Microeconomics and the Environment

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A GDAE Teaching Module on Social and Environmental Issues in Economics

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NOTE – terms denoted in **bold face** are defined in the **KEY TERMS AND CONCEPTS** section at the end of the module.

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1. INTRODUCTION

There are many controversies over environmental issues. Should oil drilling be permitted in areas that provide important wildlife habitat? Should developing countries reduce deforestation, at the risk of limiting economic development? Should society invest heavily in renewable energy to prevent global climate change?

Resolving these controversies requires us to draw upon various academic disciplines, such as ecology, political science, ethics, and sociology. Increasingly, the discipline of economics is at forefront of many environmental debates.

A common viewpoint is that economic goals generally conflict with environmental goals. But, as we will show in this module, this is not necessarily true. In fact, in many instances a strong *economic* case can be made for environmental protection. The Nobel prize-winning economist Paul Krugman has written that:

> …my unscientific impression is that economists are on average more pro-environment than other people of similar incomes and backgrounds. Why? Because standard economic theory automatically predisposes those who believe in it to favor strong environmental protection.[1]

The module is organized into five additional sections:

- In the second section, we present different economic perspectives on environmental issues. Different economists approach the analysis of environmental issues in different ways. An understanding of these differences is important to gain insight into why economists sometimes disagree about environmental policies.
- Next, we explore the main ways standard economic theory is applied to environmental issues. One application is the theory of environmental externalities. The other applications concern the management of common property resources and public goods. In all these cases, we'll see that unregulated markets fail to produce the best outcomes for society, and that some form of government regulation is necessary.
- In the fourth section, we study how economists "value" the environment in monetary terms. Through the technique of cost-benefit analysis, economists seek to determine which policies provide the greatest overall benefits to society. We consider both the advantages and limitations of this approach for guiding policy decisions.
- In the fifth section, we summarize different environmental policy options. We'll see that there is no universal "best" approach to regulating the environment. Different approaches are needed for different situations.
- Finally, we apply the economic concepts discussed in the module to three important policy issues: fisheries management, agriculture, and climate change. In each case, we'll see that economic policy tools can be used to promote more environmentally sustainable outcomes.

[1] Krugman, Paul. 1997. "Earth in the Balance Sheet: Economists Go for the Green," *Slate*, April 18, 1997.

2. ECONOMIC PERSPECTIVES ON THE ENVIRONMENT

The economic analysis of environmental issues can be approached from two different (though sometimes overlapping) perspectives, environmental economics and ecological economics. **Environmental economics**[2] applies insights from traditional economics to environmental issues. We will explore several of these insights in Section 3 of this module, such as the analysis of environmental externalities. Environmental economists recognize that the environment has value, but tend to focus on environmental values in human terms, specifically those that can be measured monetarily. **Ecological economics** places greater emphasis on sustainability based on ecosystem integrity, stressing that all economic activity occurs within the broader biological and physical systems that support life. Thus, ecological economists are more likely to see the value of nature as something extending beyond any monetary estimates.

There can be significant overlap between environmental and ecological economics. Some of the differences between the two approaches can be viewed as variations along a continuum rather than fundamental differences. But we can summarize their differences by considering how they each address three important topics: defining sustainability, defining value, and considering limits to growth.

2.1 Defining Sustainability

While the importance of sustainability is widely acknowledged, there is no universally-accepted definition of it. According to a standard environmental economics approach, sustainability is defined as providing future generations of humans the capacity to be at least as well-off as the current generation. This perspective of sustainability, sometimes referred to as **weak sustainability**, essentially seeks to maintain at least a constant level of overall human well-being over time. According to weak sustainability, **natural capital** (such as the quality of air and water, the amount of wildlife habitat, and effective nutrient cycling) is largely substitutable with **produced capital** (such as factories, roads, and schools) and **human capital** (such as knowledge and productive skills). As long as the overall level of capital is maintained over time, weak sustainability is achieved.[3]

So, for example, the loss of an area of wetlands (a reduction in natural capital) can potentially be offset by an increase in other types of capital (such as building a new hospital or increasing educational opportunities). Another way to view weak sustainability is that human well-being depends on the environment, but well-being also depends many other factors. Well-being can be maintained despite a reduction in natural capital as long as equivalent compensation is provided. Compensation may be something physical, such as a road or building, or it can be something intangible such as knowledge.

Note that weak sustainability implies that we need a metric for comparing different types of capital. For example, how do we know if building a new hospital is sufficient compensation for the loss of 100 acres of wetlands? Environmental economics tends to rely upon money as a common unit

[2] Bolded key terms are defined at the end of the module.
[3] The use of terms such as "weak" and "strong" does not imply that one is better than the other. These terms refer to the specific assumptions made in defining different concepts of sustainability.

to compare different types of capital. Thus, techniques are required for converting environmental benefits into monetary units. We will discuss some of these techniques in Section 3.

Ecological economics tends to advocate for **strong sustainability**, which does not consider natural capital substitutable with other types of capital. Instead, the objective of strong sustainability is to maintain the overall level of natural capital over time. Different types of natural capital may be considered substitutes, but only if important ecological functions can be adequately maintained. For example, cutting down a forest or filling a wetland may be consistent with strong sustainability as long as new trees of equivalent ecological value are planted or new wetlands are created elsewhere.

Like weak sustainability, strong sustainability requires a metric that will indicate whether compensation is sufficient. While natural capital can be measured in monetary terms for purposes of weak sustainability assessment, ecological economists often favor physical measures in assessing strong sustainability. For example, the biological productivity of particular habitats is sometimes used to measure their ecological value. Based on this approach, habitats such as wetlands and tropical rainforests are particularly productive, while tundra and deserts are less productive.

2.2 Defining Value

The differences between environmental and ecological economics in defining sustainability translate to different conceptions of "value." As environmental economics defines sustainability based on human well-being, the environment has value only to the extent that it is useful to humans. Some of these uses may involve extracting natural resources, such as harvesting trees or fish, but humans may also place value on passive uses of the environment such as watching a sunset or knowing that unspoiled places exist in the world.

The key concept in defining value according to environmental economics is the **willingness-to-pay (WTP) principle**. This states that the economic value of something is equivalent to the maximum amount of money people are willing to pay for it. If I am willing to pay, say, a maximum of $50 to ensure the protection of an endangered species, then $50 is the value of that species to me. In some cases, natural resources are sold in markets, and we can ascertain their economic value by studying such markets. But there are no markets for such things as clean air, endangered species, or National Parks. Environmental economists have developed various techniques for measuring economic values in these instances, as we'll discuss further in Section 4.

An advantage of the willingness-to-pay principle is that is allows economists to compare the relative value of different uses of a natural resource. The willingness-to-pay principle can also be considered as democratic in the sense that the values of all affected individuals should be elicited when making policy decisions. As long as someone is willing to back up his or her preferences with a willingness to pay amount, then their WTP will be counted in decision-making. However, we need to recognize that one's willingness-to-pay may be directly related to one's ability to pay. So instead of operating under the democratic principle of "one person, one vote," the willingness-to-pay principle is based on "one dollar, one vote."

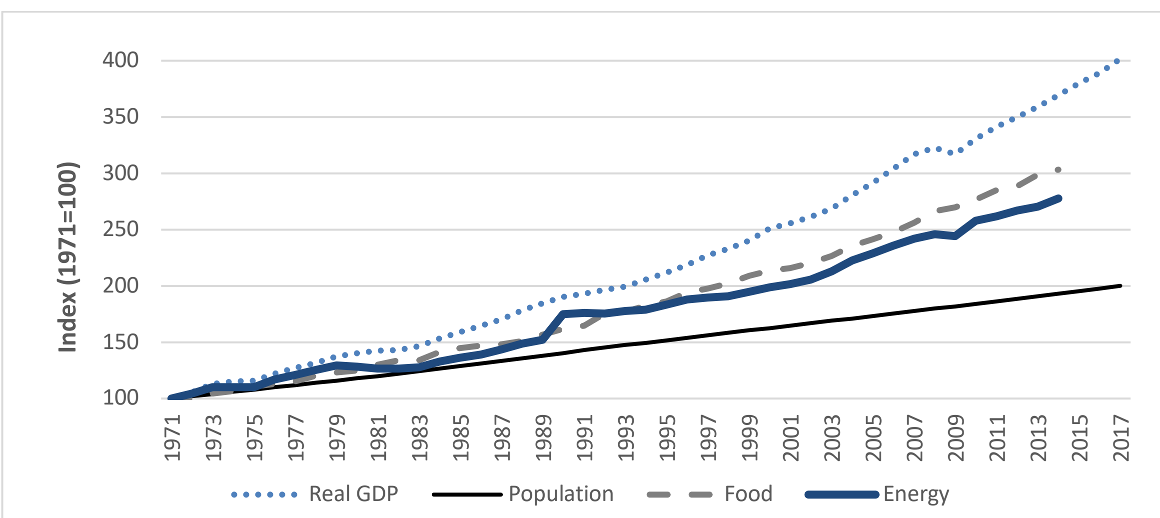
Some ecological economists also assess the value of natural capital using the willingness-to-pay principle. But ecological economists are also more likely to emphasize the limitations of this approach. Some kinds of natural capital such as ecosystems and species may have **inherent value** – a value in itself regardless of whether humans are willing to pay for it. Inherent value may derive from an ethical foundation of natural rights. Some ecological economists argue that each species has an inherent right to exist, and that driving a species to extinction, regardless of the potential economic benefits, is never justifiable. More broadly, the functions of complex ecosystems are essential to maintain life on earth, and degrading these ecosystems threatens to undermine any short-term productivity gains. These crucial ecosystem functions are unlikely to be captured by a willingness-to-pay metric.

Of course, inherent value and ecological complexity are difficult, if not impossible, to measure in a quantitative sense. Inherent value is also a subjective concept, based on individual notions of rights and fairness. A strictly economic principle would be to choose policy options that provide the maximum human benefits over time, based on the willingness-to-pay principle. But ecological economists may recommend other policies that instead maintain important ecological functions or satisfy certain ethical criteria such as providing basic needs and reducing inequality – issues that become more pressing in the light of the next topic, possible limits to economic growth.

2.3 Limits to Growth

The final difference we'll consider between environmental and ecological economics concerns whether there are limits to economic growth. We can see in Figure 1 that global economic production, measured as total GDP and adjusted for inflation, has increased by a factor of nearly 3.5 since 1971. Can such growth continue without approaching or exceeding ecological limits?

Figure 1. *Change in Global Economic Production, Energy Production, Food Production, and Population, 1971-2017*



Source: World Bank, World Development Indicators online database.

In 1798 the British economist Thomas Malthus published his famous *Essay on the Principle of Population*, in which he theorized that human population growth would tend to exceed food supplies, keeping the majority of people in a continual state of poverty. However, the original **Malthusian hypothesis** proved to be incorrect – in general, food production in Europe grew faster than population, contributing to an overall increase in average living standards.

More recently, starting in the 1960s, some researchers warned of an updated version of the Malthusian hypothesis, in which natural resource constraints and ecological degradation threaten to slow or even reverse centuries of economic progress. As we see in Figure 1, not only has economic production continued to outpace population growth, but per capita food and energy consumption are now higher than at any time in human history. But these data do not indicate the importance of issues such as ecological damage or global climate change, which have gained more attention as potential factors limiting economic growth potential. The data also does not reflect the uneven distribution of food production and energy resources across the globe.

As we mentioned above, environmental economics considers natural capital to be largely substitutable with produced and human capital. So even as some natural resources have been degraded over time, advances in technology have fostered more efficient resource use and invented substitutes. For example, as global oil production from traditional wells has leveled off in recent years, new technologies have expanded oil production from non-conventional sources such as tar sands and oil shales.

Ecological economists tend to be more concerned about the overall scale of human economic activities and their impact on the environment. Herman Daly, widely considered to be the founder of ecological economics, has noted that an economic system designed for continual growth is fundamentally incompatible with a fixed biosphere. He has written that "as long as our economic system is based on chasing economic growth above all else, we are heading for environmental, and economic, disaster."[4]

Some ecological economists have devised methods for assessing the sustainability of humanity's ecological impacts. One such measure, the ecological footprint, suggests that we are already in a state of global "overshoot," in which humanity now requires the equivalent of 1.5 Earths to supply its resources and adequately assimilate its wastes.[5] This not only implies that further economic growth based on expanded resource use is unsustainable, but also that humanity's footprint needs to be scaled back significantly from current levels. Thus, ecological economists are more likely to accept the idea that natural resource constraints infer limits to economic growth, including the limited availability of nonrenewable resources, land, and the absorptive capacity of the atmosphere.

Finally, ecological economists are more likely to support policy action even when a scientific consensus is lacking, if a failure to act could result in catastrophic impacts. Referred to as the **precautionary principle**, this approach implies that policy should err on the side of caution, even when the risks of a catastrophic outcome appear to be low. For an example of how the precautionary principle can be applied to a policy situation, see Box 1.

[4] Herman Daly. 2008. "On a Road to Disaster," *New Scientist*, vol. 200: 46-47.
[5] Global Footprint Network. 2012. *Global Footprint Network 2012 Annual Report*. Geneva, Switzerland.

BOX 1. THE PRECAUTIONARY PRINCIPLE AND CHEMICALS POLICY

The United States Congress passed the Toxic Substances Control Act (TSCA) in 1976 to regulate the production and sale of chemicals. At the time, there were approximately 62,000 chemicals in commercial use in the country. TSCA effectively allows the continued use of these chemicals unless the U.S. Environmental Protection Agency (EPA) can prove, on a case-by-case basis, that a particular chemical is unsafe. Chemical manufacturers were not required to provide the EPA with any data regarding a chemical's toxicity unless requested. While the EPA has expressed concerns about the safety of 16,000 chemicals, due to resource limitations the agency has reviewed the risks of only a couple of thousand, and fully tested only about 200.

For the approximately 23,000 new chemicals introduced since the passage of TSCA, manufacturers are required to notify the EPA of their intention to produce the chemical, and to provide any toxicity data that are available. But as there are no minimum data requirements, the law creates an incentive for manufacturers to avoid rigorous testing of new chemicals. Under TSCA, the burden of proof is clearly upon the EPA to demonstrate a chemical is unsafe.

In sharp contrast to chemicals policy in the United States, the European Union's ambitious chemicals policy, REACH (Registration, Evaluation, Authorization, and Restriction of Chemical Substances), went into effect in 2007, and was phased in over an 11 year period. According to the text of REACH, the law is "underpinned by the precautionary principle."

Under REACH the burden of proof regarding a chemical's safety is on the chemical manufacturer, not the regulating agency. If a manufacturer cannot demonstrate the safety of the chemical, its use may be restricted or banned. REACH's requirements apply to all chemicals produced in or imported into the EU. The initial focus has been on testing those chemicals produced in high volumes (greater than 1000 metric tons per year) or of the greatest concern. By 2018 all chemicals produced in excess of one metric ton annually were required to meet REACH's requirement that the chemical be registered, evaluated for safety, and been approved for manufacture.

Sources: Wilson, Michael P., and Megan R. Schwarzman. 2009. "Health Policy: Toward a New U.S. Chemicals Policy: Rebuilding the Foundation to Advance New Science, Green Chemistry, and Environmental Health," Environmental Health Perspectives, 117(8): 1202-1209; European Commission, 2006. "Environmental Fact Sheet: REACH – A New Chemicals Policy for the EU," (February).

3. APPLICATIONS OF ECONOMIC THEORY TO THE ENVIRONMENT

Standard economic theory demonstrates that under certain assumptions unregulated markets, guided by the forces of supply and demand, allocate resources in an efficient manner. In other words, market outcomes maximize the net benefits obtained by buyers and sellers. But when we consider the environmental impacts of market activity, the conclusion that unregulated outcomes are efficient is no longer valid. Using standard economic theory, we will show below how government intervention in markets can actually increase economic efficiency while also reducing environmental impacts.

In this section we also analyze the management of natural resources that tend to not be privately owned, such as ocean fisheries, groundwater, or the atmosphere. We'll see that market forces generally lead to over-exploitation of these resources. In these cases, a solution that is both economically efficient and ecologically sustainable normally requires a policy intervention.

3.1 Environmental Externalities

The concept of **externalities** is central to environmental economics. In economic terms, a market transaction creates an externality when it impacts someone other than the buyer and the seller.[6] For example, a firm which pollutes a river while manufacturing paper harms those who use the river for fishing, swimming, or drinking water. This **negative externality** might be measured in monetary terms – for example, the lost revenues of professional fishers. Some damages may be more difficult to measure but no less important – for example, health costs caused by toxins in the water, or the 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. These 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 in the area, 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 produces honey.

