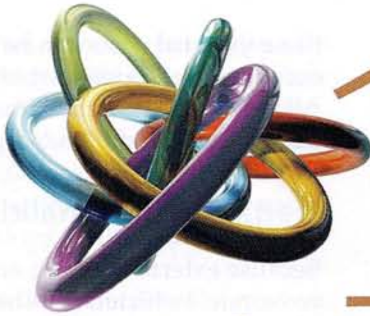
Externalities and Public Goods



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In this chapter we study *externalities*—the effects of production and consumption activities not directly reflected in the market—and *public goods*—goods that benefit all consumers but that the market either undersupplies or does not supply at all. Externalities and public goods are important sources of market failure and thus raise serious public policy questions. For example, how much waste, if any, should firms be allowed to dump into rivers and streams? How strict should automobile emission standards be? How much money should the government spend on national defense? Education? Basic research? Public television?

When externalities are present, the price of a good need not reflect its social value. As a result, firms may produce too much or too little, so that the market outcome is inefficient. We begin by describing externalities and showing exactly how they create market inefficiencies. We then evaluate remedies. While some remedies involve government regulation, others rely primarily on bargaining among individuals or on the legal right of those adversely affected to sue those who create an externality.

Next, we analyze public goods. The marginal cost of providing a public good to an additional consumer is zero, and people cannot be prevented from consuming it. We distinguish between those goods that are difficult to provide privately and those that could have been provided by the market. We conclude by describing the problem that policymakers face when trying to decide how much of a public good to provide.

CHAPTER OUTLINE

LIST OF EXAMPLES

18.1 EXTERNALITIES

Externalities can arise between producers, between customers, or between consumers and producers. They can be *negative*—when the action of one party imposes costs on another party—or *positive*—when the action of one party benefits another party.

A *negative externality* occurs, for example, when a steel plant dumps its waste in a river that fishermen downstream depend on for their daily catch. The more waste the steel plant dumps in the river, the fewer fish will be supported. The firm, however, has no incentive to account for the external costs that it imposes on fishermen when making its production decision. Furthermore, there is no market in which

• **externality** Action by either a producer or a consumer which affects other producers or consumers, but is not accounted for in the market price.

these external costs can be reflected in the price of steel. A *positive externality* occurs when a home owner repaints her house and plants an attractive garden. All the neighbors benefit from this activity, even though the home owner's decision to repaint and landscape probably did not take these benefits into account.

Negative Externalities and Inefficiency

Because externalities are not reflected in market prices, they can be a source of economic inefficiency. When firms do not take into account the harms associated with negative externalities, the result is excess production and unnecessary social costs. To see why, let's take our example of a steel plant dumping waste in a river. Figure 18.1(a) shows the production decision of a steel plant in a competitive market. Figure 18.1(b) shows the market demand and supply curves, assuming that all steel plants generate similar externalities. We assume that because the firm has a fixed-proportions production function, it cannot alter its input combinations; waste and other effluent can be reduced only by lowering output. (Without this assumption, firms would be jointly choosing among a variety of combinations of output and pollution abatement.) We will analyze the nature of the externality under two circumstances: first when only one steel plant pollutes and, second, when all steel plants pollute in the same way.

In §6.3, we explain that with a fixed-proportions production function, it is impossible to substitute among inputs because each level of output requires a specific combination of labor and capital.

In §8.3, we explain that because a competitive firm faces a horizontal demand curve, choosing its output so that marginal cost is equal to price is profit-maximizing.

The price of steel is P_1 at the intersection of the demand and supply curves in Figure 18.1(b). The MC curve in (a) gives a typical steel firm's marginal cost of production. The firm maximizes profit by producing output q_1, at which marginal cost is equal to price (which equals marginal revenue because the firm takes price as given). As the firm's output changes, however, the external cost

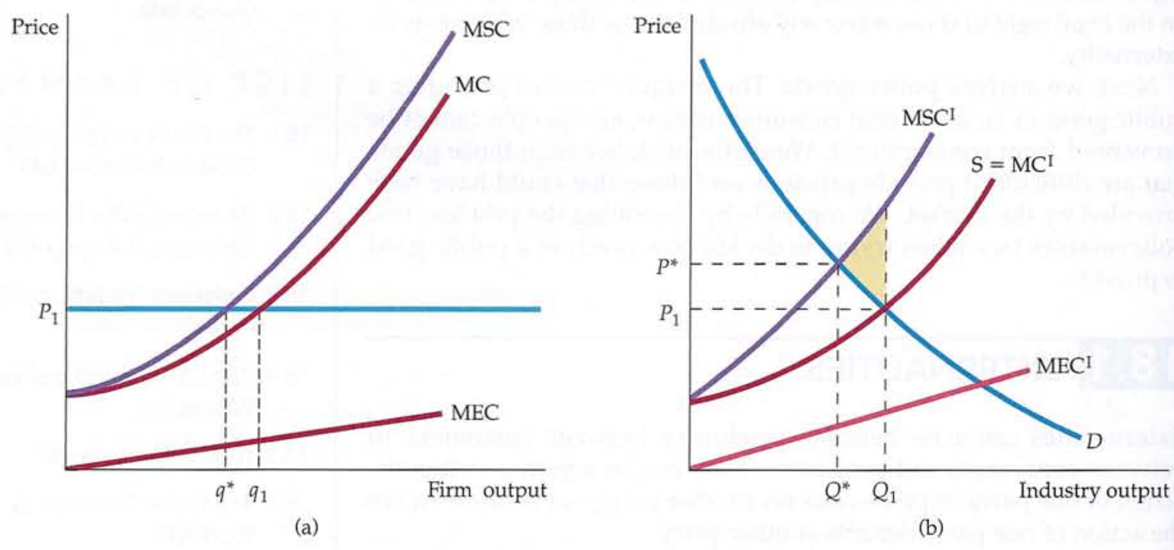

FIGURE 18.1 External Cost

When there are negative externalities, the marginal social cost MSC is higher than the marginal cost MC. The difference is the marginal external cost MEC. In **(a)**, a profit-maximizing firm produces at q_1, where price is equal to MC. The efficient output is q^*, at which price equals MSC. In **(b)**, the industry's competitive output is Q_1, at the intersection of industry supply MC^I and demand D. However, the efficient output Q^* is lower, at the intersection of demand and marginal social cost MSC^I.

imposed on fishermen downstream also changes. This external cost is given by the **marginal external cost** (MEC) curve in Figure 18.1(a). It is intuitively clear why total external cost increases with output—there is more pollution. However, our analysis focuses on the *marginal* external cost, which measures the added cost of the externality associated with each *additional* unit of output produced. In practice, the MEC curve is upward sloping for most forms of pollution: As the firm produces additional output and dumps additional effluent, the incremental harm to the fish industry increases.

• **marginal external cost** Increase in cost imposed externally as one or more firms increase output by one unit.

From a social point of view, the firm produces too much output. The efficient level of output is the level at which the price of the product is equal to the **marginal social cost** (MSC) of production: the marginal cost of production *plus* the marginal external cost of dumping effluent. In Figure 18.1(a), the marginal social cost curve is obtained by adding marginal cost and marginal external cost for each level of output (i.e., MSC = MC + MEC). The marginal social cost curve MSC intersects the price line at output q^*. Because only one plant is dumping effluent into the river, the market price of the product is unchanged. However, the firm is producing too much output (q_1 instead of q^*) and generating too much effluent.

• **marginal social cost** Sum of the marginal cost of production and the marginal external cost.

Now consider what happens when all steel plants dump their effluent into rivers. In Figure 18.1(b), the MC^I curve is the industry supply curve. The marginal external cost associated with the industry output, MEC^I, is obtained by summing the marginal cost of every person harmed at each level of output. The MSC^I curve represents the sum of the marginal cost of production and the marginal external cost *for all steel firms*. As a result, $MSC^I = MC^I + MEC^I$.

Is industry output efficient when there are externalities? As Figure 18.1(b) shows, the efficient industry output level is the level at which the marginal benefit of an additional unit of output is equal to the marginal social cost. Because the demand curve measures the marginal benefit to consumers, the efficient output is Q^*, at the intersection of the marginal social cost MSC^I and demand D curves. The competitive industry output, however, is at Q_1, the intersection of the demand curve and the supply curve, MC^I. Clearly, industry output is too high.

In §9.2, we explain that, absent market failure, a competitive market leads to the economically efficient output level.

In our example, each unit of output results in some effluent being dumped. Therefore, whether we are looking at one firm's pollution or the entire industry's, the economic inefficiency is the excess production that results in too much effluent being dumped in the river. The source of the inefficiency is the incorrect pricing of the product. The market price P_1 in Figure 18.1(b) is too low—it reflects the firms' marginal private cost of production, but not the marginal *social* cost. Only at the higher price P^* will steel firms produce the efficient level of output.

What is the cost to society of this inefficiency? For each unit produced above Q^*, the social cost is given by the difference between the marginal social cost and the marginal benefit (the demand curve). As a result, the aggregate social cost is shown in Figure 18.1(b) as the shaded triangle between MSC^I, D, and output Q_1. When we move from the profit-maximizing to the socially efficient output, firms are worse off because their profits are reduced, and purchasers of steel are worse off because the price of steel has increased. However, these losses are less than the gain to those who were harmed by the adverse effect of the dumping of effluent in the river.

Externalities generate both long-run and short-run inefficiencies. In Chapter 8, we saw that firms enter a competitive industry whenever the price of the product is above the *average cost* of production and exit whenever price is below average cost. In long-run equilibrium, price is equal to (long-run) average cost. When there are negative externalities, the average private cost of production is less than the average social cost. As a result, some firms remain in the industry even when it would be efficient for them to leave. Thus, negative externalities encourage too many firms to remain in the industry.

Positive Externalities and Inefficiency

• **marginal external benefit** Increased benefit that accrues to other parties as a firm increases output by one unit.

Externalities can also result in too little production, as the example of home repair and landscaping shows. In Figure 18.2, the horizontal axis measures the home owner's investment (in dollars) in repairs and landscaping. The marginal cost curve for home repair shows the cost of repairs as more work is done on the house; it is horizontal because this cost is unaffected by the amount of repairs. The demand curve D measures the marginal private benefit of the repairs to the home owner. The home owner will choose to invest q_1 in repairs, at the intersection of her demand and marginal cost curves. But repairs generate external benefits to the neighbors, as the **marginal external benefit** curve, MEB, shows. This curve is downward sloping in this example because the marginal benefit is large for a small amount of repair but falls as the repair work becomes extensive.

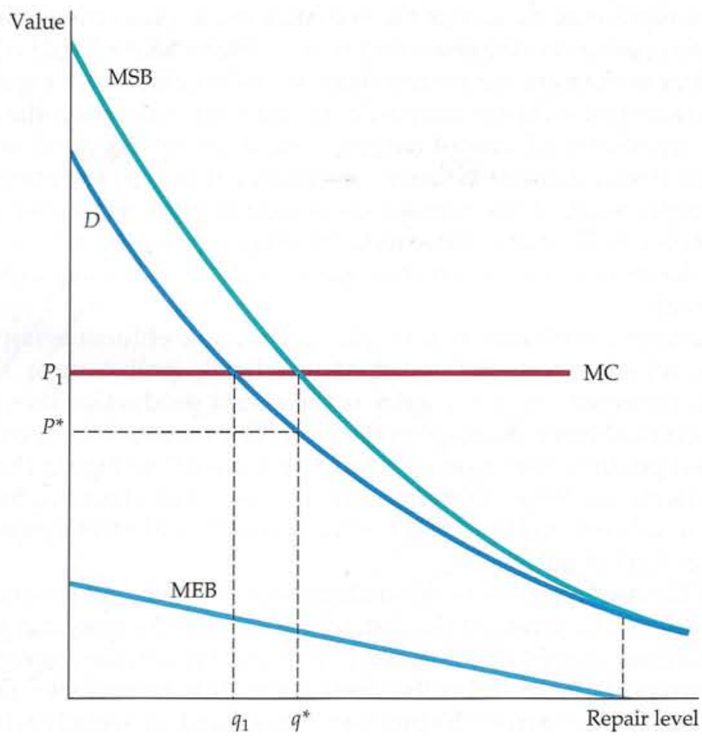

FIGURE 18.2 External Benefits

When there are positive externalities, marginal social benefits MSB are higher than marginal benefits D. The difference is the marginal external benefit MEB. A self-interested homeowner invests q_1 in repairs, determined by the intersection of the marginal benefit curve D and the marginal cost curve MC. The efficient level of repair q^* is higher and is given by the intersection of the marginal social benefit and marginal cost curves.

The **marginal social benefit** curve, MSB, is calculated by adding the marginal private benefit and the marginal external benefit at every level of output. In short, MSB = D + MEB. The efficient level of output q^*, at which the marginal social benefit of additional repairs is equal to the marginal cost of those repairs, is found at the intersection of the MSB and MC curves. The inefficiency arises because the homeowner doesn't receive all the benefits of her investment in repairs and landscaping. As a result, the price P_1 is too high to encourage her to invest in the socially desirable level of house repair. A lower price, P^*, is required to encourage the efficient level of supply, q^*.

• **marginal social benefit** Sum of the marginal private benefit plus the marginal external benefit.

Another example of a positive externality is the money that firms spend on research and development (R&D). Often the innovations resulting from research cannot be protected from other firms. Suppose, for example, that a firm designs a new product. If that design can be patented, the firm might earn a large profit by manufacturing and marketing the product. But if the new design can be closely imitated by other firms, those firms can appropriate some of the developing firm's profit. Because there is then little reward for doing R&D, the market is likely to underfund it.

The externality concept is not new: In discussing demand in Chapter 4, we explained that positive and negative network externalities can arise if the quantity of a good demanded by a consumer increases or decreases in response to an increase in purchases by other consumers. Network externalities can also lead to market failures. Suppose, for example, that some individuals enjoy socializing at busy ski resorts when many other skiers are present. The resulting congestion could make the skiing experience unpleasant for those skiers who preferred short lift lines to pleasant social occasions.

In §4.5, we explain that when there is a network externality, each individual's demand depends on the purchases of other individuals.

EXAMPLE 18.1 The Costs and Benefits of Sulfur Dioxide Emissions

Although sulfur dioxide gas can be produced naturally by volcanoes, almost two-thirds of all sulfur dioxide emissions in the United States come from electric power generation that depends on burning fossil fuels such as coal and petroleum. The effect of sulfur dioxide pollution on the environment has concerned policymakers for years, but these concerns reached new heights in the 1990s (with a series of amendments to the Clean Air Act) because of the potential adverse effects of acid rain. Acid rain—formed when sulfur dioxide and nitrogen oxides react with the atmosphere to form various acidic compounds—threatens property and health throughout the midwestern and northwestern United States.[1]

Acid rain can adversely affect human health either directly, from the atmosphere, or from the soil in which our food is grown. Acid rain has been shown to increase risk of heart and lung disorders such as asthma and bronchitis and has been linked to premature death in both adults and children. According to one estimate, if sulfur dioxide emissions had been reduced by 50 percent of 1980s levels—a time when emissions were at a historic high in the United States—over 17,000 deaths per year would have been prevented.

