CHAPTER 6

# The Economics of Climate Change and Environmental Policy

***After reading this chapter, you will understand the following:***

1. How the price of a good or service affects the quantity demanded by buyers
2. How other market conditions affect demand
3. How the price of a good affects the quantity supplied by sellers
4. How other market conditions affect supply
5. How supply and demand interact to determine the market price of a good or service
6. Why market prices and quantities change in response to changes in market conditions
7. How price supports and price ceilings affect the operations of markets

***Before reading this chapter, make sure you know the meaning of the concepts:***

1. Spontaneous order
2. Markets
3. Opportunity cost
4. Law of unintended consequences

IN CHAPTER 4 we introduced the term externality to refer to effects of production or consumption that have an impact on third parties. Problems of pollution, ranging from local smog to global climate change, are examples of externalities. They hinder the efficient operation of the price system because harm to pollution victims is not reflected in market prices. As a result, users of the product that causes the pollution receive a false signal that tells them "use more," when the true opportunity cost would tell them "use less."

For example, when you fill the gas tank on your car, the price at the pump reflects costs of extracting the crude oil, transporting it, refining it, and distributing it through the retail network. However, the price does not reflect the damage done locally, and to the whole planet, as a result of carbon dioxide and other greenhouse gasses emitted through your tailpipe. According to widely used scientific models, these greenhouse gasses contribute to global warming. The gradual average warming of the planet, in turn, has the potential to trigger many types of climate change, including not just changes in temperature, but also in rainfall patterns, storm tracks, ocean currents, and so on. On balance, the changes in climate appear more likely to be harmful than helpful. This chapter takes a closer look at the problem of climate change and other pollution issues, and at potential solutions that attempt to restore the efficient working of price systems.

## Pollution Abatement as a Problem of Scarcity

Pollution, says the *American Heritage Dictionary*, is "the contamination of soil, water, or the atmosphere by noxious substances." That is a fine definition—from the victim's point of view. An understanding of pollution as an economic problem, however, must take into account the polluter's point of view as well. People do not—at least we hope they do not—pollute the environment just for the fun of it. Instead, they pollute because it is an inexpensive way of getting rid of wastes from production or consumption. Seen from this perspective, it is clear that pollution is a problem of scarcity. The earth's scarce air, water, and other resources cannot absorb unlimited waste disposal without serious damage.

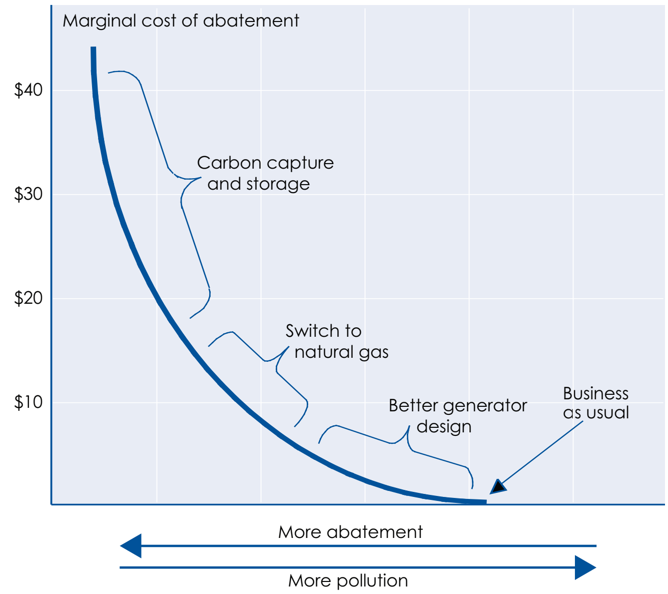
### *The Costs of Pollution Abatement*

Most of the types of pollution that dominate the news involve noxious gases, toxic chemicals, and bulky solids that are byproducts of commercial activities. Left to their own devices, polluters have an incentive to choose the lowest-cost method of getting rid of these byproducts, which often means discharging them directly into the environment. *Pollution abatement* means taking measure to reduce discharge of harmful byproducts into the environment through changes in production methods, recycling, capture and storage, or other methods. Pollution abatement reduces the impact on the environment; but, at the same time, it increases the cost to the polluter of waste disposal.

Figure 6.1 illustrates the cost of pollution abatement with the example of carbon dioxide ($CO_2$) emissions from a coal-burning power plant. If no abatement measures are undertaken, the amount of $CO_2$ emitted by the plant is marked "business as usual." Beginning from that point, the plant could reduce emissions using several strategies, some more effective, but also more expensive, than others. The least expensive

Toxic chemicals are a major concern in dealing with the pollution of the environment.

FIGURE 6.1 COST OF POLLUTION ABATEMENT




This graph shows the marginal cost of abatement for the case of carbon dioxide emitted by a coal-fired electric power plant. With no pollution control, the plant would emit an amount of $CO_2$ shown as "business as usual." The cheapest method of pollution abatement, improving the efficiency of the generating equipment, could eliminate about a third of the pollution at a cost of less that $10 per ton. Switching to natural gas would eliminate more pollution, and using still-experimental carbon capture and storage technology could eliminate almost all of it. As pollution is progressively reduced, more and more expensive abatement technologies must be introduced. For that reason, as the amount of pollution decreases, the marginal cost of abatement Increase.

approach would be to improve the efficiency of the generating equipment. All of the $CO_2$ from burning the coal would still be released into the atmosphere, but less coal would have to be burned per kilowatt-hour of electricity. Perhaps a third of the $CO_2$ could be eliminated in this way, at a cost of less than $10 per ton. If the plant wanted to reduce $CO_2$ pollution still more, it could switch its fuel from coal to natural gas. The figure suggests that doing so could eliminate about half of the remaining pollution, but at a higher marginal cost of abatement—up to $15 per ton of $CO_2$ avoided. Finally, using still-experimental technology to capture and store the $CO_2$ instead of releasing it into the atmosphere could theoretically eliminate nearly all of the $CO_2$. The figure shows that doing so might cost up to $40 per ton of avoided $CO_2$, or even more.

**Marginal cost of abatement**

The cost of reducing waste discharged into the environment by one unit

The numbers in the figure are only illustrative. The costs would vary from one source to another and would change as technology and costs of alternative fuels changed. However, they suggest a general principle that applies to nearly every source of pollution: The cost of reducing pollution by one more unit, known as the **marginal cost of abatement**, increases as the degree of abatement decreases. Since the diagram shows increasing pollution from left to right and increasing abatement from right to left, the principle of increasing marginal cost of abatement is shown by a negatively-sloped curve, one that becomes higher from right to left as it approaches the vertical axis.

## Marginal External Cost

We turn now from the cost to polluters of reducing waste to the costs that pollution imposes on others. The total of the additional costs borne by all members of society as a result of an added unit of pollution can be termed the **marginal external cost**.

**Marginal external cost**

The total of the additional costs borne by all members of society as the result of an added unit of pollution

Each type of pollution has its own particular characteristics. In some cases pollution up to a certain threshold may do no harm. For example, a small amount of carbon dioxide from human activity can be absorbed harmlessly in the natural carbon cycle of plants and oceans. After this threshold is reached, further increases become harmful. To illustrate, consider a rising sea level, only one of the many harmful effects that scientists predict as a result of climate change caused by $CO_2$ emissions. Rises of even a few inches can damage beachfront property. Further rises would cause flooding of low-lying farmland in countries like Bangladesh and could threaten to flood some small island countries completely. In principle, investment in dikes and barriers could offset some or even most of that damage; but as the ocean level rises further, the costs of barriers would increase greatly. Some models predict catastrophic sea level rises of up to 20 feet, although a majority of scientists think the probability of such a catastrophe in this century is small. A 20-foot sea-level rise would cause enormous damage and would overwhelm any human efforts to build barriers.

The same pattern is seen when other types of harm from climate change are considered—damage from changes in rainfall, from extreme weather events, from reduction in biodiversity, and so on. In short, studies of many different effects of climate change suggest that as the earth's temperature rises, the harm done by an additional degree of warming—the marginal external cost—increases.

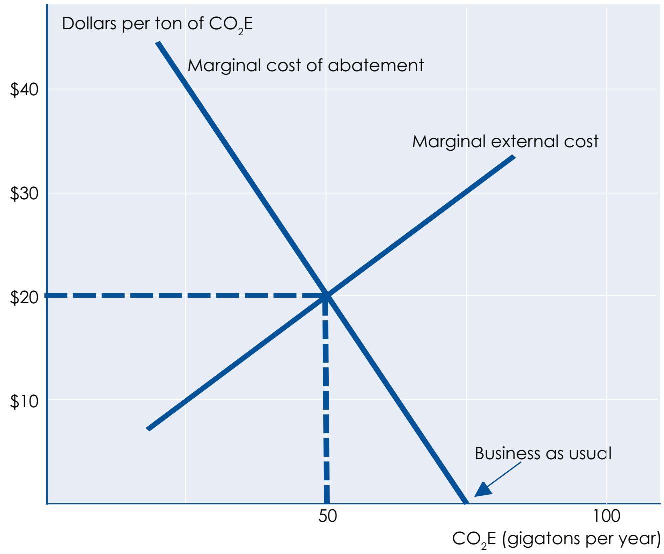
## The Optimal Quantity of Pollution

Figure 6.2 combines a marginal cost of abatement curve similar to that in Figure 6.1 with a positively sloped curve representing marginal external cost. This time, the figure represents not the $CO_2$ emissions from a single plant but emissions for the world as a whole. The horizontal axis is labeled in gigatons (billions of tons) of carbon dioxide equivalent ($CO_2E$). $CO_2E$ is a measure of greenhouse gasses that includes the effect not only of $CO_2$ but also of other gasses like methane and nitrous oxide.