3.2 Economic Analysis of Negative Externalities

In a basic economic analysis of markets, supply and demand curves represent costs and benefits. A supply curve tells us the private **marginal costs** of production—in other words, the costs of producing one more unit of a good or service. Meanwhile, a demand curve can be considered a private **marginal benefits** curve because it tells us the perceived benefits consumers obtain from consuming one additional unit. The intersection of demand and supply curves gives the **market equilibrium**, as shown in Figure 2 which presents a hypothetical market for automobiles. Notice that at the equilibrium price (P_M) the marginal benefits just equal the marginal costs. This equilibrium represents a situation of **economic efficiency** since it maximizes the total benefits to the buyers and sellers in the market – if there are no externalities.[7]

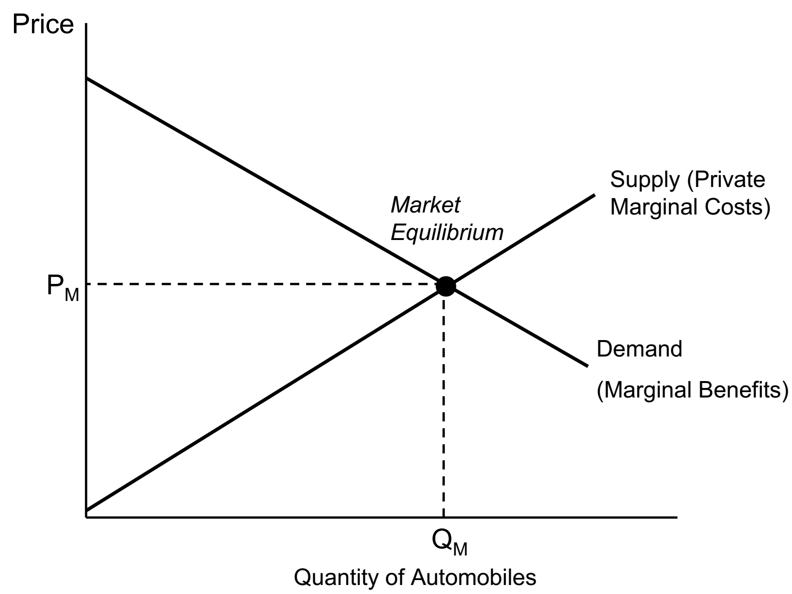
But this market equilibrium does not tell the whole story. The production and use of automobiles create numerous negative externalities. Automobiles are a major contributor to air pollution, including both urban smog and regional problems such as acid rain. In addition, their emissions of carbon dioxide contribute to global warming. Automobile oil leaked from vehicles or disposed

[6] For this reason, sometimes externalities are referred to as "third-party effects."

[7] Benefits to buyers are known as **consumer surplus** and benefits to sellers are called **producer surplus.**

of improperly can pollute lakes, rivers, and groundwater. The production of automobiles uses toxic materials which may be released to the environment as toxic wastes. The road system required for automobiles paves over many acres of rural and open land, and salt runoff from roads damages watersheds.

Figure 2. *The Market for Automobiles*



Where do these various costs appear in Figure 2? The answer is that they do not appear at all. Thus, the market overestimates the net social benefits of automobiles because the costs of the negative externalities are not considered. We need to expand our analysis so it includes all the costs and benefits of automobiles, not just the market benefits.

In order to incorporate a negative externality into our market graph, it needs to be represented in monetary terms. Yet assigning a monetary value to environmental damages is not a straightforward task. How can we reduce the numerous environmental effects of automobiles to a single dollar value? There is no clear-cut answer to this question. In some cases, economic damages may be identifiable. For example, if road runoff pollutes a town's water supply, the cost of water treatment gives at least one estimate of environmental damages. This measure, however, doesn't include less tangible factors such as damage to lake and river ecosystems.

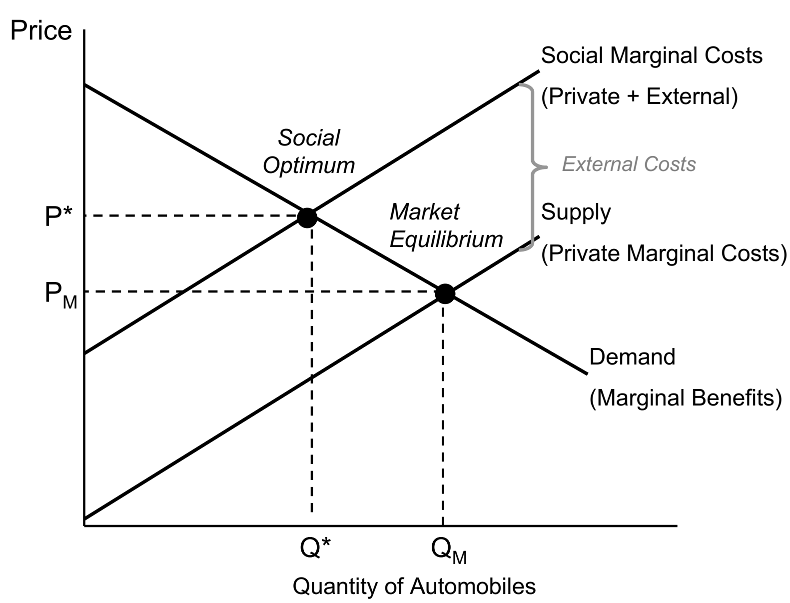
If we can identify the human health effects of air pollution, the resulting medical expenses will give us another monetary damage estimate, but this doesn't capture the aesthetic damage done by air pollution. Smoggy air limits visibility, which reduces people’s welfare even it doesn’t have a measurable effect on their health. Issues such as these are difficult to compress into a monetary indicator. Yet if we don't assign some monetary value to environmental damages, the market will automatically assign a value of zero, since none of these issues are directly reflected in consumer and producer decisions about automobiles.

Once we have a reasonable estimate of these external costs, how can these be introduced into our supply and demand analysis? Recall that a supply curve tells us the marginal costs of producing a good or service. The supply curve in Figure 2 shows what it costs automobile companies to produce vehicles. But in addition to the normal private production costs, we now also need to consider the environmental costs—the costs of the negative externalities We can add the externality costs to the production costs to obtain the total social costs of automobiles. This results in a new cost curve which we call a **social marginal cost** curve. This is shown in Figure 3.

The social marginal cost curve is above the original market supply curve because it now includes the externality costs. Note that the vertical distance between the two cost curves is our estimate of the externality costs of automobiles, measured in dollars. In this simple case, we have assumed that the external costs of automobiles are constant. Thus, the two curves are parallel. This as assumption helps to simplify our analysis, but in reality, the external costs of automobiles may change depending on the number of automobiles produced. Specifically, the external costs of an additional automobile are likely to increase when more automobiles are produced as air pollution exceeds critical levels and congestion becomes more severe. This would be represented a social marginal cost curve that slopes upward more steeply.

Considering Figure 3, is our market equilibrium still the economically efficient outcome? It is definitely not. To understand why, you can think of the social decision to produce each automobile to depend on a comparison of marginal costs and benefits. If the marginal benefit exceeds the marginal cost, considering all benefits and costs, then from the social perspective it makes sense to produce that automobile. But if the costs exceed the benefits, then it doesn't make sense to produce that automobile.

Figure 3. *The Market for Automobiles with Negative Externalities*



In Figure 3 we can see that it makes sense to produce the first automobile because the demand curve (reflecting the marginal benefits) is above the social marginal cost curve (reflecting the production and externality costs). Even though the first automobile creates some negative externalities, the high marginal benefits justify producing that automobile. This is true for each automobile produced up to a quantity of Q*. At this point, the marginal benefits equal the social marginal costs. But then notice that for each automobile produced beyond Q*, the social marginal costs are exceed the benefits. In other words, for each automobile produced above Q*, society is becoming worse off!

According to this analysis, the unregulated market outcome, at Q_M, results in a level of automobile production that is too high. We should only produce automobiles as long as the marginal benefits are greater than the social marginal costs. The optimal level of automobile production is thus Q*, not the market outcome of Q_M. Rather than producing the maximum benefits for society, the equilibrium outcome is inefficient in the presence of a negative externality. We can also see in Figure 3 that from the perspective of society, the market price of automobiles is too low—that is, it fails to reflect the true costs including the environmental impacts of automobiles. The efficient price for automobiles is P*.

3.3 Internalizing a Negative Externality

What can we do to correct this inefficient market outcome? The solution to our problem lies in getting the price of automobiles "right." The market fails to send a signal to consumers or producers that further production past Q* is socially undesirable. While each automobile imposes a cost upon society, neither the consumers nor the producers pay this cost. So, we need to "internalize" the externality so that these costs now enter into the market decisions of consumers and producers.

The most common way to internalize a negative externality is to impose a tax. This approach is known as a **Pigovian tax**, after Arthur Pigou, a well-known British economist who published his *Economics of Welfare* in 1920. It is also known as the **polluter pays principle**, since those responsible for pollution pay for the damages they impose upon society.

For simplicity, assume that the tax is paid by automobile manufacturers.[8] For each automobile produced, they must pay a set tax to the government. But what is the proper tax amount? By forcing manufacturers to pay a tax for each automobile produced, we've essentially increased their marginal production costs. A pollution tax thus has the effect of shifting the private marginal costs upwards. The higher the tax, the more we would be shifting the cost curve upwards. If we set the tax exactly equal to the externality damage associated with each automobile, then the new marginal cost of production would equal the social marginal cost curve in Figure 3. This is the "correct" tax amount—the tax per unit should equal the externality damage per unit.[9] In other words, those responsible for pollution should pay for the full social costs of their actions.

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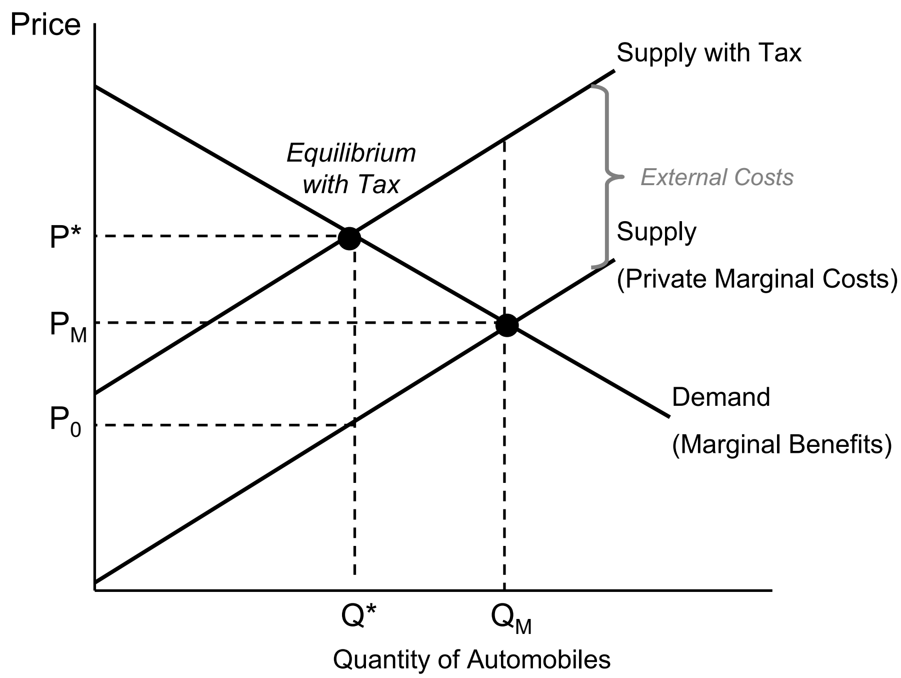
[8] If we imposed the tax on the consumer instead of the producer, we would reach the same result as we'll obtain here.

[9] Note that in our example, the externality damage is constant per automobile produced. If the externality damages weren't constant, we would set the tax equal to the marginal externality damage at the optimal level of production.

In Figure 4, the new supply curve with the tax is the same curve as the social marginal cost curve from Figure 3. It is the operative supply curve when producers decide how many automobiles to supply, because they now must pay the tax in addition to their manufacturing costs.

Figure 4. *Automobile Market with Pigovian Tax*



The new equilibrium results in a higher price of P* and a lower quantity of Q*. The tax has resulted in the optimal level of automobile production. In other words, automobiles are produced only to the point where the marginal benefits are equal to the social marginal costs. Also note that even though the tax was levied on producers, a portion of the tax is passed on to consumers in the form of a price increase for automobiles.[10] This causes consumers to cut back their automobile purchases from Q_M to Q*. From the point of view of achieving the socially optimal equilibrium, this is a good result. Of course, neither producers nor consumers will like the tax, since consumers will pay a higher price and producers will have lower sales, but from a social point of view we can say that this new equilibrium is optimal, or efficient, because it accurately reflects the true costs that automobiles impose on society.

Our story tells a convincing argument in favor of government regulation in the presence of negative externalities. The tax is an effective policy tool for producing a more efficient outcome for society.

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[10] Note that the price of automobiles did not rise by the amount of the tax. In Figure 4 the vertical distance between P_0 and P* equals the per-unit tax. But the price only rose from P_M to P*. So while some of the tax was passed on to consumers, automobile manufacturers also bear some of the burden of the tax in terms of lower profits.

But should the government always impose a tax to counter a negative externality? The production of nearly all goods or services is associated with some pollution damage. Does this mean that the government should tax *all* products on the basis of their environmental damage? Determining the appropriate tax on every product that causes environmental damage would be a monumental task. For example, we might impose a tax on shirts because the production process involves growing cotton, using petroleum-based synthetics, applying toxic dyes, etc. But we would theoretically need to set a different tax on shirts made with organic cotton, or those using recycled plastics, or even shirts of different sizes!

Rather than looking at the final consumer product, economists generally recommend applying Pigovian taxes as far "upstream" in the production process as possible. An **upstream tax** is imposed on raw materials and other inputs into production processes, such as the crude oil or raw cotton used to make a shirt. If we determine the appropriate Pigovian tax on cotton, then this cost will translate to a higher final selling price of a shirt. We could focus our taxation efforts on those raw materials that cause the most ecological damage. Thus, we might tax fossil fuels, various mineral inputs, and toxic chemicals. This limits the administrative complexity of tax collection, and avoids the need for estimating the appropriate tax for a multitude of products.

3.4 Positive Externalities

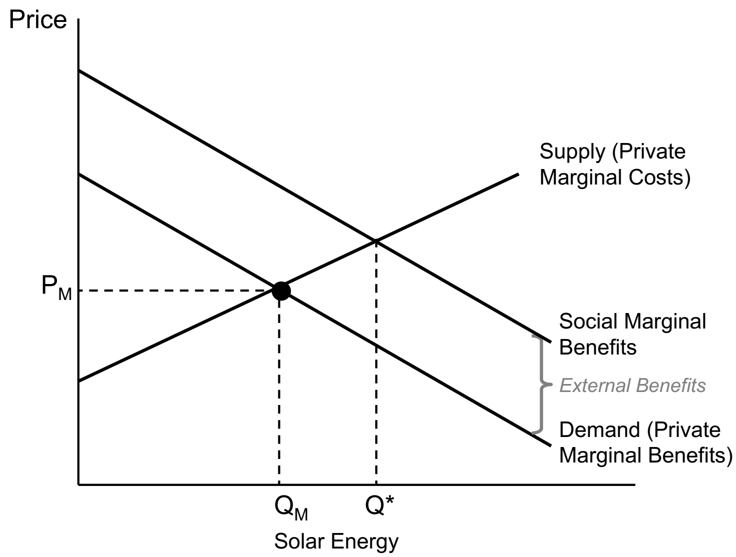
Just as it is in society's interest to internalize the social costs of pollution using Pigovian taxes, it is also socially beneficial to internalize the social benefits of activities that generate positive externalities. Just as with a negative externality, the free market will also fail to maximize social welfare in the presence of a positive externality. And for the same reason, a policy intervention will be required to reach the efficient outcome.

A positive externality is an additional social benefit from a good or service above the private, or market, benefits. Since a demand curve tells us the private marginal benefits, we can incorporate a positive externality into our analysis as an upward shift of the demand curve. This new curve represents the total social benefit of each unit.

Figure 5 shows the case of a good that generates a positive externality—solar panels. Each solar panel installed reduces emissions of carbon dioxide, and thus benefits society as a whole. The vertical distance between the market demand curve and the **social marginal benefits** curve is the positive externality per solar panel, measured in dollars. In this example, the social benefits are assumed to be constant per panel, so the two benefit curves are parallel.

