solve the problem. Major reductions in emissions levels would be needed to prevent ever-increasing atmosphere accumulations.

Despite two global conferences dealing with the climate change issue, at Rio de Janeiro in 1992 (the United Nations Conference on Environment and Development, or UNCED) and at Kyoto, Japan in 1997, progress on combating global climate change has been slow. Global emissions of greenhouse gases continue to rise (see Figure 5).

For example, one of the effects of climate change is likely to be a rise in sea level as polar ice caps and glaciers melt. The only way to stop this would be to prevent the climate change itself. But it might be possible to build dikes and sea walls to hold back the higher waters. Those who live close to the sea – including whole island nations, which could lose most of their territory to sea level rise -- are not likely to endorse this mitigation strategy. But to carry out a strategy of prevention, most of the world's countries will have to be convinced to participate. Is it in their interest to do so? To answer this question, we have to find a way of evaluating the effects of climate change.

[8] Earlier discussions of the problem referred to it as **global warming**. It is now more commonly called **global climate change**, since a basic warming effect will have complex impacts on climate patterns -- with warming in some areas, cooling in others, and increased climate variability.

Box 2: What is the Greenhouse Effect?

In 1824, French scientist Jean Baptist Fourier first described the *natural* greenhouse effect, drawing the parallel between the action of the atmosphere with the effect of glass in a greenhouse.

The sun's radiation reaching the earth is in the shorter wavelength whereas outbound radiation from the earth is in the infrared long-wave bands. Clouds, water vapor, and natural greenhouse gases such as carbon dioxide (CO_2), methane, nitrous oxide and ozone are more opaque to long-wave than short-wave, trapping 80 to 90% of the outbound radiation from the earth surface. This trapping influence is called the **greenhouse effect**. Without the greenhouse effect, the average surface temperature on the planet would be -18° C, instead of the 15°C observed today - too low for any sort of life.

The possibility of an *enhanced* or *man-made* greenhouse effect was introduced one hundred years ago by the Swedish scientist Svante Arrhenius. Arrhenius hypothesized that the increased burning of coal would lead to an increased concentration of carbon dioxide in the atmosphere and warm the earth.

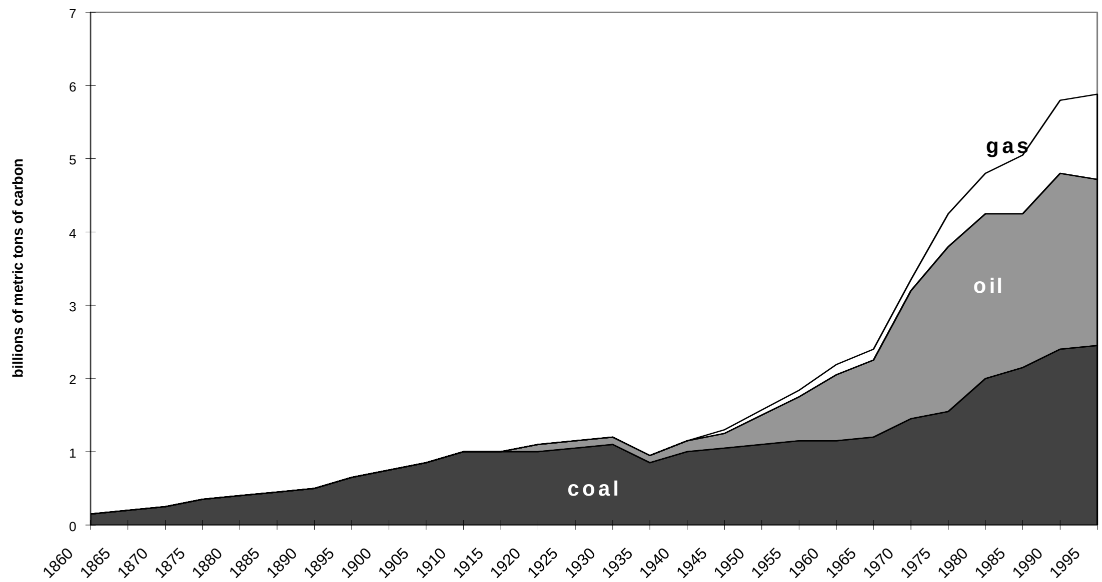
Since Arrhenius' time, the emissions of greenhouse gases have increased dramatically. The concentration of carbon dioxide in the atmosphere has increased by 25% over pre-industrial levels. In addition to increased burning of fossil fuels such as coal, oil and natural gas, man-made chemical substances such as chlorofluorocarbons (CFCs) as well as methane and nitrous oxide emissions from agriculture and industry contribute to the greenhouse effect.

In the early 1990s, the Intergovernmental Panel on Climate Change (IPCC) was set up jointly by the United Nations Environment Programme and the World Meteorological Organization to provide an authoritative international statement of scientific opinion on climate change. The global average temperature has increased by about 0.6°C (1.1°F) during the 20^{th} century. The IPCC concludes that humans are already having a discernable impact on the global climate; "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations."

Current emissions trends will lead to a doubling of greenhouse gas concentration over pre-industrial levels by around 2050. Using large mathematical models of the atmosphere, called general circulation models, scientists can simulate the effect of increased greenhouse gas concentrations. The IPCC projects a global average temperature increase of 1.5-4.5° Centigrade, or 3-8 degrees Fahrenheit by 2100, which would have significant impacts on climate throughout the world.

Sources: William R. Cline, The Economic of Global Warming, 1992; Samuel Fankhauser, Valuing Climate Change, 1995.

Figure 5: Carbon Emissions Due to Fossil Fuel Consumption, 1860-1995



Source: Adapted from Manne and Richels, 1992.

The impacts of climate change

Scientists have modeled the effects of a projected doubling of accumulated carbon dioxide in the earth's atmosphere. Some of the predicted effects are:

- Loss of land area, including beaches and wetlands, to sea-level rise
- Loss of species and forest area
- Disruption of water supplies to cities and agriculture
- Increased costs of air conditioning
- Health damage and deaths from heat waves and spread of tropical diseases
- Loss of agricultural output due to drought

There could also be some beneficial effects such as:

- Increased agricultural production in cold climates
- Lower heating costs

In addition to these effects, there are some other, less predictable but possibly more damaging effects including:

- Disruption of weather patterns, with increased frequency of hurricanes and other extreme weather events.

- Sudden major climate changes, such as a shift in the Atlantic Gulf Stream, which could change the climate of Europe to that of Alaska.
- Positive feedback[9] effects, such as an increased release of carbon dioxide from warming arctic tundra, which would speed up global warming.

How can we evaluate such major possible impacts? The problem is much more complex than the simple example of an externality generating by a factory polluting a river. In that example, the effects were straightforward enough to make us reasonable optimistic about estimating the external costs associated with the pollution, and devising policies to internalize them. Even though we might be unable to get a precise estimate of external costs, we could probably come close enough to judge what level of pollution tax or transferable permits might be appropriate. But how can we evaluate such policies when the whole future of the planet is in question?

In attempting to respond to this question, economists have employed the tool of cost-benefit analysis. Others have criticized this approach as attempting to put a monetary valuation on issues that have great social, political, and ecological implications, which go far beyond money value. But many economists feel that since there are clearly costs associated with taking action against global climate change, it is essential to seek some way to balance costs and benefits. We will examine the efforts by economists to place the issue in a cost-benefit context, then return to the debate over whether this effort is appropriate, and what policies should be implemented.

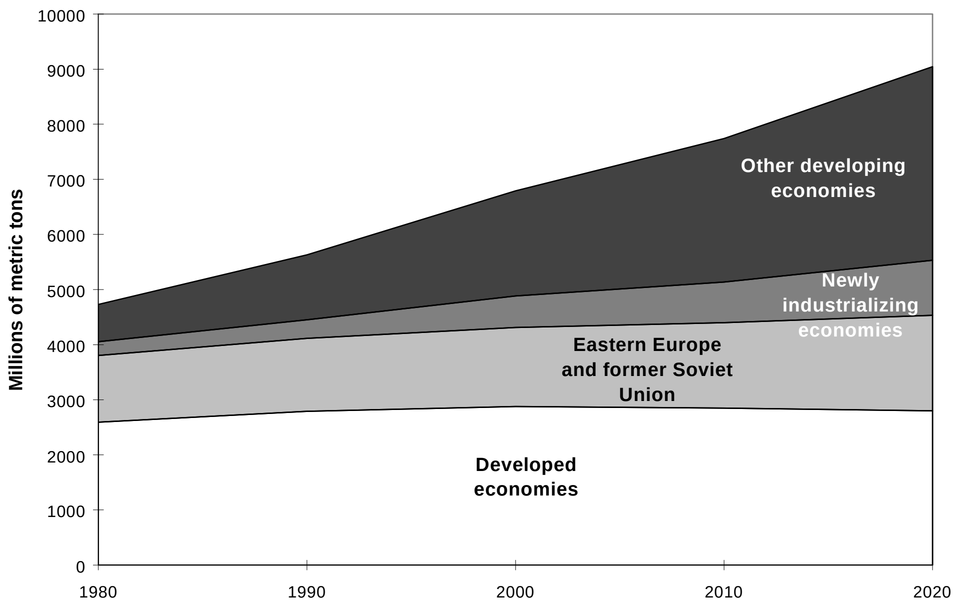
Cost-Benefit Analysis of Climate Change

We can place greenhouse policies in context by first considering first **a business as usual** scenario. In this scenario, no policy action is taken to limit emissions of greenhouse gases. As global GNP grows, the need for energy is met primarily from fossil fuel sources. The International Energy Agency projects global energy demand increasing by 1.7% per year through 2030 – resulting in a two-thirds increase in demand between 2000 and 2030. More than 60% of this increase will come from developing nations. Carbon emissions are expected to increase at a slightly higher rate than overall energy demand.[10] The resulting dramatic increase in carbon emissions is shown in Figure 6.

Today the developed world is responsible for most carbon emissions, but the largest projected increase in emissions will be in the presently developing nations. By 2020 developing nations will at least equal developed nations in emissions. But note that even with this large increase, per-capita emissions levels will remain much lower in developing nations (Figure 7). With expected population and economic growth, emissions increases in the developing world are unavoidable. Thus to reduce global emissions, there must be significant policy action by developed nations, as well as eventual limits on developing nation emissions.

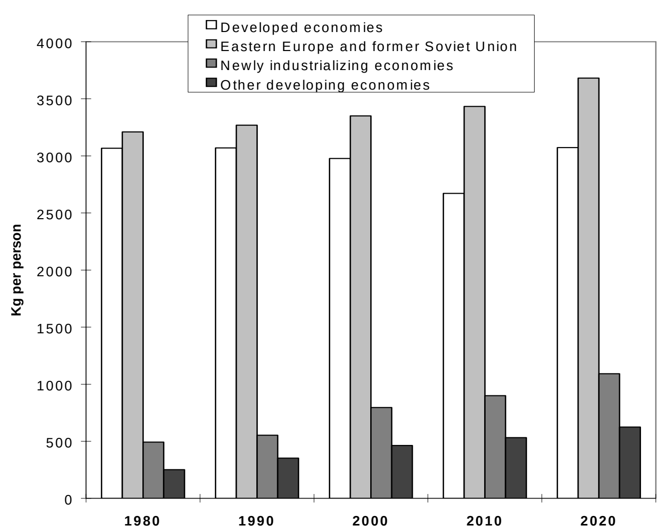
[9] In **systems theory**, a feedback effect occurs when an original change in a system causes further changes that either reinforce the original change (positive feedback) or counteract it (negative feedback).
[10] International Energy Agency, 2002.