The point of intersection of the two curves represents the economically optimal quantity of pollution. To the right of the intersection in Figure 6.2, then, it would be worthwhile to undertake additional abatement efforts because the external costs saved in the form of crop damage, sea level rise, and so on would be less than the cost of reducing greenhouse gas emissions.

To the left of the intersection, however, the marginal cost of abatement exceeds the marginal external cost. In that region, further pollution abatement is not economi-

**FIGURE 6.2 THE OPTIMAL QUANTITY OF POLLUTION**




This figure shows a positively sloped curve representing the marginal external cost of greenhouse gas emissions together with a negatively sloped curve representing the marginal cost of abatement. (To simplify the diagram, both curves are drawn as straight lines.) The point where the two curves intersect is the economically optimal quantity of pollution. To the right of that point, the harm done by pollution exceeds the cost of eliminating it. To the left of that point, the cost of abatement is greater than the harm done by pollution.

cally justified. The relatively small avoided harm done is not enough to offset the scarce resources used to further reduce pollution.

To economists, the logic of the optimal quantity of pollution is no different from that underlying the choice of the least-cost method of producing running shoes or the choice of the optimal balance of oil and vinegar in making a salad dressing. Clearly cleaning up the environment entails costs and trade-offs. Few people would advocate choosing either of the extremes—the whole world as an uninhabitable sewer or a pristine wilderness from which all humans have been eliminated. If we reject both extremes, says the economist, there must be an optimal point between them.

However, it should be pointed out that some people reject the optimal-pollution concept as a guide to public policy. The criticisms are of two types, some focusing on problems of measurement and some on problems of rights.

## *Problems of Measurement*

Economists and climate scientists working together have made many attempts to estimate both the costs of climate change (the marginal external costs in our terminology) and the costs of mitigation (marginal costs of abatement). A consensus has been reached on some aspects of the problem, but the range of estimates remains very wide.[1] Some critics say that the range of estimates is so wide as to offer no useful guidance at all. Others say the estimates are not only imprecise but are also biased toward business-as-usual policies. Only a few of the most important issues can be discussed here.

**SCIENTIFIC UNCERTAINTIES** Climate scientists understand the basic mechanisms of global warming, but they are not always able to agree on the size or geographical distribution of the specific impacts of the resulting changes in climate. One area of uncertainty is the degree of warming associated with any given increase in greenhouse gasses in the atmosphere. For example, according to the Intergovernmental Panel on Climate Change (IPCC), the amount of additional warming associated with stabilizing $CO_2$ concentrations at 550 parts per million (well below the business-as-usual level) could be anywhere from 1 to 3.5 degrees centigrade. The effects of any given amount of warming are also uncertain. For example, 2 degrees of additional warming could produce anywhere from 6 inches to as much as a meter of additional sea level rise. Another major problem is that a given increase in the average global temperature does not produce uniform changes in climate. Temperatures tend to change more near the poles and less near the equator. Storm tracks, rainfall patterns, and other details of climate change are still harder to predict, even though exactly those details may be critical to calculating damages. Complex climate feedback loops cause especially great difficulties in forecasting climate change. For example, warming increases the release of methane from permafrost, which in turn causes additional warming; but warming also may increase cloud cover, which would reflect some solar energy back into space and slow warming.

**MARKET AND NONMARKET DAMAGES** Once climate scientists have done their best to forecast the degree of future warming and the details of its effects on the climate, economists have to convert the costs and benefits into dollar terms. Costs that can, in principle, be assigned a monetary value are called market damages. For example, economists try to estimate the value of damage to crops. Many regions, especially near the tropics, will suffer a loss in farm productivity; but farm output in some northern regions will probably increase, at least with moderate degrees of warming. Monetary values can also be assigned to damage from sea level rise, increased storm intensity, and changes in energy used for heating and cooling. Nonmarket damages are harder to convert to monetary terms. For example, health effects from the spread of malaria or changes in death from heat and cold can only be partly converted to monetary terms. Damages to biodiversity and the recreational value of natural areas are even harder to estimate.

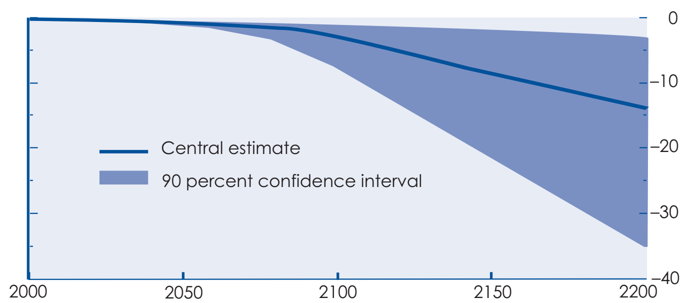
**THE INTERACTION OF ECONOMIC GROWTH AND CLIMATE CHANGE** Special problems are raised by the complex interaction between economic growth and climate change. On the one hand, economic growth is the root cause of increased greenhouse gas emissions. The global warming forecasts of the IPCC, the IMF, and others all assume continued economic growth in both developed and undeveloped countries. For example, the IMF estimates that by the middle of the twenty-first century, the level of real income (that is, income expressed in today's dollars to eliminate the effect of inflation) will be about three times what it is now in the United States and about six times what it is now in developing countries (excluding

China, where the increase will be even greater). The IPCC forecasts that by 2100, world GDP per capita will be 4 to 20 times higher than it is today. This means that the world average level of per capita income, including even the poorest countries, is likely to be substantially higher than the average level of income in the United States today. It is this enormous projected increase in economic activity that is the main driver of the expected, and feared, increase in global average temperatures.

At the same time, however, that increased incomes cause the earth to warm, warming is, on balance, harmful to economic growth. As shown in Figure 6.3, the IMF estimates that climate change is likely to cause world GDP at the end of the twenty-first century to be 1 to 7 percent below what it otherwise would be. By the end of the twenty-second century, the loss could be from 3 to 35 percent. Keep in mind, however, that these losses are relative to the baseline. They do not mean that people living in 2100 will be 1 to 7 percent poorer than those living today because the baseline projections call for a very large increase. For example, suppose that the average world level of income for a family of four in 2100 (stated in today's U.S. dollars) would be $100,000 without climate change—a figure well within the projected range of economic development, and far above today's world average of about $16,000. If so, warming would be expected to reduce that from $100,000 per family to something like $93,000 to $99,000.[2]

**COSTS OF ABATEMENT** Not surprisingly, there are difficulties in measuring the costs of abatement as well as the external costs of greenhouse gas emissions. There are obvious uncertainties regarding the future price trends for oil, coal, and other carbon-based energy sources. In addition, there are uncertainties about the price elasticity and income elasticity of demand for carbon-based energy. Most difficult of all to

**FIGURE 6.3 BASELINE CLIMATE, MARKET IMPACTS, RISK OF CATASTROPHE, AND NONMARKET IMPACTS (PERCENT LOSS IN GDP PER CAPITA)**




The figure shows a range of estimates for the costs of climate change, including market impacts like crop damage, risk of catastrophes like rapid rise in ocean levels, and nonmarket impacts like loss of biodiversity. The costs are given as percentage reductions below baseline projections of GDP growth, not reductions below today's levels. Even with the most pessimistic estimates of damage, future incomes, adjusted for damages, are still expected to be much higher than today's in both developed and developing countries.

SOURCE: IMF, World Economic Outlook, April 2008, Figure 4.7

forecast is the rate at which new, low-carbon energy sources like solar, wind, and advanced biofuels will become available. Taking all of these uncertainties into account, the best estimate of the cost of stabilizing the atmospheric $CO_2$ level at 550 parts per million (above today's level but well below business as usual) would be about 1 to 2 percent of world GDP. Again, this means a reduction from a growing baseline level of GDP, not from today's level.

**COMPARING THE PRESENT AND FUTURE** Probably the biggest difficulty of all in measuring the external costs of climate change and the costs of abatement is that of comparing costs and benefits that occur now with those that will occur in the distant future. Climate change is a process that plays out over a time frame of centuries. Even in the impossible event that we could reduce greenhouse gas emissions to zero tomorrow, the earth would continue to warm gradually and the ocean would continue to rise for hundreds of years before reaching equilibrium.