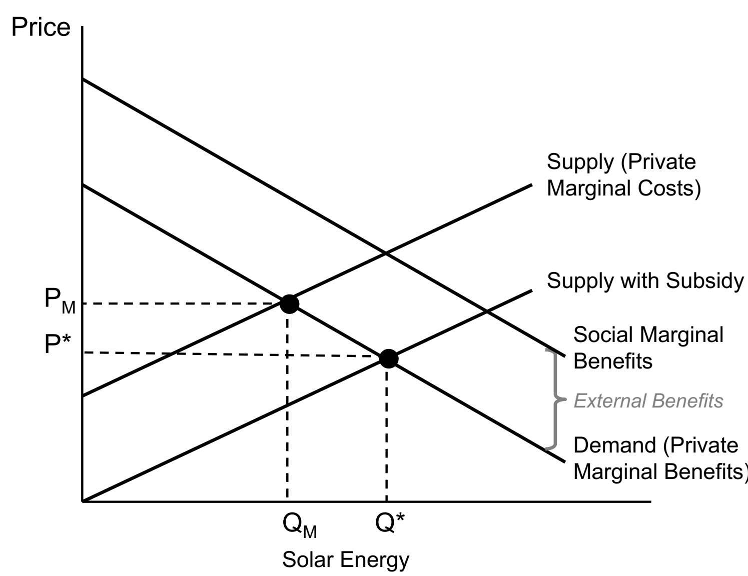
The market equilibrium price is P_M and quantity is Q_M. But notice in Figure 5 that between Q_M and Q*, marginal social benefits exceed the marginal costs. Thus, the optimal level of solar energy is Q* – where social marginal benefits just equal the marginal costs – not Q_M. We can therefore increase net social benefits by increasing the production of solar energy.

Figure 5. *The Market for Solar Energy with Positive Externalities*



In the case of a positive externality, the most common policy to correct the market inefficiency is a subsidy. A **subsidy** is a payment to producers to provide an incentive for them to produce and sell more of a good or service. The way to illustrate a subsidy in our market analysis is to realize that a subsidy effectively lowers the cost of producing something. A subsidy lowers the supply curve by the amount of the per-unit subsidy. In essence, a subsidy makes it cheaper to produce solar panels. The "correct" subsidy shifts the supply curve such that the new market equilibrium will be at Q*, which is the socially-efficient level of production. This is illustrated in Figure 6. The principle mirrors the use of a tax to discourage economic activities that create negative externalities—except that in this case we want to encourage activities that have socially beneficial side effects.

Figure 6. *Market for Solar Energy with a Subsidy Flow Model*



3.5 Public Goods and Common Property Resources

The above analysis shows that unregulated markets are not efficient in the presence of externalities. While private goods, such as automobiles, apples, and computers, are normally distributed through markets, economic analysis of other goods requires different models. In this section we consider the allocation of **common property resources** and **public goods**. These are resources and goods that are usually not privately owned, leading to different outcomes both in terms of economic equilibrium and environmental externalities.

Private goods are **excludable**, meaning that the legal owners of them can prevent other people from enjoying the goods' benefits. For example, if I am the owner of an automobile, I can legally prevent anyone else from using it. But many natural resources are **nonexcludable**, meaning that the benefits of these resources are available to anyone. For example, in absence of regulation an ocean fishery can be accessed by anyone, or the atmosphere is freely available to all as a repository of pollution.

Economists differentiate between public goods and common property resources. While both of these are nonexcludable, they differ in terms of whether multiple people can benefit from them at the same time. Public goods are **nonrival**, meaning that many people can enjoy these goods at the same time, without affecting the quantity or quality of the good available to others. An example of a public good is national defense – the benefits I get from national defense do not diminish the benefits others receive. Common property resources are more often **rival**, meaning that use of the resource by one person reduces the quantity or quality of the resource available to others. An example of a common property resource would be groundwater. If I withdraw some groundwater, that water is not available for others to use.

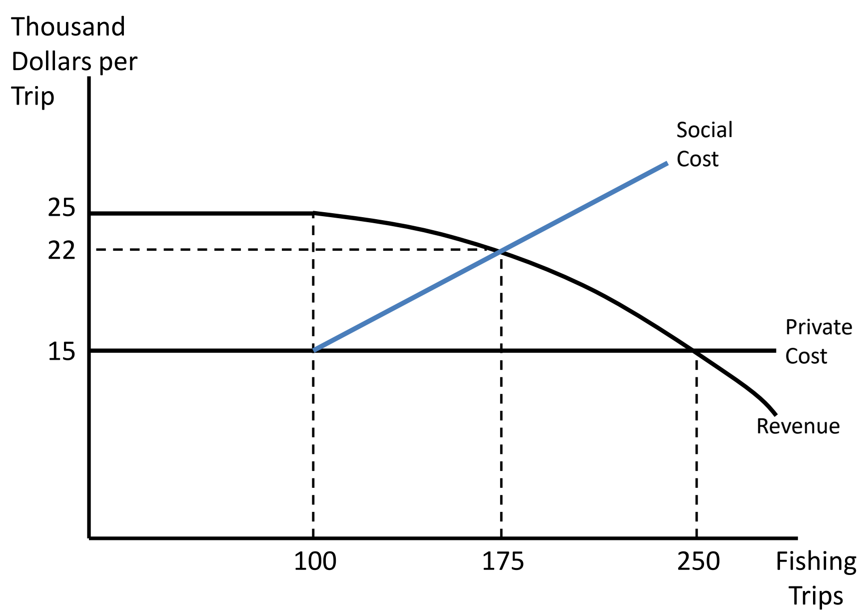
	Rival	**Nonrival**
Excludable	Private Goods *e.g. Automobile*	Club Goods *e.g. Private park*
Nonexcludable	Common Property Resources *e.g. Groundwater*	Public Goods *e.g. National defense*

3.6 Management of Common Property Resources

This section considers whether regulation is necessary in the case of a common property resource, using the example of an ocean fishery. Initially, assume that the fishery is not regulated, so that anyone who wants to can access the fishery. If only a few people access the fishery, then adding one more fisher is unlikely to affect the catch of anyone else. But as total fishing pressure increases, eventually adding more fishers will begin to harm the health of the fishery, thus reducing the catch of each fisher. We can think of this situation as similar to a negative externality – in an already crowded fishery an additional fisher imposes a cost on all other fishers. But as each fisher only considers his or her own profits, this external cost does not enter into their fishing decision.

Figure 7 illustrates this situation. Suppose that it costs $15,000 to operate a fishing trip, including the cost of labor, fuel, and supplies. If there are only a few fishing trips occurring in the fishery, each boat trip yields $25,000 in revenues, and thus a $10,000 profit.[11] This is true as long as the total number of fishing trips is less than 100, as shown in the figure.

Figure 7. *Common Property Model of a Fishery*



But once the fishing pressure exceeds 100 trips, the amount of fish caught per trip begins to decline as the health of the fishery is impaired. Each additional fishing trip above 100 trips further reduces the revenue per trip for everyone – the fishery has become rival. While the fishers will notice the decline in their revenues, as long as each one is still making a profit they will continue to fish. In the figure, we see that the revenue per trip exceeds cost per trip up to 250 fishing trips. So as long as there are less than 250 trips being taking, there is an incentive for more trips to occur as each trip will be profitable. Only when we get to 250 trips does the revenue per trip equal the cost per trip, and there is no further incentive for more trips. Thus 250 trips is the outcome in the fishery without any regulation.

[11] In this simple example we assume that all fishing trips are the same. Thus the cost of each trip is constant at $15,000 and the revenue per trip does not vary for different fishers.

Is this outcome optimal from the perspective of the fishery as a whole? When only 100 trips were being taken, each fisher was earning a $10,000 profit per trip. But at 250 trips, each fisher is barely covering his or her costs. So from the industry perspective, 250 trips are clearly not optimal. Further, from an ecological perspective the health of the fishery is likely to further decline as it is being overfished. This outcome is known as the **tragedy of the commons**, in which individuals acting in their own self-interest tend to exploit a common property resource, leading to a sub-optimal social outcome and resource degradation.

We can determine the optimal social outcome using the same principle that we applied to internalizing a negative externality. The problem is that individuals don't consider the cost their actions on others when deciding whether to fish. The blue Social Cost line in Figure 7 adds to the private cost of fishing the amount that each additional fishing trip reduces the profits of all other fishers. In other words, the Social Cost line represents the $15,000 private cost of operating a boat trip plus the external cost equal to the reduction in others' profits.

The socially efficient level of fishing trips is 175 in Figure 7. Up to this point the revenue per fishing trip exceeds the social cost. This level of fishing maximizes the profits in the fishing industry. Also, this lower level of fishing effort is more likely to be ecologically sustainable.

One solution to avoid the tragedy of the commons is to institute a fee for each fishing trip, much like a Pigovian tax. The correct fee to charge is the amount that fully internalizes the external cost of an additional fishing trip at the optimal level of fishing. At 175 trips, the external cost of an additional fishing trip is $7,000 (the difference between the social cost and the private cost). So if the fee for a fishing trip were $7,000, then there would be no incentive for fishers to take additional trips beyond 175 trips. Above 175 trips, the total cost of a fishing trip would be $22,000 (the $15,000 private cost plus the $7,000 fee) but the revenue would be less than $22,000.

Another solution is to institute **individual transferable quotas (ITQs)**. With this approach a government sets the total allowable fishing effort – in this case, 175 trips – and then permits for each trip are allocated either for free or at auction to the highest bidders. Holders of ITQs can use these permits to fish, or sell them to interested parties. In principle, the value of a permit would equal the potential profits to be made from a fishing trip. The price of ITQs are not set by the government, but allowed to vary based on supply and demand. ITQ programs for ocean fisheries have been established in several countries, including Australia, Canada, Iceland, and in some United States fisheries.

3.7 Management of Public Goods

Public goods are both nonexcludable and nonrival. So even if everyone in society benefits from a public good, degradation of the good is not a potential problem. Instead, the problem with public goods is that they tend to be under-supplied by private markets, if they are supplied at all. With a private good, the fact that people must pay the market price for it in order to receive its benefits allows sellers to make a profit from the good. But with a public good, people can obtain the benefits of the good *without paying*.

Consider national defense as an example of a public good. Could we rely upon some mega-corporation to provide national defense in a market setting? No, because there would be no way for the corporation to sell the product to individual buyers. No individual would have an incentive to pay because they could receive essentially the same level of benefits without paying. Thus the "equilibrium" quantity of public goods in a market setting is normally zero, as no company would want to produce something that no one is willing to pay for.

Perhaps we could rely on donations to supply public goods. This is done with some public goods, such as public radio and television. Also, some environmental groups conserve habitats that, while privately owned, can be considered public goods because they are open for public enjoyment. Donations, however, generally are not sufficient for an efficient provision of public goods. Since public goods are nonexclusive, each person can receive the benefits of public goods regardless of whether they pay. So while some people may be willing to donate money to public radio, many others simply listen to it without paying anything. Those who benefit from public goods but do not pay are called **free riders**.

While we cannot rely on private markets or voluntary donations to fund the provision of public goods, their adequate supply is of crucial interest to the whole society. In democracies, decisions regarding the provision of public goods are commonly decided in the political arena. This is generally true of national defense. A political decision must be made, taking into account that some citizens may favor more defense spending, others less.

Similarly, decisions on the provision of environmental public goods are made through the political system. The U.S. Congress, for example, must decide on funding for the National Park system. Will more land be acquired for parks? Might some existing park areas be sold or leased for development? We may obtain information on whether the current supply of certain public goods is too high or too low based on opinion surveys. Or we may rely upon elected officials to make public goods decisions on behalf of their constituents. Once the appropriate level of public goods provision is determined, the necessary funds are obtained through taxes.

Paying for public goods using taxes effectively avoids the free rider problem. However, issues of fairness may arise, as the structure of the tax system determines who pays for public goods, and how much. Inevitably, some people will feel they are taxed too heavily, or that they are paying for public goods from which they do not benefit personally. Resolving these issues demonstrates that management of public goods is as much a political problem as an economic problem.

4. VALUING THE ENVIRONMENT

As we discussed in Section 2, environmental economics measures value according to the willingness-to-pay principle. Ecological economic is more likely to consider the inherent value of natural capital. In either case, economists recognize that the environment has value beyond just its market uses, such as supplying timber, fish, and agricultural land. Thus, we need to assess whether natural resources should be used for market benefits such as these, or non-market benefits, including:

1. **Recreation**: natural sites provide places for outdoor recreation including camping, hiking, fishing, hunting, and viewing wildlife
2. **Ecosystem services**: these are tangible benefits obtained freely from nature as a result of natural processes, including nutrient recycling, flood protection by wetlands, waste assimilation, carbon storage in trees, water purification, and pollination by bees.
3. **Nonuse benefits**: these are non-tangible benefits that we obtain from nature. Nonuse benefits include the psychological benefits that people gain just from knowing that natural places exist, even if they will never visit them. The value that people get from knowing that ecosystems and species will be available to future generations is another type of nonuse benefit.

The **total economic value** of a natural system is the sum of all the benefits people are willing to pay for. Thus, the total economic value of a National Forest would be the sum of any profits obtained from timber harvesting, the willingness to pay of all those who recreate in the forest, the value of the ecosystem services such as soil erosion prevention and carbon storage, and the nonuse benefits people obtain by simply knowing the forest exists.

It is important to realize that in calculating total economic value priority is not given to any particular use of the forest. When uses are incompatible, such as deciding whether a particular tract of forest should be clear cut or preserved for recreation and wildlife habitat, economic analysis can help to determine which use provides the highest overall value to society.

4.1. Nonmarket Valuation Methodologies

If we are to estimate total economic value, we need techniques to estimate such values as recreation benefits, ecosystem services, and nonuse values. In addition, we need a measure of the damages caused by negative environmental externalities. These techniques are referred to as **nonmarket valuation**, because they produce benefit estimates for goods and services that aren't directly traded in markets. There are four main types of nonmarket valuation techniques:

1. Cost of illness method
2. Replacement cost methods
3. Revealed preference methods
4. Stated preference methods

Each of these methods has advantages for analyzing particular issues, and also has some disadvantages and limits, as summarized below.

4.2 Cost of Illness Method

The **cost of illness method** is used to estimate the damages of reductions in environmental quality that lead to human health consequences. Conversely, it can be used to estimate the benefits of improvements in environmental quality (i.e., the avoided damages). This method estimates the direct and indirect costs related to illnesses attributed to environmental factors. The direct costs include medical costs such as office visits and medication paid for by individuals and insurers, and lost wages due to illness. Indirect costs can include decreases in human capital (such as a child missing a significant number of school days due to illness), welfare losses from pain and suffering, and decreases in economic productivity due to work absences.

The cost of illness method generally only provides us with a **lower-bound estimate** of the willingness to pay to avoid illnesses. The true WTP could be greater, since the actual expenses may not capture the full losses to individuals or society from illness. But even a lower-bound estimate could provide policy guidance. For example, the cost of asthma in the U.S. was estimated to be $82 billion in 2013, based on direct medical costs, productivity losses from missed days of school and work, and asthma related mortality.[12] The costs for a typical affected worker amounted to about $3,500. These estimates provide a starting point to determine whether efforts to reduce asthma cases are economically efficient.

4.3 Replacement Cost Methods

Replacement cost methods can be used to estimate the value of ecosystem services. These approaches consider the cost of actions that substitute for lost ecosystem services. For example, a community could construct a water treatment plant to make up for the lost water purification benefits from a forest habitat. The natural pollination of plants by bees could, to some extent, be done by hand or machine. If we can estimate the costs of these substitute actions, in terms of construction and labor costs, these may be considered an approximation of society's willingness to pay for these ecosystem services.

While replacement cost methods are often used to estimate ecosystem service values, they are not necessarily measures of WTP. Suppose a community could construct a water treatment plant for $50 million to offset the water purification services of a nearby forest. This estimate doesn't tell us whether the community would actually be willing to pay the $50 million should the forest be damaged. Actual WTP could be greater or less than $50 million. So, in this sense, replacement cost estimates should be used with caution.

4.4 Revealed Preference Methods

While markets don't exist for many environmental goods and services, we can sometimes infer the values people place on them through their behavior in other markets. **Revealed preference methods** are techniques that obtain nonmarket values based on people's decisions in related markets. Economists generally prefer deriving nonmarket values based on actual market behavior. Thus, revealed preference methods are considered the most valid approach to nonmarket valuation. However, there is a limited category of environmental benefits that can be estimated using revealed preference methods.

One common type of revealed preference method is **travel cost models**. These models are used to estimate the economic benefits people obtain by recreating at natural sites such as National

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[12] Nurmagambetov, Tursynbek, Robin Kuwahara, and Paul Garbe. "The Economic Burden of Asthma in the United States, 2008–2013." *Annals of the American Thoracic Society* 15.3 (2018): 348-356.