Figure 6: Projected Carbon Emissions Through 2020, Business as Usual Scenario



Source: Adapted from Duchin and Lange, 1994.

Figure 7: Per Capita Emissions of Carbon by Region, Business as Usual Scenario



Source: Adapted from Duchin and Lange, 1994.

To perform a cost-benefit analysis, we need to weigh the impacts of allowing this uncontrolled emissions scenario to proceed versus the costs of policy action to prevent it. We can do this by estimating the damages from uncontrolled global climate change. Strong policy action to prevent climate change will bring benefits equal to the value of these damages[11]. Then we must compare these to benefits to the costs of taking action.

A number of economic studies have attempted to estimate these benefits and costs. The results of one such study for the U.S. economy are shown in Table 2.

Table 2: Estimates of Annual Damage to the US Economy from Global Climate Change (in billions of 1990 $)

	2*CO2 (+2.5°C)	**Very-long-term warming (+10°C)**
Agriculture	17.5	95.0
Forest loss	3.3	7.0
Species loss	4.0+Δ	16.0+Δ’
Sea-level rise		35.0
Construction of dikes, levees	1.2	
Wetlands loss	4.1	
Drylands loss	1.7	
Electricity requirements	11.2	64.1
Nonelectric heating	-1.3	-4.0
Human amenity	Xa	Ya
Human life	5.8	33.0
Human morbidity	Xm	Ym
Migration	0.5	2.8
Hurricanes	0.8	6.4
Construction	+/- Xc	+/-Yc
Leisure activities	1.7	4.0
Water supply	7.0	56.0
Urban infrastructure	0.1	0.6
Air pollution		
Tropospheric ozone	3.5	19.8
Other	Xo	Yo
Total	61.6+Xa+Xm+Xo +Δ+/-Xc	335.7+Ya+Ym+Yo +Δ+/-Yc

Adapted from William R. Cline, The Economics of Global Warming, 1992.

[11] These benefits of preventing damage can also be referred to as **avoided costs**.

How are these damage estimates obtained? Some are fairly straightforward. A warmer climate is expected to damage U.S. agriculture due to heat stress and more frequent droughts. For the U.S., these impacts would outweigh any beneficial effects in colder climate agriculture. Estimates of lost U.S. agricultural output in the event of a doubling of atmospheric carbon dioxide are about 10-20%, and these projected losses can be valued using the prices of farm produce. This gives the estimate shown in Table 2 of about $17 billion annual losses.

Forest losses can be valued by considering the costs of reforestation. The costs of sea-level rise are measured both by the value of lands lost and by the cost of construction of dikes and levees to protect other lands. Heating costs fall, cooling costs rise, and water supply costs rise by $7 billion.

When these and other costs are added up, the total annual U.S. damages are estimated at approximately $60 billion (1990 dollars). This is about 1% of U.S. GNP. While different economic studies come up with different estimates, most of them are in the range of 1-2% GNP. For larger temperature change over the longer term, estimates rise to around 5% of GNP (see Table 2).

Note, however, that there are also some “Xs”, “Ys” and “Δs” in the totals -- unknown quantities that cannot easily be measured. The value of species loss, for example, is difficult to estimate in dollar terms: the estimates used here show a cost of at least $4 billion in the short term and $16 billion in the long term, with an additional unknown cost denoted as Δ.

The damage estimates may also be challenged on other grounds. For example, oceanfront land is more than just real estate. Beaches and coastal wetlands have great social, cultural, and ecological value. The market value of these lands fails to capture the full scope of the damage society will suffer if they are lost.

In addition, these estimates omit the possibility of the much more catastrophic consequences that *could* result if weather disruption is much worse than anticipated. A single hurricane, for example, can cause over $10 billion in damage, in addition to loss of life. For example, in November 1998, a severe hurricane caused massive devastation and the loss of over 7000 lives in Central America. If climate changes cause severe hurricanes to become much more frequent, the estimate here of less than one billion annual losses could be much too low. Another of the “X” values – human morbidity or losses from disease – could well be enormous if tropical diseases extend their range significantly due to warmer weather conditions. As explained in Box 3, obtaining monetary estimates of the loss of human lives is a complicated and controversial subject.

Box 3: The Value of Human Life

One interesting feature of these estimates is that a dollar value has been placed on loss of human life. Greater heat stress is projected to cause about 9,800 extra deaths annually; the researches have placed a value of about $600,000 on each life to arrive at a total estimate of $5.8 billion. How can economists value human lives?

A simple economic measure is an estimate of what an individual contributes in terms of production of goods and services to society. To some, this seems unjustified. This approach would value the life of a CEO at a dollar value equal to twenty to thirty times the life value of a manual worker. Another approach is to consider the amounts that people spend on life insurance and safety precautions. This can give an estimated value of $2 million - $3 million for a human life[12].

Global climate change studies using this kind of life valuation have been criticized by representatives of developing nations, who point out that the life – or death – of a citizen of a developed nation is valued at $1.5 million, while each Chinese, Indian or African death is valued at $150,000. In a cost-benefit analysis of global warming performed for the Intergovernmental Panel on Climate Change (IPCC), the cost of 38,000 "Northern" (developed nation) lives projected to be lost due to heat stress and climate-caused disease was estimated at $57 billion. But five times as many "Southern" (developing nation) lives projected to be lost were valued at only $28 billion[13]. This kind of assessment, while claiming economic rationality, appears faulty on moral grounds.

Balancing costs and benefits

Clearly, these damage estimates are not precise, and are open to many criticisms. But suppose we decide to accept them – at least as a rough estimate. We must then weigh the estimated benefits of policies to prevent climate change against the costs of such policies. To estimate these costs, economists use models that show how economic output is produced from factor inputs such as labor, capital, and resources.

To lower carbon emissions, we must cut back the use of fossil fuels, substituting other energy sources that may be more expensive. In general, economic models predict that this substitution would reduce GNP growth. One major study showed GNP losses ranging from 1 to 3 percent of GNP for most countries, with higher potential long-term losses for coal-dependent developing nations such as China[14].

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[12] If, for example, someone is willing to accept a hazardous job with a 1 in 100 chance of death in return for an extra $20,000 in income, this implies a life valuation of (100)($20,000) = $2 million.

[13] S. Fankhauser, "The Social Costs of Greenhouse Gas Emissions: An Expected Value Approach", *Energy Journal*, Vol 15 (2), 1994.

[14] Manne and Richels, Buying Greenhouse Insurance, 1992.

If costs and benefits of an aggressive carbon abatement policy are both in the range of 1-3% GNP, how can we decide what to do? Much depends on our evaluation of future costs and benefits. The costs of taking action must be born today or in the near future. The benefits of taking action (the avoided costs of damages) are further in the future. How can we decide today how to balance these future costs and benefits?

The technique used by economists to evaluate future costs and benefits is called **discounting**. The theory behind discounting is that a dollar today is worth more than a dollar tomorrow – even after correcting for inflation. For most financial calculations, this makes sense.

Many people have trouble understanding why it makes economic sense to discount future costs and benefits. An example may help. Suppose someone offered you a choice of $5,000 today or $10,000 twenty years from now. If you take the $5,000 today and invest it, getting a real rate of return (after inflation) of 4%, your investment will worth more than $10,000 in twenty years. Looking at it another way, twenty years from now, we could say that the **present value** to you of that $10,000 is less than $5,000 – you would be better off with $5,000 today.

For longer time periods, the **discount rate** becomes much more dramatic. The present value of $10,000 to be received fifty years from now is only $1,400 (using the same 4% discount rate). And the present value of $10,000 to be received in 100 years is only about $200 today. See Box 4 for more details about the calculation of future benefits and costs with a discount rate.

In evaluating the long-term costs and befits of global climate change policies, economists use present value figures obtained by discounting. This means that the future benefits of avoiding climate disruption are weighed at a lower rate than present economic costs of carbon reduction policies. This has led to another serious criticism of the economic perspective. How can we justify a technique that presents serious damages to future generations as less important than moderate costs today?

Discounting makes a lot of sense if we are considering the economics of, for example, taking a mortgage to buy a house. The benefits of being able to own and live in the house today may well outweigh the future costs of paying interest on the mortgage over the next twenty years. But can we say that a GNP gain today, or in the near future, outweighs major climate change damage in the next generation?

The problems and implicit value judgments associated with discounting add to the uncertainties that we have already noted in valuing costs and benefits. This suggests that we should consider some alternative approaches – including techniques that can incorporate the ecological as well as the economic perspective.

Box 4: The Discount Rate

If r is the discount rate the present value B_p of a future benefit B_f expected in n years from now is given by: $B_p = B_f / (1+r)^n$

Consider two extreme cases:

Case 1: r=0

In this case the future is not discounted at all. Future costs and benefits are weighed as much as if they took place in the present. This is almost never the case for individuals. We are all mortals and therefore tend to always favor the present more than the future. But families or whole societies may choose to put a higher value on the future. Parents may weigh future gains or losses to their children at least as much as consumption today. Societies that set aside land for preservation as national parks willingly give up the possibilities of commercial exploitation today in order to guarantee wilderness areas to future generations.

Case 2: r is extremely high

In this case the future is totally neglected in favor of the very short term. This situation can occur in very poor societies where the struggle for survival today makes it impossible to devote any resources to future needs. But something like it can also occur in more affluent democratic societies where the vision of decision-makers does not extend beyond the next election, so that costs which will occur in ten, twenty, or fifty years are neglected in favor of present benefits.

Economic Optimum versus Climate Stabilization

Two major economic studies dealing with benefit/cost analysis of climate change have come to very different conclusions about policy. According to economic analysis conducted by William Nordhaus[15], the economic optimum would be a small reduction in greenhouse gas emissions below the business as usual emissions growth shown in Figure 8. But a study by William Cline recommends "a worldwide program of aggressive action to limit global warming" including cutting back carbon emissions well below present levels, and then freezing them at this lower level, with no future increase[16]. What explains the dramatic difference between these two benefit/cost analyses?

The two studies used similar methods to assess benefits and costs. The main differences were that the Cline study considered long-term effects and used a low discount rate (1.5%) to balance present and future costs. Thus even though costs of aggressive action appeared higher

[15] William D. Nordhaus, "Reflections on the Economics of Climate Change," Journal of Economic Perspectives, Fall 1993.

[16] William R. Cline, The Economics of Global Warming, 1992.

than benefits for several decades, the high potential long-term damages sway the balance in favor of aggressive action today.

While both of these studies used standard economic methodology, Cline's approach is closer in its conclusions to the implications of the ecological paradigm. There are two ways to look at the economy-environment equation involved in global climate change: either focus on what is "better" for the economy or on what is "better" for the environment. But in the long term, damage done to the environment by global climate change will have dramatic negative effects on the economy too.

For this reason, an ecologically oriented economist would argue that the fundamental issue is the stability of the physical and ecological systems that serve as a climate-control mechanism for the planet. This means that climate stabilization should be the goal, rather than economic optimization of costs and benefits. Stabilizing greenhouse gas emissions is not sufficient, since at the current rate of emissions carbon dioxide and other greenhouse gases will continue to accumulate in the atmosphere. In order to stabilize the accumulations of greenhouse gases, a significant cut below present emission levels is required.

Any measure taken to prevent global climate change will have economic effects on GDP, consumption, and employment, which explains the reluctance of governments to take drastic measures to reduce significantly emissions of CO_2. But will these effects necessarily be negative? A comprehensive review of economic models of climate change policy shows that the economic outcomes predicted for carbon reduction policies are very much dependent on the modeling assumptions that are used[17]. The predicted effects of stabilizing emissions at 1990 levels range from a 2% decrease to a 2% *increase* in GDP, depending on how efficiently a shift to alternative fuels is implemented, and on whether the external benefits of carbon reduction, including lower ground-level pollution, are taken into account.