What this means is that climate policy involves a trade-off between costs that must be paid now to obtain benefits not only for the children and grandchildren of those living today, but also for those tens of generations in the future. How can we compare the value of a dollar taken from consumption or production today with increased health or welfare of someone living 100 years from now? Different methods of answering this question are the single greatest source of disagreement in estimating the net costs and benefits of policies to slow climate change. The appendix to this chapter provides additional discussion of how costs and benefits can be compared over time.

## *Problems of Rights*

In addition to the criticism that external costs and abatement costs cannot be measured accurately, the optimal-pollution concept also encounters a second criticism—that environmental policy should not be guided by economic trade-offs alone, but should also respect certain basic rights.[3]

The idea here is that pollution should be viewed as a violation of the rights of its victims, similar to the crimes of theft, vandalism, or rape. Suppose that a vandal breaks into a person's home and smashes a valuable statue. How should a court decide the case? Should it listen to testimony from the owner about the statue's value, hear testimony from the vandal about the thrill of smashing it, and then make its decision by weighing the vandal's thrill-value against the owner's artistic sensibility? Most people would be outraged by such an approach. They would say that the vandal violated the owner's right to enjoy the statue and that the vandal's thrills from the smashing should count for nothing in deciding the case. Similarly, people who take the rights-based approach argue that reduction of abatement costs for the polluter should not negate the polluter's duty to respect the rights of victims. Unless the polluter gets permission from the victim, or pays full compensation for harm caused (including subjective, non-economic harm), pollution should cease, regardless of the relative levels of abatement costs and external costs.

The discussion that follows employs the optimal pollution concept, but the reader should keep in mind that there are other points of view, as well.

## Controlling Externalities Through Voluntary Exchange

In Chapter 1, we characterized markets as mechanisms for achieving coordination of plans among producers and consumers. Under proper conditions markets can be counted on to provide us with things like shoes, cars, and manicure services in something close to the optimal quantities and to use scarce labor, capital, and natural resources efficiently in the process. The question we take up here is under what conditions, markets and voluntary exchange will result in efficient waste disposal and an optimal quantity of pollution.

### *Markets Without Transaction Costs*

We can begin by seeing how voluntary exchange would handle the problem of pollution in a world without transaction costs. In that world, technical information about the causes and effects of pollution is available to everyone at no cost. Also, people do not behave opportunistically. They honestly share information about how much they suffer from pollution or how much it would be worth to them to escape its effects, and they voluntarily abide by any agreements they reach.

To keep things simple, we will illustrate the principles not with the very complex issue of climate change but with a small-scale issue of local pollution. Suppose that in our imaginary world without transaction costs there is a forest owned by Joan Forester and, upwind from it, a steel mill owned by John Miller. Noxious fumes from the steel mill are killing the trees in the forest. How can Forester and Miller resolve the problem of pollution?

**PROPERTY RIGHTS** To know how the situation will be handled, we first need to know Miller's and Forester's property rights, especially those aspects of property rights that affect use of the air. There are two possibilities. One is that ownership of the forest includes a right to prevent pollution of the forest air. The other is that ownership of the mill includes a right to emit wastes into the air regardless of where they end up. Let's consider each of these possibilities in turn.

First, suppose that the air rights belong to Forester. Acting on the basis of these rights, she approaches Miller to inform him of the damage being done to her trees by pollution from his mill. He recognizes an obligation to do something. After an open and honest discussion, they reach one of several possible agreements:

1. Miller agrees to stop the pollution. He accomplishes this either by installing pollution-control equipment or by shutting down the mill, whichever is less costly to him.
2. Miller agrees to compensate Forester for the value of the trees killed by pollution. This alternative will be better for both parties than a reduction of pollution if the value of the trees killed by the pollution is less than the cost of pollution abatement.
3. Miller agrees to buy the forest at a price acceptable to Forester. He then manages the combined steel and forestry enterprise in an efficient manner, installing whatever pollution control equipment, if any, is deemed cost-effective.

Suppose instead that the air rights belong to Miller. In that case, when Forester approaches him to discuss the pollution damage, he is under no obligation to do anything unless he is offered something of value in return. In this case there is a different set of possible outcomes for their negotiations:

1. Forester pays Miller an agreed-upon amount to stop the pollution, which he does either by installing control equipment or shutting down the mill, whichever is less costly.
2. Forester buys the mill at a price acceptable to Miller and then manages the combined enterprise in an efficient manner.
3. The parties agree that the value of the trees killed by the pollution is less than the cost of pollution abatement, in which case no action is taken.

**THE COASE THEOREM** Several generalizations can be drawn from the example of the forest and the steel mill. First, negotiations between the parties will always result in an optimal quantity of pollution in which pollution will be reduced only to the extent that the cost of abatement is less than the damage it does to the trees. Second, if pollution is to be reduced, the most efficient means of abatement—installing control equipment, shutting the mill, or whatever—will be used. Finally, these results will be achieved regardless of the initial assignment of property rights. Whether the air rights initially belong to the owner of the forest or to the owner of the steel mill will determine who must compensate whom, but will not affect the degree of pollution abatement or the means used to achieve it. Thus, for example, if it is cost-effective to install control equipment on the mill, the initial determination of property rights will determine whether Forester or Miller bears the cost of the equipment; but in either case, it will be installed.

The proposition that, in the absence of transaction costs, problems of externalities will be efficiently resolved by private agreement regardless of the initial assignment of property rights is commonly known as the **Coase theorem** after Ronald A. Coase.[4]

**Coase theorem**

The proposition that problems of externalities will be resolved efficiently through private exchange, regardless of the initial assignment of property rights, provided that there are no transaction costs

## *Market Resolution of Externalities in Practice*

Transaction costs are never zero in the real world. They are sometimes low enough, however, to permit externality issues to be resolved through voluntary exchange. *Economics in the News 6.1* provides one example.

Other examples of market-based resolution of externalities can be found closer to home. One common example is the use of restrictive covenants in real estate development—legally binding agreements that limit what owners can do on their property. Left to their own devices, people do many things that annoy their neighbors. They hold loud parties, leave bright outdoor lights on all night, park boats or junked cars in their front yards, and leave garbage uncollected. Real estate developers have found that many people will pay a premium price for a home in a neighborhood where they know their neighbors will not do those things. Accordingly, when they subdivide a tract of land for a new neighborhood, they add restrictive covenants to the deeds. When homebuyers sign the deeds,

## Economics in the News 6.1
## USING PROPERTY RIGHTS TO PROTECT THE LAND

The Brazilian Amazon, and the vast adjacent forest known as the *Mato Grosso*, is one of the world's environmental battlegrounds. Every year, deforestation adds millions of tons of carbon dioxide to the earth's atmosphere and further reduces habitat for endangered species.

The Brazilian government is well aware of the threat. It has passed laws that restrict deforestation and require ranchers to keep up to 80 percent of their land in forest. If they have previously cleared too much, they must replant. The laws, unfortunately, are not always enforced. Corrupt local officials sometimes turn a blind eye to violations. Land speculators team up with gangs of illegal land invaders who burn first and then stake claims to the devastated land. Police are sometimes afraid to go into the forest to confront the heavily armed gangs.

Fire in the Amazon rainforest in northern Brazil. Ranchers, farmers, and loggers burned and cut down a near-record area of the Amazon rainforest.

John Cain Carter is one rancher who has had enough of the lawlessness and destruction. A transplanted Texan with a Brazilian wife, he founded the *Aliança da Terra* (Land Alliance), an organization that aims to use market forces to protect the environment. In comments published on the web site *Amazônia*, Carter says, "People think farmers in the Amazon are bandits, so we're trying to show there are good people who are trying to make a difference and reduce their impact .... We're turning the system on its head, adding transparency and credibility to turn it into a worldwide example of good land stewardship."

Carter's organization sends environmental engineers and agronomists to help ranchers improve land management practices by replanting forests, protecting fragile waterways from damage done by cattle, and limiting erosion and pollution. Their reward comes not just in terms of increased self-respect but in increased profits, too. Some of the profits come from payments earned for carbon reduction credits when land is reforested. Another source of profit is the sale of beef and soy that is certified as environmentally friendly. McDonald's, Burger King, and other big buyers are willing to pay premium prices for these products to show that they are environmentally friendly.

Not-for-profit groups like the World Wildlife Fund have supported the efforts of the Land Alliance and other local groups, like the Roundtable on Responsible Soy Association. Not all environmentalists are enthusiastic. Some shun alliances with farmers and ranchers in favor of activities like eco-tourism and gathering forest products for sale. However, speaking to the *Washington Post,* Christopher Wells, head of the soy producers' group, sees cooperation of business and environmentalists as essential. Unless everyone works together, he says, "We'd go back to a world of bitter debate between NGOs (nongovernmental organizations) and big industry. That's where we were five years ago. I don't see any other way other than this."

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SOURCES: Jonathan Wheatley, "Edge of Destruction," Financial Times, April 26, 2008, Life and Arts p. 1; Monte Reel, "Applying Capitalism to Protect Dwindling Brazilian Forestland," Washington Post, April 25, 2008 (http://www.washingtonpost.com/wp-dyn/content/article/2008/04/24/AR2008042403392_pf.html); "Land Invasions Undermine Amazon Forest Law," *Amazonia*, April 3, 2008 (http://www.amazonia.org.br/english/noticias/noticia.cfm?id=265626).

they agree to a list of restrictions on loud parties, lights, boats, garbage, and so on. In most cases, neighbors comply with the covenants voluntarily because they find it mutually beneficial to do so; but the covenants can be enforced in court if necessary.