In addition to human health, acid rain causes damage to water and forests as well as to man-made structures. According to one study, a 50-percent reduction

[1]Further information on sulfur dioxide and acid rain can be found at **http://www.epa.gov**.

in sulfur dioxide levels in the 1980s would have translated into a $24 million annual value in improvements in recreational fishing, an $800 million annual value to the commercial timber sector, and a $700 million annual value to grain crop producers.[2] Furthermore, sulfur dioxide emissions have been shown to cause damage to paint, steel, limestone, and marble through increased surface erosion. While the cost of acid rain to man-made materials is difficult to quantify, automobile manufacturers are now offering acid-resistant paint on new automobiles at an average cost of $5 per car, or $61 million for all new cars and trucks sold in the United States.

What about the costs of achieving reductions in sulfur dioxide emissions? To achieve these reductions, firms need to put emissions-control equipment into use. The incremental cost of achieving some emissions reduction is likely to be small, but that cost increases as greater and greater investments in capital equipment are needed to achieve further reductions.

An example of the costs and benefits of reducing sulfur dioxide emissions is given in Figure 18.3, which is based on a study of pollution abatement in Philadelphia.[3] It is easiest to read the graph from right to left, since we are looking to see how much of a reduction in sulfur dioxide concentrations from the existing level of .08 parts per million is socially desirable. The marginal abatement cost curve is increasing (from right to left); it jumps whenever new capital-intensive pollution-control equipment is needed to improve fuel efficiency.

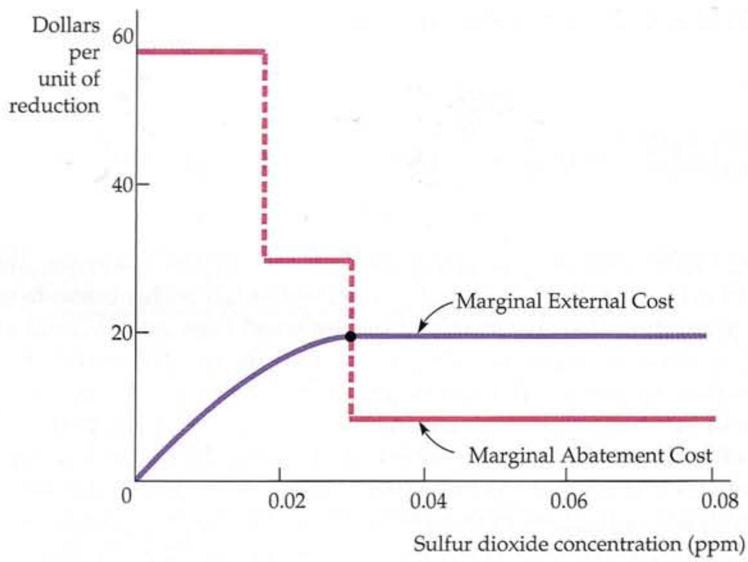

FIGURE 18.3 Sulfur Dioxide Emissions Reductions

The efficient sulfur dioxide concentration equates the marginal abatement cost to the marginal external cost. Here the marginal abatement cost curve is a series of steps, each representing the use of a different abatement technology.

[2] Spencer Banzhaf et al., "Valuation of Natural Resource Improvements in the Adirondacks" (Washington: Resources for the Future, September 2004).

[3] Thomas R. Irvin, "A Cost Benefit Analysis of Sulfur Dioxide Abatement Regulations in Philadelphia," *Business Economics*, September 1977, pp. 12–20.

The marginal external cost curve reflects (again reading from right to left) the incremental reduction in the harms caused by acid rain. For moderate concentrations, studies of respiratory diseases, corrosion of materials, and lost visibility suggest that marginal social costs are high and relatively constant. However, for very low concentrations, the marginal external cost declines, and eventually there are relatively little adverse health, material, or aesthetic effects.

The efficient level of reduced sulfur dioxide emissions is given by the number of ppm at which the marginal cost of reduced emissions is equal to the marginal external cost. We can see from Figure 18.3 that this level is approximately .0275 ppm.

To sum up, there are clearly substantial benefits to reducing sulfur dioxide emissions. What if any policies are best utilized to achieve those reductions efficiently? We will return to these questions after we consider a variety of policy options for the treatment of externalities in Section 18.2.

18.2 WAYS OF CORRECTING MARKET FAILURE

How can the inefficiency resulting from an externality be remedied? If the firm that generates the externality has a fixed-proportions production technology, the externality can be reduced only by encouraging the firm to produce less. As we saw in Chapter 8, this goal can be achieved through an output tax. Fortunately, most firms can substitute among inputs in the production process by altering their choices of technology. For example, a manufacturer can add a scrubber to its smokestack to reduce emissions.

Recall from §7.3 that a firm can substitute among inputs by changing technologies in response to an effluent fee.

Consider a firm that sells its output in a competitive market. The firm emits pollutants that damage air quality in a neighborhood. The firm can reduce its emissions, but only at a cost. Figure 18.4 illustrates this trade-off. The horizontal axis represents the level of factory emissions and the vertical axis the cost per unit of emissions. To simplify, we assume that the firm's output decision and its emissions decision are independent and that the firm has already chosen its profit-maximizing output level. The firm is therefore ready to choose its preferred level of emissions. The curve labeled MEC represents the *marginal external cost of emissions*. This social cost curve represents the increased harm associated with the emissions. We will use the terms *marginal external cost* and *marginal social cost* interchangeably in the discussion that follows. (Recall that we have assumed that the firm's output is fixed, so that the private costs of production—as opposed to pollution abatement—are unchanged.) The MEC curve slopes upward because the *marginal* cost of the externality gets higher as the externality becomes more extensive. (Evidence from studies of the effects of air and water pollution suggests that small levels of pollutants generate little harm. However, the harm increases substantially as the level of pollutants increases.)

Because our emphasis will be on reducing emissions from existing levels, we will find it useful to read the MEC graph from right to left. From this perspective, we see that the MEC associated with a small reduction in emissions from a level of 26 units, which reflects the incremental benefit of reduced emissions, is greater than \$6 per unit. However, as emissions are reduced further and further, the marginal social cost falls (eventually) to below \$2 per unit. At some point, the incremental benefit of reducing emissions becomes less than \$2.

The curve labeled MCA is the *marginal cost of abating emissions*. It measures the additional cost to the firm of installing pollution-control equipment. The

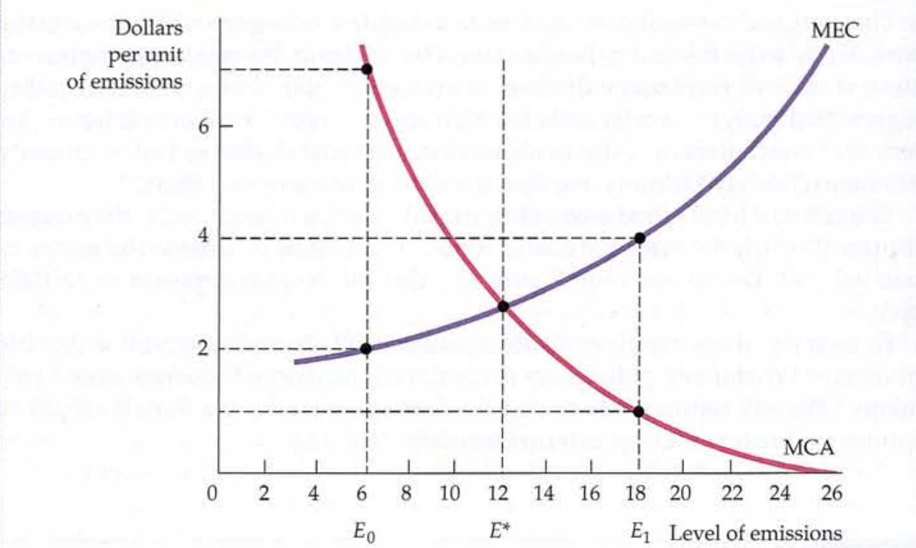

FIGURE 18.4 The Efficient Level of Emissions

The efficient level of factory emissions is the level that equates the marginal external cost of emissions MEC to the benefit associated with lower abatement costs MCA. The efficient level of 12 units is E^*.

MCA curve is downward sloping because the marginal cost of reducing emissions is low when the reduction has been slight and high when it has been substantial. (A slight reduction is inexpensive—the firm can reschedule production to generate the greatest emissions at night, when few people are outside. Large reductions require costly changes in the production process.) As with the MEC curve, reading the MCA curve from right to left will help with our intuition. From this perspective, the marginal cost of abatement increases as we seek to achieve greater and greater reductions in emissions.

With *no* effort at abatement, the firm's profit-maximizing level of emissions is 26, the level at which the marginal cost of abatement is zero. The efficient level of emissions, 12 units, is at point E^*, where the marginal external cost of emissions, \$3, is equal to the marginal cost of abating emissions. Note that if emissions are lower than E^*—say, E_0—the marginal cost of abating emissions, \$7, is greater than the marginal external cost of emissions, \$2. Emissions, therefore, are too low relative to the social optimum. However, if the level of emissions is E_1, the marginal external cost of emissions, \$4, is greater than the marginal cost of abatement, \$1. Emissions are then too high.

We can encourage the firm to reduce emissions to E^* in three ways: (1) emissions standards; (2) emissions fees; and (3) transferable emissions permits. We will begin by discussing standards and fees and comparing relative advantages and disadvantages. Then we will examine transferable emissions permits.

An Emissions Standard

• **emissions standard** Legal limit on the amount of pollutants that a firm can emit.

An **emissions standard** is a legal limit on how much pollutant a firm can emit. If the firm exceeds the limit, it can face monetary and even criminal penalties. In Figure 18.5, the efficient emissions standard is 12 units, at point E^*. The firm will be heavily penalized for emissions greater than this level.

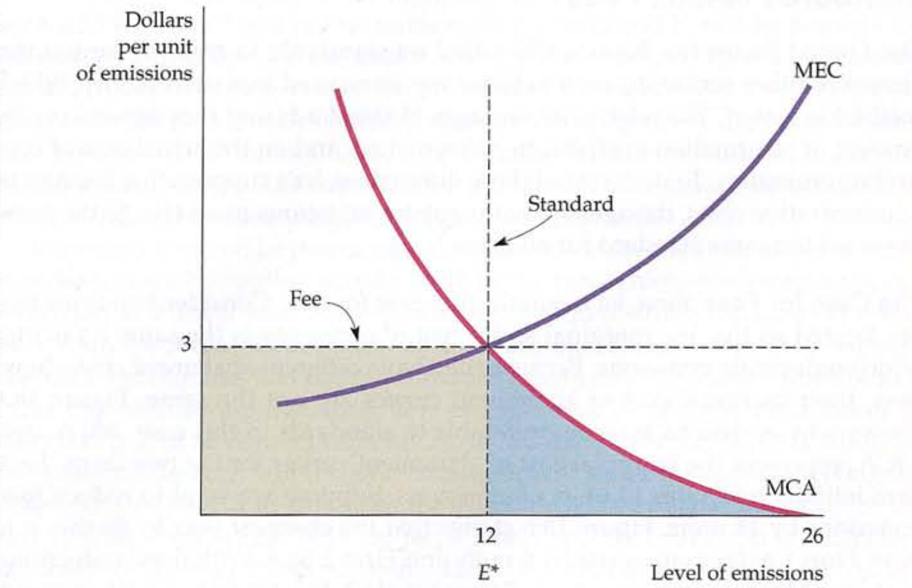

FIGURE 18.5 Standards and Fees

The efficient level of emissions at E^* can be achieved through either an emissions fee or an emissions standard. Facing a fee of $3 per unit of emissions, a firm reduces emissions to the point at which the fee is equal to the marginal cost of abatement. The same level of emissions reduction can be achieved with a standard that limits emissions to 12 units.

The standard ensures that the firm produces efficiently. The firm meets the standard by installing pollution-abatement equipment. The increased abatement expenditure will cause the firm's average cost curve to rise (by the average cost of abatement). Firms will find it profitable to enter the industry only if the price of the product is greater than the average cost of production plus abatement—the efficient condition for the industry.[4]

An Emissions Fee

An **emissions fee** is a charge levied on each unit of a firm's emissions. As Figure 18.5 shows, a $3 emissions fee will generate efficient behavior by our factory. Faced with this fee, the firm minimizes costs by reducing emissions from 26 to 12 units. To see why, note that the first unit of emissions can be reduced (from 26 to 25 units of emissions) at very little cost (the marginal cost of additional abatement is close to zero). For very little cost, therefore, the firm can avoid paying the $3 per-unit fee. In fact, for all levels of emissions above 12 units, the marginal cost of abatement is less than the emissions fee. Thus it pays to reduce emissions. Below 12 units, however, the marginal cost of abatement is greater than the fee. In that case, the firm will prefer to pay the fee rather than further reduce emissions. It will therefore pay a total fee given by the gray-shaded rectangle and incur a total abatement cost given by the blue-shaded triangle under the MCA curve to the right of $E = 12$. This cost is less than the fee that the firm would pay if it did not reduce emissions at all.

• **emissions fee** Charge levied on each unit of a firm's emissions.

[4]This analysis assumes that the social costs of emissions do not change over time. If they do, the efficient standard will also change.

Standards versus Fees

The United States has historically relied on standards to regulate emissions. However, other countries, such as Germany, have used fees successfully. Which method is better? The relative advantages of standards and fees depend on the amount of information available to policymakers and on the actual cost of controlling emissions. To understand these differences, let's suppose that because of administrative costs, the agency that regulates emissions must charge the same fee or set the same standard for all firms.

The Case for Fees First, let's examine the case for fees. Consider two firms that are located so that the marginal social cost of emissions is the same no matter which reduces its emissions. Because they have different abatement costs, however, their marginal cost of abatement curves are not the same. Figure 18.6 shows why emissions fees are preferable to standards in this case. MCA_1 and MCA_2 represent the marginal cost of abatement curves for the two firms. Each firm initially generates 14 units of emissions. Suppose we want to reduce total emissions by 14 units. Figure 18.6 shows that the cheapest way to do this is to have Firm 1 reduce emissions by 6 units and Firm 2 by 8. With these reductions, both firms have marginal costs of abatement of \$3. But consider what happens if the regulatory agency asks both firms to reduce emissions by 7 units. In that case Firm 1's marginal cost of abatement increases from \$3 to \$3.75, while Firm 2's marginal cost of abatement decreases from \$3 to \$2.50. This cannot be cost-minimizing because the second firm can reduce emissions more cheaply than the first. Only when the marginal cost of abatement is equal for both firms will emissions be reduced by 14 units at minimum cost.