Parks or lakes. Even if the recreation site doesn't charge an entry fee, all visitors must pay a "price" equal to their costs to travel to the site, such as gas, plane tickets, accommodations, and even the time required to travel to the site. As visitors to a recreation site from different regions effectively pay a different price, economists can use this information to derive a demand curve for the site using statistical models, and thus estimate **consumer surplus –** the net benefit derived by consumers from recreation at this site. Travel cost models are most applicable for recreation sites that attract visitors from distant places, in order to provide enough variation in travel costs to estimate a demand curve.

Numerous travel cost models have estimated the recreational benefits of natural sites. For example, a 2014 study of recreational visitors to the West Garda Regional Forest in northern Italy found that the average visitor received a net benefit of 5 to 9 euros per visit.[13] Travel cost models have been used to explore how changes in the fish catch rate affect the consumer surplus of anglers visiting sites in Wisconsin,[14] and how a drought affects the benefits of visitors to reservoirs in California.[15]

Another type of revealed preference method is the **defensive expenditures approach**. In some situations people are able to take actions to reduce their exposure to environmental harms. For example, people with concerns about their drinking water quality may choose to purchase bottled water or install a water filtration system. These expenditures may reflect their willingness to pay for water quality. For example, a 2006 study in Brazil found that households were paying US$16-$19 per month on defensive expenditures to improve drinking water quality.[16]

A limitation of the defensive expenditures approach is that people may be taking defensive actions for a variety of reasons, some unrelated to environmental quality. For example, other reasons for buying bottled water may include convenience or status. Thus, attributing the entire cost of bottled water as a measure of concern about drinking water quality would not be appropriate in such cases. It also suffers from the inherent problem of any market valuation: the preferences of the rich weigh much more heavily than the preferences of the poor. Plenty of people around the world who are actually suffering from the health effects of impure water may not be able to afford to buy bottled water; thus their willingness to pay is made invisible by inability to pay.

In addition to the problem of unequal ability to pay, the approaches just described—the defensive expenditures approach and travel cost models—cannot be used to obtain benefit estimates for many ecosystem services and nonuse values. Thus, in order to obtain estimates of total economic value for many environmental goods and services, we need a technique that can provide us some estimate of these values.

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[13] Martina, Menon, Federico Perall, and Marcella Vernonesi. 2014. "Recovering Individual Preferences for Non-Market Goods: A Collective Travel-Cost Model," *American Journal of Agricultural Economics*, 96(2): 438-457.
[14] Murdock, Jennifer, 2006. "Handling Unobserved Site Characteristics in Random Utility Models of Recreation Demand," *Journal of Environmental Economics and Management*, 51(1): 1-25.
[15] Ward, Frank, Brian Roach, and Jim Henderson, 1996. "The Economic Value of Water in Recreation: Evidence from the California Drought," *Water Resources Research*, 32(4): 1075-1081.
[16] Rosado, Marcia A., Maria A. Cunha-e-Sa, Maria M. Dulca-Soares, and Luis C. Nunes, 2006. "Combining Averting Behavior and Contingent Valuation Data: An Application to Drinking Water Treatment in Brazil," *Environment and Development Economics*, 11(6): 729-746.

4.5 Stated Preference Methods

The final nonmarket valuation technique we consider is the most used, as well as the most controversial. **Stated preference methods** directly obtain information on someone's preferences in a hypothetical scenario. The most common stated preference method is **contingent valuation**, in which survey respondents are asked questions about their willingness to pay for hypothetical outcomes.

The main advantage of contingent valuation is that surveys can be designed to ask respondents about *any* type of environmental benefit. For example, a 2014 study found that citizens in the Philippines were willing to pay 233 to 437 pesos (about $5 - $10) to preserve an important coral reef.[17] A 2012 study found that households in Spain were willing to pay an average of $22 per year for a hypothetical reduction in highway noise and air pollution.[18]

While hundreds of contingent valuation studies have been conducted over the last several decades, the validity of the results remains highly controversial. Given that respondents' preferences are based on a hypothetical scenario, and they don't have to actual pay anything, some economists consider the results flawed due to various biases. For example, a respondent who generally favors habitat preservation may have an incentive to overstate his or her actual WTP in order to influence the policy process. Some respondents may not accurately consider their income limitations when stating WTP values; this gets around the "ability to pay" problem, but does not produce the kind of WTP estimates that many economists seek as "realistic".

Some of the problems associated with contingent valuation can be avoided by using **contingent ranking**, another stated preference method. With contingent ranking, respondents are asked to rank various hypothetical scenarios according to their preferences. Thus there is no potential for respondents to exaggerate their willingness to pay.

4.6. Cost-Benefit Analysis

The nonmarket valuation methods discussed above can be used to estimate the positive and negative externalities associated with different products. They can also provide guidance on appropriate public policies. For example, consider how we might evaluate a proposed law to increase air quality standards. We might ask whether the benefits of the policy exceed its costs. Environmental economists use the technique of **cost-benefit analysis** (CBA) to estimate the net benefits (i.e., the benefits minus the costs) of proposed projects or policies, measuring impacts in monetary units.

In theory, measuring all impacts in dollars (or some other currency) produces a "bottom-line" result (i.e., a single number) so we can choose which option results in the greatest net social value. In practice, however, cost-benefit analyses are often incomplete. The results may be dependent

[17] Subade, Rodelio F., and Herminia A. Francisco. 2014. "Do Non-users Value Coral Reefs? Economic Valuation of Conserving Tubbataha Reefs, Philippines." *Ecological Economics* 102:24-32.

[18] Lera-Lopez, Fernando, Javier Faulin, and Mercedes Sanchez. 2012. "Determinants of the Willingness-to-Pay for Reducing the Environmental Impacts of Road Transportation," *Transportation Research: Part D: Transport and Environment* 17(3):215-220.

on specific assumptions. Sometimes one side of the analysis—the costs, or the benefits—may be much more fully developed than the other, making it difficult to obtain an objective recommendation.

The basic steps of a cost-benefit analysis are relatively straightforward:

1. List all costs and benefits of the project or policy proposal. Typically this is done for several different scenarios.
2. Convert all costs and benefits to monetary values. Some values can be obtained based on market analysis, while other values will require nonmarket valuation.
3. Add up all the costs and benefits to determine the net benefits of each scenario. Sometimes the results are expressed as a ratio (i.e., benefits divided by costs).
4. Choose the scenario that is the most economically efficient.

Perhaps the most appealing feature of CBA is its seeming objectivity. It also presents a way to argue for environmental protection in economic terms, rather than on ethical or ecological terms. Many CBAs have shown that the willingness to pay for environmental protection can be quite large.

Of course, all the problems with the nonmarket valuation techniques discussed earlier can complicate cost-benefit analysis. Two additional issues often arise in environmental CBAs: how to value costs and benefits that occur in the future, and how to value human lives.

4.7 Discounting the Future

Many environmental policies involve paying costs in the short term, while the benefits arise further in the future. For example, the cost of installing pollution control equipment is an upfront cost, while the health benefits of reduced cancer rates will only be realized decades in the future. Thus we need a way to compare impacts that occur at different times.

There is a natural human tendency to focus on the present more than the future. Most people would prefer to receive a benefit now than a similar benefit in the future. This may be a simple matter of personal preference, or it may be based on the economic logic that having resources in the present allows for investment to receive greater benefits in the future.

Economists incorporate this concept into CBA through **discounting**. Discounting effectively reduces the weight placed on any cost or benefit that occurs in the future, relative to the same impact occurring now. The further the cost or benefit occurs in the future, the less weight is given to that impact. In order to compare an impact that occurs in the present to an impact that occurs in the future, the future impact must be converted to an equivalent **present value** using the following formula:

$$PV(X_n) = X_n / (1 + r)^n$$

where X_n is the monetary value of the cost or benefit, n is the number of years in the future the impact occurs and r is the **discount rate**—the annual rate by which future impacts are reduced, expressed as a proportion (i.e., r=0.03 for a 3% discount rate).

A simple example will illustrate how discounting works. Suppose we are analyzing a proposal to improve air quality. Assume that the cost of this proposal, including the installation of new pollution control equipment, is $10 million, to be paid right now. The benefits of cleaner air are estimated to be $20 million, but these benefits will occur 25 years in the future.[19] Should we proceed with this proposal?

In order to obtain the present value of the $20 million benefit, we need to choose a discount rate. Suppose we apply a discount rate of 5%. The present value of the benefits would be:

$$PV = \$20{,}000{,}000 / (1.05)^{25} = \$5{,}906{,}055$$

As the present value of the $20 million benefit is only about $6 million, it does not make economic sense to pay $10 million now to obtain this benefit. But suppose that we instead apply a discount rate of 2%. In this case the present value of the benefits is:

$$PV = \$20{,}000{,}000 / (1.02)^{25} = \$12{,}190{,}617$$

In this case the net benefits of the proposal are positive (i.e., the present value of the benefits exceeds the costs by about $2 million). At the lower discount rate, the proposal makes economic sense. This example illustrates the importance of the choice of a discount rate. We will see later in the module that this is particularly true when we discuss analyses of global climate change.

One approach for choosing a discount rate is to set it equal to the rate of return on low-risk investments such as government bonds. The rationale behind this is that any funds used for a beneficial public project could otherwise be invested to provide society with greater resources in the future. In late 2018 the nominal rate of return on a 30-year U.S. Treasury Bond was about 3.3%.[20] However this rate has varied considerably over time, reaching 13% in the early 1980s. Thus some economists question whether we should base the valuation of long-term environmental impacts upon an interest rate subject to the whims of financial market conditions.

Other approaches to choosing a discount rate consider the ethical dimension of valuing future impacts. In some sense, a positive discount rate implies that future generations count less than the current generation. While nearly all economists believe in the principle of discounting, those economists more concerned about long-term environmental damages tend to prefer lower discount rates.[21]

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[19] In reality the benefits would occur over numerous future years. Here for simplicity we assume all the benefits occur in a single year, 25 years from now.
[20] U.S. Department of the Treasury. Daily Treasury Yield Curve Rates. http://www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/TextView.aspx?data=yield.
[21] A 0% discount rate would imply that any impact that occurs in the future, even those in the very far future, count the same as a current impact. Economists have tended to justify some discounting on the assumption that future generations will have higher incomes and better technology, and will thus be better equipped to deal with problems created in the present. However there are economists who focus on the possibility of a significant number of future decades in which the problems of fossil fuel use cause an overall decline in energy available to human beings; they do not assume higher incomes or better standards of living for those generations.

4.8 Valuing Human Lives

Another controversial aspect of CBA is analyzing policies that affect human mortality rates. The benefits of many environmental policies, such as those addressing air and water quality, are often expressed in terms of the number of avoided deaths. In a CBA framework, we seek to convert all benefits to monetary values to make them directly comparable to the costs. Suppose we are analyzing a policy that will improve air quality at a cost of $500 million to society, but reduce the number of deaths associated with air pollution by fifty. Is such a policy "worth it" to society?

While economists don't value any particular person's life, they instead estimate how people value relatively minor changes in mortality risk, and use this information to infer the **value of a statistical life (VSL)**. A VSL estimate, in theory, indicates how much society is willing to pay to reduce the number of deaths from environmental pollution by one, without any reference to whose death will be avoided.

An example illustrates how a VSL is estimated. Let's assume we conduct a contingent valuation survey to ask people how much they would pay to improve air quality such that the number of deaths from air pollution would decline by fifty. Each respondent's risk of dying from air pollution would decline slightly as a result of the policy. Suppose the survey results indicate that the average household is willing to pay $10 per year for this policy. If society comprises 100 million households, then the total willingness to pay for the policy would be:

$$100 \text{ million} * \$10 = \$1 \text{ billion}$$

Since this is the WTP to reduce deaths by fifty, the VSL would be:

$$\$1 \text{ billion} / 50 = \$20 \text{ million}$$

Some people object to valuing human lives on ethical grounds. Others counter that we must explicitly or implicitly analyze the tradeoffs between public expenditures and health benefits. According to statutory law, major environmental policy proposals in the United States must be reviewed using cost-benefit analysis, and thus government agencies must often apply a VSL. The VSLs used by government agencies have varied but generally increased over time, from around $2 million in the 1980s to nearly $10 million more recently. In other words, regulations that can reduce environmental deaths at a cost of less than $10 million per avoided death would be considered economically efficient. For more on the economic, and political, debate about the VSL in the United States see Box 2.

BOX 2. THE POLITICS OF VALUING LIFE

The valuation of human lives is not merely an economic issue but a political issue as well, as demonstrated by changes in the VSLs used by United States federal agencies in recent years. During the George W. Bush administration, the VSL used by the U.S. Environmental Protection Agency was as low as $6.8 million. But in 2010, the EPA increased their VSL to $9.1 million in a cost-benefit analysis of air pollution standards. As of 2016 the EPA was using the value of approximately $10 million. Under the Barack Obama administration, the Food and Drug Administration also increased its VSL, from $5 million in 2008 to $9.5 million in 2016. Based on higher VSLs, the Transportation Department has decided to require stronger car roofs – a regulation that was rejected under the Bush administration as too expensive.

Some federal regulators have also considering adjusting the VSL based on the type of risk. For example, the EPA has considered applying a "cancer differential" that would increase the VSL for cancer risks, based on surveys that show people are willing to pay more to avoid cancer as opposed to other health risks, however these adjustments have not yet been put into practice in their calculations.

Manufacturers and power companies have traditionally advocated the use of cost-benefit analysis for environmental policies, essentially forcing regulators to prove the economic efficiency of environmental improvements. But the recent VSL increases have led them to reconsider their approach. Though a small change in VSL can have a large impact on policy analysis, VSL numbers are not likely to drop anytime soon, with the Office of Management and Budget advocating for values as high as $10 million.

Sources: Appelbaum, Binyamin. 2011. "As U.S. Agencies Put More Value on a Life, Businesses Fret," *New York Times*, February 16, 2011; Merrill, Dave. 2017. "No One Values Your Life More Than the Federal Government." *Bloomberg*, October 19th, 2017.

4.9 Other Issues with Cost Benefit Analysis

Most environmental cost-benefit analyses are further complicated by several other issues. These include:

1. Analysis of uncertainty
2. Missing monetary values
3. Sensitivity to assumptions

Consider a proposal to build a large dam for flood protection. The benefits of flood protection depend somewhat on future climate conditions, which are difficult to predict with a high degree of certainty. There may also be a small chance that the dam will fail, perhaps causing catastrophic damage. Another example would be analyzing the risk of a major oil spill. Incorporating such uncertainty into a CBA may be possible if we have some idea of the probability of various outcomes, but some risks are fundamentally difficult to predict. In such cases, some economists advocate the **precautionary principle**: the idea that policies should err on the side of caution when there is a low-probability risk of a catastrophic outcome.

In almost any real-world environmental CBA we will be unable to estimate all impacts in monetary terms. For example, how can we estimate the benefits of a proposed National Park if the park doesn't exist yet? We may be able to "transfer" an estimate from an existing similar park, but we can't be sure the transferred estimate is valid for the new site. Also, government agencies frequently don't have the resources to fund original studies to estimate all needed values. We may be able to make an educated guess about certain missing values, but this obviously reduces the objectivity of a CBA.

Finally, the recommendations of many CBAs are highly dependent upon various assumptions. As we saw earlier, the choice of a discount rate may determine whether a particular policy is recommended or not. Other assumptions may have to do with how risk is analyzed, or how contingent valuation results are interpreted. Ideally, a CBA should consider a broad range of assumptions. Of course, if different assumptions produce different results, then we must make a subjective decision about which result we should rely upon. Again, this issue implies that CBA may not be as objective as it may seem at first.

5. ENVIRONMENTAL POLICY ALTERNATIVES

In devising policies to internalize environmental externalities, a Pigovian tax is just one type of environmental policy. Decision-makers generally have other policy options, and which one is appropriate depends on the particular context. The four basic environmental policy options are:

1. Pollution standards
2. Technology-based regulation
3. Pigovian (or pollution) taxes
4. Tradable pollution permits

5.1. Pollution Standards

Pollution standards regulate environmental impacts by setting allowable pollution levels or specifying the acceptable uses of a product or process. Many people experience pollution standards at an annual automobile inspection. Cars must meet certain standards for tailpipe emissions; if your car fails, you must correct the problem before receiving an inspection sticker.

The clear advantage of standards is that they can specify a definite result. This is particularly important in the case of substances that pose a clear hazard to public health. By imposing a uniform rule on all producers, we can be sure that no factory or product will produce hazardous levels of pollutants. In extreme cases, a regulation can simply ban a particular pollutant, as has been the case with DDT (a toxic pesticide) in most countries.