Another example of the use of markets to handle externalities concerns the pollination of crops by honeybees. Although most of the examples discussed in this chapter concern harmful externalities, this one concerns a beneficial externality. In this case, farmers pay fees to beekeepers to bring their hives by truck to locations near their apple orchards, blueberry farms, or whatever. Such fees total tens of millions of dollars a year in the United States. The fees the farmers pay are more than compensated by the increase in crop yield. Beekeepers, in turn, gain a second source of revenue, in addition to sales of honey.

Without such a market, beekeepers would limit the number of hives to the quantity justified by sales of honey alone. The external benefit to fruit growers would not enter into their calculations. When they can earn extra revenue by selling pollination services, they expand the number of hives. Doing so benefits not only beekeepers and fruit growers but also consumers, who get more of both honey and fruit.

## *Transaction Costs as Barriers to Voluntary Resolution of Externalities*

In practice, private negotiations are not always able to resolve problems of externalities because, in the real world, transaction costs are far from zero. To see why, we will move away from small-scale local externalities, like those of land use and beekeeping, and resume our earlier discussion of climate change.

**SCIENTIFIC UNCERTAINTIES** To resolve a pollution dispute through private negotiations, one must know the source of the pollution and the nature of the damage. Acquiring such knowledge is often expensive and sometimes impossible. As we saw earlier, it is known that emissions of $CO_2$ and other greenhouse gasses contribute to global warming; but beyond that, there are many scientific uncertainties. We do not know exactly where the greatest damages will occur. We do not know how to trace the damage in a certain place (for example, coastal flooding damage to the land of a farmer in Bangladesh) back to a certain source of pollution (for example, an electric power plant in Illinois). Because of this, victims of climate change do not know with whom they should negotiate. Also, because we do not know the exact magnitude of the relationship between a given amount of $CO_2$ emissions and a given rise in the sea level (or other form of damage), we cannot know how much damage will be avoided by any given reduction in emissions. Because of this, victims would not know how much compensation for which to ask—even if they knew from whom to ask it.

**EFFECTIVENESS OF THE LEGAL SYSTEM** Resolution of disagreements over environmental property rights depend, in part, on the effectiveness of *tort law*—the area of civil law concerned with harms (torts) done by one person to another. Lawsuits involving accidental personal injury, product defects, and damage to property through negligence are familiar examples of tort litigation.

The areas of tort law that touch most directly on pollution are *nuisance and trespass.* The law of nuisance can be used for protection against externalities such as a neighbor's noisy parties or a firm's malodorous manufacturing processes. Trespass traditionally covers one person's entry onto another person's land; but it has been extended to include harmful invasions by smoke, chemical leakage, and so on. Pollution often raises issues of both nuisance and trespass.

However, the successful use of tort law to enforce property rights and provide a clear framework for private negotiation requires agreement about the initial distribution of property rights and a court willing to rule on disputes. In practice, environmental property rights are often unclear, and there are often no courts with the needed authority. In the case of climate change, industries in developed countries may claim a right to continue emitting greenhouse gasses on the grounds that their factories complied with all pollution regulations that existed at the time those factories were built. The government of a low-income country like China may counter that industry in developed countries has already used more than its fair share of the limited capacity of the earth's atmosphere to absorb pollution. The advanced countries should start cleaning up their act now, while low-income countries get their chance to catch up. There are no global legal codes or courts to resolve disputes of this kind. Without the backup of appeal to effective courts, private negotiations among citizens living in different countries have small chance of succeeding.

**COSTS OF NEGOTIATION AMONG MANY PARTIES** Still another factor increasing transaction costs is the large number of parties involved in many environmental disputes. When there are many parties, the process of negotiating and enforcing an agreement to resolve an externality might be prohibitively expensive even if there were no legal or scientific uncertainties. In the case of climate change, the parties include millions of businesses and billions of individuals throughout the world. It is hard to imagine successful private negotiations on such a scale.

In sum, private negotiations supported by tort law cannot be relied on to resolve all large-scale environmental problems, however useful they may be on a local scale. We turn next to the possibility of controlling pollution through regulation.

## Controlling Externalities Through Regulation

As awareness of environmental problems has increased, the pressure has grown for governments in the United States and around the world to do something. The response has included a wide variety of environmental laws and regulation. This section provides an overview of the three most common types of environmental policies: command and control, emission charges, and cap-and-trade systems that use marketable permits.

### *Command and Control*

Many of the U.S. government's earliest efforts to control pollution took a command-and-control approach. This strategy was embodied in the Clean Air Act, the Clean Water Act, the National Environmental Policy Act, the Noise Control Act, and several other laws enacted during the 1970s. Command-and-control laws often state that a specific pollution control technology must be used, without considering its cost compared with alternative methods. In other cases a quantitative goal, such as 90 percent cleanup, is applied to all pollution sources without consideration of differences in cost of abatement among sources. Sometimes, in areas in which pollution is especially bad, new pollution sources are banned entirely.

The early command-and-control regulations had some success in reducing air and water pollution. Over time, though, they have come under increasing criticism because requirements to use specific cleanup technologies reduce the incentive to discover new, lower-cost methods. If no attempt is made to balance marginal abatement costs among various cleanup technologies, various sources, and various categories of pollution, the total costs of achieving any given environmental goal is increased. High costs can lead to political pressure to cut back on pollution-control efforts. For that reason, excessive reliance on command-and-control can be self-defeating.

Today economists see command-and-control as the wrong response to most environmental problems. At best, command-and-control may make sense for a narrow range of pollutants where a zero emission level is both desirable and technologically feasible—for example, banning lead additives for gasoline. For broader categories of pollution, where 100 percent cleanup is not a possible or appropriate goal, other approaches are likely to be both more cost effective and more politically feasible.

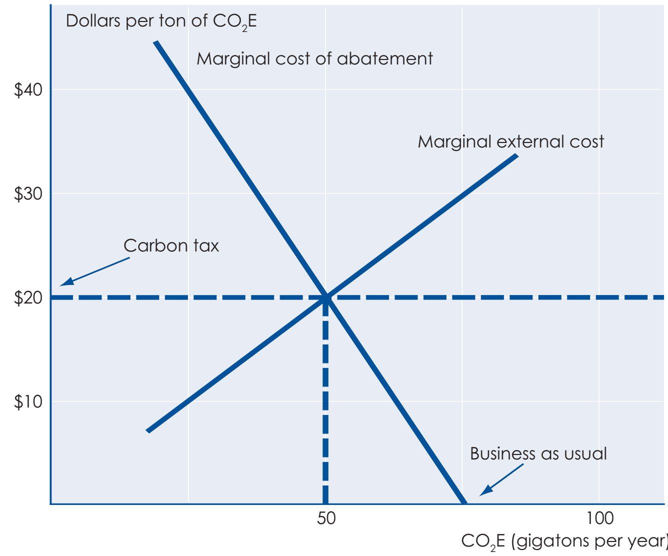
## Emission Charges (Pollution Taxes)

Economic approaches to pollution control operate by bringing external costs to bear on the pollution source. When this happens, polluters are given an incentive to balance marginal abatement costs with the marginal external costs and move toward an optimal level of pollution. The most direct way to do this is for the government to impose an *emission charge*, sometimes also called a *pollution tax*, of a fixed amount per unit of waste. For example, all sources of sewage might be required to pay a charge of $40 per ton of sewage discharged into lakes and rivers. In the case of climate change, a *carbon tax* has been proposed, which would be a charge per ton of carbon dioxide (or $CO_2$ equivalent) that is released into the atmosphere.

Figure 6.4 shows how a carbon tax would work. As discussed earlier, the optimal quantity of pollution is determined by the intersection of the curves for marginal cost of abatement and marginal external cost of pollution. With a carbon tax in force, pollution sources will prefer to reduce emissions rather than pay the charge whenever the marginal cost of abatement is less than the charge. In Figure 6.4, that would be the case for levels of pollution greater than 50 gigatons per year. For levels of pollution less than 50 gigatons per year, polluters would prefer to pay the tax. If, as in the figure, the tax is set exactly at the level where the marginal abatement cost and marginal external cost curves intersect, the result will be the optimal level of pollution.