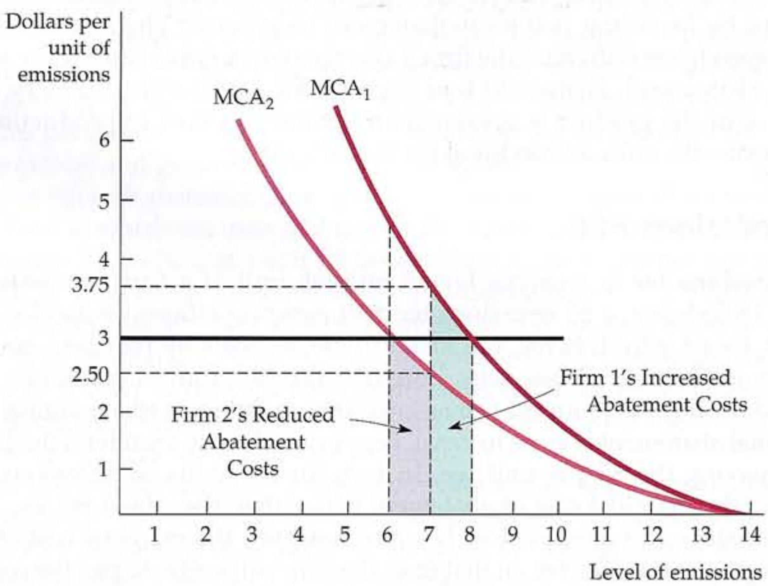

FIGURE 18.6 The Case for Fees

With limited information, a policymaker may be faced with the choice of either a single emissions fee or a single emissions standard for all firms. The fee of \$3 achieves a total emissions level of 14 units more cheaply than a 7-unit-per-firm emissions standard. With the fee, the firm with a lower abatement cost curve (Firm 2) reduces emissions more than the firm with a higher cost curve (Firm 1).

Now we can see why a fee ($3) might be preferable to a standard (7 units). Faced with a $3 fee, Firm 1 will reduce emissions by 6 units and Firm 2 by 8 units—the efficient outcome. By contrast, under an emissions standard, Firm 1 incurs additional abatement costs given by the green-shaded area between 7 and 8 units of emissions. But Firm 2 enjoys reduced abatement costs given by the purple-shaded area between 6 and 7 units. Clearly, Firm 1's added abatement costs are larger than Firm 2's reduced costs. The emissions fee thus achieves the same level of emissions at a lower cost than the equal per-firm emissions standard.

In general, fees can be preferable to standards for several reasons. First, when standards must be applied equally to all firms, fees achieve the same emissions reduction at a lower cost. Second, fees give a firm a strong incentive to install new equipment that would allow it to reduce emissions *even further*. Suppose the standard requires that each firm reduce its emission by 6 units, from 14 to 8. Firm 1 is considering installing new emissions devices that would lower its marginal cost of abatement from MCA_1 to MCA_2. If the equipment is relatively inexpensive, the firm will install it because it will lower the cost of meeting the standard. However, a $3 emissions fee would provide a greater incentive for the firm to reduce emissions. With the fee, not only will the firm's cost of abatement be lower on the first 6 units of reduction, but it will also be cheaper to reduce emissions by 2 more units: The emissions fee is greater than the marginal abatement cost for emissions levels between 6 and 8.

The Case for Standards Now let's examine the case for standards by looking at Figure 18.7. While the marginal external cost curve is very steep, the marginal cost of abatement is relatively flat. The efficient emissions fee is $8. But suppose

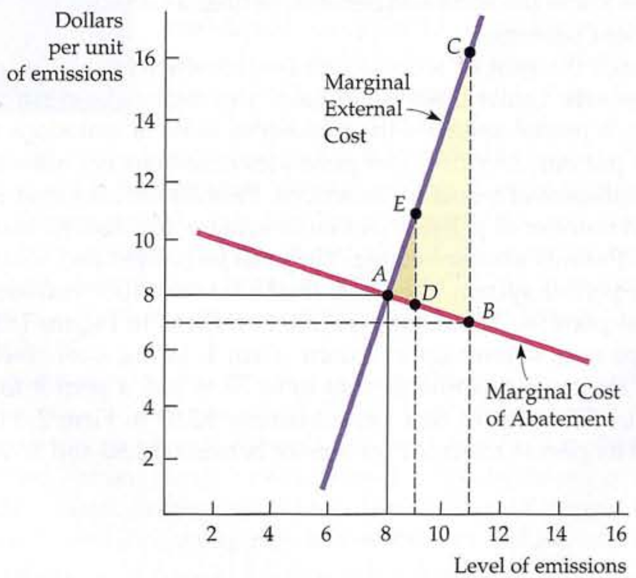

FIGURE 18.7 The Case for Standards

When the government has limited information about the costs and benefits of pollution abatement, either a standard or a fee may be preferable. The standard is preferable when the marginal external cost curve is steep and the marginal abatement cost curve is relatively flat. Here a 12.5 percent error in setting the standard leads to extra social costs of triangle *ADE*. The same percentage error in setting a fee would result in excess costs of *ABC*.

that because of limited information, a lower fee of $7 is charged (this fee amounts to a 1/8 or 12.5 percent reduction). Because the MCA curve is flat, the firm's emissions will be increased from 8 to 11 units. This increase lowers the firm's abatement costs somewhat, but because the MEC curve is steep, there will be substantial additional social costs. The increase in social costs, less the savings in abatement costs, is given by the entire shaded (light and dark) triangle *ABC*.

What happens if a comparable error is made in setting the standard? The efficient standard is 8 units of emissions. But suppose the standard is relaxed by 12.5 percent, from 8 to 9 units. As before, this change will lead to an increase in social costs and a decrease in abatement costs. But the net increase in social costs, given by the small triangle *ADE*, is much smaller than before.

This example illustrates the difference between standards and fees. When the marginal external cost curve is relatively steep and the marginal cost of abatement curve relatively flat, the cost of not reducing emissions is high. In such cases, a standard is preferable to a fee. With incomplete information, standards offer more certainty about emissions levels but leave the costs of abatement uncertain. Fees, on the other hand, offer certainty about the costs of abatement but leave the reduction of emissions levels uncertain. The preferable policy depends, therefore, on the nature of uncertainty and on the shapes of the cost curves.[5]

Tradeable Emissions Permits

If we knew the costs and benefits of abatement and if all firms' costs were identical, we could apply a standard. Alternatively, if the costs of abatement varied among firms, an emissions fee would work. However, when firms' costs vary and we do not know the costs and benefits, neither a standard nor a fee will generate an efficient outcome.

• **tradeable emissions permits** System of marketable permits, allocated among firms, specifying the maximum level of emissions that can be generated.

We can reach the goal of reducing emissions efficiently by using **tradeable emissions permits**. Under this system, each firm must have permits to generate emissions. Each permit specifies the number of units of emissions that the firm is allowed to put out. Any firm that generates emissions not allowed by permit is subject to substantial monetary sanctions. Permits are allocated among firms, with the total number of permits chosen to achieve the desired maximum level of emissions. Permits are marketable: They can be bought and sold.

Under the permit system, the firms least able to reduce emissions are those that purchase permits. Thus, suppose the two firms in Figure 18.6 (page 654) were given permits to emit up to 7 units. Firm 1, facing a relatively high marginal cost of abatement, would pay up to $3.75 to buy a permit for one unit of emissions, but the value of that permit is only $2.50 to Firm 2. Firm 2 should therefore sell its permit to Firm 1 for a price between $2.50 and $3.75.

[5]Our analysis presumes that the emissions fee is levied as a fixed fee per unit of emissions. If the fee is set too low because of limited information, the firm will generate a substantial amount of excess emissions. Suppose, however, that a fixed fee were replaced with a fee schedule designed so that the higher the level of emissions the higher the per-unit fee. In this case, if the fee schedule is set too low, the increasing fee will discourage the firm from generating substantial excess emissions. In general, a variable fee is preferable to a standard if the fee schedule can be designed to match the environmental harm caused by the emissions. In this case, firms know that the payment they make will be approximately equal to the harm that they cause and will *internalize* that harm in making their production decisions. See Louis Kaplow and Steven Shavell, "On the Superiority of Corrective Taxes to Quantity Regulation," *American Law and Economics Review* 4 (Spring 2002): 1–17.

If there are enough firms and permits, a competitive market for permits will develop. In market equilibrium, the price of a permit equals the marginal cost of abatement for all firms; otherwise, a firm will find it advantageous to buy more permits. The level of emissions chosen by the government will be achieved at minimum cost. Those firms with relatively low marginal cost of abatement curves will be reducing emissions the most, and those with relatively high marginal cost of abatement curves will be buying more permits and reducing emissions the least.

Marketable emissions permits create a market for externalities. This market approach is appealing because it combines some of the advantageous features of a system of standards with the cost advantages of a fee system. The agency that administers the system determines the total number of permits and, therefore, the total amount of emissions, just as a system of standards would do. But the marketability of the permits allows pollution abatement to be achieved at minimum cost.[6]

EXAMPLE 18.2 Reducing Sulfur Dioxide Emissions in Beijing

Taken together, sulfur dioxide emissions produced through the burning of coal for use in electric power generation and the wide use of coal-based home furnaces have caused a huge problem in Beijing as well as other cities in China. Not only have emissions created an acid rain problem, but they have combined with emissions from the growing number of automobiles to make Beijing one of the most polluted cities not only in China, but in the world. In 1995, for example, the level of sulfur dioxide in Beijing was 90 milligrams per cubic meter, which compares unfavorably to Berlin (18 mg/m^3), Copenhagen (7), London (25), New York (26), Tokyo (18), and Mexico City (74). Of the major cities in the world, only Moscow had higher sulfur dioxide levels (109 mg/m^3).

Over the long term, the key to solving Beijing's problem is to replace coal with cleaner fuels, to encourage the use of public transportation, and, when necessary, to introduce fuel-efficient hybrid vehicles. But prior to its hosting of the Olympics in 2008, Beijing had a problem. What could it do to reduce sulfur dioxide emissions so as to offer a cleaner environment to the Olympic athletes and to the visiting public?

Beijing's choice was to shut down a large number of coal-fired plants. This strategic choice can obviously accomplish the stated goal of reducing emissions. But is it the most efficient policy choice? Our study of pollution-abatement strategies suggests not. For one thing, we have experience with the use of standards for regulating sulfur dioxide emissions in Philadelphia (recall Example 18.1). In 1968, Philadelphia imposed air-quality regulations that limited the maximum allowable sulfur content in fuel oil to 1.0 percent or less. This regulation decreased sulfur dioxide levels in the air substantially—from 0.10 parts per million (ppm) in 1968 to below 0.030 ppm in 1973. Improved air quality led to better human health,

[6]With limited information and costly monitoring, a marketable permit system is not always ideal. For example, if the total number of permits is chosen incorrectly and the marginal cost of abatement rises sharply for some firms, a permit system could drive those firms out of business by imposing high abatement costs. (This would also be a problem for fees.)

less damage to materials, and higher property values. Example 18.1 shows that the imposed standards made sense on cost-benefit grounds.

Would the imposition of a system of emissions fees—or better yet a regime of tradeable emissions permits—do even better in Beijing? A study of the regulation of electric-utility sulfur dioxide tradeable emissions shows that marketable permits in the United States can cut in half the cost of complying with a regulatory-based standard.[7] Can similar gains be achieved in Beijing? The answer lies in part on whether the market for tradeable emissions will itself work efficiently. But it also depends on the shape of the marginal abatement cost and marginal external cost curves. As our prior discussion has shown, the case for emissions fees (and for tradeable permits) is strongest (1) when firms vary substantially in their marginal abatement costs; and (2) when the marginal external cost of emissions curve is relatively steep and the marginal cost of abatement curve relatively flat.

EXAMPLE 18.3 Emissions Trading and Clean Air

Controlling emissions cost companies approximately $18 billion during the 1980s, and it cost even more during the first half of the 1990s.[8] An effective emissions trading system could reduce those costs substantially in the decades to come. The Environmental Protection Agency's "bubble" and "offset" programs were modest attempts to use a trading system to lower cleanup costs.

A bubble allows an individual firm to adjust its pollution controls for individual sources of pollutants as long as a *total pollutant limit* for the firm is not exceeded. In theory, a bubble could be used to set pollutant limits for many firms or for an entire geographic region; in practice, however, it has been applied to individual firms. As a result "permits" are, in effect, traded within the firm: If one part of the firm can reduce its emissions, another part will be allowed to emit more. Abatement cost savings associated with the EPA's program of 42 bubbles have been approximately $300 million per year since 1979.

Under the offset program, new sources of emissions may be located in geographic regions in which air-quality standards have not been met, but only if they offset their new emissions by reducing emissions from existing sources by at least as much. Offsets can be obtained by internal trading, but external trading among firms is also allowed. A total of more than 2000 offset transactions have occurred since 1976.

Because of their limited natures, bubble and offset programs substantially understate the potential gain from a broad-based emissions trading program. In one study, the cost of achieving an 85-percent reduction in hydrocarbon emissions in all U.S. DuPont plants was estimated under three alternative policies: (1) each source at each plant must reduce emissions by 85 percent; (2) each plant must reduce its overall emissions by 85 percent with only internal trading possible; and (3) total emissions at all plants must be reduced by 85 percent, with both internal and external trading possible.[9] When no trading was allowed, the

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[7]Don Fullerton, Shaun P. McDermott, and Jonathan P. Caulkins, "Sulfur Dioxide Compliance of a Regulated Utility," NBER Working Paper No. 5542, April 1996.

[8]See Robert W. Hahn and Gordon L. Hester, "The Market for Bads: EPA's Experience with Emissions Trading," *Regulation* (1987): 48–53; Brian J. McKean, "Evolution of Marketable Permits: The U.S. Experience with Sulfur-Dioxide Allowance Trading," Environmental Protection Agency, December, 1996.

[9]M. T. Maloney and Bruce Yandle, "Bubbles and Efficiency: Cleaner Air at Lower Cost," *Regulation* (May/June 1980): 49–52.

cost of emissions reduction was \$105.7 million. Internal trading reduced the cost to \$42.6 million. Allowing for both external and internal trading reduced the cost even further, to \$14.6 million.

Clearly, the potential cost savings from an effective tradeable emissions program can be substantial. This may explain why Congress focused on transferable permits as a way of dealing with "acid rain" in the 1990 Clean Air Act. Acid rain can be extremely harmful to people, animals, vegetation, and buildings. The government initially authorized a permit system to reduce annual sulfur dioxide emissions by 10 million tons and nitrogen oxide emissions by 2.5 million tons by the year 2000. That program remains in place today.

Under the plan, each tradeable permit allows a maximum of one ton of sulfur dioxide to be released into the air. Electric utilities and other polluting entities are allocated permits in proportion to their current level of emissions. Companies can make the capital investments necessary to reduce emissions, perhaps selling excess permits, or they can buy permits and avoid having to make costly emissions-reducing investments.