Thus policies for emissions reduction could range from a minimalist approach of slightly reducing the rate of increase in emissions to a dramatic CO_2 emissions reduction of 40 or 50%. The nations of the world have acknowledged the problem, and are negotiating over the scope of reductions. The scope of the reductions now being discussed falls well short of what would be required for climate stabilization. Most economists who have analyzed the problem agree that action is necessary, but there is a wide scope of opinion on how drastic this action should be, and how soon it should occur (see Box 5).

Whatever the outcome of these negotiations, any effort to reduce carbon emissions will require the kinds of economic policies to deal with negative externalities which we began discussing in Section 1. We will now turn to an analysis of some possible policies.

[17] Repetto and Austin, The Costs of Climate Protection: A Guide for the Perplexed. WRI, 1997.

BOX 5: Economists' Statement on Climate Change

Endorsed by over 2500 economists including eight Nobel Laureates

I. The review conducted by a distinguished international panel of scientists under the auspices of the Intergovernmental Panel on Climate Change has determined that "the balance of evidence suggests a discernible human influence on global climate." As economists, we believe that global climate change carries with it significant environmental, economic, social, and geopolitical risks, and that preventive steps are justified.

II. Economic studies have found that there are many potential policies to reduce greenhouse-gas emissions for which the total benefits outweigh the total costs. For the United States in particular, sound economic analysis shows that there are policy options that would slow climate change without harming American living standards, and these measures may in fact improve U.S. productivity in the longer run.

III. The most efficient approach to slowing climate change is through market-based policies. In order for the world to achieve its climatic objectives at minimum cost, a cooperative approach among nations is required – such as an international emissions trading agreement. The United States and other nations can most efficiently implement their climate policies through market mechanisms, such as carbon taxes or the auction of emissions permits. The revenues generated from such policies can effectively be used to reduce the deficit or to lower existing taxes.

Source: Redefining Progress, San Francisco, California (http://www.rprogress.org).

Policy Responses to Climate Change

There are two types of measures to address climate change, **preventive measures** which tend to lower or mitigate the greenhouse effect and **reactive measures**, dealing with the consequences of the greenhouse effect and trying to minimize their impact.

Preventive measures include:

- Reducing emissions of greenhouse gases, either by reducing the level of economic activities which are responsible for it or by shifting to more energy-efficient technologies which would allow the same level of economic activity at a lower level of CO_2 emissions.
- Enhancing greenhouse gas sinks: since forests recycle CO_2 into oxygen, maintaining forested areas intact and implementing significant campaigns of reforestation will reduce the concentration of CO_2 in the atmosphere.

Reactive measures include:

- Construction of dikes and seawalls to protection against rising sea level and extreme weather events such as floods and hurricanes.
- Shifting cultivation patterns in agriculture to adapt to changed weather conditions in different areas.

The large uncertainties associated with cost-benefit analysis of climate change do not provide us with the confidence to determine clearly appropriate policies. When CBA is unable to provide reliable policy recommendations, an alternative approach is needed. **Cost-effectiveness analysis** instead seeks to determine the most efficient way to reach a policy goal. Note that cost-effectiveness analysis is not used to determine the best policy goal. Instead, the policy goal is obtained from other methods, such as scientific evidence or the political process.

In general, economists favor approaches that work through market mechanisms to achieve their goals. Market-oriented approaches are considered to be cost-effective – rather than attempting to control market actors directly, they shift incentives so that individuals and firms will change their behavior to take account of external costs and benefits. We have already mentioned the examples of pollution taxes and transferable permits. Both of these are potentially useful tools for greenhouse gas reduction. Other relevant economic policies include measures to create incentives for the adoption of renewable energy sources and energy-efficient technology.

Policy tools: Carbon taxes

The release of greenhouse gases in the atmosphere is a clear example of a negative externality, imposing significant costs on a global scale. In the language of economic theory, the market for carbon-based fuels such as coal, oil, and natural gas takes into account only private costs and benefits, which leads to a market equilibrium that does not correspond to the social optimum.

As we have seen, a standard remedy that can internalize the external costs is a per-unit tax on the pollutant. In this case, what is called for is a carbon tax (see Box 6). This is similar to any other pollution tax, but it is levied exclusively on carbon-based fossil fuels.

Some countries in Europe have already implemented carbon taxes. These taxes range between $1 and $25 per ton of carbon emitted. This is consistent with the principle of internalizing externalities – but how much impact will it have on actual fuel use and carbon emissions?

Box 6: A Carbon Tax

How does a carbon tax work? It is an **excise tax**[18] levied on the sale of fossil fuels. Some fuels release more carbon than others per unit of heat released. Carbon taxes are levied in proportion to CO_2 emissions when fuel is burned (if no cost-effective method of reducing CO_2 emissions from these gases is available). Coal is the most carbon-intensive fuel per unit of heat released, followed by crude oil and natural gas. Thus carbon taxes would have the heaviest impact on coal.

Carbon taxes would appear to consumers and manufacturers as energy price increases. But since taxes would be levied on primary energy, which represents only one part of the cost of delivered energy (such as gasoline or electricity) and more important, since one fuel can in many cases be substituted for another, overall price increases may not be jolting. Consumers can respond to new prices by reducing energy use and buying fewer carbon-intensive products (those that require great amounts of carbon-based fuels to produce). In addition, some of these savings could be used to buy other less carbon-intensive goods and services.

Clearly, a carbon tax creates an incentive for producers and consumers to avoid paying the tax by reducing their use of carbon-intensive fuels. Contrary to other taxed items and activities, this avoidance has social benefits – reduced energy use and reduced CO_2 emissions. Thus, declining tax revenues over time indicate policy success – just the opposite of what happens when tax policy seeks to maintain steady or increasing revenues.

Adapted from Roger Dower and Mary Zimmerman, The Right Climate for Carbon Taxes, World Resources Institute, 1992.

Consider Table 3, which shows the impact which different levels of carbon tax will have on the prices of coal, oil and gas. A $10/ton carbon tax, for example, raises the price of a barrel of oil by $1.30, which is about 3 cents a gallon. Will this affect people's driving or home heating habits very much? Probably not – we would expect that the **elasticity of demand** for gasoline or heating oil would not be very high (why not?).

Figure 8 shows a cross-country relationship between gasoline prices and per capita use. Notice that the pattern of this relationship is similar to a demand curve: higher prices are associated with lower consumption, lower prices with higher consumption. The relationship shown here is not exactly the same as a demand curve – since we are looking at data from different countries, the assumption of "other things equal", which is needed to construct a demand curve, doesn't hold.

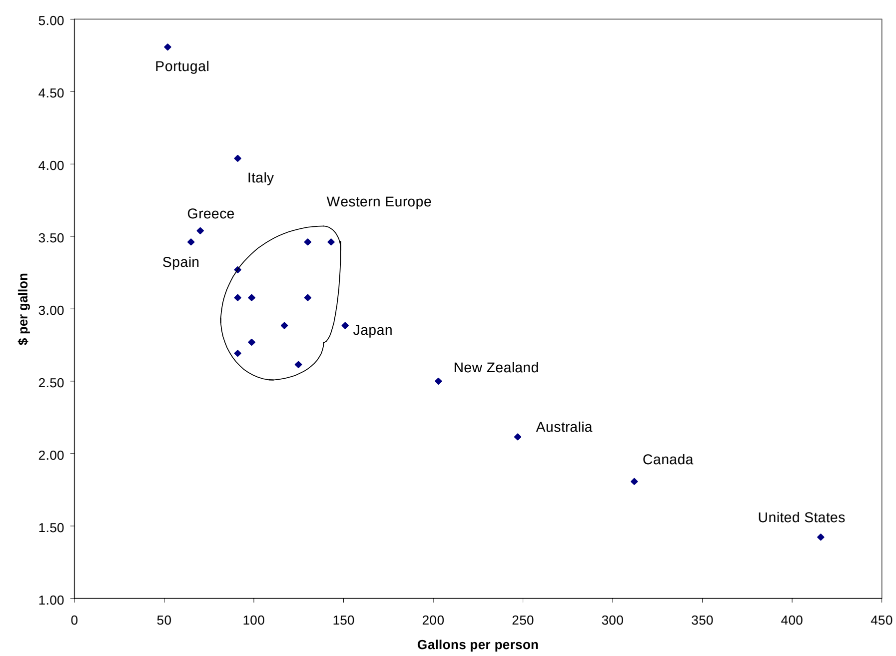
[18] An excise tax is a tax levied on a good or service traded in the market. Typical excise taxes include taxes on liquor, cigarettes, and automobiles.

Table 3: Alternative Taxes on Fossil Fuels

	Coal	***Oil***	***Natural Gas***
Unit of measure	**ton**	**barrel**	**ccf (hundred cubic feet)**
Tons of carbon per unit of fuel	.605	.130	.016
Average mine-mouth or wellhead price, 1989	$23.02	$17.70	$1.78
Carbon tax:			
Absolute tax:	**$/ton**	**$/barrel**	**$/ccf**
$10/ton of carbon	$6.34	$1.30	$0.016
$100/ton of carbon	$63.4	$13.00	$0.16
Tax as % of price:			
$10/ton of carbon	26%	8%	10%
$100/ton of carbon	260%	80%	100%

Adapted from James Poterba, "Global Warming Policy: A Public Financing Perspective," Journal of Economic Perspectives, 1993.

Figure 8: Gasoline Price versus Use in Industrial Countries, 1994 (Circled area represents European price/consumption range)



Source: adapted from David Malin Roodman, Getting the Signals Right, 1997.

People in the United States, for example, may drive more partly because travel distances (especially in the U.S. West) are greater than in many European countries. But there does seem to be a clear price/consumption relationship. The data shown here suggest that it would take a fairly big price hike – in the range of $0.50- $1.00 per gallon or more – to affect fuel use substantially.

To promote a major shift away from fossil fuels, a much larger tax would be needed. According to one study, a carbon tax in the range of $200/ton would be required to stabilize global CO_2 emissions[19]. This would more than double the price of oil and quadruple the price of coal. That would certainly affect consumption patterns. But would it ever be politically feasible? In the United States, high taxes on gasoline and other fuels might face much opposition, especially if people saw it as infringing on their freedom to drive. Note that in Figure 8 the U.S. has by far by the lowest price and the highest consumption per person.

But let's note two things about the proposal for substantial carbon taxes:

First, the revenues from such taxes could be used to lower other taxes. Much of the political opposition to high energy taxes comes from the perception that they would be an *extra* tax – on top of the income, property, and social security taxes that people already pay. If a carbon tax was matched, for example, with a substantial cut in income and social security taxes, it might be more politically acceptable.

The idea of increasing taxes on economic "bads" such as pollution and reducing taxes on things we want to encourage, such as labor and capital investment, is fully consistent with principles of economic efficiency[20]. Rather than a net tax increase, this would be a **tax shift** that is **revenue-neutral** – the total amount which citizens pay to the government in taxes is unchanged.

Second, if such a tax shift did take place, individuals or businesses whose operations were more energy-efficient would actually save money. The higher cost of energy would also create a powerful incentive for energy-saving technological innovation. For example, if the price of gasoline doubled, the average car might soon have doubled fuel efficiency, so that the net cost of driving would be no higher. Economic adaptation would be easier if the higher carbon taxes (and lower income and capital taxes) were phased-in over time.

Policy tools: Tradable permits

As we have seen, one alternative to a pollution tax is a system of tradable pollution permits. In the international negotiations over greenhouse gas reduction, the United States has advocated the implementation of a tradable permit system for carbon emissions. How would such a system work?