Of course, it is possible that the charge would be set too low or too high. Measurement problems may make it hard to tell just where the curves intersect and how high the tax should be. Even if the tax is initially set at the optimal level, changes in economic conditions may shift one or both of the curves, in which case the old tax will be too high or too low. However, advocates point out that a carbon tax would encourage the use of efficient techniques to achieve a given level of emissions even if the chosen tax rate is not the optimal one. That is so because a charge applied

**FIGURE 6.4 EFFECT OF A CARBON TAX**




This figure shows the effect of a carbon tax. For levels of pollution above 50 gigatons per year, marginal abatement cost is less than the tax, so it would be more profitable for pollution sources to reduce $CO_2$ output than to pay the tax. For pollution levels less than 50 gigatons per year, it would cost less to pay the tax than to make further reductions in emissions. If the carbon tax is set at a level equal to the intersection of the marginal abatement cost and marginal external cost curves, the result will be an optimal level of emissions. A tax that was too high, too low, or that did not apply equally to all pollution sources would still result in a reduction of pollution relative to the business-as-usual level, but it would not be fully efficient.

uniformly to all pollution sources would exert equal pressure on all polluters to cut back at least a few units on their output of wastes. It would encourage them to eliminate pollution first from the sources that can be controlled most cheaply, using the least-cost available technology. Thus, it would avoid the problem that occurs under command-and-control, in which all sources are subject to the same regulations even though some sources cause less harm than others. For example, a command-and-control approach to $CO_2$ emissions might impose strict mileage standards on cars regardless of the number of miles per year the car is driven or the purpose for which it is used. If the marginal cost of abatement is not equalized for all sources of pollution, the cost of a given degree of pollution reduction will be higher than it needs to be.

One example of the successful use of emission charges was the control of chlorofluorocarbons under the 1987 Montreal Protocol. These chemicals, once used for items ranging from spray cans to refrigerators, are damaging to the earth's protective ozone layer. To meet its initial commitment to reduce emissions of chlorofluorocarbons under the Montreal Protocol, the U.S. government imposed a heavy tax. Later, after less environmentally damaging substitutes had been developed and brought into production, the most damaging chemicals were banned altogether.

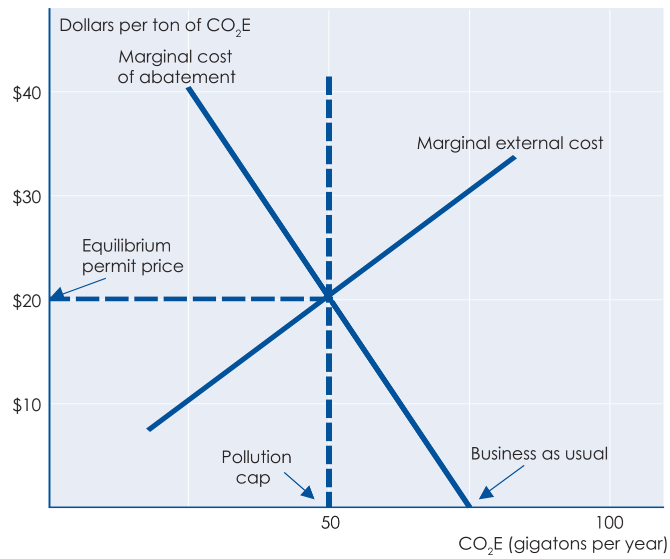
## Cap and Trade

Emission charges are one way of using market incentives to encourage efficiency in attaining environmental goals. Another approach to the same goal is the use of marketable waste-discharge permits, a technique commonly known as "cap-and-trade."

Figure 6.5 shows how a cap-and-trade system works. The vertical line in the diagram corresponds to the "cap," that is, the overall limit on the amount of pollution allowed from all sources in the affected area. As applied to greenhouse gasses and climate change, the area would be the entire country; but for some other types of pollutants, it might be a region or a single city. Ideally, as shown in the figure, the limit corresponds to the optimal quantity of pollution.

Once the overall limit has been determined, it is divided into a fixed number of permits that are distributed among pollution sources. The permits can then be freely bought and sold. Polluters whose marginal cost of abatement is relatively high become buyers of permits, and those with relatively low marginal abatement costs become sellers. As the market for permits approaches equilibrium, the marginal cost of abatement will be equalized for all firms. Thus, as in the case of emission charges, there is an incentive to use efficient means to achieve the target level of pollution abatement.

**FIGURE 6.5 EFFECT OF EMISSIONS TRADING**




This figure shows the effect of a policy of a cap and trade regulation strategy applied to greenhouse gas emissions. The total amount of $CO_2$ equivalent that may be discharged is limited by the number of permits issued, in this case, 50 gigatons. Permits will be traded among pollution sources. Those with higher marginal abatement costs will buy permits from those with lower marginal abatement costs. An equilibrium will be established when the marginal cost of abatement is equalized among all pollution sources. The equilibrium price of a permit will be determined by the intersection of the marginal cost of abatement curve with the line representing the number of permits. If the correct number of permits is issued, the optimum quantity of pollution will be achieved.

The cap-and-trade approach has been used to control pollution both in the United States and abroad. It has been used to control air pollution from electric power plants under 1990 amendments to the *Clean Air Act*. It is also used in several cities to control local air pollution. More recently, it has been used in the European Union to control carbon emissions.

## Environmental Policy and Public Choice

Chapter 1 introduced a distinction between positive and normative economics. Our discussion of environmental policy to this point has taken a normative perspective. It has focused on how policy ought to be designed in order to avoid market failure and achieve the goal of efficiency. This section offers a positive perspective on environmental policy. It uses concepts of public choice theory to explain why real-world environmental policies are not always crafted to achieve the goal of efficiency, and why the political process sometimes leads to government failure rather than the correction of market failure.

### *Environmental Policy in a Democracy*

Public choice theory looks at environmental policy in terms of the way people pursue their economic interests through the political process. In a democracy, the focus is on political choices made by voters and by their elected representatives.

**Median voter model**

A model showing that there is a tendency for decisions in a democracy to reflect the interests of voters whose preferences lie near the middle of the scale

One of the simplest models in public choice theory is the **median voter model**. This model suggests that political choices in a democracy reflect the interests of voters whose preferences lie near the middle of the range represented in the community. To use a simple example, consider a community where all citizens gather once a year to vote on important issues. This year the big issue is whether the town should use some tax money to improve its schools or, instead, give a tax break to an organization that wants to construct an assisted living facility. Young parents are more likely to vote in favor of schools, while older voters are more likely to favor tax breaks for assisted living. According to the model, the outcome of the vote will depend on the age of the *median* voter—that is, the voter whose age is such that exactly half the citizens are older and half are younger. In a community where the median age is young, families that favor schools are likely to be in the majority. In a community where the median age is older, assisted living is more likely to win.

It is not hard to find examples in which environmental policy appears to be consistent with the median voter model. For example, in 2007, California's Republican governor proposed the nation's strongest policies for reducing carbon dioxide emissions. Could it be that the median California voter is more concerned about the environment than in other parts of the country? Very likely so, but environmentalism is not confined to California. Economists consider environmental quality to have a relatively high income elasticity of demand. Over time, as economic growth raises the income of the median voter, we would expect stronger political support for policies that promote clean air, improved opportunities for outdoor recreation, and increased concern for the future of the planet. That is just what democratic political systems have produced in most high-income countries.

## *Vote Trading and Special Interests*

Despite the ability of the median voter model to explain some trends in environmental policy, it is by no means a complete theory. Public choice economists are quick to point out that the median voter model, which emphasizes the political choices of individual citizens, must be modified to take into account the frequently disproportionate influence of small groups that share intensely felt interests.

Just what features of the political system tend to amplify the voice of special interests—even when they represent a small minority of voters? Public choice theory identifies two that are especially important.

**COSTS OF LOBBYING AND POLITICAL EXPRESSION** Like everything we do, participation in democratic politics has an opportunity cost. The opportunity cost is not limited to making the effort to roll out of bed early once a year in order to vote in an election. Other forms of political action, like writing to elected representatives, calling in to local talk shows, attending meetings, or marching in demonstrations also take time and effort from other activities. Actions like making campaign contributions or employing professional lobbyists cost not just time but also money. Finally, there is a large opportunity cost just to keeping informed about how you yourself are affected by what goes on in the political world.

When you are a member of an organized group, all members of which are affected similarly by some policy, you can often share the opportunity cost of political action. You can keep informed through a web site or newsletter supported by your organization. Your job or your leisure interests naturally keep you in touch with like-minded people. Your organization may use dues or a special fund-raising drive to sponsor lobbyists or political ads. As a result of lower opportunity costs, members of groups speak with a louder voice, relative to their numbers, than do unorganized individuals.

Small, well-organized groups also have another source of strength. Political action by a group has the property of a public good—all members benefit whether they contribute or not. As explained in Chapter 4, production of public goods is hampered by the *free rider problem*. Group members would like to gain from the group's political activities without bearing their fair share of the costs. Small, well-organized groups have ways of overcoming the free-rider problem. Some, like labor unions and professional associations, may have compulsory dues. Others, like churches or parent-teacher groups, may bring social pressures to bear on group members that don't seem willing to do their fair share. In contrast, the free rider problem makes it nearly impossible to mobilize large groups in pursuit of shared interests that are not central to the life of each member.

**LOGROLLING** Representative democracy is a second factor that increases the political impact of small groups that share intense interests. In the modern world, relatively few issues are decided by direct democracy, in which individual citizens vote on specific issues. Local town meetings and referendums in some states are the exception, not the rule. Instead, citizens usually express themselves in a two-stage process: First they vote for representatives—senators, members of congress, state legislators—and then the representatives vote on each issue.