However, requiring all firms or products to meet the same standard is often not cost-effective. The overall cost of a regulation can be lowered if firms that can reduce pollution at low marginal costs reduce pollution more than firms that have high marginal reduction costs. Thus requiring all firms to reduce pollution by the same amount, or to meet the same standard, is not the least-cost way to achieve a given level of pollution reduction. Another problem with standards is that once firms meet the standard they have little incentive to reduce pollution further.

5.2. Technology-based Regulation

A second approach to environmental regulation is to require that firms or products incorporate a particular pollution-control technology. For example, in 1975 the United States required that all new automobiles include a catalytic converter to reduce tailpipe emissions. While auto manufacturers are free to design their own catalytic converters, each must meet certain emissions specifications.

Perhaps the main advantage of technology-based regulation is that enforcement and monitoring costs are relatively low. Unlike a pollution standard, which requires that firms' pollution levels be monitored to ensure compliance, a technology-based approach might only require an occasional check to ensure that the equipment is installed and functioning properly.

Technology-based approaches may not be cost-effective, because they do not provide firms the flexibility to pursue a wide range of options. Technology-based approaches may, however, offer a cost advantage due to standardization. If all firms must adopt a specific technology, then widespread production of that technology may drive down its production cost down over time.

5.3. Pigovian (or Pollution) Taxes

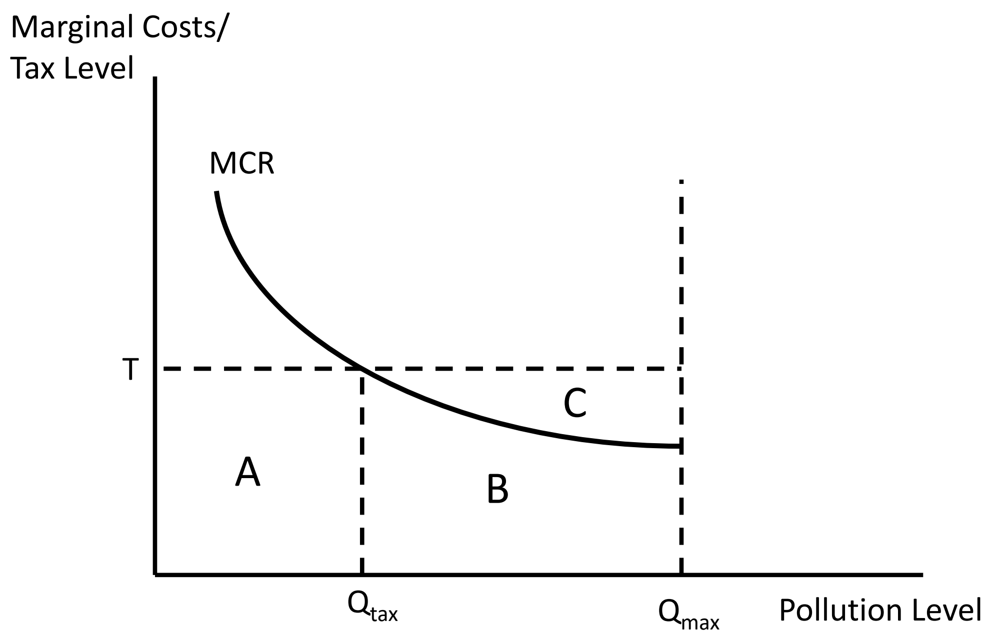
Pollution taxes, along with tradable pollution permits, are considered **market-based approaches** to pollution regulation because they send information to polluters about the costs of pollution without mandating that firms take specific actions. Individual firms are not required to reduce pollution under a market-based approach, but the regulation creates a strong incentive for action.

As we saw earlier in the module, a pollution tax reflects the principle of internalizing externalities. If producers must bear the costs associated with pollution by paying a tax, they will find it in their interests to reduce pollution so long as the marginal costs of reducing pollution are less than the tax.

Figure 8 illustrates how an individual firm will respond in the presence of a pollution tax. Q_{max} is the level of pollution emitted without any regulation. The curve MCR shows the marginal cost of pollution reduction for the firm. If a pollution tax equal to *T* is imposed, the firm will be motivated to reduce pollution to level Q_{tax}, at a total cost of B (equal to the area under their MCR curve between Q_{tax} and Q_{max}). If the firm maintained pollution at Q_{max} it would have to pay a tax of (B + C) on these units of pollution. Thus the firm saves area C by reducing pollution to Q_{tax}.

After reducing pollution to Q_{tax}, the firm will still need to pay a tax on its remaining units of pollution, equal to area A. The total cost to the firm from the pollution tax is the sum of its reduction costs and tax payments, or areas (A + B). This is less than areas (A + B + C), which is what they would have to pay in taxes if they undertook no pollution reduction. The firm's response to the tax is cost-effective, as any other level of pollution different from Q_{tax} would impose higher costs.

Figure 8. *A Firm's Response to a Pollution Tax*



All other firms in the industry will determine how much to reduce their pollution based on their own MCR curve. Assuming that each firm is acting in a cost-effective manner, the total cost of pollution reduction is minimized. Those firms that can reduce pollution at low costs will reduce pollution more than firms that face higher costs. This is the main advantage of market-based approaches to pollution regulation—they achieve a given level of pollution reduction at the lowest overall cost. In other words, they are economically efficient compared to pollution standards or technology-based approaches.

5.4. Tradable Pollution Permits

Economic efficiency in pollution control is clearly an advantage. One disadvantage of pollution taxes, however, is that it is very difficult to predict the total amount of pollution reduction a given tax will produce. It depends on the shape of each firm's MCR curve, which is usually not known to policymakers.

An alternative is to set up a system of **tradable pollution permits**. The total number of permits issued equals the desired target level of pollution. These permits can then be allocated freely to existing firms or sold at auction. Once allocated, they are fully tradable, or transferable, among firms or other interested parties. Firms can choose for themselves whether to reduce pollution or to purchase permits for the pollution they emit—but the total volume of pollution emitted by all firms cannot exceed a maximum amount equal to the total number of permits.

Those firms with higher MCR curves will generally seek to purchase permits so they don't have to pay high pollution reduction costs. Firms that can reduce pollution at lower cost may be willing to sell permits, as long as they as they can receive more money for the permits than it would cost them to reduce pollution. With this system private groups interested in reducing pollution could purchase permits and permanently retire them, thus reducing total emissions below the original target level. Pollution permits are normally valid only for a specific time period. After this period expires the government can choose to issue fewer permits, resulting in lower overall pollution levels in the future.

A detailed analysis of tradable permits, which we don't present here, demonstrates that a given level of pollution reduction is achieved at the same total cost as a tax.[22] Thus whether one prefers pollution taxes or tradable permits depends on factors other than pollution reduction costs (however, the administrative costs of the approaches may differ). Taxes are generally easier to understand and implement. But taxes are politically unpopular, and firms may prefer a permit system if they believe they can successfully lobby to receive the permits for free.

The main difference between the two approaches is where the uncertainty lies. With pollution taxes, firms have certainty about the cost of emissions, which makes it easier for them to make decisions about long-term investments. But the resulting level of total pollution with a tax is unknown in advance. If pollution levels turn out to be higher than expected, then the government might have to take the unpopular step of raising taxes further.

With a permit system, the level of pollution is known because the government sets the number of available permits. But the price of permits is unknown, and permit prices can vary significantly over time. This has been the case with the European permit system for carbon emissions. The price of permits initially rose to around €30/ton in 2006, shortly after the system was instituted. But then prices plummeted all the way down to €0.10/ton in 2007 when it became evident that too many permits had been allocated. After some changes to the system, prices rose back to over €20/ton in 2008 but then fell again down to less than €3/ton in 2013. Such **price volatility** makes it difficult for firms to decide whether they should make investments in technologies to reduce emissions. In 2017 the European Union agreed on reforms to control the oversupply of permits, which are set to take effect in 2019 and are expected to drive prices back up to around €20/ton by 2020.

[22] For a more detailed analysis, see Harris, Jonathan, and Brian Roach. 2018. Harris *Environmental and Natural Resource Economics: A Contemporary Approach* (4th Edition). Routledge, New York.

6. ECONOMIC ANALYSIS OF CURRENT ENVIRONMENTAL POLICY ISSUES

We now apply the lessons from this module to three current environmental policy issues: fisheries management, agriculture, and climate change. We'll present relevant data for each issue, focusing on historical trends and projections. In each case we'll see how the insights from environmental and ecological economics can help design policies that promote sustainability.

6.1. Fisheries Management

As we have seen earlier, without sufficient regulation ocean fisheries are likely to be subject to the tragedy of the commons. Individual fishers have little incentive to practice conservation, for they know that if they do not catch the available fish, someone else probably will. Technological improvements that make it easier to find and catch fish only make matters worse. With the introduction of modern vessels like commercial trawlers, fishing is often 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."[23]

Fisheries are examples of **renewable resources**, which regenerate over time through natural processes. One basic rule for renewable resource management derived from ecological principles is that harvest levels should be kept below the **maximum sustained yield (MSY)**. In other words, the annual harvest of the resource should be no more than what is regenerated annually through natural processes.

The world's fisheries are classified into the categories, roughly based on a comparison between harvest levels and the MSY[24]:

1. *Underfished:* Fisheries with harvest levels below their MSY. A potential may exist to increase harvest levels.
2. *Maximally sustainably fished:* Fisheries with harvest levels approximately equal to their MSY. Increasing production is not ecologically sustainable.
3. *Overfished:* Fisheries with harvest levels above their MSY. Strict management plans are needed to improve the biological health of these fisheries (although such plans are normally not currently in place).

As shown in Figure 9, the world's fisheries are becoming more exploited over time. In recent decades the percentage of fisheries classified as overfished has approximately tripled. Meanwhile, the percentage of fisheries that are underfished, with the potential for expanded harvest, has decreased from about 40% to 7%. The depleted state of fisheries is due to overfishing and increasing habitat degradation.

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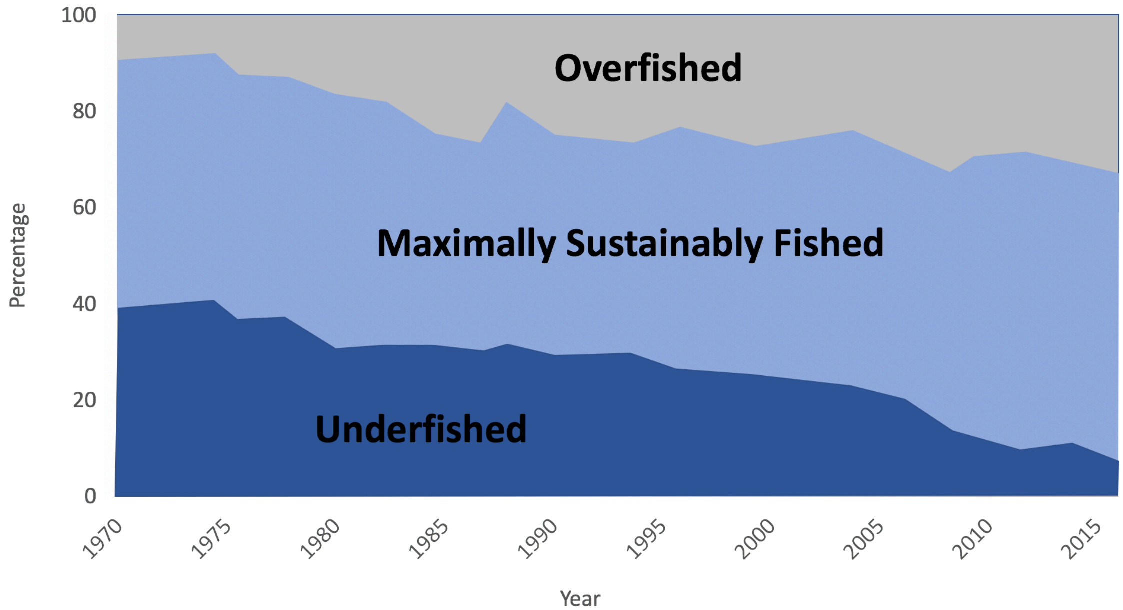
[23] McGinn, Anne Platt. 1998. "Rocking the Boat: Conserving Fisheries and Protecting Jobs," Worldwatch Paper 142, Worldwatch Institute, June 1998, p. 15.

[24] Fishery classification from the FAO (Food and Agriculture Organization of the United Nations).

Figure 9. *State of the World's Fish Stocks, 1974-2015*



Source: FAO. 2018. "The State of World Fisheries and Aquaculture," Rome.

6.2 Global Fish Production and Consumption

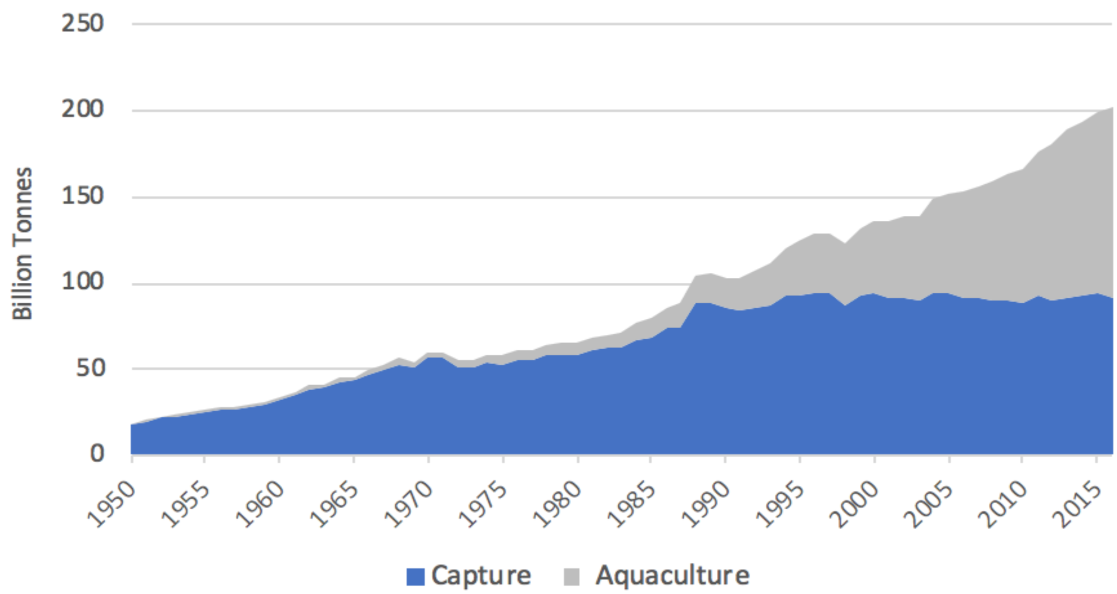
People in developed countries currently consume approximately 21 percent of the global fish catch; the other 79 percent is consumed in the developing world, where fish is an important protein source.[25] Increasing population and income in developing countries will likely produce steady growth in the global demand for fish and fish products, but supply expansion, at least from wild fisheries, may be close to its limits.

Figure 10 shows global fish production from 1950 to 2016. World fish harvest of naturally-occurring stocks steadily increased from 1950 until 1990. However, since then the wild catch has leveled off at about 90 million tons annually. This is consistent with the decline in underfished stocks shown in Figure 9. But the global fish harvest has continued to increase as an increasing share of the total catch is produced using aquaculture – essentially fish farming. As of 2016, about 47% of global fish production was due to aquaculture. While aquaculture has provided a means to meet the growing global demand for fish, a challenge is to reduce the environmental impacts associated with aquaculture, as discussed in Box 3.

Per-capita fish consumption has doubled globally since the 1960s. The greatest growth has occurred in developing countries, driven by population growth, higher incomes, and improved distribution infrastructure. However, the expansion of fish consumption has been highly uneven. China has been responsible for most of the increase in global fish consumption, while many countries in Sub-Saharan Africa have seen fish consumption remain constant or even decrease.

[25] FAO, 2018.

Figure 10. *Global Fish Production, 1950-2016*



Source: FAO. 2018. "The State of World Fisheries and Aquaculture," Rome

BOX 3: REDUCING THE ENVIRONMENTAL IMPACT OF SALMON AQUACULTURE

As shown in Figure 10, global aquaculture production has increased significantly over the last couple of decades. Production has increased so much that in 2012 the global production of aquaculture surpassed the global production of beef. Salmon is a species that is now predominantly produced using aquaculture. According to the environmental group WWF, salmon farming is the fastest growing food production system in the world.

A set of standards for sustainable salmon farming was established in 2010 by the Aquaculture Stewardship Council (ASC). Among the ASC standards are limits on the proportion of escaping salmon, a prohibition on genetic engineering, limits on antibiotics, and guidelines on the food that is fed to salmon. Farms that meet these standards are given the ASC's "responsibly farmed" eco-label.