In the early 1990s, economists expected these permits to trade for around \$300. In fact, as Figure 18.8 shows, between 1993 and 2003, prices fluctuated between \$100 and \$200. Why? It turned out that reducing sulfur dioxide emissions was less costly than anticipated (it had become cheaper to mine low-sulfur coal), and many electric utilities took advantage of this development to reduce emissions. During 2005 to 2006, however, the price of permits rose sharply, hitting a high of nearly \$1600 in December 2005. This was the result of an increase in the price of low-sulfur coal and, more importantly, the increased

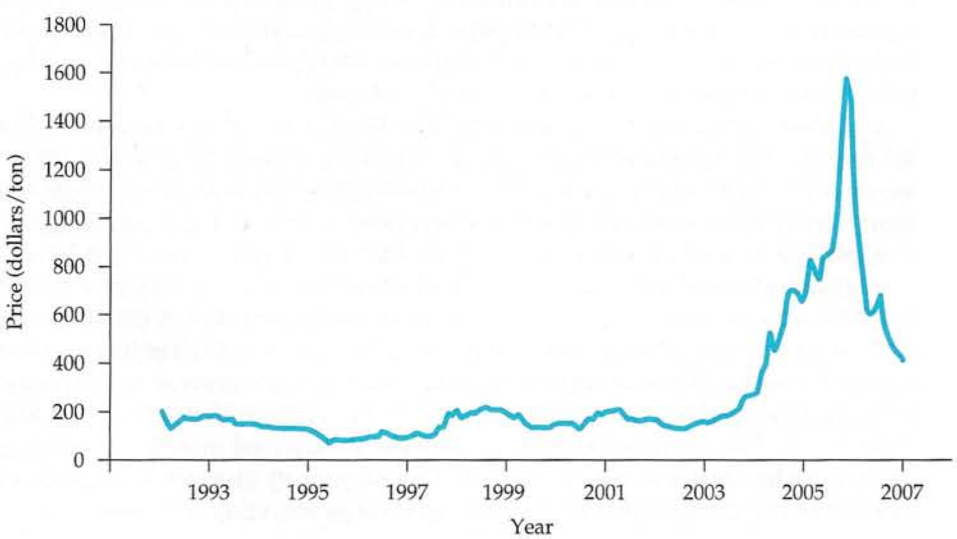

FIGURE 18.8 Price of Tradeable Emissions Permits

The price of tradeable permits for sulfur dioxide emissions fluctuated between \$100 and \$200 in the period 1993 to 2003, but then increased sharply during 2005 and 2006 in response to an increased demand for permits. Since then, the price has fluctuated around \$400 to \$500 per ton.

demand for permits that resulted as more electric power plants were required to meet tight emissions standards. By 2007, prices had stabilized at around $400 to $500. But the lesson for electric utilities is not only that the cost of abatement had become higher than anticipated, but that it is volatile and difficult to predict.[10]

Recycling

To the extent that the disposal of waste products involves little or no private cost to either consumers or producers, society will dispose of too much waste material. The overutilization of virgin materials and the underutilization of recycled materials will result in a market failure that may require government intervention. Fortunately, given the appropriate incentive to recycle products, this market failure can be corrected.[11]

To see how recycling incentives can work, consider a typical household's decision with respect to the disposal of glass containers. In many communities, households are charged a fixed annual fee for trash disposal. As a result, these households can dispose of glass and other garbage at very low cost—only the time and effort to put the materials in a trash receptacle.

The low cost of disposal creates a divergence between the private and the social cost of disposal. The marginal private cost, which is the cost to the household of throwing out the glass, is likely to be constant (independent of the amount of disposal) for low to moderate levels of disposal. It will then increase for large disposal levels involving additional shipping and dump charges. In contrast, the social cost of disposal includes the harm to the environment from littering, as well as the injuries caused by sharp glass objects. Marginal social cost is likely to increase, in part because the marginal private cost is increasing and in part because the environmental and aesthetic costs of littering are likely to increase sharply as the level of disposal increases.

Both cost curves are shown in Figure 18.9. The horizontal axis measures, from left to right, the amount of scrap material m that the household disposes, up to a maximum of 12 pounds per week. Consequently, the amount recycled can be read from right to left. As the amount of scrap disposal increases, the marginal private cost, MC, increases, but at a much lower rate than the marginal social cost MSC.

Recycling of containers can be accomplished by a municipality or a private firm that arranges for collection, consolidation, and processing of materials. The marginal cost of recycling is likely to increase as the amount of recycling grows, in part because collection, separation, and cleaning costs grow at an increasing rate. The marginal cost of recycling curve, MCR, in Figure 18.9 is best read from right to left. Thus, when there are 12 pounds of disposed material, there is no recycling; the marginal cost is zero. As the amount of disposal decreases, the amount of recycling increases; the marginal cost of recycling increases.

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[10]Our thanks to Elizabeth Bailey, Denny Ellerman and Paul Joskow for providing the emissions permit price data and for helpful comments. For a more detailed explanation of permit prices, see A. D. Ellerman, P. L. Joskow, R. Schmalensee, J. P. Montero, and E. M. Bailey, *Markets for Clean Air: The U.S. Acid Rain Program* (Boston: MIT Center for Energy and Environmental Policy Research, 1999). For more information on tradeable permits generally, go to the EPA Web site at **www.epa.gov**.

[11]Even without market intervention, some recycling will occur if the price of virgin material is sufficiently high. For example, recall from Chapter 2 that when the price of copper is high, there is more recycling of scrap copper.

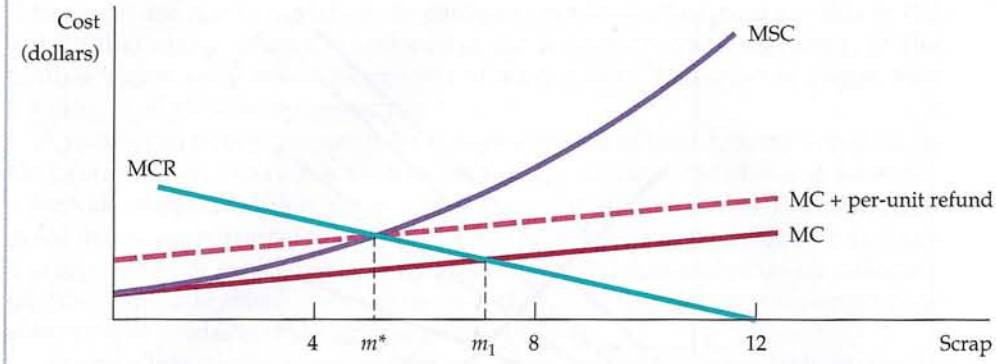


FIGURE 18.9 The Efficient Amount of Recycling

The efficient amount of recycling of scrap material is the amount that equates the marginal social cost of scrap disposal, MSC, to the marginal cost of recycling, MCR. The efficient amount of scrap for disposal m^* is less than the amount that will arise in a private market, m_1.

The efficient amount of recycling occurs at the point at which the marginal cost of recycling, MCR, is equal to the marginal *social* cost of disposal, MSC. As Figure 18.9 shows, the efficient amount of scrap for disposal m^* is less than the amount that will arise in a private market, m_1.

Why not utilize a disposal fee, a disposal standard, or even transferable disposal permits to resolve this externality? Any of these policies can help in theory, but they are not easy to put into practice and are rarely used. For example, a disposal fee is difficult to implement because it would be very costly for a community to sort through trash to separate and then to collect glass materials. Pricing and billing for scrap disposal would also be expensive, because the weight and composition of materials would affect the social cost of the scrap and, therefore, the appropriate price to be charged.

Refundable Deposits One policy solution that has been used with some success to encourage recycling is the *refundable deposit*.[12] Under a refundable deposit system, an initial deposit is paid to the store owner when the glass container product is purchased. The deposit is refunded if and when the container is returned to the store or to a recycling center. Refundable deposits create a desirable incentive: The per-unit refund can be chosen so that households (or firms) recycle more material.

From an individual's point of view, the refundable deposit creates an additional private cost of disposal: the opportunity cost of failing to obtain a refund. As shown in Figure 18.9, with the higher cost of disposal, the individual will reduce disposal and increase recycling to the optimal social level m^*.

A similar analysis applies at the industry level. Figure 18.10 shows a downward-sloping market demand for glass containers, D. The supply of virgin glass containers is given by S_v and the supply of recycled glass by S_r. The market supply S is the horizontal sum of these two curves. As a result, the market price of glass is P and the equilibrium supply of recycled glass is M_1.

By raising the relative cost of disposal and encouraging recycling, the refundable deposit increases the supply of recycled glass from S_r, to S_r', the aggregate

[12]See Frank Ackerman, *Why Do We Recycle: Markets, Values, and Public Policy* (Washington: Island Press, 1997), for a general discussion of recycling.

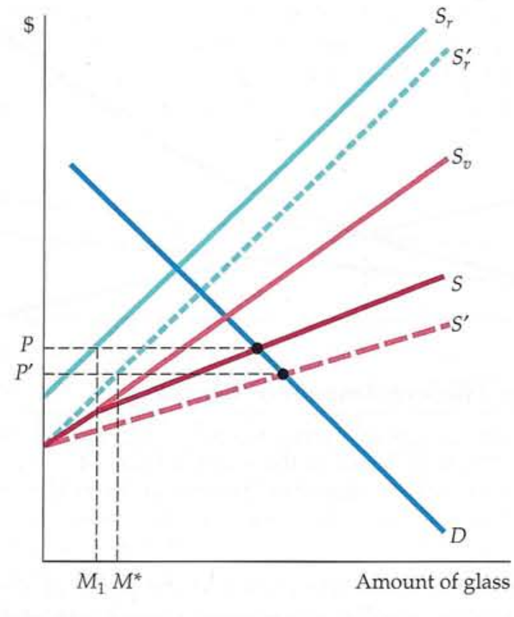


FIGURE 18.10 Refundable Deposits

Initially, equilibrium in the market for glass containers involves a price P and a supply of recycled glass M_1. By raising the relative cost of disposal and encouraging recycling, the refundable deposit increases the supply of recycled glass from S_r to S'_r and the aggregate supply of glass from S to S'. The price of glass then falls to P', the quantity of recycled glass increases to M^*, and the amount of disposed glass decreases.

supply increases from S to S', and the price of glass falls to P'. As a result, the quantity of recycled glass increases to M^*, resulting in a decrease in the amount of disposed glass.

The refundable deposit scheme has another advantage: A market for recycled products is created. In many communities, public or private firms as well as private individuals specialize in collecting and returning recyclable materials. As this market becomes larger and more efficient, the demand for recycled rather than virgin materials increases, therefore increasing the benefit to the environment.

EXAMPLE 18.4 Regulating Municipal Solid Wastes

By 1990, the average resident of Los Angeles was generating about 6.4 pounds of solid waste per day, and residents of other large American cities were not far behind. By contrast, residents of Tokyo, Paris, Hong Kong, and Rome generated 3 pounds, 2.4 pounds, 1.9 pounds, and 1.5 pounds, respectively.[13] Some of these

[13]This example is based on Peter S. Menell, "Beyond the Throwaway Society: An Incentive Approach to Regulating Municipal Solid Waste," *Ecology Law Quarterly* (1990): 655–739. See also Marie Lynn Miranda et al., "Unit Pricing for Residential Municipal Solid Waste: An Assessment of the Literature," U.S. Environmental Protection Agency, March 1996.

differences are due to variations in consumption levels, but most are due to the efforts that many other countries have made to encourage recycling. In the United States, only about 25 percent of aluminum, 23 percent of paper, and 8.5 percent of glass scrap are recycled.

A number of policy proposals have been introduced to encourage recycling in the United States. The first is the refundable deposit described above. A second is a *curbside charge*, in which communities charge individuals a fee for refuse disposal that is proportional to the weight (or the volume) of the refuse. To encourage separation of recyclable materials, all separable glass materials are collected for free. Curbside charges encourage recycling, but they fail to discourage consumption of products that might require recycling.

A third alternative is to require the *mandatory separation* of recyclable materials such as glass. Random spot checks with substantial penalties for violations are required to make the system effective. Mandatory separation is perhaps the least desirable of the three alternatives, not only because it is difficult to implement, but also because individuals, if the cost of separation is sufficiently high, may be encouraged to shift to alternative containers such as plastic, which are environmentally damaging and cannot readily be recycled.

The potential effectiveness of each of these three policies is illustrated by a study that focused on the mix between glass and plastic. Consumers were assumed to have varying preferences, with half preferring glass and half preferring plastic, for products that are otherwise identical in price, quantity, and quality. Without any incentive to recycle, a 50–50 division between glass and plastic would result. From a social perspective, however, greater use of recyclable glass would be preferred.

Mandatory separation fails as a policy in this case: The cost of separation is so high that the percentage of glass container materials purchased actually falls to 40 percent. A curbside charge, however, does much better: It leads to a 72.5 percent use of recyclable glass. Finally, a refundable deposit system does best, with 78.9 percent of consumers purchasing recyclable glass containers.

A recent case in Perkasie, Pennsylvania, shows that recycling programs can indeed be effective. Prior to implementation of a program combining all three economic incentives just described, the total amount of unseparated solid waste was 2573 tons per year. When the program was implemented, this amount fell to 1038 tons—a 59-percent reduction. As a result, the town saved $90,000 per year in disposal costs.

18.3 STOCK EXTERNALITIES

We have studied the negative externalities that result directly from *flows* of harmful pollution. For example, we saw how sulfur dioxide emissions from power plants can adversely affect the air that people breathe, so that government intervention in the form of emissions fees or standards might be warranted. Recall that we compared the marginal cost of reducing the *flow* of emissions to the marginal benefit in order to determine the socially optimal level of emissions.

Sometimes, however, the damage to society comes not directly from the emissions flow, but rather from the *accumulated stock* of the pollutant. A good example is global warming. Global warming is thought to result from the accumulation of carbon dioxide and other greenhouse gasses (GHGs) in the atmosphere. (As the GHG concentration grows, more sunlight is absorbed into the atmosphere rather than being reflected away, causing an increase in average temperatures.) GHG emissions do not cause the kind of immediate harm that sulfur dioxide emissions cause. Rather, it is the *stock of accumulated GHGs in the atmosphere* that ultimately causes harm. Furthermore, the *dissipation rate* for accumulated GHGs is very low: Once the GHG concentration in the atmosphere has increased substantially, it will remain high for many years, even if further GHG emissions were reduced to zero. That is why there is concern about reducing GHG emissions now rather than waiting for concentrations to build up (and temperatures to start rising) fifty or more years from now.

• **stock externality** Accumulated result of action by a producer or consumer which, though not accounted for in the market price, affects other producers or consumers.

Stock externalities (like flow externalities) can also be positive. An example is the stock of "knowledge" that accumulates as a result of investments in R&D. Over time, R&D leads to new ideas, new products, more efficient production techniques, and other innovations that benefit society as a whole, and not just those who undertake the R&D. Because of this positive externality, there is a strong argument for the government to subsidize R&D. Keep in mind, however, that it is the *stock* of knowledge and innovations that benefits society, and not the flow of R&D that creates the stock.

Recall from §15.1 that a firm's capital is measured as a stock, while the investment that creates the capital is a flow. The firm's output is also measured as a flow.

Recall from §15.2 that the present discounted value (PDV) of a series of expected future cash flows is the sum of those cash flows discounted by the appropriate interest rate. Moreover, we observe in §15.4 that, according to the net present value (NPV) rule, a firm should invest if the PDV of the expected future cash flow from an investment is greater than the cost.

We examined the distinction between a stock and a flow in Chapter 15. As we explained in Section 15.1 (page 552), the capital that a firm owns is measured as a *stock*, i.e., as a quantity of plant and equipment that the firm owns. The firm can increase its stock of capital by purchasing additional plant and equipment, i.e., by generating a *flow* of investment expenditures. (Recall that inputs of labor and raw materials are also measured as *flows*, as is the firm's output.) We saw that this distinction is important, because it helps the firm decide whether to invest in a new factory, equipment, or other capital. By comparing the *present discounted value (PDV)* of the additional profits likely to result from the investment to the cost of the investment, i.e., by calculating the investment's *net present value (NPV)*, the firm can decide whether or not the investment is economically justified.