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[19] Manne and Richels, Buying Greenhouse Insurance: The Economic Costs of CO_2 Emissions Controls, 1992.

[20] To encourage higher investment, carbon tax revenues could be used to lower capital gains or corporate taxes.

- Each nation would be allocated a certain permissible level of carbon emissions. The total number of carbon permits issued would be equal to the desired goal. For example, if global emissions of carbon are 6 billion tons and the goal is to reduce this by 1 billion, permits for 5 billion tons of emissions would be issued.

- The allocation of permits would be based on agreed-on targets for national or regional reductions. For example, under the Kyoto agreement of 1997, the U.S. agreed to set a goal of cutting its greenhouse emissions 7% below 1990 levels by 2008-2012. Japan agreed to a 6% cut, and Europe to an 8% cut.

- Nations could then trade permits among themselves. For example, if the U.S. failed to meet its target, but Europe exceeded its target, the U.S. could purchase permits from Europe.

- The permits might also be tradable among firms, with countries setting targets for major industrial sectors, and allocating permits accordingly. Firms could then trade among themselves, or internationally.

- Nations and firms could also receive credit for reductions that they help to finance in other countries. For example, U.S. firms could get credit for installing efficient electric generating equipment in China, replacing highly polluting coal plants.

From an economic point of view, the advantage of a tradable permit system is that it would encourage the least-cost carbon reduction options to be implemented. Depending on the allocation of permits, it might also mean that developing nations could transform permits into a new export commodity by choosing a non-carbon path for their energy development. They would then be able to sell permits to industrialized nations who were having trouble meeting their targets.

The stumbling block to an international tradable permit system is obtaining agreement on the target levels. Developing nations have resisted *any* limitations on their emissions – which are currently much lower per capita than those of industrialized nations -- until the developed nations show significant progress in reducing theirs. But some developed nations, such as the U.S. and Australia, are reluctant to implement any reduction policy until developing nations have signed on to some commitments (see Box 7).

The Transition to Sustainable Energy Systems

According to the Intergovernmental Panel on Climate Change (IPCC), a global transition away from oil and coal to renewable climate-friendly energy sources is technically feasible[21]. What economic policies would help to promote such a transition?

[21] Intergovernmental Panel on Climate Change (IPCC), Climate Change 1995, Volume 2: Impacts, Adaptations, and Mitigation of Climate Change (1996), p. 16.

Box 7: The Kyoto Process and Global Equity Issues

The Kyoto Conference, held in December 1997 under the auspices of the United Nations, produced an agreement on greenhouse gas reduction called the Kyoto Protocol. Whereas the previous Framework Convention on Climate Change (FCCC), agreed to at the Rio Conference on Environment and Development in 1992, was entirely voluntary, the Kyoto protocol is intended to be binding on its signatory nations.

The Kyoto Protocol provides several mechanisms for cooperation between the nations of the world in order to control the level of CO_2 and other greenhouse gases emitted into the atmosphere. Industrialized countries have accepted goals for emissions reduction over a fifteen-year period. Developing countries argue that it is only fair that industrialized countries that were able to develop economically by releasing CO_2 into the atmosphere, and are now rich enough to pay for measures to lower their emissions, should reduce their emissions first. Developing countries, however, are not willing to agree to emissions limits in the short term, fearing reductions in economic growth.

Under the Kyoto Protocol, the Clean Development Mechanism allows cooperative projects, such as construction of highly efficient power plants in developing countries, where an industrialized country con receive emissions reduction credit for aid given to a developing country. Another cooperative or "joint implementation" mechanism is sink enhancement, where common efforts between industrialized countries and developing countries could promote forest conservation and reforestation.

These mechanisms do not add up to a global tradable permit system. Limited trading may be possible between nations that have agreed to specific emissions limits. But for a global emission trading system to work, all nations would have to agree to emissions caps – which would require breaking the deadlock between developed and developing nations.

One set of policies could involve redirecting the government spending now going into subsidies to fossil fuels. The U.S. spends $21 billion a year on federal funding for oil and coal research and development, tax credits for enhanced oil recovery, tax deductions for oil and coal exploration, oil and coal depletion allowances, and exempting sport-utility vehicles from "gas guzzler" taxes. On a global scale, government subsidies to fossil fuels are estimated at over $300 billion[22].

Economic theory certainly supports the removal of subsidies from industries that create negative externalities. But we have also seen that subsidies may be appropriate in the case of positive externalities. To the extent that there are perceived social benefits from shifting to a renewable fuel economy, subsidizing the development of new renewable and energy-efficient technologies is therefore economically justifiable.

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[22] Ross Gelbspan, "A Good Climate for Investment," Atlantic Monthly, June 1998; IPCC, op. cit., p. 638.

The benefits of renewable energy systems are not limited to preventing climate change; massive ground-level pollution is also associated with the burning of coal and oil. Replacing fossil-fuel-burning systems would significantly improve air quality both in industrialized economies and in developing nations such as China, where air pollution from uncontrolled industrial development has become a major health hazard.

Once the market for renewable energy sources expands to the point where these industries can achieve significant **economies of scale**[23], costs of production will fall substantially, and subsidies will no longer be required. Development of highly efficient and renewable energy systems could eventually provide a huge boost to economic investment and create millions of jobs in an expanding industry.

For the already industrialized economies, large stocks of existing machinery and plant would be replaced, as they wear out over time, with new non-carbon energy systems. For the developing world, rapid growth in energy demand is expected during the next few decades. Meeting these needs with renewable energy sources would be an economic transition comparable to the introduction of petroleum and the automobile a century ago, but on a global scale.

The Kyoto Protocol represents only a small step towards such a major transition – but global climate change may yet prove to be the area in which environmental issues have the greatest implications for the shaping of economic activity.

3. INTEGRATING ECONOMICS AND ENVIRONMENT

Sustainable Natural Resource Management

In Section 1 we discussed the differences between economic and ecological perspectives. In our analysis of global climate change, we have seen how economic tools and policies can be applied to an environmental issue. Now we turn to the second major area of environmental and resource economics: the management of natural resources.

One way of viewing resources is simply as inputs into production. A broader view sees resources, especially renewable resources, in terms of their own internal logic of recycling and regeneration. In some resource management approaches, these two perspectives are compatible, but in others they clash. Integrating economic and ecological goals is often a difficult problem.

We will examine this problem first with relation to renewable resources such as fisheries. Then we will take a broader view of the economic system as a whole, including its use of non-renewable resources and its generation of wastes and pollutants, a perspective that has come to be known as **industrial ecology**.

[23] Recall that economies of scale occur when per-unit average costs decline as the scale of production increases.

To understand the relationships between the economics system, natural resources, and the environment it is useful to define the different functions for which human beings depend on natural systems.

- The **sink function** of the natural environment is its ability to absorb and render harmless the waste by-products of human activity. The sink function is overtaxed when the volume of waste is too great in a given time period, or when the waste is too toxic. When that happens, aspects of the environment on which we depend (most often soil, water and atmosphere) become damaged, polluted or poisoned.

- The **source function** of the environment is its ability to make available for human use the services and raw materials that we need. Degradation of the source function can occur for two reasons: one is depletion: the resource declines in quantity because humans have drawn on it more rapidly than it could be regenerated. The other is pollution, reducing the quality and/or the availability of the resource.

Having looked at global climate change as an example of the sink-function issues of pollution, we will now turn to the source-function issue of management of natural resources. We will focus especially on the renewable resource of fisheries. Then in discussing industrial ecology, we will look at the relationship of the whole industrial system to the natural sources and sinks on which it depends.

The Economics of Fisheries

Fishing in open seas is a typical illustration of a situation where the tragedy of the commons is likely to occur. All the conditions described by Hardin are met in this case: an unrestricted number of users, unfettered by any limits on their access, extract an increasing share of a resource until natural resources are severely depleted, sometimes to the point of no return.

Fishers tend to have little incentive to practice conservation, for they know that if they do not catch the available fish, someone else probably will. Without limits in place, fishers try to catch as many fish as they possibly can.

Many traditional societies have evolved rules limiting the seasons or days when particular seafood species could be harvested (for example, prohibiting fishing at spawning season), or the amount that could be taken. In recent years these rules have in many cases been swept aside, in part due to population pressures. Other reasons for a break-down in the balance have included institutional failures, when some interest from outside of the community acquires the power to override the traditional patterns of property-rights.

In industrial societies, the problem of over-fishing rapidly affects whole lake and ocean fisheries. Today the problem is global in scope:

> In 1871, the U.S. government created its first federal conservation agency, the Commission of Fish and Fisheries, in response to the decline of fisheries off the coast of New England and in inland lakes. Fishery declines were nothing new even in 1871 – in the mid-1800's drastic declines of whales had captured people's attention.
>
> [Today] as a result of excessive exploitation and other abuses, most of the highly prized marine fisheries around the world are on the verge of collapse. The warning signs are clear: 11 of the world's 15 most important fishing areas and 60% of major fish species are in decline, according to the U.N. Food and Agriculture Organization (FAO)[24].

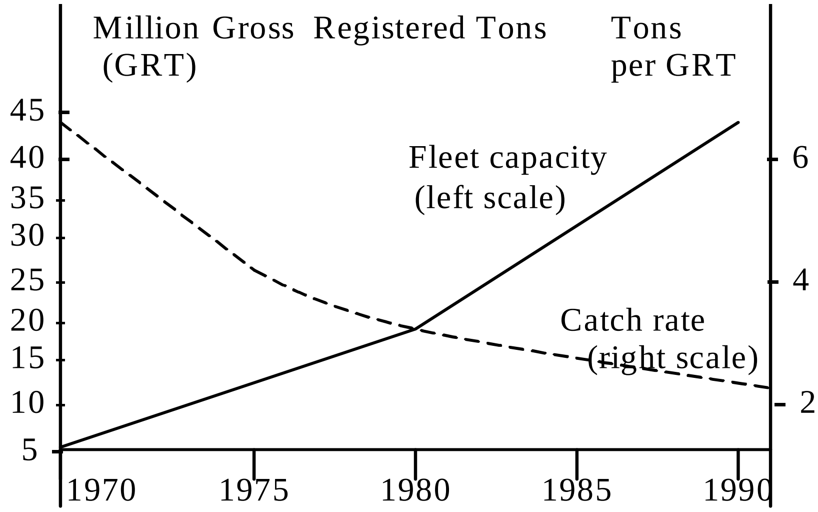
With the introduction of modern vessels like commercial trawlers, fishing became an operation of massive harvesting without discrimination. Fishers can now "wipe out entire populations of fish and then move on either to a different species or to a fishing area in some part of the world."[25]

One fourth of all catches are discarded, either because they are undersized or non-marketable. Fish or marine mammals brought on board and then thrown back – usually dead or dying -- are known as **bycatch**. "Global bycatch was estimated at more than 28 million tons in 1994. . . bycatch is associated with industrialized fishers who use indiscriminate gear to catch as much as they can, but generally keep only the fish they are legally permitted to catch or those that make money."[26]

In the case of a common property resource such as a fishery, economic incentives work in a perverse way. In response to declining yields, operators increase their effort, often investing in more efficient equipment, which accelerates the decline of the fishery. In most economic situations, competition and increased efficiency are good market characteristics, but in the case of a free-access resource, they lead to over-investment and rapid resource depletion (see Box 8). Between 1970 and 1990, global fleet capacity has more than quadrupled, whereas the average catch per boat (catch rate) has dropped by a factor of three (see Figure 9).

[24] Anne Plat McGinn, Rocking the Boat: Conserving Fisheries and Protecting Jobs, Worldwatch Paper #142, June 1998.
[25] Ibid.
[26] Ibid.