In 2013 a group of 15 large salmon farmers, representing 70% of the global market, pledged that all of their salmon would meet ASC standards by 2020, but as of 2018 only 27% of farmed salmon by volume and 11% of certified salmon farms held the ASC eco-label.

Sources: Howard, Brian Clark. 2014. "Salmon Farming Gets Leaner and Greener," National Geographic News, March 19; WWF website. 2013. "Spawning a Sustainable Industry for Farm-Raised Salmon," August 15, http://www.worldwildlife.org/stories/spawning-a-sustainable-industry-for-farm-raised-salmon; SeaChoice. 2018. "Holding Eco-Certifications Responsible to Their Claims," November 6th, 2018.

6.3 Sustainable Fisheries Policies

Clearly the open-access outcome described in Section 3 is not consistent with environmental sustainability. 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.

Open-access fisheries pose additional ecological problems because modern fishing methods often cause a high death rate among non-target species. Also, many target species fish are discarded after being caught, because they are either undersized or nonmarketable. This wasted portion of the global harvest is called **bycatch.** A 2009 paper found that:

> 38.5 million tonnes of annual bycatch can be identified, representing 40.4 percent of the estimated annual global marine catch of 95.2 million tones. … [E]normous quantities of biomass are being removed from the ocean without any form of effective management. The approach outlined in this paper therefore exposes bycatch as an insidious problem of invisible fishing resulting from widespread unmanaged fisheries. … Few industries would tolerate levels of wastage and/or lack of sustainable management of around 40 percent.[26]

Although identifying the maximum sustainable yield for a fishery can help 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 species fill the ecological niche formerly occupied by the harvested species.[27] For example, dogfish and skates have replaced overfished cod and haddock in major areas of the North Atlantic fishery, and are now themselves threatened with overfishing. 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 Atlantic, formerly productive ocean floor ecological communities have been severely damaged by repeated trawling.

The World Bank and FAO stress the critical need to reform fisheries management:

> Failure to act implies increased risks of fish stock collapses, increasing political pressure for subsidies, and a sector that, rather than being a net contributor to global wealth, is an increasing drain on society. … The most critical reform is the effective removal of the open access condition from marine capture fisheries and the institution of secure marine tenure and property rights systems. Reforms in many instances would also involve the reduction or removal of subsidies that create excess fishing effort and fishing capacity. Rather than subsidies, the World Bank has emphasized investment in quality public goods such as science, infrastructure, and human capital, in good governance of natural resources, and in an improved investment climate.[28]

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[26] Davies, R.W.D., S.J. Cripps, A. Nickson, and G. Porter. 2009. "Defining and Estimating Global Marine Fisheries By-catch." *Marine Policy* 33(4):661-672.
[27] See, for example, Ogden, John C. 2001. "Maintaining Diversity in the Oceans." *Environment* 43(3):28-37.
[28] World Bank and FAO, 2009, "The Sunken Billions: The Economic Justification for Fisheries Reform." Washington, DC. p. xxi

From an economic point of view, the tragedy of the commons occurs because important productive resources—fisheries in this case—are treated as free resources, and are therefore overused. One potential solution is to privatize fisheries, in the hopes that owners would manage fisheries for sustainable profitability. However, an ocean fishery does not permit the private ownership solution. The oceans have been called a comm. on heritage resource—they belong to everyone and no one. But under the 1982 Law of the Sea treaty, agreed to under United Nations auspices, nations can claim territorial rights to many important offshore fisheries. They can then limit access to these fisheries by requiring a fishing license within their Exclusive Economic Zones (EEZs), which normally extend 200 miles from their coastlines.

Within each country's EEZ, they can implement the economic policies we discussed in Section 3, including charging fishing license fees or instituting individual transferable quotas. To determine the maximum sustainable yield, policymakers must consult marine biologists. Once ecological sustainability has been assured, the ITQ market will promote economic efficiency. Those who can fish most effectively will be able to outbid others to acquire the ITQs.

A more difficult problem concerns species that are highly migratory, or are principally located outside of any nation's EEZ. Tuna and swordfish, for example, continually travel between national fishing areas and the open ocean. Even with good policies for resource management in national waters, these species can be harvested as an open-access global resource, which almost inevitably leads to stock declines. Only an international agreement can solve an issue concerning global commons.

In 1995, the first such international agreement was signed – the Straddling Fish Stocks Agreement.[29] This treaty embodies the precautionary principle, discussed in Section 2. For example, the treaty states that the "absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures."[30]

Changes in human consumption patterns are also important. Public education campaigns that identify fish and seafood produced with environmentally damaging techniques may lead consumers to avoid these species.

Ecolabeling, which identifies products produced in a sustainable manner, has the potential to encourage sustainable fishing techniques. Products of certifiably sustainable fishing practices can often command a slightly higher market price. By accepting this price premium, consumers implicitly agree to pay for something more than the fish they eat. They pay a little extra for the health of the ocean ecosystem and the hope of a supply of 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.

Governments can also institute subsidies when certain activities create positive externalities, as discussed in Section 3. For example, subsidies can assist in developing or acquiring equipment designed especially to release bycatch, or to avoid major disturbances of the seabed. This may

[29] A straddling fish stock is one that migrates through or occurs in more than one EEZ.
[30] United Nations. 1995. "Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks," A/CONF.164/37. Article 6, page 6.

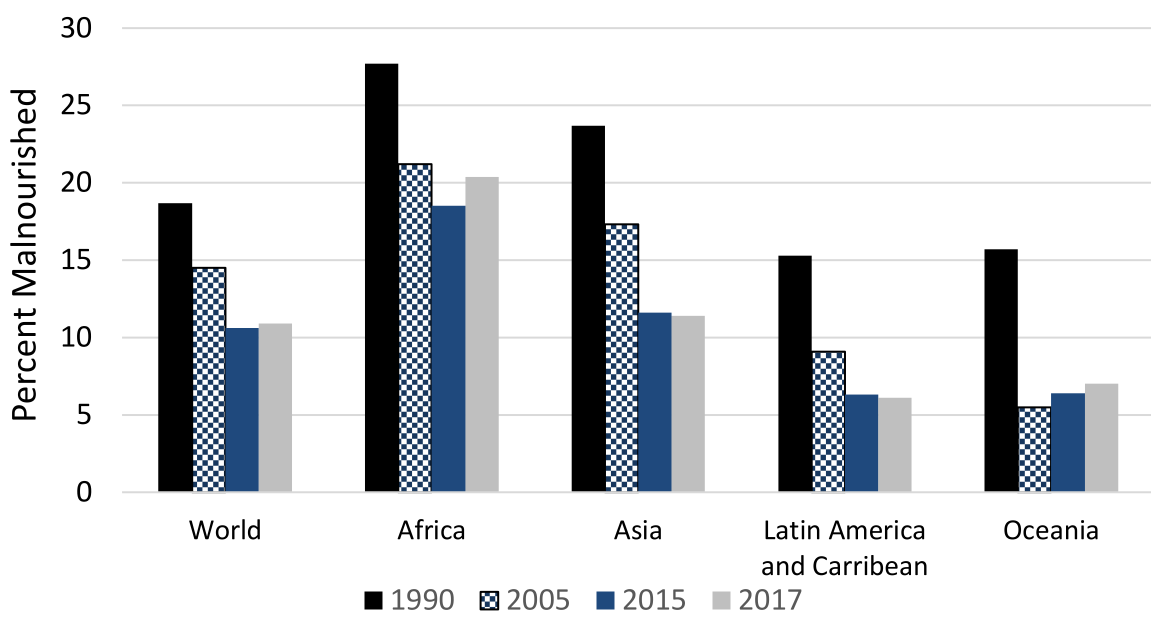
moderate political opposition from fishing communities to government intervention aimed at eliminating destructive fishing practices. Unfortunately, most current fishery subsidies are counterproductive, increasing economic incentives for overfishing.

6.4 Sustainable Agriculture

We saw in Section 2 that predictions indicating that humanity will be unable to feed itself have been proven wrong. On average, food consumption per capita has steadily increased, as shown in Figure 1 (i.e. food consumption has grown faster than population). Among the Sustainable Development Goals set by the United Nations in 2015 is the goal of zero hunger globally by 2030. Though overall progress has been made on this front, after a decline from 19% undernourishment worldwide in the 1990s to a low of 10.6% in 2015, 2016 and 2017 have seen increases back up to 11% due largely to conflict, drought, and climate related disasters.[31]

Like the expansion of fish consumption, progress on reducing hunger has been uneven across global regions. As shown in Figure 11, the greatest progress has occurred in Asia and Latin America, while Africa and Oceana have seen a recent increase in hunger after several decades of improvement. Even though the increase in the percentage of malnourished people in Africa has been small, the actual number of people affected by hunger has increased from 196 million in 2005 to 256.5 million in 2017, mainly due to population growth.

Figure 11. *Percentage of Undernourished People, by Region, 1990-2017*



Sources: FAO. 2014; FAO 2018. "The State of Food Insecurity in the World," Rome.

[31] FAO. 2018. "The State of Food Insecurity and Nutrition in the World." Rome.

The overall reduction in malnourishment over the past two decades is not only attributed to increased food production, but also to higher incomes and wider food availability. One factor that hasn't contributed to the increase in the global food supply is an expansion of agricultural land – according to the World Bank agricultural land area has remained relatively constant since the early 1990s. Instead, improvements in agricultural technology and efficiency have been the drivers leading to a larger food supply.

With the human population projected to increase to 9.8 billion by 2050 according to the United Nations, can we further increase the global food supply to meet expected demands? Even as diets change with higher incomes and changing preferences, most researchers conclude that the answer is yes.[32] However, there are several important caveats to this conclusion:

1. *Biofuel expansion:* **Biofuels** are fuels made from living organisms, most commonly crops such as corn and sugar cane. Currently, less than 10% of the world's crops are used for biofuels and other industrial uses.[33] While some expansion of biofuels is expected, a significant reallocation of crops away from human consumption toward biofuels could reduce the ability to meet future food demands.
2. *Climate change:* The impact of climate change on agricultural production is not precisely known. While production could increase in some areas due to an expansion of the growing season, such as in Canada and Russia, the net impact of long-term climate change on global food production is expected to be negative. Further, the increasing incidence of extreme weather events and climate related disaster is already reducing food security in many regions. Current models of the future food supply do not adequately account for climate change.
3. *Environmental damage:* While total agricultural production may rise, this may mask long-term damage to water, soil, and ecological systems. We address these issues in the next section.

6.5 Environmental Impacts of Modern Agriculture

In addition to being affected by a changing environment, modern agricultural practices impact the environment on local and global scales. We consider four environmental impacts in this section:

1. Deforestation
2. Soil erosion
3. Use of chemical inputs
4. Emissions of greenhouse gases

While the overall land area devoted to agriculture globally has not significantly changed recently, new lands are constantly brought into agricultural production as the productivity of existing plots decline. Through the practice of **slash-and-burn agriculture**, primarily practiced in tropical regions, land is cleared for farming by first cutting and burning the existing vegetation. The

[32] Wise, Timothy A. 2013. "Can We Feed the World in 2050? A Scoping Paper to Assess the Evidence." Global Development and Environment Institute, Working Paper 13-04.
[33] Cassidy, Emily S., Paul C. West, James S. Gerber, and Jonathan A. Foley. 2013. "Redefining Agricultural Yields: Tonnes to People Nourished per Hectare," *Environmental Research Letters* 8:1-8.

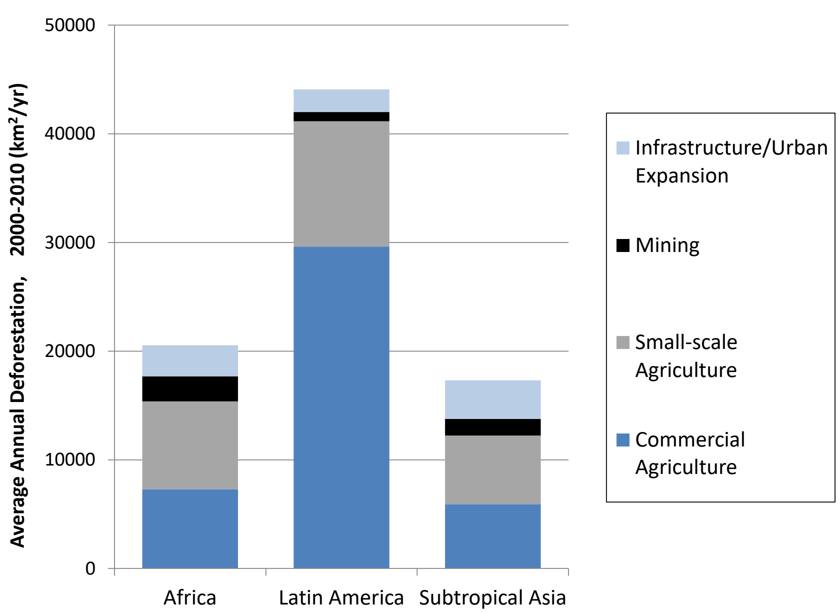
remaining ash infuses the soil with nutrients, which are then used to support agriculture. However, the soils in tropical forests tend to be nutrient-poor. Thus once the nutrients from the burnt vegetation are depleted, often in a matter of a few years, farmers must move on to new lands and repeat the cycle.

While slash-and-burn agriculture has primarily been practiced on a small scale by subsistence farmers, increasingly deforestation is occurring as a result of large-scale commercial agriculture. According to a 2012 report prepared for the governments of the UK and Norway:

> Commercial agriculture (including livestock) is the most important driver of deforestation in Latin America leading to around 2/3 of total deforested area. In both Africa and (sub)tropical Asia commercial agriculture accounts for around 1/3 of deforestation and is of similar importance as subsistence agriculture. Based on this synthesis of nationally reported data, agriculture is estimated to be the proximate driver for around 80% of deforestation worldwide.34

The causes of deforestation are presented in more detail in Figure 12. We see that more deforestation is occurring in Latin American than in Africa and subtropical Asia. In Latin America, commercial agriculture is responsible for nearly three times as much deforestation as subsistence agriculture. In Africa and Asia, small-scale and large-scale agriculture are responsible for about an equal amount of deforestation. In all three regions, agriculture is clearly the dominant cause of deforestation.

Figure 12. *Causes of Deforestation, 2000-2010*



Source: Kissinger et al et al., 2012.

[34] Kissinger, Gabrielle, Martin Herold, and Veronique De Sy. 2012. "Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers," Lexeme Consulting, Vancouver, Canada, August 2012, p. 11.

Rates of forest loss in the developing world have been increasing in recent decades.[35] Tropical deforestation is a particular problem, as these forests provide habitat for a majority of the world's biodiversity. As we have seen before, economic theory can provide insight into both the nature of the problem and potential solutions. Farmers, small- or large-scale, tend to only consider their own financial situation when making decisions, failing to account for social costs. Thus even if sustainable uses of forests provide society with the greatest net benefits, forests will still be converted to agriculture if the private benefits exceed the private costs. Thus the challenge is:

> to make users internalize all the social costs associated with converted forests. This will both increase the price and cost of the converted forest, and will also reduce the net marginal benefits of converted forest.[36]

Another environmental impact of modern agricultural is excessive soil erosion. Soil is a natural resource that regenerates over very long time periods – the average rate of soil formation is only one centimeter every 178 years.[37] Yet soil can be eroded at much higher rates when it is left exposed to rain and wind, commonly 10-40 times the rate of natural formation.

Soil erosion results in economic losses as agricultural land becomes less productive. In the United States, annual economic losses from soil erosion have been estimated at around $40 billion, and globally the cost is 10 times higher.[38] Soil erosion also results in environmental problems. For example, when eroded soil is deposited into rivers and lakes it can harm the health of these ecosystems. The siltation of rivers in the United States due to soil erosion is considered the second leading cause of water quality impairment in the country.[39] Soil erosion can also contribute to air pollution when winds carry off exposed soils.

Rates of soil erosion can be significantly reduced by implementing good agricultural practices that minimize soil disturbance, reduce soil exposure to the elements, and slow down water runoff. For example, rather than intensively tilling the soil prior to planting, in which nearly all plant residue is buried below the surface, the practice of conservation tillage leaves at least 30% of these residues on the soil surface in order to reduce soil exposure and slow runoff.