The same net present value concept applies when we want to analyze how the government should respond to a stock externality—though with an additional complication. For the case of pollution, we must determine how any ongoing level of emissions leads to a buildup of the stock of pollutant, and we must then determine the economic damage likely to result from that higher stock. We will then be able to compare the present value of the ongoing costs of reducing emissions each year to the present value of the economic benefits resulting from a reduced future stock of the pollutant.

Stock Buildup and Its Impact

Let's focus on pollution to see how the stock of a pollutant changes over time. With ongoing emissions, the stock will accumulate, but some fraction of the stock, δ, will dissipate each year. Thus, assuming the stock starts at zero, in the first year, the stock of pollutant (S) will be just the amount of that year's emissions (E):

$$S_1 = E_1$$

In the second year, the stock of pollutant will equal the emissions that year plus the nondissipated stock from the first year—

$$S_2 = E_2 + (1 - \delta)S_1$$

—and so on. In general, the stock in any year t is given by the emissions generated that year plus the nondissipated stock from the previous year:

$$S_t = E_t + (1 - \delta)S_{t-1}$$

If emissions are at a constant annual rate E, then after N years, the stock of pollutant will be[14]:

$$S_N = E[1 + (1 - \delta) + (1 - \delta)^2 + \cdots + (1 - \delta)^{N-1}]$$

As N becomes infinitely large, the stock will approach the long-run equilibrium level E/δ.

The impact of pollution results from the accumulating stock. Initially, when the stock is small, the economic impact is small; but the impact grows as the stock grows. With global warming, for example, higher temperatures result from higher concentrations of GHGs: Thus the concern that if GHG emissions continue at current rates, the atmospheric stock of GHGs will eventually become large enough to cause substantial temperature increases—which, in turn, could have adverse effects on weather patterns, agriculture, and living conditions. Depending on the cost of reducing GHG emissions and the future benefits of averting these temperature increases, it may make sense for governments to adopt policies that would reduce emissions now, rather than waiting for the atmospheric stock of GHGs to become much larger.

Numerical Example We can make this concept more concrete with a simple example. Suppose that, absent government intervention, 100 units of a pollutant will be emitted into the atmosphere every year for the next 100 years; the rate at which the stock dissipates, δ, is 2 percent per year, and the stock of pollutant is initially zero. Table 18.1 shows how the stock builds up over time. Note that after 100 years, the stock will reach a level of 4,337 units. (If this level of emissions continued forever, the stock will eventually approach $E/\delta = 100/.02 =$ 5,000 units.)

Suppose that the stock of pollutant creates economic damage (in terms of health costs, reduced productivity, etc.) equal to $1 million per unit. Thus, if

TABLE 18.1 Buildup in the Stock of Pollutant

Year	E	S_t	Damage ($ Billion)	Cost of $E = 0$ ($ Billion)	Net Benefit ($ Billion)
2010	100	100	0.100	1.5	−1.400
2011	100	198	0.198	1.5	−1.302
2012	100	296	0.296	1.5	−1.204
...	...	...	...	...	...
2110	100	4,337	4.337	1.5	2.837
...	...	...	...	...	...
∞	100	5,000	5.000	1.5	3.500

[14]To see this, note that after 1 year, the stock of pollutant is $S_1 = E$, in the second year the stock is $S_2 = E + (1 - \delta)\,S_1 = E + (1 - \delta)\,E$, in the third year, the stock is $S_3 = E + (1 - \delta)\,S_2 = E + (1 - \delta)\,E + (1 - \delta)^2\,E$, and so on. As N becomes infinitely large, the stock approaches E/δ.

the total stock of pollutant were, say, 1000 units, the resulting economic damage for that year would be \$1 billion. And suppose that the annual cost of reducing emissions is \$15 million per unit of reduction. Thus, to reduce emissions from 100 units per year to zero would cost 100 × \$15 million = \$1.5 billion per year. Would it make sense, in this case, to reduce emissions to zero starting immediately?

To answer this question, we must compare the present value of the annual cost of \$1.5 billion with the present value of the annual benefit resulting from a reduced stock of pollutant. Of course, if emissions were reduced to zero starting immediately, the stock of pollutant would likewise be equal to zero over the entire 100 years. Thus, the benefit of the policy would be the savings of social cost associated with a growing stock of pollutant. Table 18.1 shows the annual cost of reducing emissions from 100 units to zero, the annual benefit from averting damage, and the annual *net* benefit (the annual benefit net of the cost of eliminating emissions). As you would expect, the annual net benefit is negative in the early years because the stock of pollutant is low; the net benefit becomes positive only later, after the stock of pollutant has grown.

To determine whether a policy of zero emissions makes sense, we must calculate the NPV of the policy, which in this case is the present discounted value of the annual net benefits shown in Table 18.1. Denoting the discount rate by R, the NPV is:

$$\text{NPV} = (-1.5 + .1) + \frac{(-1.5 + .198)}{1 + R} + \frac{(-1.5 + .296)}{(1 + R)^2} + \cdots + \frac{(-1.5 + 4.337)}{(1 + R)^{99}}$$

Recall from §15.1 that the NPV of an investment declines as the discount rate becomes larger. Figure 15.3 shows the *NPV* for an electric motor factory; note the similarity to our environmental policy problem.

Is this NPV positive or negative? The answer depends on the discount rate, R. Table 18.2 shows the NPV as a function of the discount rate. (The middle row of Table 18.2, in which the dissipation rate δ is 2 percent, corresponds to Table 18.1. Table 18.2 also shows NPVs for dissipation rates of 1 percent and 4 percent.) For discount rates of 4 percent or less, the NPV is clearly positive, but if the discount rate is large, the NPV will be negative.

Table 18.2 also shows how the NPV of a "zero emissions" policy depends on the dissipation rate, δ. If δ is lower, the accumulated stock of pollutant will reach higher levels and cause more economic damage, so the future benefits of reducing emissions will be greater. Note from Table 18.2 that for any given discount rate, the NPV of eliminating emissions is much larger if $\delta = .01$ and much smaller if $\delta = .04$. As we will see, one of the reasons why there is so much concern over global warming is the fact that the stock of GHGs dissipates very slowly; δ is only about .005.

TABLE 18.2 NPV of "Zero Emissions" Policy

		Discount Rate, R				
		.01	.02	.04	.06	.08
Dissipation Rate, δ	.01	108.81	54.07	12.20	−0.03	−4.08
	.02	65.93	31.20	4.49	−3.25	−5.69
	.04	15.48	3.26	−5.70	−7.82	−8.11

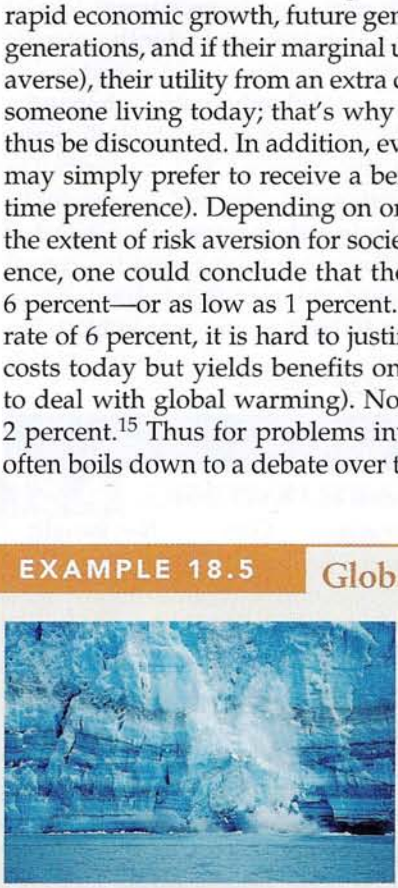
Note: Entries in table are NPVs in \$billions. Entries for δ = .02 correspond to net benefit numbers in Table 18.1.

Formulating environmental policy in the presence of stock externalities therefore introduces an additional complicating factor: What discount rate should be used? Because the costs and benefits of a policy apply to society as a whole, the discount rate should likewise reflect the opportunity cost to society of receiving an economic benefit in the future rather than today. This opportunity cost, which should be used to calculate NPVs for government projects, is called the **social rate of discount**. But as we will see in Example 18.5, there is little agreement among economists as to the appropriate number to use for the social rate of discount.

• **social rate of discount** Opportunity cost to society as a whole of receiving an economic benefit in the future rather than the present.

In principle, the social rate of discount depends on three factors: (1) the expected rate of real economic growth; (2) the extent of risk aversion for society as a whole; and (3) the "rate of pure time preference" for society as a whole. With rapid economic growth, future generations will have higher incomes than current generations, and if their marginal utility of income is decreasing (i.e., they are risk-averse), their utility from an extra dollar of income will be lower than the utility to someone living today; that's why future benefits provide less utility and should thus be discounted. In addition, even if we expected no economic growth, people may simply prefer to receive a benefit today than in the future (the rate of pure time preference). Depending on one's beliefs about future real economic growth, the extent of risk aversion for society as a whole, and the rate of pure time preference, one could conclude that the social rate of discount should be as high as 6 percent—or as low as 1 percent. And herein lies the difficulty. With a discount rate of 6 percent, it is hard to justify almost any government policy that imposes costs today but yields benefits only 50 or 100 years in the future (e.g., a policy to deal with global warming). Not so, however, if the discount rate is only 1 or 2 percent.[15] Thus for problems involving long time horizons, the policy debate often boils down to a debate over the correct discount rate.

EXAMPLE 18.5 Global Warming



Emissions of carbon dioxide and other greenhouse gases have increased dramatically over the past century as economic growth has been accompanied by the greater use of fossil fuels, which has in turn led to an increase in atmospheric concentrations of GHGs. Even if worldwide GHG emissions were to be stabilized at current levels, atmospheric GHG concentrations would continue to grow throughout the next century. By trapping sunlight, these higher GHG concentrations are likely to cause a significant increase in global mean temperatures in 50 years or so and could have severe environmental consequences—flooding of low-lying areas as the polar ice caps melt and sea levels rise, more extreme weather patterns, disruption of ecosystems, and reduced agricultural output. GHG emissions could be reduced from their current levels—governments, for example, could impose stiff taxes on the use of gasoline and other fossil fuels—but this solution would be costly. The problem is that the costs

[15]For example, with a discount rate of 6 percent, \$100 received 100 years from now is worth only \$0.29 today. With a discount rate of 1 percent, that same \$100 is worth \$36.97 today, i.e., 127 times as much.

of reducing GHG emissions would occur today but the benefits from reduced emissions would be realized only in some 50 or more years. Should the world's industrialized countries agree to adopt policies to dramatically reduce GHG emissions, or is the present discounted value of the likely benefits of such policies simply too small?

There have been many studies by physical scientists and economists of the buildup of GHG concentrations and the resulting increases in global temperatures if no steps are taken to reduce emissions. Although there is considerable disagreement over the exact economic impact of higher temperatures, there is at least a consensus view that the impact would be significant; thus there would be a future benefit from reducing emissions today.[16] The cost of reducing emissions (or preventing them from growing above current levels) can be assessed as well, although, again, there is disagreement over the specific numbers.

Table 18.3 shows GHG emissions and average global temperature change for two scenarios. The first is a "business as usual" scenario in which GHG emissions more than double over the next century, the average GHG concentration rises, and by 2110 the average temperature increases by 4 degrees Celsius over its current level. The resulting damage from this temperature increase is estimated at 1.3 percent of world GDP per year. World GDP is in turn assumed to grow at 2.5 percent per year in real terms from its 2010 value of $65 trillion. Thus, the damage from global warming reaches about $40 trillion per year in 2110. The

TABLE 18.3 Reducing GHG Emissions

	"Business as Usual"				Emissions Reduced by 1% per Year					
Year	E_t	S_t	ΔT_t	Damage	E_t	S_t	ΔT_t	Damage	Cost	Net Benefit
2010	50	430	0°	0	50	430	0°	0	0.65	−0.65
2020	55	460	0.5°	0.54	45	460	0.5°	0.43	0.83	−0.72
2030	62	490	1°	1.38	41	485	1°	1.11	1.07	−0.79
2040	73	520	1.5°	2.66	37	510	1.4°	2.13	1.36	−0.83
2050	85	550	2°	4.54	33	530	1.8°	3.63	1.75	−0.84
2060	90	580	2.3°	6.77	30	550	2°	5.81	2.23	−1.27
2070	95	610	2.7°	9.91	27	550	2°	7.44	2.86	−0.38
2080	100	640	3°	14.28	25	550	2°	9.52	3.66	1.10
2090	105	670	3.3°	20.31	22	550	2°	12.18	4.69	3.44
2100	110	700	3.7°	28.59	20	550	2°	15.60	6.00	7.00
2110	115	730	4°	39.93	18	550	2°	19.97	7.68	12.28

Notes: E_t is measured in gigatonnes (billions of metric tons) of CO_2 equivalent (CO_2e), S_t is measured in parts per million (ppm) of atmospheric CO_2e, the change in temperature ΔT_t is measured in degrees Celsius, and costs, damages, and net benefits are measured in trillions of 2007 dollars. Cost of reducing emissions is estimated to be 1 percent of GDP each year. World GDP is projected to grow at 2.5% in real terms from a level of $65 trillion in 2010. Damage from warming is estimated to be 1.3% of GDP per year for every 1°C of temperature increase.

[16]See, for example, the 2007 *Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press or online at **http://www.ipcc.ch**; and the U.K. Government's Stern Review, online at **http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/**.

second scenario is one in which the GHG concentration is stabilized so that the temperature increase is limited to only 2 degrees Celsius, which is reached in 2060. To achieve this, GHG emissions must be reduced by 1 percent per year starting in 2010. The annual cost of this emissions reduction policy is estimated to be 1 percent of world GDP.[17] (Because world GDP is assumed to increase each year, so too does the cost of this policy.) Also shown in Table 18.3 is the annual net benefit from the policy, which equals the damage under the "business as usual" scenario minus the (smaller) damage when emissions are reduced minus the cost of reducing emissions.

Does this emissions-reduction policy make sense? To answer that question, we must calculate the present value of the flow of net benefits, which depends critically on the discount rate. A review conducted in the United Kingdom recommends a social rate of discount of 1.3 percent. With that discount rate, the NPV of the policy is \$21.3 trillion, which shows that the emissions-reduction policy is clearly economical. The NPV is smaller but still positive (\$1.63 trillion) if we use a discount rate of 2 percent. But with a discount rate of 3 percent, the NPV is –\$9.7 trillion; with a discount rate of 5 percent, the NPV is –\$12.7 trillion.

We have examined a particular policy—and a rather stringent one at that—to reduce GHG emissions. Whether that policy or any other policy to restrict GHG emissions makes economic sense clearly depends on the rate used to discount future costs and benefits. Be warned, however, that economists disagree about what rate to use, and as a result, they disagree about what should be done about global warming.[18]

18.4 EXTERNALITIES AND PROPERTY RIGHTS

We have seen how government regulation can deal with the inefficiencies that arise from externalities. Emissions fees and transferable emissions permits work because they change a firm's incentives, forcing it to take into account the external costs that it imposes. But government regulation is not the only way to deal with externalities. In this section we show that in some circumstances, inefficiencies can be eliminated through private bargaining among the affected parties or by a legal system in which parties can sue to recover the damages they suffer.