Figure 9: Global Fleet Capacity and Catch Rate, 1970-90



Source: Adapted from Anne Platt McGinn, 1998.

Box 8: The Breakdown of Traditional Fishing Systems in Thailand

For centuries, villages clustered around Thailand's mangrove swamps, surviving off the sea life that flourished in their brackish waters. But in the 1980s, a subtle invasion began that would bring pollution and ruin to the villages. The prawn industry offered a get-rich-quick scheme, if the villagers agreed to clear their mangrove forests and harvest prawns.

The honeymoon was lucrative indeed: during the first one to three years, the villagers' investments sometimes yielded a 1000% profit. Then, polluted by toxic prawn excrement, the pits that harbored the prawns would become worse than useless. In many areas, the hazardous substances produced by the prawns spread to the sea and killed off coastal life. Seawater, imported into the ponds to nourish the prawns, salinated groundwater and ruined farmland.

"One to two years of profit, after that losses" says one prawn farmer in Songkhla Province: "If I had it to do over again, I'd stay in mixed agriculture. But the incentives were greater than the warnings, and so people took chances". Prawn farmers have scrambled to save themselves, sinking deeper and deeper into debt in a vain quest to rid their property of pollutants.

When the pollution begins to eat away at its profits, the industry turns to a new village, leaving in its wake a trail of filthy ponds, dry pits, and polluted soils. Bankrupt and faced with an exhausted environment, villagers have moved in droves to cities, where they live in shantytowns and work for scant wages.

Excerpt from Alfredo Quarto and Betsy Reed, "Prawn fever: Thailand's high-stakes jumbo shrimp business," Dollars & Sense, July/August 1993.

Policies for sustainable fisheries management

From an economic point of view, the problem with fisheries is that important productive resources – lakes and oceans – are treated as free resources, and are therefore overused. A simple solution is to place a price on the resource. In the case of a small lake, this might be done by a private owner.

Certainly no private owner would allow unlimited numbers of people to fish for free, depleting the stock of fish until the resource was worthless. S/he would charge a fee to fish, which would bring income to the owner and limit the number of people who would fish. While the owner's motivation would be to collect **economic rent**[27], the people doing the fishing would also benefit – despite having to pay a fee – because they would have access to continued good fishing instead of suffering depletion of the fish stock.

In the case of an ocean fishery, the private ownership solution is not possible. The oceans have been called a common heritage resource – they belong to everyone and no one. But under the 1982 **Law of the Sea,** agreed to under United Nations auspices, nations can claim territorial rights to many important offshore fisheries. They can them limit access to these fisheries by requiring fishing licenses.

Fishing licenses can be sold for a set fee, or a limited number can be sold at auction. In effect, this establishes a price for access to the resource. Notice that we can also view this as internalizing a negative externality. Each fisher now has to pay a price for the effect that one extra boat has in depleting the resource. The economic signal sent by this price will result in fewer people entering the fishery.

This approach, however, will not necessarily solve the problem of over-investment. Once a boat owner has paid for a license, there will be an incentive to obtain the maximum catch by adding new equipment such as sonar devices to track fish, bigger nets, and more powerful engines to travel further. There will also be an incentive to spend as much time as possible at sea, to get the maximum return for the investment in the license and equipment. If all fishers do this, the depletion problem might remain just as bad. A possible policy response is the use of **individual transferable quotas (ITQ's)**.

Like transferable emissions permits, ITQ's impose a maximum limit on the quantity of fish that can be taken. Anyone purchasing such a permit can catch and sell a certain number of fish – or can sell the permit, and fishing rights, to someone else. Assuming the quota limits can be enforced, the total catch from the fishery will not exceed a certain predetermined level.

[27] **Economic rent** is the return which flows to the owner of a scarce resource.

To determine the **maximum sustainable yield** level, policy-makers will need to consult marine biologists, who can estimate the sustainable level of fish population. Once ecological sustainability has been assured in this way, the permit market will promote economic efficiency – those who can fish most effectively will be able to outbid others to acquire the ITQ's.

A more difficult problem concerns species that are highly migratory. Species like tuna and swordfish continually travel between national fishing areas and the open ocean. Even if good policies for resource management exist in national waters, these species can be harvested as a global resource in open access, which almost inevitably leads to the tragedy of the commons. Only an international agreement can solve an issue concerning global commons.

In 1995, the first such agreement was signed: The Convention on Highly Migratory and Straddling Stocks. "This convention marks the first international fisheries treaty or agreement to reject maximum sustainable yield as the standard for fisheries management, and the first to advocate a new standard: the **precautionary principle**."[28] Rather than waiting until depletion is obvious, this principle suggests controlling access to the fishery early, before problems appear, establishing data collection and reporting systems, and minimizing by-catch through the use of more selective gear.

Demand side issues: changing consumption patterns

The demand for fish and fish products is unevenly distributed. People in industrialized countries (about one fifth of the world's population), consume 40% of the global fish catch. But fish is especially important in the diets of people in developing countries, supplying them with a large share of their animal protein needs. With increasing population and income in developing countries, global demand for fish and fish products can be expected to grow steadily. But most ocean and inland fisheries are clearly at or near their capacity limits, or already in decline. World fish catch per person has not increased significantly for over 20 years, and may now be starting to decline.[29]

About one third of world fish production is not consumed directly by humans, but is used as feed for livestock and in aquaculture. With appropriate economic incentives, other sources of protein, such as soymeal, might be substituted for fish in animal and fish feed. This would relieve pressure on fisheries, and potentially make more fish available for direct human consumption.[30]

Shifting human consumption patterns is also important. Public education campaigns which identify fish and seafood produced with environmentally damaging techniques may lead consumers to avoid these species. For example, a boycott of swordfish aimed at stopping the decline of this species has gained the support of numerous restaurant chefs and consumers.

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[28] McGinn, op. cit.
[29] McGinn, op. cit.; Brown et al., Vital Signs 1998.
[30] Ibid.

Ecolabeling, which identifies products that are produced in a sustainable manner, has the potential to encourage sustainable fishing techniques. Sometimes the products of certifiably sustainable fishing practices can command a slightly higher market price. In this case, consumers are implicitly agreeing to pay for something more than the fish they eat; they are paying a little extra for the health of the ocean ecosystem, and the hope that there will be fish to feed people in the future as well as in the present. These consumer choices give the fishing industry a financial incentive to use sustainable methods.

In economic terminology, we can say that consumers are internalizing the positive externalities associated with sustainable fishing techniques through their willingness to buy ecolabeled products. The certification of sustainable fish products can be done by governments or by well-respected private agencies. A prominent example is "dolphin-safe" ecolabeling, which has been instrumental in reducing the numbers of dolphin killed as bycatch during tuna fishing.

Another area where government policies can assist in internalizing positive externalities is the provision of subsidies -- for example, to assist in developing or acquiring equipment designed especially to release bycatch, or to avoid major disturbances of the seabed.

Policies for ecological sustainability

While the identification of the maximum sustainable yield for a fishery can help to maintain an individual species, the issues of ecological sustainability are more complex. Depleting one species may lead to an irreversible change in ocean ecology as other, often less desirable species, fill the ecological niche formerly occupied by the harvested species. For example, dogfish and skates have replaced cod and haddock in major areas of the North Atlantic fishery.

Fishing techniques such as trawling, in which nets are dragged along the bottom of the ocean, are highly destructive to all kinds of benthic (bottom-dwelling) life. In large areas of the Gulf of Maine, formerly productive ocean floor ecological communities have been reduced to virtual deserts by repeated trawling. Thus fisheries management needs to be guided by information about whole ecosystems, not just individual species.

The most rapidly growing area of fish production is **aquaculture** – fish farming, often in large offshore pens. Recent increases in world fish production have been primarily due to rapidly expanding aquaculture. However, from an environmental point of view aquaculture may pose as many questions as it solves (see Box 9).

Modern aquaculture techniques rely on "very intensive **monoculture** systems raising predominantly carnivorous, highly profitable species that demand large amounts of feed, water and fertilizers."[31] The economic returns from aquaculture do not take into account ecological losses such as habitat degradation. By converting diverse ecosystems to simple ones, a whole set

[31] Ibid.

of ecological goods and services are lost – fish, shellfish, timber, charcoal, services of filtering and purifying water, cycling nutrients, removing contaminants and buffering the land from coastal storms.

Given the rapid growth in aquaculture, a global strategy to encourage less-resource-intensive forms of production is needed. Reviving and encouraging traditional pond systems, which used to be well integrated with the local environment and within the boundaries of available resources, would contribute to minimizing aquaculture's impact on the environment.

On a modest local scale, inland aquaculture can be environmentally beneficial, encouraging multiple use of water systems for crops such as rice as well as fishponds. Whether ocean aquaculture can be practiced on a large scale without irreversible damage to ecosystems remains to be seen.

Box 9: Scientists Criticize Salmon Aquaculture

Despite their image as potential saviors of the world's beleaguered fisheries, some of the most successful forms of fish farming may do more harm than good by depleting marine resources and polluting the water, according to a paper in the journal Science.

Researchers from Stanford University and the Environmental Defense Fund argue that salmon and shrimp aquaculture are especially damaging to the environment because the animals are carnivorous, consuming smaller fish that could have been eaten by humans or other marine life.

The world's salmon farmers fed their fish 1.8 million tons of wild fish to harvest just 644,000 tons of salmon. At the same time, water pollution from shrimp and salmon farms have grown with industries. Salmon farms in Norway alone discharge nutrients in their feces equivalent to a city of at least 1.7 million people.

Shrimp farming, which has grown 700 percent since the 1980s, also leaves a trail of ecologically crippled ponds in China, Thailand, and Indonesia where low-income people formerly harvested shellfish. "Rapid growth in shrimp and salmon farming has clearly caused environmental degradation, while contributing little to world food security" the paper concludes.

Source: Scott Allen, "Fish farming pollutes, harms marine life," The Boston Globe, October 30, 1998.

Industrial Ecology

The economic view of production is as a process of transforming raw materials into finished products. This "straight-line" process -- from raw materials to the final product -- is usually accompanied, however, by the unwanted by-products of pollution and wastes. In addition, once products wear out, they too become wastes.

Natural systems, in contrast, typically follow a cyclical pattern, with wastes being recycled and reused. In healthy natural systems, there is no buildup of pollution and wastes. Can this principle be applied to the economic system? Many industrial inputs are non-renewable, but opportunities often exist for resource recycling. Recycling promotes resource conservation – since less new resources are needed – and also reduces the volume of wastes generated by the industrial system.

The economic view of the industrial process is illustrated in Figure 10. **Industrial ecology** is the application of ecosystem principles of recycling to the industrial realm, replacing the straight- line process with a circular pattern, as shown in Figure 11.