A third environmental impact of agriculture is the release of numerous chemicals into the environment. The widespread use of pesticides, herbicides, and other chemicals has clearly increased agricultural productivity and reduced global hunger. But this has come at an environmental cost. The negative impacts of these chemicals first came to light in the 1960s, most famously with the publication of Rachel Carson's *Silent Spring*. Carson documented the problem

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[35] Benhin, James K.A. 2006. "Agriculture and Deforestation in the Tropics: A Critical Theoretical and Empirical Review," *Ambio* 35(1): 9-16.
[36] Benhin, JK. 2006. "Agriculture and Deforestation in the Tropics: A Critical Theoretical and Empirical Review." *Ambio* 35(1):9-16. p. 15.
[37] See http://www.swac.umn.edu/classes/soil2125/doc/s4chp4.htm.
[38] Lanf, Susan S. 2006. "'Slow, insidious' soil erosion threatens human health and welfare as well as the environment, Cornell study asserts," Cornell Chronicle, March 20, 2006. http://news.cornell.edu/stories/2006/03/slow-insidious-soil-erosion-threatens-human-health-and-welfare
[39] Kertis, Carol A., and Thomas A. Iivari . 2006. "Soil Erosion on Cropland in the United States: Status and Trends for 1982-2003," Proceedings of the Eighth Federal Interagency Sedimentation Conference (8thFISC), April 2-6, 2006, Reno, NV.

of bioaccumulation, whereby pesticides stored in the fat tissue of animals become more concentrated further up the food chain. Top predators such as bald eagles are particular susceptible to high concentrations of toxic chemicals, leading to egg shell thinning and increased mortality.

Environmental problems are also associated with the application of fertilizers to agricultural crops. For example, nitrogen fertilizers can run off into waterways and promote algal blooms (a process known as eutrophication) that can kill fish and other aquatic animals. The production of fertilizers, along with other agricultural chemicals, can release toxic chemicals into air and water. The production of phosphorus fertilizer in India leads to air pollution from sulfur dioxide and heavy metals. Inhalation of the emissions from fertilizer plants have been associated with increased risk of autoimmune disorders and lung disease.[40]

Once again, this issue can be framed as a negative externality. As long as chemical manufacturers and farmers do not pay for the external costs of agricultural chemicals, these chemicals will be overused from the viewpoint of economic efficiency. Thus, a tax is one economic instrument that could reduce chemical use toward an economic optimum.

Denmark is one of a handful of countries that have instituted taxes on agricultural chemicals. First implemented in the mid-1980s, during the 1990s the Danish tax rates reached 54% of the wholesale price of pesticides and 34% of the wholesale price of herbicides and fungicides.[41] To reduce the net impact of the tax on farmers, over 80% of the revenue is returned back to the agricultural sector in the form of subsidies for sustainable agricultural practices. Initially, the benefits of the tax were less than expected, as it did not differentiate between the most harmful pesticides and those that are less damaging – all pesticides were taxed at the same rate. To address this, the Danish government restructured the program in 2013 to tax each chemical at its own rate based on toxicity level and human health impacts, with a new goal of reducing pesticide load 40% by the year 2015 from the 2011 level.[42] Though this ambitious goal has not yet been met, the policy has been successful in taking some of the worst chemicals off of the market, and in increasing the area of land cultivated without pesticides.[43]

The final environmental impact of modern agriculture that we consider is its contribution to global climate change (discussed in more detail below). Agriculture directly contributes to climate change by releasing various gases into the atmosphere. According to the United States Environmental Protection Agency, most of the total greenhouse gas emissions related to agriculture is due to nitrous oxide released by fertilizer application and methane released by the digestive process of farm animals. Overall, agriculture is responsible for about 9% of total U.S. greenhouse gas emissions.[44]

[40] Mishra, C.S.K., Soumya Nayak, B.C. Guru, and Monalisa Rath. 2010. "Environmental Impact and Management of Wastes from Phosphate Fertilizer Plants," *Journal of Industrial Pollution Control*, 26(1):57-60.
[41] PAN Europe. 2005. "Danish Pesticide Use Reduction Programme," London, June 2005.
[42] See https://eng.mst.dk/chemicals/pesticides/reducing-the-impact-on-the-environment/initiatives-under-the-green-growth-action-plan/pesticide-tax/
[43] Pedersen, A. B. and Nielsen, H. Ø. 2017. "Effectiveness of Pesticide Policies. In Environmental Pest Management" (eds M. Coll and E. Wajnberg). doi:10.1002/9781119255574.ch13
[44] U.S. EPA. 2018. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016," Washington, D.C., April 12, 2018.

But other estimates suggest that agriculture's contribution to climate change is much greater. Indirectly, the overall food production system contributes to climate change in other ways besides direct emissions, including:[45]

- As stated earlier, agriculture is responsible for the majority of deforestation globally. Forests natural store carbon, thus reducing the amount of carbon in the atmosphere. When forests are lost, so is their carbon storage potential.
- The processing, packaging, and transportation of agricultural and food products also contributes to climate change. For example, about one-quarter of all transportation in the European Union involves the commercial transport of food. This percentage is even higher in developing countries.
- The decomposition of agricultural wastes also releases greenhouse gases into the atmosphere. These wastes are responsible for 3-4 of global greenhouse gas emissions.

When all these other factors are considered, the overall contribution to greenhouse gas emissions from agriculture may be much higher than the 11-15% often quoted:

> Considering all these factors, it would appear that the current global food system, propelled by an increasingly powerful transnational food industry, is responsible for around half of all anthropogenic GHG [greenhouse gas] emissions – between a low of 44 percent and a high of 57 percent.[46]

6.6 Making Agriculture Sustainable

Traditional economic analysis has considered agricultural production as a process of combining inputs, including land, water, fertilizer, and pesticides to maximize output (measured as yields or profits). Environmental economics focuses on the negative externalities associated with agriculture, such as soil erosion, deforestation, toxic chemicals, and greenhouse gases as described above. These externalities can be addressed with economic policies such as taxes and subsidies.

From an ecological economics point of view, that the crux of the problem with modern large-scale agriculture is that it runs counter to the equilibrium that is found in natural ecosystems. Through natural processes, important nutrients are cycled through an ecosystem as plants die, decompose, enrich the soil, and then provide nutrients for the next generation of plants. Different plants may serve different purposes in an ecosystem. For example, certain plants "fix" nitrogen, a process by which nitrogen in the atmosphere is converted into a form that is usable by other plants in the soil. The diversity of natural ecosystems also makes them highly resilient – able to bounce back in the presence of disturbances such as disease or extreme weather.

Industrial agriculture is normally a monoculture – meaning that a single plant species is grown exclusively on a plot year after year. Unlike natural systems, monocultures tend to be more vulnerable to diseases and pests, require the constant input of nutrients, and degrade the soil. An

[45] United Nations Conference on Trade and the Environment. 2013. "Trade and Environment Review 2013: Wake Up Before It Is Too Late," Commentary IV: "Food, Climate Change, and Healthy Soils: The Forgotten Link."
[46] Ibid., p. 20.

ecological view of agricultural production sees crop output as one part of a diverse agroecological system, which aims to maintain natural processes and nutrient cycles. To achieve long-term sustainability, 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.

A sustainable agricultural system is defined here as one that produces a stable level of output without degrading the environmental systems that support it. In economic terms, this means no significant un-internalized externalities or excessive depletion of common property resources. From an ecological point of view, a sustainable system minimizes disruption to natural cycles.

Production techniques such as organic fertilization by recycling of plant and animal wastes, crop rotation and intercropping of grains and nitrogen-fixing legumes help to maintain the soil's nutrient balance and minimize the need for artificial fertilizer. The use of reduced tillage, terracing, fallowing, and agroforestry (planting trees in and around fields) all help to reduce erosion. Integrated pest management (IPM) uses natural pest controls such as predator species, crop rotation, and labor-intensive early pest removal to minimize use of chemical pesticides. Efficient irrigation techniques and the use of drought- and salt-tolerant crop varieties can reduce water use. Species diversity is promoted by multiple cropping (planting several different crops in the same field) rather than monocultures.

The traditional view has been that sustainable agricultural methods are less profitable than industrial agriculture. However, recent research suggests that this may not be true over the long run, particularly when one considers that organic agricultural products sell at a price premium. In a study conducted in Minnesota over 18 years, researchers compared the profitability of several of the main U.S. grain crops (corn, soybeans, oats, and alfalfa) using both organic and chemical-intensive methods.[47] The paper concludes:

> These results show that with current price premiums, an organic crop farm in the Upper Midwest can earn greater per-hectare profits … than a conventional farm using [the practices that are] predominant in the region. [Further,] organic premiums could decline in the future without necessarily causing organic production to lose its profitability advantage over conventional, [chemically-intensive] cropping systems.[48]

A 2009 study sponsored by the FAO reviewed the research comparing the profitability of organic and non-organic farming techniques and found that:

> … in the majority of cases, organic systems are more profitable than non-organic systems. There are wide variations among yields and production costs, but either higher market price and premiums, or lower production costs, or the combination of these two generally result in higher relative profit in organic agriculture in developed countries. The same conclusion can be drawn from studies in developing countries but there, higher yields

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[47] Delbridge, Timothy A., Jeffrey A. Coulter, Robert P. King, Craig C. Sheaffer, and Donald L. Wyse. 2011. "Economic Performance of Long-Term Organic and Conventional Cropping Systems in Minnesota," *Agronomy Journal*, 103(5): 1372-1382.
[48] Ibid., p. 1381.

combined with high premiums are the underlying cause for higher relative profitability.49

Further, the paper noted that the advantage of organic farming is even larger when one considers that non-organic farming creates more negative externalities and receives greater government support. A 2015 meta-analysis of studies of organic and conventional farming that included 55 crops on 5 continents showed similar results, finding organic agriculture to be significantly more profitable while also benefiting human health, the environment, and helping to achieve socioeconomic objectives.[50] A complete economic analysis of farming techniques should not only consider financial results, but social, environmental, and health factors.

Still, the barriers to implementing sustainable farming in the U.S. and worldwide are considerable. One major problem is access to information. Sustainable techniques tend to be both labor-intensive and information-intensive. In developed countries, many farmers are not sufficiently knowledgeable about the complex techniques of organic and low-input agriculture to be able to make them pay. It is often much easier to read the instructions on a bag of fertilizer or a canister of pesticide. In developing countries, traditional low-input farming systems have often been displaced by modernized "Green Revolution" techniques, which are advocated by large agricultural companies and many governments.

In recent years, organic agriculture has expanded rapidly. Sales of organic agricultural products in the U.S. have increased from about $15 billion annually in 2006 to over $40 billion in 2016.[51] But organic products still only account for about 5% of at-home food sales. Government policies, such as the establishment of organic standards, reform of agricultural subsidy policies, and internalization of externalities will have an important influence of the future of organic farming.

6.7 Global Climate Change

Global warming, more accurately described as **climate change**, has become a major environmental and economic issue in recent decades. The vast majority of scientists (aproximately 97%) concur that global climate change[52] is in significant part caused by human actions, in particular the increased emissions of various **greenhouse gases** (GHGs).[53] These gases act much like the glass in a greenhouse—allowing solar radiation to penetrate, but then trapping it and increasing temperatures.

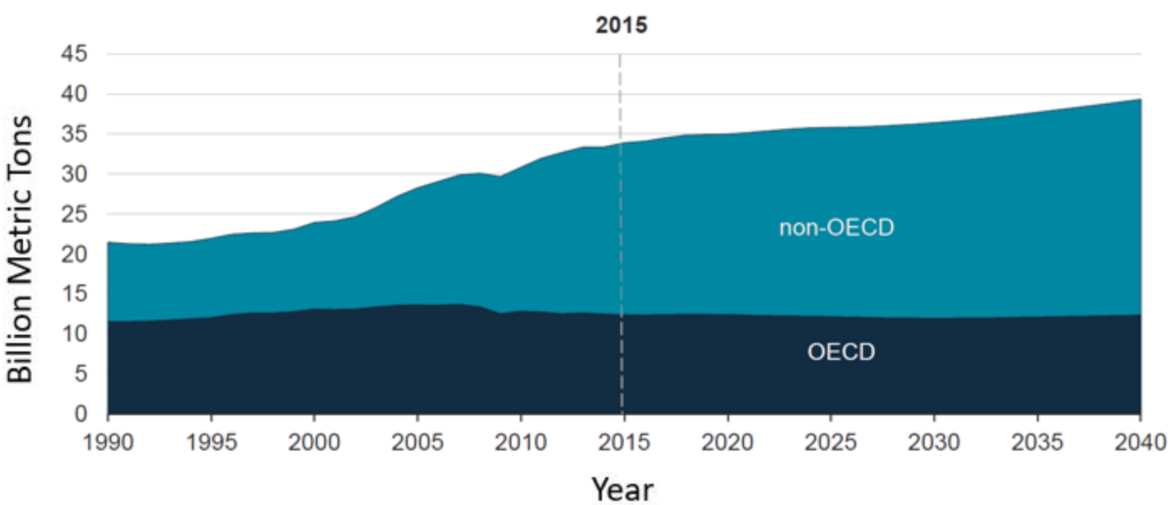
[49] Nemes, Neomi. 2009. "Comparative Analysis of Organic and Non-organic Farming Systems: A Critical Assessment of Farm Profitability," Food and Agriculture Organization of the United Nations, Rome, June 2009.
[50] Crowder, David W., and John P. Reganold. 2015. "Financial competitiveness of organic agriculture on a global scale." Proceedings of the National Academy of Sciences 112, no. 24: 7611-7616.
[51] Greene, Catherine. 2017. "The Outlook for Organic Agriculture," 94th Annual USDA Agricultural Outlook Forum, U.S. Department of Agriculture, Economic Research Service, February 22, 2017.
[52] We use the term "climate change" instead of "global warming" because in addition to warmer average temperatures there are numerous other effects of this hugely complex system change—sometimes even including colder than normal temperatures in certain locations.
[53] See, for example, Cook, John, Naomi Oreskes, Peter T. Doran, William RL Anderegg, Bart Verheggen, Ed W. Maibach, J. Stuart Carlton et al. 2016. "Consensus on Consensus: A Synthesis of Consensus Estimates on Human-caused Global Warming." *Environmental Research Letters* 11(4): 048002**.**

While most greenhouse gases exist naturally in the earth's atmosphere and make life possible on earth, human activities have increased the concentration of many of these gases, as well as introduced entirely new greenhouse gases into the atmosphere. The most important greenhouse gas emitted by humans is carbon dioxide (CO_2), which is formed when fossil fuels (coal, oil, and natural gas) are burned. Other greenhouse gases include methane, nitrous oxide, and chlorofluorocarbons (CFCs).[54]

6.8 Data and Projections

As shown in Figure 13 global emissions of carbon dioxide have increased significantly over the last couple of decades, and are projected to increase a further 34% between 2015 and 2040. We see that virtually all of the increase in emissions in the coming decades will be a result of higher emissions in developing (non-OECD) countries. However, we need to be aware that most of the carbon emitted from human activities so far has come from developed nations. Also, CO_2 emissions per capita are much higher in developed countries, and will continue to be so for the foreseeable future. For example, annual CO_2 emissions per capita are currently about 16.5 tons in the United States, 9 tons in Germany, 7.5 tons in China, 2 tons in India, and 0.3 tons in Kenya.[55]

Figure 13. *Past and Projected Global Emissions of Carbon Dioxide, 1990-2040*



Note: OECD is the Organization for Economic Co-Operation and Development, comprised mostly of developed nations.
Source: United States Energy Information Administration's International Energy Outlook, 2017.

[54] CFCs have also been implicated as ozone depleting substances. It is important to note that the degradation of the ozone layer, while serious, is an issue almost entirely unrelated to global climate change.
[55] World Bank, World Development Indicators Databank, 2018.

As atmospheric concentrations of GHGs increase, the world is expected to become warmer, on average. Not all regions will warm equally, and some regions may actually become cooler. Warmer average temperatures increase evaporation, which in turn leads to more frequent precipitation. But again, all regions will not be affected equally. In general, already wet areas will become wetter and dry areas will become drier. Climate change is also expected to result in more frequent and more intense tropical storms. The melting of polar ice caps and glaciers will contribute to rising sea levels. Sea levels are also rising because the volume of ocean water expands when it is heated. Among the ecological and human effects climate change are higher rates of species extinctions, lower average agricultural production, reduced freshwater availability, higher rates of several diseases, and increased risk of violent regional conflicts.[56]

Global average temperatures have already increased by about one degree Celsius (1.8 degrees Fahrenheit) over the last several decades. At a 2009 international meeting on climate change in Copenhagen, Denmark with the parties of the United Nations Framework Convention on Climate Change (UNFCCC) more than 130 nations agreed that it was necessary to limit the eventual warming to no more than two degrees Celsius, based on the scientific consensus that warming above this level is likely to cause dangerous impacts. A more ambitious goal of limiting temperature rise to well below 2.0°C, with a target of 1.5°C, was set in 2015 with the creation of the Paris Agreement, which had been ratified by 181 UNFCCC parties as of 2018.