Property Rights

Property rights are the legal rules that describe what people or firms may do with their property. If you have property rights to land, for example, you may build on it or sell it and are protected from interference by others.

• **property rights** Legal rules stating what people or firms may do with their property.

[17]This policy is the one recommended by the Stern Review, which was commissioned by the U.K. government. The cost estimate of 1 percent of GDP is from the Stern Review. The estimate of the damage from higher temperatures (1.3 percent of GDP for each 1 degree Celsius increase) is an amalgam of estimates from the Stern Review and the IPCC Report.

[18]This disagreement over the discount rate and its crucial role in assessing policies to reduce GHG emissions is spelled out quite nicely in Martin Weitzman, "The Stern Review of the Economics of Climate Change," *Journal of Economic Literature* (September 2007). Also, there are many uncertainties about the size of possible future temperature increases and their social and economic impact. Those uncertainties can have implications for policy but have been ignored in this example. See, for example, R. S. Pindyck, "Uncertainty in Environmental Economics," *Journal of Environmental Economics and Policy* (Winter 2007).

To see why property rights are important, let's return to our example of the firm that dumps effluent into the river. We assumed both that it had a property right to use the river to dispose of its waste and that the fishermen did not have a property right to "effluent-free" water. As a result, the firm had no incentive to include the cost of effluent in its production calculations. In other words, the firm *externalized* the costs generated by the effluent. But suppose that the fishermen had a property right to clean water. In that case, they could demand that the firm pay them for the right to dump effluent. The firm would either cease production or pay the costs associated with the effluent. These costs would be *internalized* and an efficient allocation of resources achieved.

Bargaining and Economic Efficiency

Economic efficiency can be achieved without government intervention when the externality affects relatively few parties and when property rights are well specified. To see how, let's consider a numerical version of our effluent example. Suppose the steel factory's effluent reduces the fishermen's profit. As Table 18.4 shows, the factory can install a filter system to reduce its effluent, or the fishermen can pay for the installation of a water treatment plant.[19]

The efficient solution maximizes the joint profit of the factory and the fishermen. Maximization occurs when the factory installs a filter and the fishermen do not build a treatment plant. Let's see how alternative property rights lead these two parties to negotiate different solutions.

Suppose the factory has the property right to dump effluent into the river. Initially, the fishermen's profit is \$100 and the factory's \$500. By installing a treatment plant, the fishermen can increase their profit to \$200, whereby the joint profit, without cooperation, is \$700 (\$500 + \$200). Moreover, the fishermen are willing to pay the factory up to \$300 to install a filter—the difference between the \$500 profit with a filter and the \$200 profit without cooperation. Because the factory loses only \$200 in profit by installing a filter, it will be willing to do so because it is more than compensated for its loss. In this case, the gain to both parties by cooperating is equal to \$100: the \$300 gain to the fishermen less the \$200 cost of a filter.

Suppose the factory and the fishermen agree to split this gain equally by having the fishermen pay the factory \$250 to install the filter. As Table 18.5 shows, this bargaining solution achieves the efficient outcome. Under the column "Right to Dump," we see that without cooperation, the fishermen earn a profit of \$200 and the factory \$500. With cooperation, the profit of both increases by \$50.

TABLE 18.4 Profits under Alternative Emissions Choices (Daily)

	Factory's Profit (\$)	Fishermen's Profit (\$)	Total Profit (\$)
No filter, no treatment plant	500	100	600
Filter, no treatment plant	300	500	800
No filter, treatment plant	500	200	700
Filter, treatment plant	300	300	600

[19]For a more extensive discussion of a variant of this example, see Robert Cooter and Thomas Ulen, *Law and Economics* (Reading, MA: Addison Wesley Longman, Inc., 2000), ch. 4.

TABLE 18.5 Bargaining with Alternative Property Rights

	Right to Dump ($)	Right to Clean Water ($)
No Cooperation		
Profit of factory	500	300
Profit of fishermen	200	500
Cooperation		
Profit of factory	550	300
Profit of fishermen	250	500

Now suppose the fishermen are given the property right to clean water, which requires the factory to install the filter. The factory earns a profit of $300 and the fishermen $500. Because neither party can be made better off by bargaining, having the factory install the filter is efficient.

This analysis applies to all situations in which property rights are well specified. *When parties can bargain without cost and to their mutual advantage, the resulting outcome will be efficient, regardless of how the property rights are specified.* The italicized proposition is called the **Coase theorem,** after Ronald Coase who did much to develop it.[20]

• **Coase theorem** Principle that when parties can bargain without cost and to their mutual advantage, the resulting outcome will be efficient regardless of how property rights are specified.

Costly Bargaining—The Role of Strategic Behavior

Bargaining can be time-consuming and costly, especially when property rights are not clearly specified. In that case, neither party is sure how hard to bargain before the other party will agree to a settlement. In our example, both parties knew that the bargaining process had to settle on a payment between $200 and $300. If the parties are unsure of the property rights, however, the fishermen might be willing to pay only $100, and the bargaining process would break down.

Bargaining can break down even when communication and monitoring are costless if both parties believe they can obtain larger gains. For example, one party might demand a large share and refuse to bargain, assuming incorrectly that the other party will eventually concede. Another problem arises when many parties are involved. Suppose, for example, that the emissions from a factory are adversely affecting hundreds or thousands of households who live downstream. In that case, the costs of bargaining will make it very difficult for the parties to reach a settlement.

A Legal Solution—Suing for Damages

In many situations involving externalities, a party who is harmed (the victim) by another has the legal right to sue. If successful, the victim can recover monetary damages equal to the harm that it has suffered. A suit for damages is different from an emissions or effluent fee because the victim, not the government, is paid.

To see how the potential for a lawsuit can lead to an efficient outcome, let's reexamine our fishermen–factory example. Suppose first that the fishermen are given the right to clean water. The factory, in other words, is responsible for

[20]Ronald Coase, "The Problem of Social Cost," *Journal of Law and Economics* 3 (1960): 1–44.

harm to the fishermen *if* it does not install a filter. The harm to the fishermen in this case is \$400: the difference between the profit that the fishermen make when there is no effluent (\$500) and their profit when there is effluent (\$100). The factory has the following options:

1. Do not install filter, pay damages: Profit = \$100 (\$500 – \$400)
2. Install filter, avoid damages: Profit = \$300 (\$500 – \$200)

The factory will find it advantageous to install a filter, which is substantially cheaper than paying damages, and the efficient outcome will be achieved.

An efficient outcome (with a different division of profits) will also be achieved if the factory is given the property right to emit effluent. Under the law, the fishermen would have the legal right to require the factory to install the filter, but they would have to pay the factory for its \$200 lost profit (not for the cost of the filter). This leaves the fishermen with three options:

1. Put in a treatment plant: Profit = \$200
2. Have factory put in a filter but pay damages: Profit = \$300 (\$500 – \$200)
3. Do not put in treatment plant or require a filter: Profit = \$100

The fishermen earn the highest profit if they take the second option. They will thus require the factory to put in a filter but compensate it \$200 for its lost profit. Just as in the situation in which the fishermen had the right to clean water, this outcome is efficient because the filter has been installed. Note, however, that the \$300 profit is substantially less than the \$500 profit that the fishermen get when they have a right to clean water.

This example shows that a suit for damages eliminates the need for bargaining because it specifies the consequences of the parties' choices. Giving the party that is harmed the right to recover damages from the injuring party ensures an efficient outcome. (When information is imperfect, however, suing for damages may lead to inefficient outcomes.)

EXAMPLE 18.6 The Coase Theorem at Work

As a September 1987 cooperative agreement between New York City and New Jersey illustrates, the Coase theorem applies to governments as well as to people and organizations.

For many years, garbage spilling from waterfront trash facilities along New York harbor had adversely affected the quality of water along the New Jersey shore and occasionally littered the beaches. One of the worst instances occurred in August 1987, when more than 200 tons of garbage formed a 50-mile-long slick off the New Jersey shore.

New Jersey had the right to clean beaches and could have sued New York City to recover damages associated with garbage spills. New Jersey could have also asked the court to grant an injunction requiring New York City to stop using its trash facilities until the problem was removed.

But New Jersey wanted cleaner beaches, not simply the recovery of damages. And New York wanted to be able to operate its trash facility. Consequently, there was room for mutually beneficial exchange. After two weeks of negotiations, New York and New Jersey reached a settlement. New Jersey agreed not to bring a lawsuit against the city. New York City agreed to use special boats and other flotation devices to contain spills that might originate from Staten Island and Brooklyn. It also agreed to form a monitoring team to survey all trash facilities and to shut down those failing to comply. At the same time, New Jersey officials were allowed unlimited access to New York City trash facilities to monitor the program's effectiveness.

18.5 COMMON PROPERTY RESOURCES

Occasionally externalities arise when resources can be used without payment. **Common property resources** are those to which anyone has free access. As a result, they are likely to be overutilized. Air and water are the two most common examples. Others include fish, animal populations, mineral exploration, and extraction. Let's look at some of the inefficiencies that can occur when resources are common property rather than privately owned.

• **common property resource** Resource to which anyone has free access.

Consider a large lake with trout to which an unlimited number of fishermen have access. Each fisherman fishes up to the point at which the marginal revenue from fishing (or the marginal value, if fishing is for sport instead of profit) is equal to the cost. But the lake is a common property resource, and no fisherman has the incentive to take into account how his fishing affects the opportunities of others. As a result, the fisherman's private cost understates the true cost to society because more fishing reduces the stock of fish, making less available for others. This leads to an inefficiency—too many fish are caught.

Figure 18.11 illustrates this situation. Suppose that because the catch is sufficiently small relative to demand, fishermen take the price of fish as given.

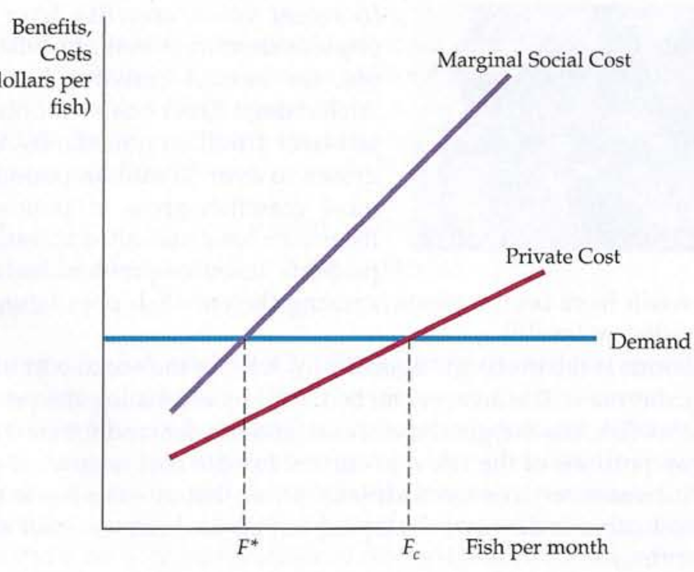


FIGURE 18.11 Common Property Resources

When a common property resource, such as a fishery, is accessible to all, the resource is used up to the point F_c at which the private cost is equal to the additional revenue generated. This usage exceeds the efficient level F^* at which the marginal social cost of using the resource is equal to the marginal benefit (as given by the demand curve).

Suppose also that someone can control the number of fishermen with access to the lake. The efficient level of fish per month F^* is determined at the point at which the marginal benefit from fish caught is equal to the marginal social cost. The marginal benefit is the price taken from the demand curve. The marginal social cost shown in the diagram includes not only the private operating costs but also the social cost of depleting the stock of fish.

Now compare the efficient outcome with what happens when the lake is common property. In this case, the marginal external costs are not taken into account, and each fisherman fishes until there is no longer any profit to be made. When only F^* fish are caught, the revenue from fishing is greater than the cost, and there is a profit to be earned by fishing more. Entry into the fishing business occurs until the point at which the price is equal to the marginal cost, point F_c in Figure 18.11. At F_c, however, too many fish will be caught.

There is a relatively simple solution to the common property resource problem—let a single owner manage the resource. The owner will set a fee for use of the resource that is equal to the marginal cost of depleting the stock of fish. Facing the payment of this fee, fishermen in the aggregate will no longer find it profitable to catch more than F^* fish. Unfortunately, because single ownership is not always practical, most common property resources are vast. In such cases government ownership or direct government regulation may be needed.

EXAMPLE 18.7 Crawfish Fishing in Louisiana

In recent years, crawfish have become a popular restaurant item. In 1950, for example, the annual crawfish harvest in the Atchafalaya River basin in Louisiana was just over 1 million pounds. By 1995, it had grown to over 30 million pounds. Because most crawfish grow in ponds to which fishermen have unlimited access, a common property resource problem has arisen: Too many crawfish have been trapped, causing the crawfish population to fall far below the efficient level.[21]

How serious is the problem? Specifically, what is the social cost of unlimited access to fishermen? The answer can be found by estimating the private cost of trapping crawfish, the marginal social cost, and the demand for crawfish. Figure 18.12 shows portions of the relevant curves. Private cost is upward-sloping: As the catch increases, so does the additional effort that must be made to obtain it. The demand curve is downward sloping but elastic because other shellfish are close substitutes.

[21]This example is based on Frederick W. Bell, "Mitigating the Tragedy of the Commons," *Southern Economic Journal* 52 (1986): 653–64.

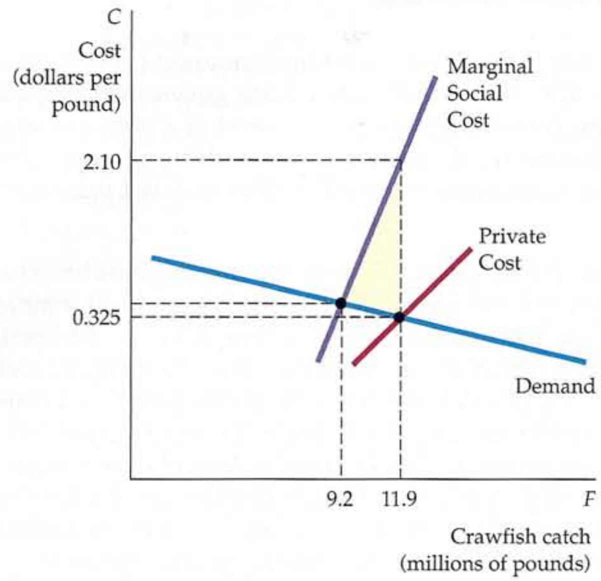


FIGURE 18.12 Crawfish as a Common Property Resource

Because crawfish are bred in ponds to which fishermen have unlimited access, they are a common property resource. The efficient level of fishing occurs when the marginal benefit is equal to the marginal social cost. However, the actual level of fishing occurs at the point at which the price for crawfish is equal to the private cost of fishing. The shaded area represents the social cost of the common property resource.