Figure 10: The "Straight-Line" Pattern of Traditional Industrial Processes:

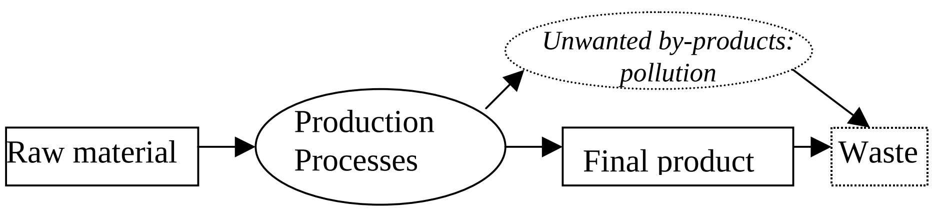
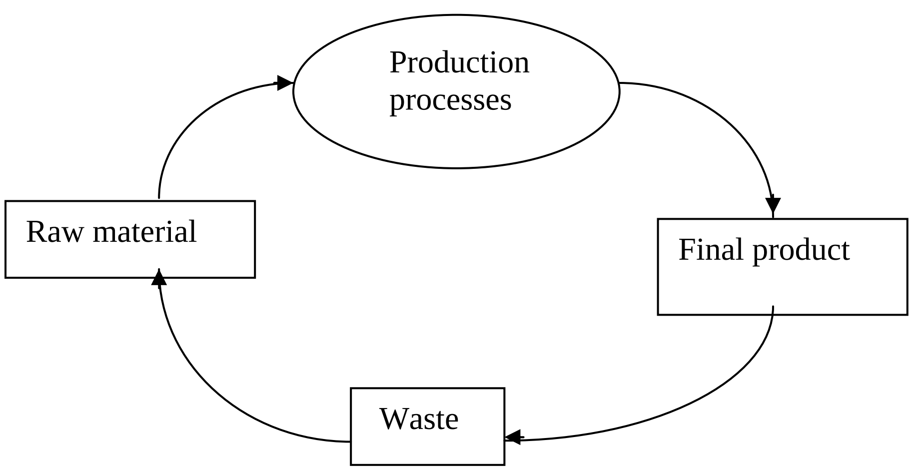
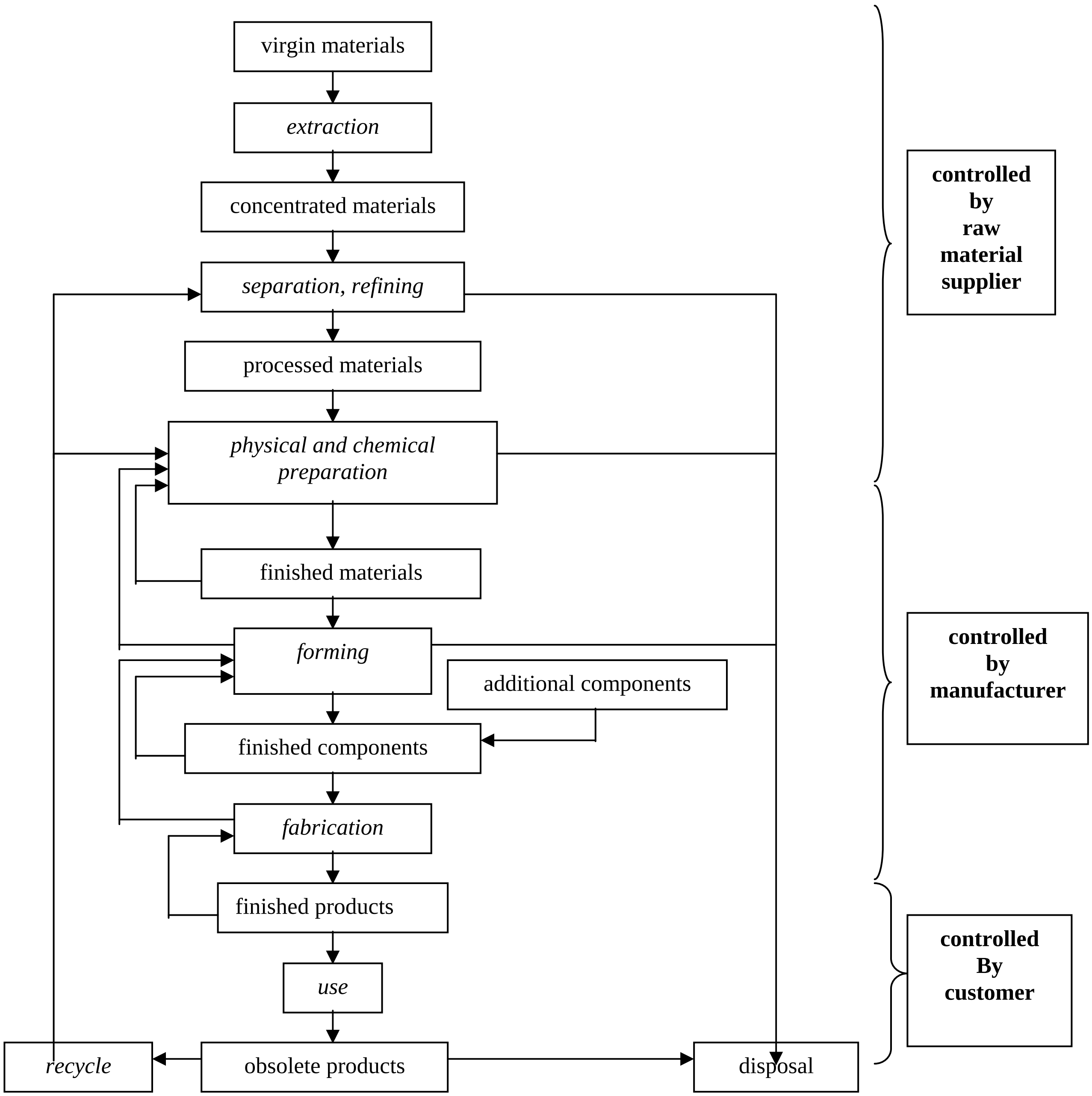


Figure 11: The Cyclic Production Processes of Industrial Ecology



A more complete view of the industrial cycle, taking into account the various stages in the processes of production and consumption, is shown in Figure 12. This gives some indication of the complexity of real-life industrial processes.

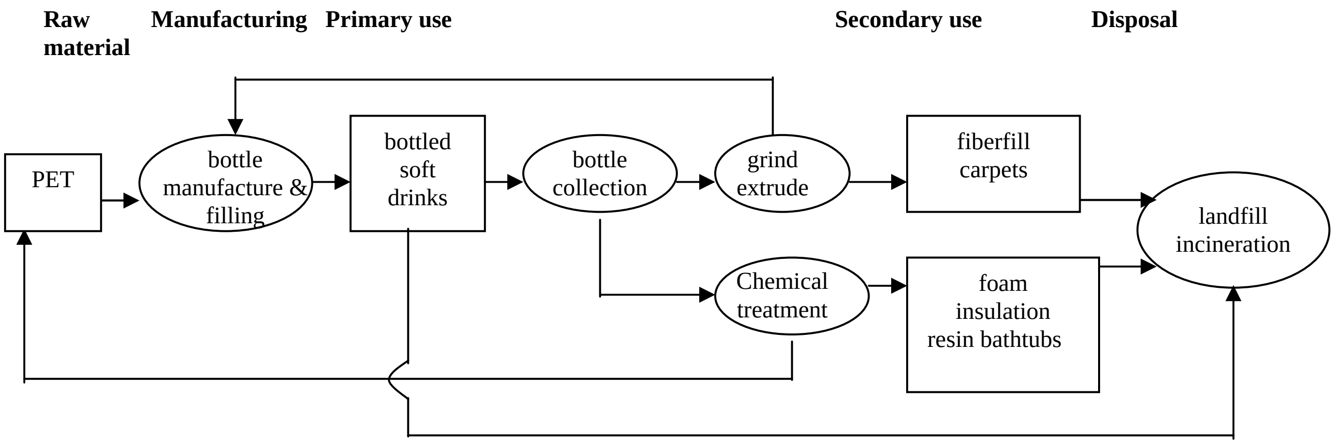
Figure 12: The Total Industrial Ecology Cycle



Source: Adapted from R. Socolow et. al., Industrial Ecology and Global Change, 1994.

A specific example gives some insight into the policy challenges associated with creating a system of industrial ecology. The production of plastic beverage bottles offers various opportunities for recycling materials either into new bottles or into other products, as seen in Figure 13. From an economic point of view, important issues include the incentives for recycling – such as bottle deposit/return systems – and the institutions that support recycling, such as curbside collection of used bottles and other recyclables.

Figure 13: Beverage Bottle Life Cycle



Source: Adapted from R. Socolow et. al., 1994.

Green taxes and green subsidies

To reorient not only bottle production but much of the economic system in this manner requires major technological innovation oriented towards:

- Minimizing the level of unwanted by-products such as pollution and CO_2 emissions.
- Recycling the wastes from industrial processes and worn-out goods into raw materials for further production.

The development of such "green technologies" can be encouraged by economic incentives such as **green taxes** (Pigovian taxes on negative externalities) and **green subsidies** (subsidies for technologies which are environmentally friendly and therefore provide positive externalities), as well as transferable permit systems. Table 4 gives some examples of ecologically-oriented economic policies in practice.

Table 4: Selected "Green" Tax and Permit Systems

Environmental Problem	Policy	Country, year	Description
Overfishing	Fishing permit systems	New Zealand, 1986	Overfishing reduced. Many stocks appear to be rebuilding. Fishing industry, unlike that of most countries, seems stable and profitable despite lack of subsidies
Excessive water demand	Tradable water rights	Chile, 1981	Existing users grandfathered. Rights to new suppliers auctionned. Total water use capped
Solid waste	Toxic waste charge	Germany, 1991	Toxic waste production fell more than 15% in three years
	Solid waste charge	Denmark, 1986	Recycling rate for demolition waste shot from 12 to 82% over 6-8 years
Water pollution	Fees to cover waste-water treatment costs	Netherlands, 1970	Main factor behind 86-97 percent drop in industrial heavy metals discharges and substantial drops in organic emissions
	Fertilizer sales taxes	Sweden, 1982 and 1984	One charge, 1982-92, funded agricultural subsidies; the other pays for education programs on fertilizer use reduction. Use of nitrogen dropped 25%; potassium, 60%; phosphorus 64%.
Acid rain	Nitrogen oxide charge on electricity producers	Sweden, 1992	Refunded as electricity production subsidy. Contributed to 35% emissions reduction in two years.
SO2 Air pollution	Sulfur permit system	USA, 1995	Nearly all permits allocated free to past emitters. Forcing total emissions to about half the 1980 level by 2000; cost of compliance far lower than predicted.
Ozone depletion	Ozone-depleting substance tax	USA, 1990	Smoothing and enforcing phase-outs
	Chlorofluorocarbon permit system	Singapore, 1989	Half of permits auctioned, half allocated to past producers and importers. Smoothing and enforcing phase-out
Global Climate Change	Carbon dioxide tax	Norway, 1991	Emissions appear 3-4% lower than they would have been without the tax
Uncontrolled Development	Tradable development rights	USA, New Jersey pinelands, 1982	Land use pan sets density limits on development in forested, agricultural, and designated growth zones. In growth zones, developers may build beyond density limits if they buy credits from landowners agreeing to develop less than they could. Owners of 5,870 hectares in more protected areas have sold off development rights.
General	Linking investment tax credits to environmental and employment records	USA, Louisiana, 1991	Tax credits reduced up to 50% for firms that pollute most and employ least. Twelve firms aggreed to cut toxic emissions enough to lower the state'' total by 8.2%. Repealed after one year.