Climate scientists have developed complex models to predict how much average temperatures will increase as carbon dioxide concentrations in the atmosphere increase. Because there are considerable uncertainties in predicting long-term climate trends, these models have produced a range of potential outcomes. Adding to the uncertainty in models, the extent of warming will also be influenced by the policy decisions made in the next couple of decades.

The Intergovernmental Panel on Climate Change (IPCC) is an organization created by the United Nations to assess the science of climate change. A 2013 IPCC report estimated that ambitious policy efforts, with global CO_2 emissions peaking by 2020 and rapidly declining thereafter, could limit warming to the two degree Celsius target.[57] However, as Figure 13 suggests, this scenario is highly unlikely based on current emissions projections. According to a 2014 analysis by MIT:

> Progress on climate change mitigation through international agreement has been slow, and efforts appear to be falling well behind the ambitious long-term goals set by the international community. Whether those goals are achieved or not, any hope of averting considerable climate consequences by stabilizing atmospheric GHG concentrations will require significant emissions reduction. Another 20 or 30 years of increasing emissions suggest substantial risks of dangerous climate change.[58]

A 2018 special report by the IPCC projecting the global impacts of a 1.5°C increase (which could occur as early as 2030) found that while impacts will be less severe than those of a 2°C rise, they

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[56] Intergovernmental Panel on Climate Change. 2014. "Climate Change 2014: Impacts, Adaptation, and Vulnerability: Summary for Policymakers," Cambridge, UK and New York: Cambridge University Press.
[57] Intergovernmental Panel on Climate Change. 2013. "Climate Change 2013: The Physical Science Basis: Summary for Policymakers," Cambridge, UK and New York: Cambridge University Press.
[58] MIT Joint Program on the Science and Policy of Global Change. 2014. "2014 Energy and Climate Outlook," Cambridge, MA.

will still be greater than previously expected. Further, the report found that achieving the 1.5°C goal is highly unlikely, as we are currently on track for a 3°C rise by 2100.[59]

6.9 Economic Analysis of Climate Change

Most of the topics discussed in Sections 2 through 5 of this module are relevant to the economics of global climate change. Environmental economists tend to view climate change within a traditional cost-benefit analysis framework, applying the standard techniques of economic valuation and discounting. Ecological economists are more likely to view climate change from a strong sustainability perspective, arguing for policy action on the basis of ecological and ethical, as well as economic, justifications.

Virtually all economists agree that carbon emissions, as a negative externality, should be internalized through market mechanisms such as a Pigovian tax or a tradable permit system. However, there is a lively debate among economists about how aggressive such policies should be. Until recently, most economic studies of climate change suggested a relatively modest carbon tax, perhaps around $20-$40 per ton of carbon. For context, a $30 per ton tax on carbon would increase the price of gasoline by about 8 cents per gallon.

The economic debate on climate change changed significantly in 2007, when Nicholas Stern, a former chief economist for the World Bank, released a 700-page report, sponsored by the British government, titled "The Stern Review on the Economics of Climate Change." Publication of the Stern Review generated significant media attention and has intensified the debate about climate change in policy and academic circles. Unlike previous studies, the Stern Review strongly recommends immediate and substantial policy action:

> The scientific evidence is now overwhelming: climate change is a serious global threat, and it demands an urgent global response. This Review has assessed a wide range of evidence on the impacts of climate change and on the economic costs, and has used a number of different techniques to assess costs and risks. From all these perspectives, the evidence gathered by the Review leads to a simple conclusion: the benefits of strong and early action far outweigh the economic costs of not acting.

The Stern Review estimated that if humanity continues "business as usual", the costs of climate change in the 21st century would reach at least 5% of global GDP, and could be as high as 20%. The Review also suggested the need for a much higher carbon tax—over $300 per ton of carbon.

What accounts for the difference between the Stern Review and most earlier analyses? The primary difference was that Stern applied a discount rate of 1.4%, significantly lower than the 4-5% rate used in most other studies. Stern argued that his discount rate reflected the view that each generation should have approximately the same inherent value. Stern's analysis also incorporated the precautionary principle (discussed in Section 2), in that he placed greater weight on the possibility of catastrophic damages.

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[59] IPCC, 2018: "Global warming of 1.5°C." An IPCC Special Report on the impacts of global warming of 1.5°C. October 8th, 2018.

6.10 Climate Change Policy

While the vast majority of physical scientists agree that humans are causing climate change, and the vast majority of economists support policies to reduce carbon emissions, so far the policy response has been somewhat limited. As discussed above, any chance of limiting warming to 1.5 or even 2 degrees Celsius will require significant policy changes.

The first international attempt to address climate change was the Kyoto Protocol, adopted in 1997. Under this treaty industrialized countries agreed to emission reduction targets by 2012 compared to their baseline emissions, normally set to 1990 levels. For example, the United States agreed to a 7 percent reduction, France to an 8 percent reduction, and Japan to a 6 percent reduction. Developing countries such as China and India were not bound to emissions targets under the treaty (an omission that drew objections from the United States and some other countries). The overall Kyoto program target of a 5% reduction in industrial country emissions was met, but primarily as a result of very large reductions in Russia due largely to the collapse of Communist industries rather than any deliberate policy.

The Paris Climate Agreement was drafted at the 2015 UNFCCC meeting in Paris, France to replace the Kyoto Protocol. Unlike the Kyoto Protocol, the Paris Agreement covers both developed and developing countries. Its objective is to limit the increase in global temperature to well below 2°C, with a target goal of 1.5°C. To do this, each participating country sets their own nationally determined contributions (NDCs) towards this goal. This bottom up approach of using NDCs is based on equity, with an understanding that developing countries will take a longer time to reach peak emissions. Each country's NDCs will be evaluated and reported on every 5 years, and are expected to get progressively more ambitious over time.

As of 2018 the Paris agreement has been ratified by 184 of the 197 parties of the UNFCCC. In 2017, however, US President Donald Trump declared that the United States will withdraw from the agreement[60], making the US the only UNFCCC member state not intending to participate. Despite this federal level withdrawal, 17 states, which together make up 41% of the US population, have joined together and formed the United States Climate Alliance, agreeing to uphold the objectives of the agreement.[61]

As part of its efforts to meet its carbon reduction obligations, the European Union instituted a carbon trading system in 2005. The system covers more than 11,000 facilities that collectively emit nearly half the EU's carbon emissions. After the system's implementation, it soon became evident that carbon permits were over-allocated, leading to a significant drop in the price of permits – from around €20 per ton in 2005 to less than €1 per ton in 2007. With a reduction in the number of available permits, prices recovered but generally trended downward after the global financial crisis, with prices down around €4.5 per ton in 2017

In 2017 the EU agreed on reforms to control the oversupply of permits, which are set to take effect in 2019 and are expected to drive prices back up to around €20/ton by 2020. Already prices have risen to approximately €18 in 2018 anticipation of these reforms. Despite initial allocation problems, the EU trading system has led to emissions reductions estimated to be 8% below

[60] The earliest possible withdrawal date from the accord for the United States is November 4th, 2020.
[61] United States Climate Alliance, 2018.

business-as-usual, while having no negative effects on the overall European economy.[62] Long term goals of the trading system include reducing emissions to 20% below 1990 levels by 2020, and 40% below 1990 levels by 2030.

Other efforts to reduce carbon emissions are being implemented at national and local levels. Carbon taxes have been instituted in several countries, including a nationwide tax on coal in India (about $1/ton, enacted in 2010), a tax on new vehicles based on their carbon emissions in South Africa (also enacted in 2010), a carbon tax on fuels in Costa Rica (enacted in 1997), and local carbon taxes in the Canadian provinces of Quebec, British Columbia, and Alberta that apply to large carbon emitters and motor fuels.

The first mandatory cap and trade emissions program in the United States, the Regional Greenhouse Gas Initiative (RGGI) was established in 10 northeastern and mid-Atlantic states in 2009 to curb emissions from the power sector. Despite early overallocation of allowances, resulting in little impact in the first few years, the program is credited with a 45% reduction of emissions below 2005 levels, decreased electricity prices for consumers, and significant health related savings from reduced nitrogen oxides and sulfur dioxide emissions[63]. Additionally, the program has had positive economic impacts, with the $2.7 billion in revenue generated through permit sales put towards energy efficiency measures, community-based renewable power projects, financial assistance to low income utility customers, and greenhouse-gas-reduction measures[64].

The U.S. state of California instituted a cap-and-trade system in 2013 for electric utilities and large industrial facilities, with a goal of decreasing carbon dioxide emissions by 3% annually. Like the RGGI program, this system was also initially considered to be a failure due to an oversupply of permits, however this is being corrected due in part to new ambitious reduction targets set in 2016.

Ultimately, climate change is a global problem that requires a global response. Each individual country has little incentive to reduce its emissions if other countries do not agree to similar reductions. Action to reduce climate change can be regarded as a public good, and as we have noted, in the case of public goods the problem of free riders means that they will not be provided effectively without collective action. In the case of a global public good such as climate stabilization, this requires an international agreement.

The Paris Accord is an attempt to do just that. For it to be successful however, participation is needed from all nations. Participation is especially important for major polluters, including the world's two largest carbon emitters: China and the United States. Even with the US vowing to back out of the accord (see Box 4 for more on current US climate change policy), China has reaffirmed their commitment, pledging along with the EU, to uphold the agreement while calling for other nations to step up.

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[62] Brown, Lucas Merrill, Alex Hanafi, and Annie Petsonk. 2012. "The EU Emissions Trading System: Results and Lessons Learned," Environmental Defense Fund, Washington D.C.
[63] RGGI. 2017. RGGI Program Review: September 25, 2017 Stakeholder Meeting.
[64] Hibbard, P. J., Okie, A. M., Tierney, S. F., & Darling, P. G. 2015. "The economic impacts of the Regional Greenhouse Gas Initiative on nine Northeast and Mid-Atlantic states." *Analysis Group, July*.

BOX 4: U.S. ENVIRONMENTAL POLICY UNDER THE TRUMP ADMINISTRATION

In contrast to the Obama administration's commitment to reducing carbon dioxide emissions and focusing on renewable energy, the Trump administration has aimed to reverse many environmental regulations and increase production from non-renewable energy sources, while denying human contributions to global warming.

Shortly after taking office, President Trump announced the "America First Energy Plan" which included eliminating policies such as the Climate Action Plan and the Waters of the US rule; increasing production from untapped shale, oil and natural gas reserves; and focusing on clean coal.

After proposing the elimination of the Environmental Protection Agency (EPA) during his campaign, President Trump has proposed major budget cuts to the agency, while shrinking the workforce by 8% and appointing administrators with connections to the fossil fuel industry. Current acting EPA administrator, Andrew Wheeler, who replaced Trump's first nominee Scott Pruitt after he resigned while under multiple federal investigations for misconduct, has a background as a coal lobbyist and has previously questioned the scientific rigor of the IPCC.

In November of 2018 the US Government released The Fourth National Climate Assessment, a report authored by the National Oceanic and Atmospheric Administration (NOAA) and 12 other federal agencies. The report found a high likelihood that current warming trends are caused by human activities and will cause major damage to American health, the environment, and the economy. Economic losses due to climate change were predicted to reach up 10% of the county's GDP by the end of the century.

EPA chief Wheeler's response to the report has been to question the methodology used, criticizing the emphasis on worst case warming scenarios, while President Trump has stated that he does not believe the economic impacts projected. These responses combined with past actions show that the current administration is unlikely to take serious action to address global climate change.

Sources: USGCRP, 2018. 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. doi: 10.7930/NCA4.2018.

KEY TERMS AND CONCEPTS

Biofuels: fuels derived from recently-living biological sources, normally plant matter.

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

Climate change: changes in the earth's climate, such as warmer average temperatures and shifting precipitation patterns, attributed to either natural or human causes

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.

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

Contingent ranking: a survey method whereby respondents are asked to rank a list of alternatives.

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 of illness method: an approach for valuing the negative impacts of pollution by estimating the cost of treating illnesses caused by the pollutant.

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.

Defensive expenditures approach: a pollution valuation methodology based on the expenditures households take to avoid or mitigate their exposure to a pollutant.

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

Discounting: the concept that future benefits or costs should not count as much as 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 economics: a economic perspective that views the economic system as a subset of the broader ecosystem and subject to biophysical laws.

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

Ecosystem services: beneficial services provided freely by nature such as flood protection, water purification, and soil formation.

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

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

Externalities: effects of market transactions that change the utility, positively or negatively, of those outside of the transaction.

Free rider: someone who avoids 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.

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

Human capital: the knowledge, skills, and abilities of the labor force, reflecting investments in education and training.

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

Inherent value: the value of an organism, species, habitat, or other natural system independent of its economic value.

Lower-bound estimate: an economic estimate that provides the lowest possible value for some cost or benefit.

Malthusian hypothesis: the theory proposed by Thomas Malthus in 1798 that population would eventually outgrow available food supplies.

Marginal benefits: the benefits of producing or consuming one more unit of a good or service.

Marginal costs: the costs of producing or consuming one more unit of a good or service.

Market equilibrium: the market outcome that results from the interaction of supply and demand, i.e., the point where the supply and demand curves intersect.

Market-based approaches: economic regulations that create market incentives for behavioral change among participants (buyers and sellers), including taxes and tradable permits.

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

Natural capital: the available endowment of land and resources including air, water, soil, forests, fisheries, minerals, and ecological life-support systems.

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.

Nonexcludable: a characteristic of goods where the one person’s use of the good does not prohibit others from using the good also.

Nonmarket valuation: economic valuation of goods and services not traded in markets.

Nonrival: goods that can be used by more than one user at a time.

Nonuse benefits: benfits people obtain without actually using a resource; nonuse benefits include existence and bequest values.

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.

Polluter pays principle: the view that those responsible for pollution should pay for the associated external costs such as health costs and damage to wildlife habitats.

Positive externalities: the positive impacts of a market transaction which affect those not involved in 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.

Price volatility: large or frequent changes in the price of a good or service.

Produced capital: productive physical resources that are manufactured by humans, such as buildings, roads, and computers.

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

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

Replacement cost methods: an approach to measuring environmental damages that estimates the costs necessary to restore or replace the resource, such as applying fertilizer to restore soil fertility.

Revealed preference methods: methods of economic valuation based on market behaviors, including travel cost models, hedonic pricing, and the defensive expenditures approach.

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

Slash-and-burn agriculture: agricultural production technique where existing vegetation is cut then burned to allow for the planting of crops, typically at a subsistence level.

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

Social marginal 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.

Stated preference methods: economic valuation methods based on survey responses to hypothetical scenarios, including contingent valuation and contingent ranking.

Strong sustainability: the view that natural and human-made capital are generally not substitutable and, therefore, natural capital levels should be maintained.

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

Total economic value: the value of a resource considering both use and non-use values.

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.

Travel cost models: the use of statistical analysis to determine people's willingness to pay to visit a natural resource such as a National Park or river; a demand curve for the resource is obtained by analyzing the relationship between visitation choices and travel costs.

Upstream tax: a tax to regulate emissions or production as near as possible to the point of natural resource extraction.

Value of a statistical life (VSL): the willingness to pay of society to avoid one death based on valuations of changes in the risk of death.

Weak sustainability: the view that natural capital depletion is justified as long as it is compensated for with increases in human-made capital; assumes that human-made capital can substitute for most types of natural capital.

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

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DISCUSSION QUESTIONS

1. Which definition of sustainability, strong or weak, do you think is the most appropriate? Based on the material discussed in this module, how would you quantitatively measure whether your preferred definition of sustainability is being achieved?

2. Explain in your own words why an unregulated market outcome will not be economically efficient in the presence of a negative externality. Then explain how the market can achieve efficiency through the internalization of the externality.

3. Discuss how the global atmosphere can be considered a common property resource. Do you think the atmosphere is suffering from the tragedy of the commons? If so, what policy solutions would you recommend?

4. Do you think contingent valuation produces valid economic estimates of the benefits of environmental resources? Can you think of ways to ask contingent valuation questions in order to improve the validity of the responses?

5. What do you think is the main advantage of cost-benefit analysis? What do you think is its main disadvantage? Do you think cost-benefit analysis should be the basis for choosing environmental policy options? Why or why not?

6. List the main advantage and main disadvantage of each of the four environmental policy options discussed in this module: pollution taxes, tradable pollution permits, pollution standards, and technology-based regulation. Then for each of the four options discuss one pollution scenario for which you think it would be the best policy option to regulate pollution.

7. Do you think a carbon tax or a tradable permit system is the best approach for regulating the emissions of greenhouse gases? Explain your choice.