We can find the efficient crawfish catch both graphically and algebraically. Let F represent the catch of crawfish in millions of pounds per year (shown on the horizontal axis), and let C represent cost in dollars per pound (shown on the vertical axis). In the region where the various curves intersect, the three curves in the graph are as follows:

Demand:	$C = 0.401 - 0.0064F$
Marginal social cost:	$C = -5.645 + 0.6509F$
Private cost:	$C = -0.357 + 0.0573F$

The efficient crawfish catch of 9.2 million pounds, which equates demand to marginal social cost, is shown as the intersection of the two curves. The actual catch, 11.9 million pounds, is determined by equating demand to private cost and is shown as the intersection of those two curves. The yellow-shaded triangle in the figure measures the social cost of free access. This figure represents the excess of social cost above the private benefit of fishing summed from the efficient level (where demand is equal to marginal social cost) to the actual level (where demand is equal to private cost). In this case, the social cost is approximated by the area of a triangle with a base of 2.7 million pounds (11.9 – 9.2) and a height of \$1.775 (\$2.10 – \$0.325), or \$2,396,000. Note that by regulating the ponds—limiting either access or the size of the catch—this social cost could be avoided.

18.6 PUBLIC GOODS

We have seen that externalities, including common-property resources, create market inefficiencies that sometimes warrant government regulation. When, if ever, should governments replace private firms as a producer of goods and services? In this section we describe a set of conditions under which the private market either may not provide a good at all or may not price it properly once it is available.

• **public good** Nonexclusive and nonrival good: the marginal cost of provision to an additional consumer is zero and people cannot be excluded from consuming it.

• **nonrival good** Good for which the marginal cost of its provision to an additional consumer is zero.

Nonrival Goods As we saw in Chapter 16, **public goods** have two characteristics: They are *nonrival* and *nonexclusive*. A good is **nonrival** if for any given level of production, the marginal cost of providing it to an additional consumer is zero. For most goods that are provided privately, the marginal cost of producing more of the good is positive. But for some goods, additional consumers do not add to cost. Consider the use of a highway during a period of low traffic volume. Because the highway already exists and there is no congestion, the additional cost of driving on it is zero. Or consider the use of a lighthouse by a ship. Once the lighthouse is built and functioning, its use by an additional ship adds nothing to its running costs. Finally, consider public television. Clearly, the cost of one more viewer is zero.

Most goods are rival in consumption. For example, when you buy furniture, you have ruled out the possibility that someone else can buy it. Goods that are rival must be allocated among individuals. Goods that are nonrival can be made available to everyone without affecting any individual's opportunity for consuming them.

• **nonexclusive good** Good that people cannot be excluded from consuming, so that it is difficult or impossible to charge for its use.

Nonexclusive Goods A good is **nonexclusive** if people cannot be excluded from consuming it. As a consequence, it is difficult or impossible to charge people for using nonexclusive goods; the goods can be enjoyed without direct payment. One example of a nonexclusive good is national defense. Once a nation has provided for its national defense, all citizens enjoy its benefits. A lighthouse and public television are also examples of nonexclusive goods.

Nonexclusive goods need not be national in character. If a state or city eradicates an agricultural pest, all farmers and consumers benefit. It would be virtually impossible to exclude a particular farmer from the benefits of the program. Automobiles are exclusive (as well as rival). If a dealer sells a new car to one consumer, then the dealer has excluded other individuals from buying it.

Some goods are exclusive but nonrival. For example, in periods of low traffic, travel on a bridge is nonrival because an additional car on the bridge does not lower the speed of other cars. But bridge travel is exclusive because bridge authorities can keep people from using it. A television signal is another example. Once a signal is broadcast, the marginal cost of making the broadcast available to another user is zero; thus the good is nonrival. But broadcast signals can be made exclusive by scrambling the signals and charging for the codes that unscramble them.

Some goods are nonexclusive but rival. An ocean or large lake is nonexclusive, but fishing is rival because it imposes costs on others: the more fish caught, the fewer fish available to others. Air is nonexclusive and often nonrival; but it can be rival if the emissions of one firm adversely affect the quality of the air and the ability of others to enjoy it.

Public goods, which are both nonrival and nonexclusive, provide benefits to people at zero marginal cost, and no one can be excluded from enjoying them.

The classic example of a public good is national defense. Defense is nonexclusive, as we have seen, but it is also nonrival because the marginal cost of providing defense to an additional person is zero. The lighthouse is also a public good because it is nonrival and nonexclusive; in other words, it would be difficult to charge ships for the benefits they receive from it.[22]

The list of public goods is much smaller than the list of goods that governments provide. Many publicly provided goods are either rival in consumption, exclusive, or both. For example, high school education is rival in consumption. Because other children get less attention as class sizes increase, there is a positive marginal cost of providing education to one more child. Likewise, charging tuition can exclude some children from enjoying education. Public education is provided by local government because it entails positive externalities, not because it is a public good.

Finally, consider the management of a national park. Part of the public can be excluded from using the park by raising entrance and camping fees. Use of the park is also rival: because of crowded conditions, the entrance of an additional car into a park can reduce the benefits that others receive from it.

Efficiency and Public Goods

The efficient level of provision of a private good is determined by comparing the marginal benefit of an additional unit to the marginal cost of producing it. Efficiency is achieved when the marginal benefit and the marginal cost are equal. The same principle applies to public goods, but the analysis is different. With private goods, the marginal benefit is measured by the benefit that the consumer receives. With a public good, we must ask how much each person values an additional unit of output. The marginal benefit is obtained by adding these values for *all* people who enjoy the good. To determine the efficient level of provision of a public good, we must then equate the sum of these marginal benefits to the marginal cost of production.

Figure 18.13 illustrates the efficient level of producing a public good. D_1 represents the demand for the public good by one consumer and D_2 the demand by a second consumer. Each demand curve tells us the marginal benefit that the consumer gets from consuming every level of output. For example, when there are 2 units of the public good, the first consumer is willing to pay \$1.50 for the good, and \$1.50 is the marginal benefit. Similarly, the second consumer has a marginal benefit of \$4.00.

To calculate the sum of the marginal benefits to *both* people, we must add each of the demand curves *vertically*. For example, when the output is 2 units, we add the marginal benefit of \$1.50 to the marginal benefit of \$4.00 to obtain a marginal social benefit of \$5.50. When this sum is calculated for every level of public output, we obtain the aggregate demand curve for the public good D.

In §4.3, we show that a market demand curve can be obtained by summing individual demand curves horizontally.

The efficient amount of output is the one at which the marginal benefit to society is equal to the marginal cost. This occurs at the intersection of the demand and the marginal cost curves. In our example, because the marginal cost of production is \$5.50, 2 is the efficient output level.

To see why 2 is efficient, note what happens if only 1 unit of output is provided: Although the marginal cost remains at \$5.50, the marginal benefit is approximately

[22]Lighthouses need not be provided by the government. See Ronald Coase, "The Lighthouse in Economics," *Journal of Law and Economics* 17 (1974): 357–76, for a description of how lighthouses were privately funded in nineteenth-century England.

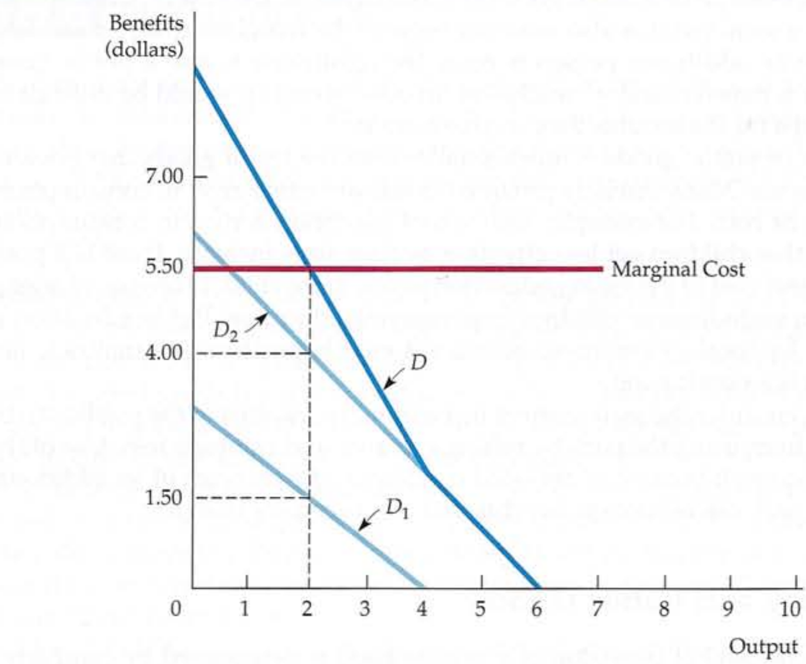


FIGURE 18.13 Efficient Public Good Provision

When a good is nonrival, the social marginal benefit of consumption, given by the demand curve D, is determined by vertically summing the individual demand curves for the good, D_1 and D_2. At the efficient level of output, the demand and the marginal cost curves intersect.

$7.00. Because the marginal benefit is greater than the marginal cost, too little of the good has been provided. Similarly, suppose 3 units of the public good have been produced. Now the marginal benefit of approximately $4.00 is less than the marginal cost of $5.50; too much of the good has been provided. Only when the marginal social benefit is equal to the marginal cost is the public good provided efficiently.[23]

Public Goods and Market Failure

Suppose you want to offer a mosquito abatement program for your community. You know that the program is worth more to the community than the $50,000 it will cost. Can you make a profit by providing the program privately? You would break even if you assessed a $5.00 fee to each of the 10,000 households in your community. But you cannot force them to pay the fee, let alone devise a system in which those households that value mosquito abatement most highly pay the highest fees.

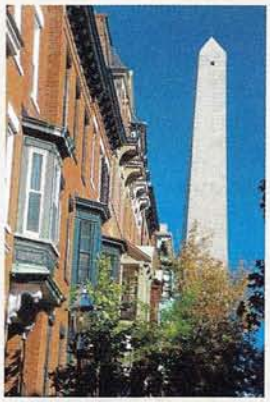
Unfortunately, mosquito abatement is nonexclusive: There is no way to provide the service without benefiting everyone. As a result, households have no incentive to pay what the program really is worth to them. People can act as **free riders**, who understate the value of the program so that they can enjoy the benefit of the good without paying for it.

• **free rider** Consumer or producer who does not pay for a nonexclusive good in the expectation that others will.

[23]We have shown that nonexclusive, nonrival goods are inefficiently provided. A similar argument would apply to nonrival but exclusive goods.

With public goods, the presence of free riders makes it difficult or impossible for markets to provide goods efficiently. Perhaps if few people were involved and the program were relatively inexpensive, all households might agree voluntarily to share costs. However, when many households are involved, voluntary private arrangements are usually ineffective. The public good must therefore be subsidized or provided by governments if it is to be produced efficiently.

EXAMPLE 18.8 The Demand for Clean Air



In Example 4.5 (page 134), we used the demand curve for clean air to calculate the benefits of a cleaner environment. Now let's examine the public-good characteristics of clean air. Many factors, including the weather, driving patterns, and industrial emissions, determine a region's air quality. Any effort to clean up the air will generally improve air quality throughout the region. As a result, clean air is nonexclusive: It is difficult to stop any one person from enjoying it. Clean air is also nonrival: My enjoyment does not inhibit yours.

Because clean air is a public good, there is no market and no observable price at which people are willing to trade clean air for other commodities. Fortunately, we can infer people's willingness to pay for clean air from the housing market—households will pay more for a home located in an area with good air quality than for an otherwise identical home in an area with poor air quality.

Let's look at the estimates of the demand for clean air obtained from a statistical analysis of housing data for the Boston metropolitan area.[24] The analysis correlates housing prices with the quality of air and other characteristics of the houses and their neighborhoods. Figure 18.14 shows three demand curves in which the value put on clean air depends on the level of nitrogen oxides and on income. The horizontal axis measures the level of air pollution in terms of parts per hundred million (pphm) of nitrogen oxide in the air. The vertical axis measures each household's willingness to pay for a one-part-per-hundred-million reduction in the nitrogen oxide level.

The demand curves are upward-sloping because we are measuring pollution rather than clean air on the horizontal axis. As we would expect, the cleaner the air, the lower the willingness to pay for more of the good. These differences in the willingness to pay for clean air vary substantially. In Boston, for example, nitrogen oxide levels ranged from 3 to 9 pphm. A middle-income household would be willing to pay $800 for a 1 pphm reduction in nitrogen oxide levels when the level is 3 pphm, but the figure would jump to $2200 for a 1 pphm reduction when the level is 9 pphm.

Note that higher-income households are willing to pay more than lower-income households to obtain a small improvement in air quality. At low nitrogen oxide levels (3 pphm), the differential between low- and middle-income households is only $200, but it increases to about $700 at high levels (9 pphm).

[24]David Harrison, Jr., and Daniel L. Rubinfeld, "Hedonic Housing Prices and the Demand for Clean Air," *Journal of Environmental Economics and Management* 5 (1978): 81–102.

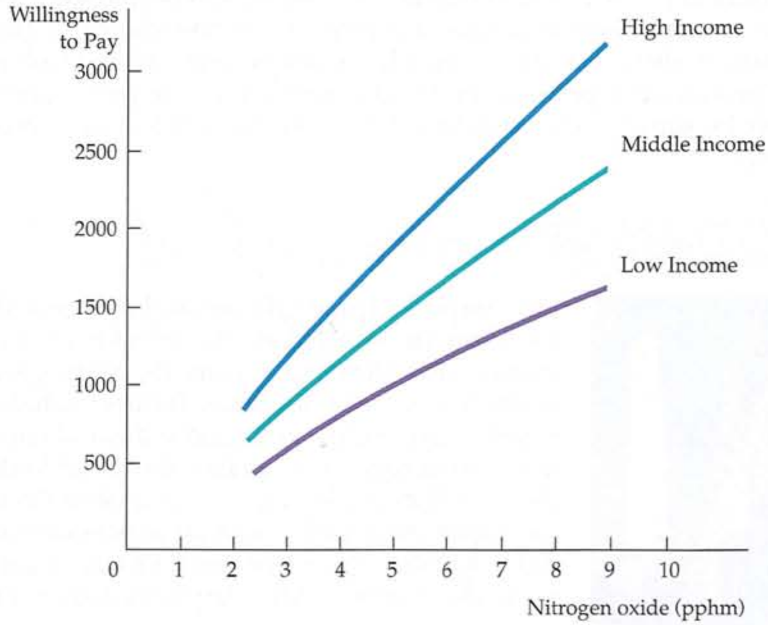


FIGURE 18.14 The Demand for Clean Air

The three curves describe the willingness to pay for clean air (a reduction in the level of nitrogen oxides) for each of three different households (low income, middle income, and high income). In general, higher-income households have greater demands for clean air than lower-income households. Moreover, each household is less willing to pay for clean air as the level of air quality increases.

With quantitative information about the demand for clean air and separate estimates of the costs of improving air quality, we can determine whether the benefits of environmental regulations outweigh the costs. A study by the National Academy of Sciences of regulations on automobile emissions did just this. The study found that controls would lower the level of pollutants, such as nitrogen oxides, by approximately 10 percent. The benefit of this 10-percent improvement to all residents of the United States was calculated to be approximately \$2 billion. The study also estimated that it would cost somewhat less than \$2 billion to install pollution control equipment in automobiles to meet emissions standards. The study concluded, therefore, that the benefits of the regulations did outweigh the costs.