**Logrolling**

The practice of trading votes among members of a legislative body

Representative democracy adds an important element to the political process—vote trading, or **logrolling** as it is popularly known. Logrolling is possible because voting in legislatures differs in two important ways from voting in general elections. First, legislative voting is almost never by secret ballot. Second, legislators vote frequently on very specific issues, rather than only now and then on more general issues. As a result, it is possible for one representative to promise her vote on issue A in exchange for a promise that her colleague will provide his vote on issue B.

Logrolling often allows minority interests to prevail, provided they are strongly felt. Senators from dairy states can gather votes for higher milk prices by trading away votes on issues like flood control or highway funds that are important to voters in other states, but not theirs. Although logrolling is sometimes used to pursue the narrowly economic interests of groups like dairy farmers, it can also be used to promote non-economic interests of any minority group. For example, logrolling has helped pass civil rights laws and protections for disabled persons, causes that might have been slow to win majority support if every issue were decided according to the preferences of the median voter.

**SPECIAL INTERESTS AND ENVIRONMENTAL POLICY** When it comes to specific issues of environmental policy, majority interests, as expressed through the influence of the median voter, and special interests, expressed through small-group action and logrolling, can interact in complex ways. The case of regulations controlling sulfur dioxide emissions from coal-fired electric power plants provides a case in point.

There are a variety of technologies for reducing sulfur dioxide emissions. Typically, switching to a low-sulfur coal is the cheapest alternative, and scrubbing the sulfur from combustion gases is the most expensive. Nonetheless, in its 1977 amendments to Section 111 of the *Clean Air Act*, Congress required that any newly constructed electric power plant meet the emissions limit by scrubbing. That requirement applied, regardless of how clean or dirty the plant's fuel or combustion technology was. Many old plants, including some of the dirtiest ones that burned the most sulfurous midwestern coal, were not forced to scrub. Instead, they were allowed to meet standards for local pollution by building tall smokestacks—up to 1,000 feet high—that keep the air in surrounding communities fairly clean. However, pollution injected into the upper atmosphere by the tall stacks contributes to the problem of acid rain hundreds of miles downwind.

To meet local pollution standards some smoke stacks were built up to 1,000 feet high rather than installing scrubbers.

Why did Congress choose this approach to controlling sulfur dioxide emissions? The answer appears to lie in the coalition that passed the *Clean Air Act*, which included the following:

- Coal-mining interests in the high-sulfur areas of Ohio, Illinois, and elsewhere wanted to strengthen demand for their product. These factions, including both unions and mine owners, were afraid that changing fuels would result in the loss of coal production jobs to western states where low-sulfur coal is found.
- Industrial and political interests from eastern and midwestern states wanted to protect profits by stopping the flight of industry to western and southern states. By focusing control efforts on newly built plants, the *Clean Air Act* gave old, dirty plants a few more years of life. Moreover, by focusing on scrubbing rather than changing fuels, the act ensured that coal-burning plants in the South and West are unable to exploit the cost advantage of a location close to sources of low-sulfur coal.
- Environmentalists, who were unable to obtain a majority in Congress by themselves, were willing to enter an "unholy alliance" on the theory that any pollution control measure was better than none.

After the passage of the 1977 Clean Air amendments, environmentalists became dissatisfied with the deal that had been made. The degree of pollution reduction was less than had been hoped, partly because scrubbers are not always reliable and partly because the regulations slowed the replacement of old, dirty facilities with new, cleaner ones. Thus, important elements of the coalition changed by the time the 1990 amendments were under consideration. This time, environmentalists broke with the midwestern coal and industrial interests, supporting the use of a cap-and-trade strategy. As discussed in *Applying Economic Ideas 6.1*, the new approach turned out to be much more effective.

Alternative energy resources are another area in which economics, science, and politics clash. Many analysts see alternative energy from windmills, solar arrays, or biomass fuels as the best approach to reducing carbon dioxide emissions. Each alternative technology has its supporters and critics. Given a level playing field, we might hope over time that the forms of alternative energy that produce the greatest environmental benefits at the lowest costs would be developed most rapidly. However, that has not happened. As the Case for Discussion at the end of this chapter shows, political considerations have led to a disproportionately rapid development of one technology, namely, corn-based ethanol, despite its questionable environmental effects and serious, unintended consequences.

The examples given help explain why government policies do not always resolve environmental issues in an efficient manner and, sometimes, even make environmental problems worse rather than better. The insights of public choice theory suggest the evaluation of policy alternatives comes down to a matter of balancing market failures, on the one hand, against government failures, on the other.

## Applying Economic Ideas 6.1

## CAP AND TRADE FOR ACID RAIN

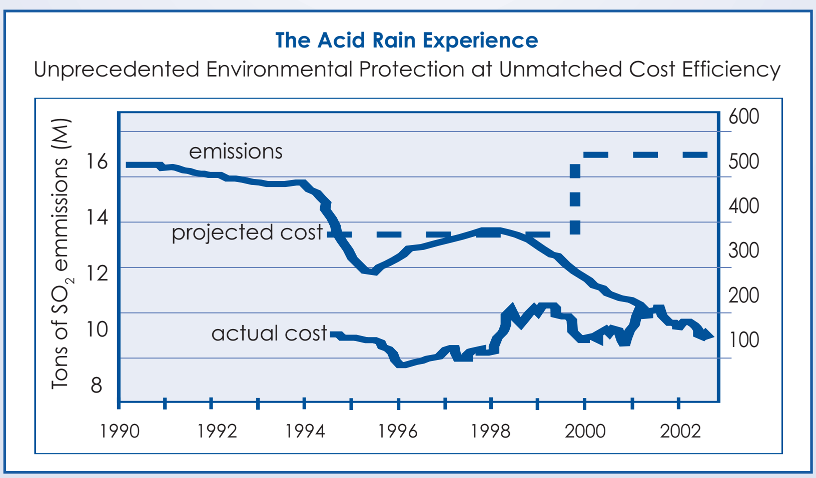
In the 1980s, before climate change began to make the headlines, acid rain was the most widely discussed environmental problem in the United States. Acid rain occurs when sulfur dioxide ($SO_2$) and other pollutants, mainly from coal-fired power plants, rise into the atmosphere and undergo chemical reactions that increase the acidity of rain that falls on areas downwind. Steadily increasing acidity of rain was destroying forests, damaging crops, and creating a constant haze throughout the Eastern United States. Early environmental legislation took a command-and-control approach by mandating stack scrubbers and other technology for midwestern power plants. However, those controls turned out to be insufficient, and damage from acid rain continued to increase.

Bavarian Forest around the Lusen mountain—the old forest died as a result of acid rain and the bark beetle in 1996, but now a new forest is growing.

By 1990, it was time to try a new approach. A set of amendments to the *Clean Air Act* permitted the Environmental Protection Agency (EPA) to try a cap-and-trade approach to control of $SO_2$ emissions. There were many skeptics. Some environmentalists feared that the incentives of cap-and-trade would be too weak to persuade industry to cut back on pollution. Representatives of industry feared that the controls would be too tight and that the market price of permits would soar to unaffordable levels. However, despite the many doubts, the EPA went ahead with its program.

The result surprised almost everyone. Cap-and-trade for acid rain control became one of the greatest environmental success stories of recent time. As the chart shows, $SO_2$ emissions fell by more than half over the next decade; and the cost of the program was far below projections. Rather than rising to a range of $500 to $2,000 per ton, as had been projected by some critics, the equilibrium price of permits fell steadily. By 2003, it was only $150 per ton. The acidity of rain in the Adirondacks and New England fell by 25 to 50 percent. Forests and streams began to recover their ecological health. The success of the acid rain program has become one of the strongest arguments in favor of using a similar approach to the problem of climate change.

SOURCES: Environmental Defense Fund, "The Cap-and-Trade Success Story," www.edf.org/page.cfm?tagID=1085; Environmental Protection Agency, "Cap and Trade: Acid Rain Program Results", www.epa.gov/airmarkets.



## Summary

1. **How can the problem of pollution be understood in terms externalities?** Pollution occurs when firms (or sometimes consumers) discharge wastes into soil, water, or the atmosphere. The optimal quantity of pollution is the quantity beyond which the marginal external cost of pollution exceeds the marginal cost of abatement.

2. **How can property rights and private negotiation help control externalities?** In a world without transaction costs, problems of externalities would be resolved through voluntary negotiation. According to the *Coase theorem*, voluntary exchange would result in efficient resource allocation regardless of the initial assignment of property rights, provided that there were no transaction costs. In practice, high transaction costs limit the power of negotiations to resolve environmental problems.

3. **What government policies are available to control pollution?** Early pollution control policies in the United States followed a command-and-control approach. Economists have criticized the command-and-control approach for poor performance in terms of efficiency because they often do not take marginal abatement costs into account and do not provide incentives to employ the least-cost control technology. One alternative to the command-and-control approach is the imposition of emission charges (pollution taxes), which would require pollution sources to pay a per-unit fee for the discharge of wastes into the environment. Another is the cap-and-trade approach based on marketable waste-discharge permits. Economists favor these approaches because they include incentives to meet a given pollution control target in an efficient manner.