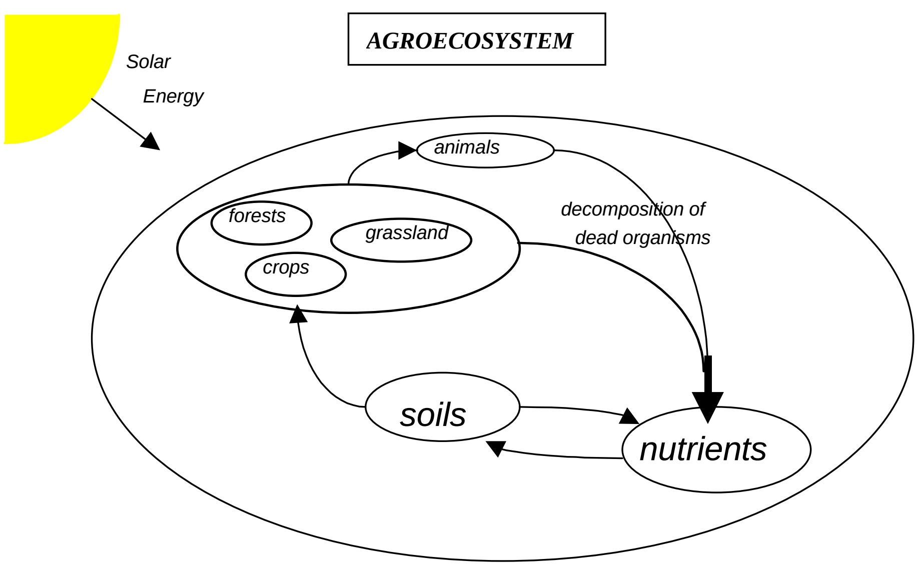
Source: David M. Roodman, Getting the Signals Right: Tax Reform to Protect the Environment and the Economy, 1997.

Economic and ecological views of agriculture

In the area of agricultural production economic and ecological values may conflict. Economic analysis generally focuses on increasing agricultural yields per acre cultivated, through the use of diverse inputs like chemical fertilizers, pesticides, and intensive irrigation. However, this type of agriculture can be damaging for the environment (see Box 10). Chemical inputs can pollute groundwater and rivers, and pesticides can kill beneficial species and disturb the food chain of the surrounding ecosystems. Excessive irrigation can deplete water supplies and contribute to erosion, soil degradation, and groundwater pollution.

An ecological view of agricultural production sees crop output as one part of a diverse **agro-ecological system**, including water, carbon, nitrogen and other nutrient cycles (see Figure 14). To maintain the long-term sustainability of this system, cultivating practices must minimize chemical inputs and rely more on organic techniques, which return nutrients to the soil, control pests by natural methods, and are not harmful to other species. Agriculture of this type may not offer such high single-crop yields in the short term, but will make it possible to raise a variety of crops and animals without damaging ecosystems or polluting water supplies.

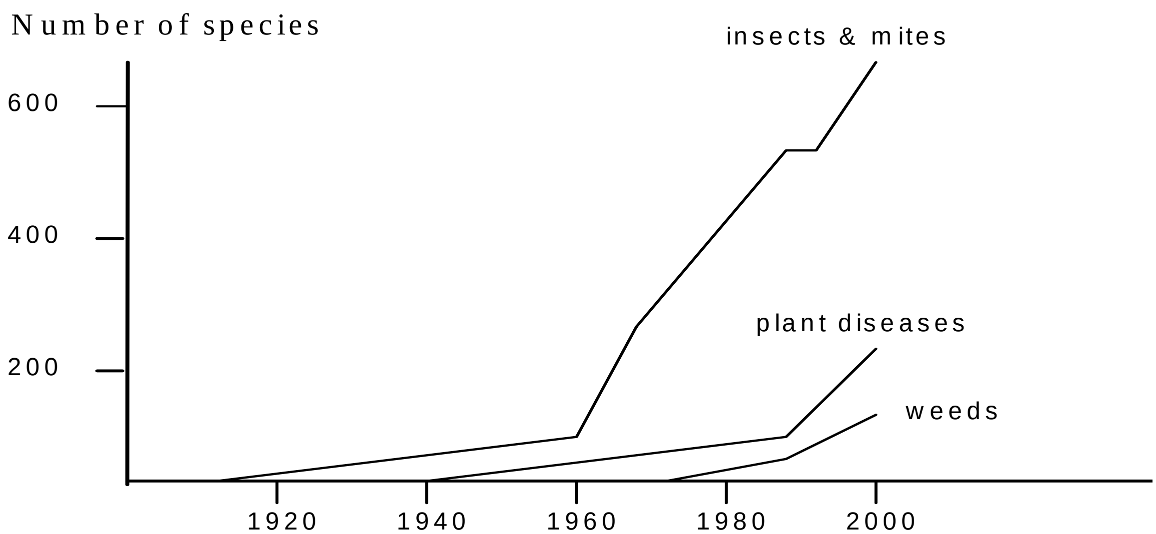
Figure 14: The Ecological View of Cycles



Box 10: Ecological Consequences of Modern Agriculture Practices

Among modern agricultural techniques, pesticide use is playing an increasingly important role. This practice is illustrative of a unidimensional approach, ignoring the complex set of ecosystem interactions in which crops are embedded. Pests quickly develop resistance to the chemicals, making higher doses and eventually new products necessary to achieve the same level of control. Species resistant to common pesticides are now more than 900, up from 182 in 1965.

Evolution of the number of pesticide-resistant species in the 20th century



Source: Adapted from Gardner, 1996

But pesticide use has also human costs. Though it had contributed in the sixties to a massive reduction of the incidence of malaria in the developing world, as mosquito resistance to pesticides increased, the disease has been taking off again. Moreover, pesticide use has also a direct health cost by inducing poisoning of 3 to 25 million people worldwide.

Overuse of pesticides can also disrupt the stability of an agroecosystem by eliminating the pests' natural enemies and poisoning the whole food chain. At the same time, "secondary pests" – those originally found in small numbers in an ecosystem - often multiply when major pests are decimated. Recent episodes of catastrophic devastation of rice crops by the proliferation of planthoppers in Indonesia, are illustrative of this phenomenon.

Source: Gary Gardner, "Preserving Agricultural Resources," in Brown et al., State of the World 1996.

Conclusion: Ecological Economics in the Twenty-First Century

We began by noting the differences between economic and ecological perspectives. Environmental economics applies the techniques of economic analysis, such as valuation and cost-benefit analysis, to environmental and resource issues. As we have seen in examining a number of issues, these techniques are valuable and provide insights for policy-making -- but they are also limited in some crucial ways.

Sometimes the essence of an environmental issue simply cannot be reduced to dollar terms. In such cases, we must look to other areas of knowledge for insight into environmental policy. We have seen that atmospheric science, ecology, marine biology, and hydrology are essential in analyzing the issues of global climate change, forest preservation, fisheries management, and water conservation. But in each case economic techniques such as taxes, subsidies, transferable permits and quotas, and market price mechanisms are crucial in devising policies to respond to the problems.

Ecological economics -- as distinct from the more traditional field of environmental economics -- seeks to balance the insights of the natural sciences with those of economics. In some cases, such as the valuation of human life or the intrinsic value of ecosystems, ethical considerations are also important[32].

In the early days of environmental policy-making, issues were often simpler. If a factory emitted pollution, an "end-of-pipe" solution was often appropriate, such as requiring specific emissions standards to be met. For many problems this approach may still work well. But as the pressures of population and economic growth affect virtually all areas of the global environment, it becomes more important to take a systems perspective, looking not just at individual problems but at the structure of economic and ecological systems.

Bringing these two systems into better balance will be a major challenge for the twenty-first century. Meeting this challenge will require the best insights of economics, taking maximum advantage of the flexibility and incentives that characterize market-oriented approaches. But it will also require economists to accept guidance from natural scientists, and to recognize that economic valuation is not always consistent with broader public values. For the student of economics, an understanding of the workings of economic tools must be accompanied by good judgment regarding when and how to use them.

[32] For a more extensive discussion of ecological economics, see Costanza, Ecological Economics (1991) and Krishnan, Harris, and Goodwin, A Survey of Ecological Economics (1995).

KEY CONCEPTS

Agroecosystems: a system of agricultural production in which crop output is integrated with a diverse ecological system.

Aquaculture: raising fish in controlled conditions for harvest.

Avoided costs: costs which can be avoided by environmental preservation or improvement.

Benefit/cost ratio: a ratio of total benefits over total costs; a ratio greater than one indicates net benefits.

Bequest value: the value people place on the knowledge that a resource will be available for future generations.

Biosphere: all areas on earth that contain life forms, including air, soil, land, and water.

Business as usual: a policy of maintaining the status quo; for example estimates of the level of greenhouse gas emissions if no policy measures are taken to counteract global climate change.

Bycatch: fishery catch that is discarded because it is undersized or non-marketable.

Common property resources: a resource that is not subject to private ownership and is available to all, such as a public park or the oceans.

Congestion threshold: the level of density or concentration of users such that the property of non-rivalry no longer applies to a good.

Consumer surplus: the benefits consumers receive from a product in excess of the amount they pay for it.

Contingent valuation: an economic tool that uses surveys to question people regarding their willingness to pay for a good or service such as the preservation of hiking opportunities or air quality.

Cost-benefit analysis: a tool for policy analysis that attempts to monetize all the costs and benefits of a proposed action to determine the net benefit.

Cost-effectiveness analysis: a policy tool that determines the least-cost approach for achieving a given goal.

Club goods: goods that require an “access-right” to be enjoyed, but can be consumed jointly by all the authorized users.

Discounting: the concept that future benefits or costs should not count as much as current benefits or costs.

Discount rate: the annual rate that future benefits or costs are discounted relative to current benefits or costs.

Ecolabeling: a label on a good that provides information concern the environmental impacts that resulted from the production of the good.

Ecological costs: damages to ecosystems that may be difficult to measure in monetary terms.

Ecological economics: a economic perspective that views the economic system as a subset of the broader ecosystem and subject to biophysical laws.

Ecological paradigm: a viewpoint based on the science of ecology that stresses the health and survival of ecosystems.

Ecology: the science that studies the interactions among living things.

Economies of scale: an expanded level of output increases returns per unit of input.

Economic efficiency: an allocation of resources that maximizes net social benefits; perfectly competitive markets in the absence of externalities are efficient.

Economic paradigm: a viewpoint that relies on environmental economics and emphasizes maximizing the welfare of humans, even if this means harming the environment.

Economic rent income that accrues to the owner of a scarce resource

Ecosystems: a relatively self-contained entity including the living things in an environment along with their habitat.

Efficiency: the use of resources in a way that does not involve any waste. Inputs are used in such a way that they yield the highest possible value of output, or a given output is produced using the lowest possible value of inputs.

Elasticity of demand: the sensitivity of quantity demanded to prices; an elastic demand means that a proportional increase in prices results in a larger proportional change in quantity demanded; an inelastic demand means that a proportional increase in prices results in a smaller proportional change in quantity demanded.

Environmental economics: economics that applies the techniques of economic analysis, such as valuation and cost-benefit analysis, to environmental and resource issues.

Excise tax: a tax imposed on the production or sale of a good or service.

Excludable: the characteristic goods where use of the good by one person exludes the potential for use by others.

Existence value: the value people place on a resource that they do not intend to ever use, such as the benefit one obtains from knowing an area of rain forest is preserved even thought he or she will never visit it.

Externality: an effect of a market transaction that changes the utility, positively or negatively, of those outside of the transaction.

Free-riders: people who avoid paying for a resource when the benefits they obtain from the resource are unaffected by whether they pay; results in the undersupply of public goods.

Global climate change: the changes in global climate, including temperature, precipitation, and storm frequency and intensity, that result with changes in the concentrations of greenhouse gases in the atmosphere.

Global commons: global common property resources such as the atmosphere and the oceans.

Global warming: the increase in average global temperature as a result of emissions from human activities.

Greenhouse effect: the effect of certain gases in the earth's atmosphere trapping solar radiation, resulting in an increase in global temperatures and other climatic impacts.

Greenhouse gases: gases such as carbon dioxide and methane whose atmospheric concentrations influence global climate by trapping solar radiation.

Green subsidies: subsidies on a good or service based on the reduction of environmental impacts.

Green taxes: taxes based on the environmental impact of a good or service.

Individual transferable quotas (ITQ's): tradable rights to harvest a resource, such as a permit to harvest a particular quantity of fish.

Industrial ecology: the application of ecological principles to the management of industrial activity.