4. **How can public choice theory be applied to environmental issues?** Public choice economics can help explain what environmental policies are politically successful. The median voter model suggests that the relatively high income elasticity of demand for environmental quality helps explain the strengthening of environmental policy over time in high-income countries. Public choice theory can, also, help explain why the pollution control policies adopted by government are not always the most efficient ones. Often those policies reflect the influence of regional interests and logrolling. Environmental policy thus provides many examples of government failure as well as market failure.

## Key Terms

| Key Terms | Page # |
|---|---|
| Marginal cost of abatement | 149 |
| Marginal external cost | 150 |
| Coase theorem | 156 |
| Median voter model | 163 |
| Logrolling | 165 |
| Present value | 171 |

## Problems and Topics for Discussion

1. **Environmental rights** "Pollution is garbage. Just as no one has a right to dump garbage on his/her neighbor's property, no one has a right to pollute the planet. A pollution-free environment is a basic human right." Do you agree, disagree, or agree in part? What are the economic implications of your position? Discuss.

2. **Beneficial externalities and property rights** Beekeepers need flowers to produce honey, and farmers need bees to pollinate crops. At present, beekeepers have the right to place hives where their bees will fly onto neighbors' property, and the neighbors do not have the right to exclude the bees. Suppose instead that invasion by bees was considered a form of trespass, so that property owners could sue beekeepers who allowed the insects to fly onto their land without permission. How would this alter the economic relations between farmers and beekeepers? Do you think

that it might lead to a situation in which beekeepers have to pay farmers for access to the blossoms of their crops? Discuss in terms of the Coase theorem and the Miller-Forester example.

3. **Smoking in restaurants** Smoking results in externalities that are unpleasant for nonsmokers. Given this fact, why would a restaurant find it profitable to establish smoking and nonsmoking areas? Do you think that the problem of smoking in restaurants is adequately resolved by voluntary market incentives, or should there be a government policy mandating (or preventing) designated smoking areas in restaurants? Do you think that the same conclusions apply to smoking on airplanes? In a government office? Discuss.
4. **Automobile pollution** One way to control automobile pollution is by the use of catalytic converters and other devices that limit pollution to a certain quantity per mile driven. For comparison, imagine a system in which drivers had to pay an annual tax based on the total pollution emitted by their cars. The tax would be calculated by measuring the quantity of pollution per mile, using a testing device such as those now used for vehicle inspections, and multiplying that figure by the number of miles per year shown on the car's odometer. People could choose to buy catalytic converters, more expensive and more effective devices, or no control devices at all. What considerations would determine the type of pollution control device purchased? Do you think that the tax system would be more efficient than the current command-and-control system? Would it be as effective in reducing pollution? Would it be as fair? Discuss.

## Case for Discussion

### *Fill It Up with Ethanol?*

Stand on any street corner in Rio de Janeiro, and you will notice a faint aroma reminiscent of a camping trip or a fondue feast—the aroma of burning alcohol. Nearly all cars in Brazil run on alcohol, more exactly, ethanol produced from sugar cane. Brazilians can buy gasoline at their local filling station if they must, but the price is higher, even taking into account the fact that gasoline has higher energy content than ethanol and, accordingly, produces better mileage.

Ethanol-based motor fuel is growing in popularity in the United States, as well. Unlike the case in Brazil, few U.S. cars can run on pure ethanol, but blends containing anywhere from 10 percent to 85 percent ethanol are being promoted as a solution to the national "addiction" to imported oil. Since little sugar cane is grown in the United States, most ethanol produced there is made from corn. In late 2007, Congress passed new energy legislation that further increased already generous subsidies for ethanol production. Does it make economic or environmental sense?

Among the first scientists to cast suspicion on the case for corn-based ethanol were Cornell University's David Pimentel and Tad Patzek of the University of California, Berkeley. Their research showed that corn-based ethanol consumes about 30 percent more energy than the fuel yields. Furthermore, much of the energy used to drive tractors and fuel ethanol plants is petroleum based. Far from being a solution to the energy crisis, corn-based ethanol makes it worse. The corn lobby soon struck back with new research sponsored by the U.S. Department of Agriculture. Those studies said that Pimentel and Patzek based production costs on average technology, which included some now-obsolete plants, not the most efficient technology embodied in the newest plants. They also failed to include the energy-saving value of ethanol byproducts like high-protein cattle feed. When these and other considerations are added, corn-based ethanol appeared to produce a small but positive net gain to the nation's energy balance. Still more recent research, published in *Science* in early 2008, argues that all of the earlier studies failed to include the effects of land use. As farmers in the U.S. and around the world plow up previously unfarmed land for crops, massive amounts of $CO_2$ and other greenhouse gasses are released into the air. When land use effects are taken into account, corn-based ethanol and most other biofuels unambiguously do more harm than good to the environment.

If food-based biofuels are such a bad idea, why are they so heavily subsidized? The answer is to be found not in economics but in politics. Midwestern corn farmers are delighted to see the demand for their product grow as more and more subsidized ethanol plants are built. Use of corn to make ethanol drives up world food prices, but hungry people in Africa and Asia do not vote in U.S. elections. U.S. consumers (at least this is what members of Congress seem to hope) can be easily fooled into believing that, when they fill up their tank with ethanol, they are helping make the world a better place to live in.

## QUESTIONS

1. Suppose each gallon of gasoline consumed results in $.50 of harmful externalities while each gallon of ethanol results in just $.15 of harmful externalities. If ethanol costs $.35 cents more per gallon to produce, would it be efficient to encourage ethanol-based fuels? Why or why not? What if, when land-use effects are taken into account, the externalities from corn-based ethanol are the same as those from gasoline? Discuss in terms of concepts from this chapter.
2. In order to persuade motorists to use ethanol as fuel, the price of ethanol (adjusted for its lower energy content) must be the same as or lower than gasoline. Do you think it would be better to encourage use of ethanol by putting a tax on gasoline or by subsidizing production of ethanol? Which would result in the greater total saving in gasoline use? Why? What political considerations might affect the choice between tax and subsidy?
3. If there are fewer corn farmers than motorists, why has Congress blocked imports of Brazilian ethanol, which is much cheaper than that produced in the United States, rather than encouraging such imports? Discuss in terms of concepts from public choice theory.

## End Notes

1. For an overview of the issues involved in measuring the impacts of climate change and the costs of mitigation, consult one or both of the following studies: Intergovernmental Panel on Climate change, *Climate Change 2007 Synthesis Report, Summary for Policymakers,* http://www.ipcc.ch/, or International Monetary Fund, *World Economic Outlook,* April 2008, Chapter 4: Climate Change and the Global Economy, http:// www.imf.org/ external/pubs/ ft/weo/2008/01/index.htm.
2. Although IPCC and IMF forecasts show world income increasing steadily for the indefinite future, there is one grim scenario that could produce an absolute decrease in world income, not just a decrease relative to a growing baseline. That scenario is one in which rising greenhouse gas concentrations reached a "tipping point" that triggered strong feedback effects, like melting permafrost or collapsing polar icecap. Once the feedback effects materialized, no possible reduction in the human component of global warming would be enough to stop further catastrophic climate change. At present, this is considered a low-probability scenario, but not one that can be excluded altogether.
3. For a more extended discussion of the issues raised in this section, see Edwin G. Dolan, "Science, Public Policy, and Global Warming: Rethinking the Market Liberal Position," *Cato Journal*, Fall 2006, http://www.cato.org/ pubs/journal/ cj26n3/cj26n3-3.pdf.
4. The theorem is implicit in Ronald Coase, "The Problem of Social Cost," *Journal of Law and Economics* (October 1960): 1–44. Coase's colleague, George Stigler, first used the term "Coase theorem" for this proposition. Since then, there has been a long controversy regarding how the theorem should be interpreted. For a thorough review, see Glenn Fox, "The Real Coase Theorems," *Cato Journal*, Fall, 2007.

# Appendix to Chapter 6:
# VALUING COSTS AND BENEFITS OVER TIME

In the world of business, managers frequently encounter situations that require the comparison of the value of costs and benefits that occur at different points in time. Should a trucking company build a new warehouse in Tulsa? Doing so will require an investment now and will produce cost savings and service improvements over many years in the future. If the warehouse is built, how much insulation should be put in the roof? More insulation increases the immediate construction cost but saves future heating costs.

**Discounting** The method used to make comparisons between costs and benefits that occur at different points in time is known as *discounting*. To understand discounting, begin by imagining a firm that has surplus funds available for investment. If it puts funds to work earning interest by placing them in a bank account, making a loan, or buying a security, the original sum it invests will grow year by year. At 10 percent interest per year, $100 invested today will be worth $110 a year from now. After two years, it will be worth $121—the $11 gain in the second year reflects interest of $10 on the original principal and $1 interest on the $10 interest earned in the first year. Because interest is paid on previously earned interest, this process is termed *compound interest*. Mathematically, we can say that the value V of $1 invested for *t* years at a rate of interest of *r* percent per year is given by the formula $Vt = (1 + r)^t$.

In a world in which funds can be loaned out at compound interest, it is always advantageous to receive a payment earlier rather than later. The opportunity cost of receiving a sum later rather than sooner is the interest that could have been earned otherwise. Consider, for example, the cost of receiving $100 a year from now rather than today, assuming an interest rate of 10 percent per year. Delaying receipt of the sum would mean forgoing a year's interest. Rather than give up that interest, a firm would be just as well off to receive a smaller sum now as to receive the $100 a year from now. To be precise, it would be just as good to get $91 now as $100 a year from now because the $91 placed for a year at 10 percent would grow to $100 (give or take a few cents). Similarly, $100 payable two years from now is equivalent to about $83 today, assuming 10 percent interest; $100 three years from now is worth about $75 today; and so on.

**Present value**

The value today of a sum payable in the future (In mathematical terms, the present value of a sum $V_p$, payable *t* years in the future, discounted at *r* percent interest, would grow to the value *Vt* in *t* years; the present value formula is $V_p = V_t / (1 + r)^t$.)

This kind of example can be generalized to any time period and any interest rate. Let $V_p$ be the sum of money that, if it is invested today at *r* percent interest, will grow to the sum $V_t$ after *t* years. $V_p$ is known as the **present value** of the sum $V_t$, payable *t* years from now, discounted at *r* percent per year. The formula for calculating the present value of any future sum is

$$V_p = \frac{V_t}{(1 + r)^t}$$

**An Example** Suppose you own a chain of stores selling hiking shoes. You think your customers will react favorably if you "go green" by converting your stores to a carbonneutral source of electric power. A supplier of electrical equipment gives you a choice of two methods for doing this: a solar-electric panel or a bio-diesel generator. For the sake of discussion, we will consider the environmental benefits of the two methods to be equal.

The economic costs and benefits are not the same, however. The solar panel will cost $25,000 to install, but it has very low operating cost. It requires no fuel and just $100 per year for routine maintenance. The bio-diesel generator is much less expensive to install—just $10,000. However, it will require annual costs of $2,000 per year for fuel and maintenance. Both installations have an expected lifetime of 10 years. Which should be chosen?

If we just add up total expenses over the 10-year period, the solar solution wins hands down. It has a total cost of just $26,000, compared to $30,000 for the bio-diesel alternative. However, that comparison is misleading. The major cost of the solar electric panel occurs immediately, while the high fuel costs of the bio-diesel generator occur later. If future dollars are worth less than present dollars, as the discounting approach suggests, a more detailed analysis is required.

The complete analysis of the problem is given in Table 6A.1. There, in addition to the undiscounted information of costs and benefits, additional columns give the discounted value of future costs and benefits at two possible discount rates, 4 percent per year and 6 percent per year. For example, we can use the table to determine that the present value of the $2,000 that will be spent on diesel fuel in year 5 is $1,494.52 if a 6 percent discount rate is used ($2000 \times (1.06)^5$) and $1,643.85 if a 4 percent discount rate is used ($2000 \times (1.04)^5$).

Looking across the bottom row, we see that the total present value of installation costs plus future operating costs, discounted at 6 percent, is $25,736.01 for the solar

**TABLE 6A.1 COST COMPARISON**

| Year | Solar-Electric Panel | | | Bio-Diesel Generator | | |
|---|---|---|---|---|---|---|
| | Undiscounted Expense | Discounted at 6% | Discounted at 4% | Undiscounted Expense | Discounted at 6% | Discounted at 4% |
| 0 | 25,000 | 25,000 | 25,000 | 10,000 | 10,000 | 10,000 |
| 1 | 100 | 94 | 96 | 2,000 | 1,887 | 1,920 |
| 2 | 100 | 89 | 92 | 2,000 | 1,780 | 1,849 |
| 3 | 100 | 84 | 89 | 2,000 | 1,679 | 1,778 |
| 4 | 100 | 79 | 85 | 2,000 | 1,584 | 1,710 |
| 5 | 100 | 75 | 82 | 2,000 | 1,495 | 1,644 |
| 6 | 100 | 70 | 79 | 2,000 | 1,410 | 1,581 |
| 7 | 100 | 67 | 76 | 2,000 | 1,330 | 1,520 |
| 8 | 100 | 63 | 73 | 2,000 | 1,255 | 1,461 |
| 9 | 100 | 59 | 70 | 2,000 | 1,184 | 1,405 |
| 10 | 100 | 56 | 68 | 2,000 | 1,117 | 1,351 |
| TOTAL | 25,000 | 25,736 | 25,811 | 30,000 | 24,720 | 26,219 |

installation compared to just $24,720.17 for the bio-diesel option. At that interest rate, the benefit of postponing some expenses to a future date outweighs the fact that total undiscounted expenses are greater. However, discounted at a 4 percent discount rate, the solar electric option is less expensive by a small margin.

It turns out, then, that the choice between solar electric and bio-diesel depends not just on the pattern of costs over time but also on the discount rate used. For the case under discussion, it is not hard to determine the proper discount rate. The discount rate used should be the opportunity cost of funds for the firm. If the firm must borrow money to install the equipment, the opportunity cost is the interest rate charged on the loan. If it has spare cash that can be used for the project, the opportunity cost is the next-best alternative investment, for example, using the funds to buy government bonds.

**Applying Discounting to Climate Change** The problem of deciding how much to spend now to mitigate future climate change is similar in some ways to the problem of deciding between alternative methods of generating electricity. In both cases, costs and benefits are spread over time. In both cases, costs are concentrated more heavily in the near future while benefits accrue over the more distant future. In both cases, the method of discounting can be applied to compare the present value of costs and benefits that occur at different times.

The main difference is that the costs and benefits of climate change policy are spread over a vastly longer time horizon. Decisions made now to slow emissions of greenhouse gasses will affect atmospheric concentrations of gasses, global temperatures, and sea levels for centuries to come. When the discount formula is applied over such very long periods, it tells us that costs and benefits in the far distant future have very little value today. For example, the present value of $1,000, discounted at 4 percent for 100 years, is less than $20. Discounted for 300 years at 4 percent, the present value of $1,000 is only about one cent. Translated into everyday language, the discount formula seems to tell us that we should hardly care at all about something that will not happen for 100 years and that we should be almost completely indifferent even to huge catastrophes if we think they will not happen for 300 years.

Many people, confronted with the mathematics of discounting over long periods, reject the results out of hand. Forget the math, they say—we do care! We like our little planet; it's the only one we have! We do not want to destroy it—not tomorrow and, just as certainly, not 100, 300, or even 1,000 years from now!

Economists who study climate change policy react to these protests in different ways. Some brush them aside, saying, in effect, that it is not rational to care much about the distant future. Others attempt to reconcile the protests with the discounting method by reconsidering the proper interest rate that should be applied. Perhaps the market-based interest rates in the range of 3 to 5 percent that are appropriate for ordinary commercial decisions and short-term policy making should not be applied when thinking about the distant future. Perhaps instead we should use a much smaller interest rate or one that starts at a market-based rate for the near future and falls over time.

It turns out that for the question of how much to do now to mitigate climate change, the choice of a discount rate makes more difference than any other consideration. One way to compare policy recommendations is to frame them in terms of a carbon tax. A strong policy recommendation is equivalent to a high tax (or a strict cap-and-trade policy that would produce a high price for carbon permits). A weak policy recommendation is equivalent to a low tax, or even none. Often the carbon tax is expressed in dollars per ton. In more familiar terms, a carbon tax of $1 per ton is equivalent to a tax of about one cent per gallon of gasoline.

William Nordhaus of Yale University is one of the best known among economists who applies the standard discounting approach to climate change. His work uses a discount rate that starts with a market-based rate of about 4 percent, gradually decreasing to about 2 percent for the distant future. Based on these discount rates, Nordhaus calculates that an optimal carbon tax (or equivalent cap-and-trade permit price) would be about $35 per ton, as of 2008. That is close to the market price for carbon permits being traded in the European Union as of mid-2008. In consumer terms, such a tax would add about $.35 per gallon to the cost of gasoline. Some economists who use market-based discount rates come up with even lower recommendations for the optimal carbon tax.

On the other hand, economists like Nicholas Stern, author of a widely-cited climate change study sponsored by the British Treasury, advocates using a much lower discount rate based on the ethical principle that human life has equal value regardless of the century in which people are born. As a result of applying a low discount rate, Stern estimates the optimal carbon tax to be more than $300 per ton, almost 10 times as high as Nordhaus's recommendation. A carbon tax of that level would impose much higher costs on consumers and businesses, and would be equivalent to a much stricter cap-and-trade program than that implemented by the European Union, currently the world's strictest policy.

Who is right? Economics, in this case, simply cannot supply the answer. Either we care about the distant future, or we do not. Either we believe that human life has equal value regardless of a person's century of birth, or we believe current life has greater value than future life. The most economics can do is to help us understand the consequences of whatever policy choices we make.