Law of the Sea: a 1982 international treaty regulating marine fisheries.

Local and regional air pollutants: pollutants that cause adverse impacts only within the area where they are emitted.

Marginal private benefits: the additional market benefits obtained by consumers by purchasing an additional unit of a good or service.

Marginal private costs: the additional market costs of producing an additional unit of a good or service.

Marginal social benefits: the additional benefits obtained by everyone in society by the provision of an additional unit of a good or service.

Marginal social costs: the additional costs that must be borne by all members of society associated with the production of an additional unit of a good or service.

Market failure: the failure of certain markets to provide a socially efficient allocation of resources.

Maximum sustainable yield: the maximum quantity of a natural resource that can be harvested annually without depleting the stock or population of the resource.

Monoculture: an agricultural system involving the growing of the same crop exclusively on a piece of land year after year.

Negative externalities: harmful side effects, or unintended consequences, of economic activity that affect persons, or entities (such as the environment) that are not among the economic actors directly responsible for the activity.

Non-excludable: a characteristic of goods where the one person's use of the good does not prohibit others from using the good also.

Nonrenewable resource: resources that are available in a fixed supply, such as metal ores and oil.

Non-rival: goods that can be used by more than one user at a time.

Non-use values: values people obtain without actually using a resource; non-use values include existence, option, and bequest values.

Open access: a resource that offers unrestricted access such as an ocean fishery or the atmosphere.

Option value: the value people place on the maintenance of future options for resource use.

Paradox of aggregation: a situation where every user of a resource attempts to obtain more for himself or herself but this results in less for everyone.

Paradigm: a vision of the world that corresponds to a certain set of values and principles.

Pigovian tax: a per-unit tax set equal to the external damage caused by an activity, such as a tax per ton of pollution emitted equal to the external damage of a ton of pollution.

Pollution tax: a per-unit tax based on the level of pollution.

Positive externality: an effect of a market transaction that increases the welfare of those outside of the transaction.

Precautionary principle: the view that policies should account for uncertainty by taking steps to avoid low-probability but catastrophic events.

Present value: the current value of a steam of future costs and/or benefits; a discount rate is used to convert future costs and/or benefits to present values.

Preventive measures: the contrasting perspectives of primarily trying to prevent adverse environmental impacts or mainly trying to adapt to those impacts once they occur.

Private good: a good that is both rival and excludable.

Private optimum: the optimal allocation or production of a resource based on market behavior.

Producer surplus: the excess (summed over all the sellers in a market) of the amounts sellers actually receive, over the amounts that would make them just willing to supply the good or service.

Public good: goods that are available to all (non-exclusive) and whose use by one person does not reduce their availability to others (non-rival).

Reactive measures: measures dealing with the consequences of the greenhouse effect and trying to minimize their impact.

Regulation: a policy where every company or individual has to meet the same standard regardless of cost.

Renewable resource: a resource that is supplied on a continuing basis by ecosystems; renewable resources such as forests and fisheries can be depleted through exploitation.

Revenue-neutral tax shift: policies that are designed to balance tax increases on certain products or activities with a reduction in other taxes, such as a reduction in income taxes which offsets a carbon-based.

Rival: goods whose use is limited to one user at a time.

Sink function: is the natural environment's ability to absorb and render harmless the waste by-products of human activity.

Social optimum: an allocation of resources that maximizes net social benefits (equal to social benefits minus social costs).

Source function: is the natural environment's ability to make available for human use the services and raw materials that we need.

Subsidy: government assistance to an industry or economic activity; subsidies can be direct, through financial assistance, or indirect, through protective policies.

Sustainability (of ecosystems): management of natural resources such that natural capital remains constant over time.

Systems theory: a broad-based management approach that considers the linkages among various components of a system.

Tradable pollution permits: tradable permits that allow a firm to emit a certain quantity of a pollutant.

Tragedy of the commons: the tendency for common property resources to be over-exploited because no one has an incentive to conserve the resource while individual financial incentives promote expanded exploitation.

Transferable permit: tradable permit that allows a firm to emit a certain quantity of a pollutant.

Use value: the value that people place on the use of a good or service.

Willingness to accept: the minimum amount of money people would accept as compensation for an action that reduces their utility.

Willingness to pay: the maximum amount of money people are willing to pay for a good or service that increases utility.

REFERENCES

Brown, Lester R., Michael Renner and Christopher Flavin. Vital Signs 1998. (Worldwatch Institute.) New York: W.W. Norton, 1998.

Cline, William R.,1992. The Economics of Global Warming. Washington D.C.: Institute for International Economics.

Costanza, Robert (ed.), 1991. Ecological Economics: The Science and Management of Sustainability. New York: Columbia University Press.

Dower, Roger C. and Zimmerman, Mary. 1992. The Right Climate for Carbon Taxes, Creating Economic Incentives to Protect the Atmosphere. Washington D.C.: World Resources Institute.

Duchin, Faye and Lange, Glenn-Marie, 1994. The Future of the Environment, Ecological Economics and Technological Change. Oxford: Oxford University Press.

Fankhauser, Samuel. 1995. Valuing Climate Change: the economics of the greenhouse. London: Earthscan publications.

Fankhauser, Samuel. 1994. "The Social Costs of Greenhouse Gas Emissions: An Expected Value Approach", *Energy Journal,* Vol 15 (2). pp. 157-84.

Gardner, Gary. 1996. "Preserving Agricultural Resources" in Brown et al. (eds.), State of the World 1996: A Worldwatch Institute Report on Progress Toward a Sustainable Society. New York: W.W. Norton.

Gelbspan, Ross. 1998. "A Good Climate for Investment," *Atlantic Monthly*, June 1998.

Hardin, Garrett. 1968. "The Tragedy of the Commons", *Science*, #162.

Intergovernmental Panel on Climate Change (IPCC), 1996. Climate Change 1995, Volume 2: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses. Cambridge, UK: Cambridge University Press.

International Energy Agency, 2002. World Energy Outlook 2002. Paris, France

Krishnan, Rajaram, Jonathan M. Harris, and Neva R. Goodwin (eds.), 1995. A Survey of Ecological Economics. Washington, D.C.: Island Press.

Manne, Alan S. and Richels, Richard G., 1992. Buying Greenhouse Insurance: The Economic Costs of CO2 Emissions Limits. Cambridge, Mass: The MIT Press.

McGinn, Anne Platt, 1998. Rocking the boat: conserving fisheries and protecting jobs. Worldwatch Paper #142. Washington, D.C.: Worldwatch Institute.

Nordhaus, William D., 1993. "Reflections on the Economics of Climate Change," *Journal of Economic Perspectives*, Fall 1993.

Ostrom, Vincent and Elinor, 1977. "Public Goods and Public Choices", in Salvas (ed.), Alternatives for delivering public services; toward improved performance. Boulder (Colorado): Westview Press.

Poterba, James. 1993. "Global Warming Policy: A Public Finance Perspective," *Journal of Economic Perspectives*, Fall 1993.

Quarto, Alfredo and Reed, Betsy, 1993. "Prawn fever, Thailand's high-stakes jumbo shrimp business", *Dollars & Sense*, July/August 1993.

Repetto, Robert and Austin, Duncan, 1997. The Costs of Climate Protection: A Guide for the Perplexed. Washington, D.C.: World Resources Institute.

Roodman, David M., 1997. Getting the signals right: tax reform to protect the environment and the economy. Worldwatch Paper # 134. Washington, D.C.: Worldwatch Institute.

Socolow R., C. Andrews, F. Berkhout, and V. Thomas (eds.), 1994. Industrial Ecology and Global Change. Cambridge, UK: Cambridge University Press.

Tuxill, John. 1998. Losing strands in the web of life: vertebrate declines and the conservation of biological diversity. Worldwatch paper #141. Washington D.C.: Worldwatch Institute.

DISCUSSION QUESTIONS

1- What are the positive externalities associated with land conservation? How about reforestation? What kinds of external benefits are created in each case, and who receives them? What does this suggest about government policies toward land conservation and reforestation? Is it reasonable to ask people to pay local taxes to support land conservation? How about state or national taxes?

2- China has started to build the largest dam ever on the Yangtse River: the Three Gorges Dam. The dam would create a reservoir approximately 400 miles long, permanently submerge approximately 150,000 acres, including 1500 factories, at least 160 towns and 16 archeological sites and require the resettlement of 1.3 million people. It is designed to generate over 18,000 megawatts of electricity, providing electricity to rural Chinese provinces, and to provide flood management and improved navigation for the upper Yangtse. However, scientists have questioned the effectiveness of the proposed dam for flood control, and suggested that it may create new problems of reservoir siltation.

   If your assignment were to undertake a cost-benefit of the project for the World Bank, in order to recommend whether or not to invest in the project, how would you proceed? What would your recommendation be based on?

3- How manageable and practical do you think an international market for trading emissions of CO_2 would be? What major obstacles to a smooth functioning of such a market could you foresee? What would be the advantages of such a market if it worked?

4- The fisheries in the Gulf of Maine are severely over-fished, but there is significant local opposition to government imposition of catch limits. Fishers argue that such limits will force them into bankruptcy. What kinds of policies would you recommend, taking into account social, economic, and environmental factors?

PROBLEMS

1) Consider the following supply and demand schedule for steel:

Price per ton ($)	20	40	60	80	100	120	140	160	180
Q_D (million tons)	200	180	160	140	120	100	80	60	40
Q_S (million tons)	20	60	100	140	180	220	260	300	340

Pollution from steel production is estimated to create an external cost of $60 per ton.

Show the external cost, market equilibrium and social optimum on a graph. What kinds of policies might help to achieve the social optimum? What would be the effects of these policies on the behavior of consumers and producers? What would be the effect on market equilibrium price and quantity?

2) Suppose that under the terms of an international agreement, U.S. CO_2 emissions are to be reduced by 200 million tons, and those of Brazil by 50 million tons.

Here are the policy options that the U.S. and Brazil have to reduce their emissions:

USA:

Policy options	Total emissions reduction (million tons carbon)	Cost ($ billion)
A: Efficient machinery	60	12
B: reforestation	40	20
C: Replace coal fueled power plants	120	30

Brazil:

Policy options	Total emissions reduction (million tons carbon)	Cost ($ billion)
A: Efficient machinery	50	20
B: Protection Amazon forest	30	3
C: Replace coal fueled power plants	40	8

a) What are the most efficient policies for the U.S. and Brazil to use in meeting their targets? What will be the cost to each nation if they must operate independently?

b) Suppose a market of transferable permits allows the U.S. and Brazil to trade permits to emit CO_2. Who has an interest in buying permits? Who has an interest in selling permits? What agreement can be reached between the U.S. and Brazil so that they can meet the overall emissions reduction target of 250 at the least cost? Can you estimate a range for the price of a permit to emit one ton of carbon? (Hint: calculate the average cost per unit for each reduction policy.)

3) Suppose that the annual consumption of an average American household is 2000 gallons of oil in heating and transportation and 2000 ccf (hundred cubic feet) of gas in cooking. Using the figures given in table 3 on the effects of a carbon tax, calculate how much an average American household would pay per year if a tax of $10 per ton of carbon was implemented.

Considering that there are around 100 million households in the United States, what would be the revenue to the U.S. Treasury of such a carbon tax? What would be the national revenue of a tax of $100 per ton of carbon? How might such revenues be used? What would the impact be on the average family?

4) Taking the example of the paper production, analyze the industry according to the principles of industrial ecology. Draw the basic scheme of production of books, newspapers, etc… from paper made out of timber, including the loop of paper collection and recycling. Is there an economic logic that supports paper recycling? What kinds of economic incentives and institutions would be necessary to promote recycling?