18.7 PRIVATE PREFERENCES FOR PUBLIC GOODS

Government production of a public good is advantageous because the government can assess taxes or fees to pay for it. But how can government determine how *much* of a public good to provide when the free rider problem gives people an incentive to misrepresent their preferences? In this section we discuss one mechanism for determining private preferences for government-produced goods.

Voting is commonly used to decide allocation questions. For example, people vote directly on some local budget issues and elect legislators who vote on others. Many state and local referenda are based on *majority-rule voting*: Each person has one vote, and the candidate or the issue that receives more than 50 percent of the votes wins. Let's see how majority-rule voting determines the provision of public education. Figure 18.15 describes the preferences for spending on education (on a per-pupil basis) of three citizens who are representative of three interest groups in the school district.

Curve W_1 gives the first citizen's willingness to pay for education, minus any required tax payments. The willingness to pay for each spending level is the maximum amount of money the citizen will pay to enjoy that spending level rather than no spending at all.[25] In general, the benefit from increased spending on education increases as spending increases. But the tax payments required to pay for that education increase as well. The willingness-to-pay curve, which represents the net benefit of educational spending, initially slopes upward because the citizen places great value on low spending levels. When spending increases beyond \$600 per pupil, however, the value that the household puts on education increases at a diminishing rate. The net benefit, therefore, actually declines. Eventually, the spending level becomes so great (at \$2400 per pupil) that the citizen is indifferent between this level of spending and no spending at all.

Curve W_2, which represents the second citizen's willingness to pay (net of taxes) is similarly shaped but reaches its maximum at a spending level of \$1200 per pupil. Finally, W_3, the willingness to pay of the third citizen, peaks at \$1800 per pupil.

The dark line labeled AW represents the aggregate willingness to pay for education—the vertical summation of the W_1, W_2, and W_3 curves. The AW

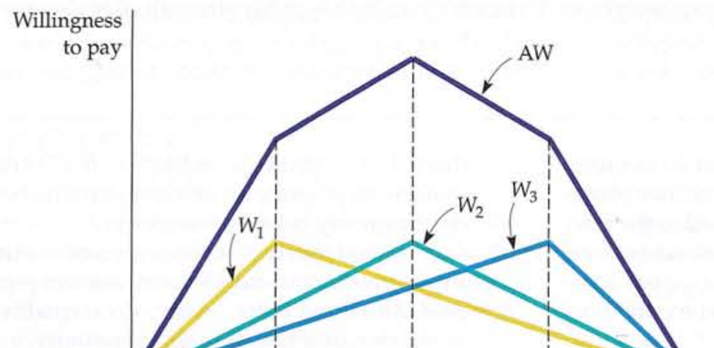


FIGURE 18.15 Determining the Level of Educational Spending

The efficient level of educational spending is determined by summing the willingness to pay for education (net of tax payments) of each of three citizens. Curves W_1, W_2, and W_3 represent their willingness to pay, and curve AW represents the aggregate willingness to pay. The efficient level of spending is \$1200 per pupil. The level of spending actually provided is the level demanded by the median voter. In this particular case, the median voter's preference (given by the peak of the W_2 curve) is also the efficient level.

[25]In other words, the willingness to pay measures the consumer surplus that the citizen enjoys when a particular level of spending is chosen.

curve measures the maximum amount that all three citizens are willing to pay to enjoy each spending level. As Figure 18.15 shows, the aggregate willingness to pay is maximized when $1200 per pupil is spent. Because the AW curve measures the benefit of spending net of the tax payments required to pay for that spending, the maximum point, $1200 per pupil, also represents the efficient level of spending.

Will majority-rule voting achieve the efficient outcome in this case? Suppose the public must vote whether to spend $1200 or $600 per pupil. The first citizen will vote for $600, but the other two citizens will vote for $1200, which will then have been chosen by majority rule. In fact, $1200 per pupil will beat any other alternative in a majority-rule vote. Thus, $1200 represents the most preferred alternative of the *median voter*—the citizen with the median or middle preference. (The first citizen prefers $600 and the third $1800.) *Under majority rule voting, the preferred spending level of the median voter will always win an election against any other alternative.*

But will the preference of the median voter be the efficient level of spending? In this case yes, because $1200 is efficient. But the preference of the median voter is often *not* the efficient spending level. Suppose the third citizen's preferences were the same as the second's. In that case, although the median voter's choice would still be $1200 per pupil, the efficient level of spending would be less than $1200 (because the efficient level involves an average of the preferences of all three citizens). In this case, majority rule would lead to too much spending on education. If we reversed the example so that the first and second citizens' preferences were identical, majority rule would generate too little educational spending.

Thus, although majority-rule voting allows the preferences of the median voter to determine referenda outcomes, these outcomes need not be economically efficient. Majority rule is inefficient because it weighs each citizen's preference equally: The efficient outcome weighs each citizen's vote by his or her strength of preference.

SUMMARY

1. An externality occurs when a producer or a consumer affects the production or consumption activities of others in a manner that is not directly reflected in the market. Externalities cause market inefficiencies because they inhibit the ability of market prices to convey accurate information about how much to produce and how much to buy.
2. Pollution is a common example of an externality that leads to market failure. It can be corrected by emissions standards, emissions fees, marketable emissions permits, or by encouraging recycling. When there is uncertainty about costs and benefits, any one of these mechanisms can be preferable, depending on the shapes of the marginal social cost and marginal benefit curves.
3. Sometimes it is the accumulated stock of a pollutant, rather than current level of emissions, that causes damage. An example of such stock externality is the buildup of greenhouse gases, which may lead to global warming.
4. Inefficiencies due to market failure may be eliminated through private bargaining among the affected parties. According to the Coase theorem, the bargaining solution will be efficient when property rights are clearly specified, when transactions costs are zero, and when there is no strategic behavior. But bargaining is unlikely to generate an efficient outcome because parties frequently behave strategically.
5. Common property resources are not controlled by a single person and can be used without a price being paid. As a result of free usage, an externality is created in which current overuse of the resource harms those who might use it in the future.
6. Goods that private markets are not likely to produce efficiently are either nonrival or nonexclusive. A good is nonrival if for any given level of production, the marginal cost of providing it to an additional consumer is zero. A good is nonexclusive if it is expensive or impossible to exclude people from consuming it. Public goods are both nonrival and nonexclusive.
7. A public good is provided efficiently when the vertical sum of the individual demands for the good is equal to the marginal cost of producing it.
8. Majority-rule voting is one way for citizens to voice their preference for public goods. Under majority rule, the level of spending provided will be that preferred by the median voter. This level need not be the efficient outcome.

QUESTIONS FOR REVIEW

1. Which of the following describes an externality and which does not? Explain the difference.
   a. A policy of restricted coffee exports in Brazil causes the U.S. price of coffee to rise—an increase which in turn also causes the price of tea to rise.
   b. An advertising blimp distracts a motorist who then hits a telephone pole.
2. Compare and contrast the following three mechanisms for treating pollution externalities when the costs and benefits of abatement are uncertain: (a) an emissions fee, (b) an emissions standard, and (c) a system of transferable emissions permits.
3. When do externalities require government intervention? When is such intervention unlikely to be necessary?
4. Consider a market in which a firm has monopoly power. Suppose in addition that the firm produces under the presence of either a positive or a negative externality. Does the externality necessarily lead to a greater misallocation of resources?
5. Externalities arise solely because individuals are unaware of the consequences of their actions. Do you agree or disagree? Explain.
6. To encourage an industry to produce at the socially optimal level, the government should impose a unit tax on output equal to the marginal cost of production. True or false? Explain.
7. George and Stan live next door to each other. George likes to plant flowers in his garden, but every time he does, Stan's dog comes over and digs them up. Stan's dog is causing the damage, so if economic efficiency is to be achieved, it is necessary that Stan pay to put up a fence around his yard to confine the dog. Do you agree or disagree? Explain.
8. An emissions fee is paid to the government, whereas an injurer who is sued and held liable pays damages directly to the party harmed by an externality. What differences in the behavior of victims might you expect to arise under these two arrangements?
9. Why does free access to a common property resource generate an inefficient outcome?
10. Public goods are both nonrival and nonexclusive. Explain each of these terms and show clearly how they differ from each other.
11. A village is located next to 1000 acres of prime grazing land. The village presently owns the land and allows all residents to graze cows freely. Some members of the village council have suggested that the land is being overgrazed. Is this likely to be true? These same members have also suggested that the village should either require grazers to purchase an annual permit or sell off the land to the grazers. Would either of these be a good idea?
12. Public television is funded in part by private donations, even though anyone with a television set can watch for free. Can you explain this phenomenon in light of the free rider problem?
13. Explain why the median voter outcome need not be efficient when majority-rule voting determines the level of public spending.

EXERCISES

1. A number of firms have located in the western portion of a town after single-family residences took up the eastern portion. Each firm produces the same product and in the process emits noxious fumes that adversely affect the residents of the community.
   a. Why is there an externality created by the firms?
   b. Do you think that private bargaining can resolve the problem? Explain.
   c. How might the community determine the efficient level of air quality?
2. A computer programmer lobbies against copyrighting software, arguing that everyone should benefit from innovative programs written for personal computers and that exposure to a wide variety of computer programs will inspire young programmers to create even more innovative programs. Considering the marginal social benefits possibly gained by this proposal, do you agree with this position?
3. Assume that scientific studies provide you with the following information concerning the benefits and costs of sulfur dioxide emissions:

   Benefits of abating (reducing) emissions: $MB = 500 - 20A$

   Costs of abating emissions: $MC = 200 + 5A$

   where A is the quantity abated in millions of tons and the benefits and costs are given in dollars per ton.
   a. What is the socially efficient level of emissions abatement?
   b. What are the marginal benefit and marginal cost of abatement at the socially efficient level of abatement?
   c. What happens to net social benefits (benefits minus costs) if you abate one million more tons than the efficient level? One million fewer?
   d. Why is it socially efficient to set marginal benefits equal to marginal costs rather than abating until total benefits equal total costs?
4. Four firms located at different points on a river dump various quantities of effluent into it. The effluent adversely affects the quality of swimming for homeowners who live downstream. These people can build swimming pools to avoid swimming in the river, and

the firms can purchase filters that eliminate harmful chemicals dumped in the river. As a policy adviser for a regional planning organization, how would you compare and contrast the following options for dealing with the harmful effect of the effluent:
   a. An equal-rate effluent fee on firms located on the river.
   b. An equal standard per firm on the level of effluent that each can dump.
   c. A transferable effluent permit system in which the aggregate level of effluent is fixed and all firms receive identical permits.

5. Medical research has shown the negative health effects of "secondhand" smoke. Recent social trends point to growing intolerance of smoking in public areas. If you are a smoker and you wish to continue smoking despite tougher anti-smoking laws, describe the effect of the following legislative proposals on your behavior. As a result of these programs, do you, the individual smoker, benefit? Does society benefit as a whole?
   a. A bill is proposed that would lower tar and nicotine levels in all cigarettes.
   b. A tax is levied on each pack of cigarettes.
   c. A tax is levied on each pack of cigarettes sold.
   d. Smokers would be required to carry government-issued smoking permits at all times.

6. The market for paper in a particular region in the United States is characterized by the following demand and supply curves:

$$Q_D = 160{,}000 - 2000P \quad \text{and} \quad Q_S = 40{,}000 + 2000P$$

where Q_D is the quantity demanded in 100-pound lots, Q_S is the quantity supplied in 100-pound lots, and P is the price per 100-pound lot. Currently there is no attempt to regulate the dumping of effluent into streams and rivers by the paper mills. As a result, dumping is widespread. The marginal external cost (MEC) associated with the production of paper is given by the curve $\text{MEC} = 0.0006Q_S$.
   a. Calculate the output and price of paper if it is produced under competitive conditions and no attempt is made to monitor or regulate the dumping of effluent.
   b. Determine the socially efficient price and output of paper.
   c. Explain why the answers you calculated in parts (a) and (b) differ.

7. In a market for dry cleaning, the inverse market demand function is given by $P = 100 - Q$ and the (private) marginal cost of production for the aggregation of all dry-cleaning firms is given by $\text{MC} = 10 + Q$. Finally, the pollution generated by the dry cleaning process creates external damages given by the marginal external cost curve $\text{MEC} = Q$.
   a. Calculate the output and price of dry cleaning if it is produced under competitive conditions without regulation.
   b. Determine the socially efficient price and output of dry cleaning.
   c. Determine the tax that would result in a competitive market producing the socially efficient output.
   d. Calculate the output and price of dry cleaning if it is produced under monopolistic conditions without regulation.
   e. Determine the tax that would result in a monopolistic market producing the socially efficient output.
   f. Assuming that no attempt is made to monitor or regulate the pollution, which market structure yields higher social welfare? Discuss.

8. Refer back to Example 18.5 on global warming. Table 18.3 (page 668) shows the annual net benefits from a policy that reduces GHG emissions by 1 percent per year. At what discount rate is the NPV of this policy just equal to zero?

9. A beekeeper lives adjacent to an apple orchard. The orchard owner benefits from the bees because each hive pollinates about one acre of apple trees. The orchard owner pays nothing for this service, however, because the bees come to the orchard without his having to do anything. Because there are not enough bees to pollinate the entire orchard, the orchard owner must complete the pollination by artificial means, at a cost of \$10 per acre of trees.

Beekeeping has a marginal cost $\text{MC} = 10 + 5Q$, where Q is the number of beehives. Each hive yields \$40 worth of honey.
   a. How many beehives will the beekeeper maintain?
   b. Is this the economically efficient number of hives?
   c. What changes would lead to a more efficient operation?

10. There are three groups in a community. Their demand curves for public television in hours of programming, T, are given respectively by

$$W_1 = \$200 - T$$
$$W_2 = \$240 - 2T$$
$$W_3 = \$320 - 2T$$

Suppose public television is a pure public good that can be produced at a constant marginal cost of \$200 per hour.
   a. What is the efficient number of hours of public television?
   b. How much public television would a competitive private market provide?

11. Reconsider the common resource problem given in Example 18.7. Suppose that crawfish popularity continues to increase, and that the demand curve shifts from $C = 0.401 - 0.0064F$ to $C = 0.50 - 0.0064F$. How does this shift in demand affect the actual crawfish catch, the efficient catch, and the social cost of common access? (*Hint:* Use the marginal social cost and private cost curves given in the example.)

12. The Georges Bank, a highly productive fishing area off New England, can be divided into two zones in terms of fish population. Zone 1 has the higher population per square mile but is subject to severe diminishing returns to fishing effort. The daily fish catch (in tons) in Zone 1 is

$$F_1 = 200(X_1) - 2(X_1)^2$$

where X_1 is the number of boats fishing there. Zone 2 has fewer fish per mile but is larger, and diminishing returns are less of a problem. Its daily fish catch is

$$F_2 = 100(X_2) - (X_2)^2$$

where X_2 is the number of boats fishing in Zone 2. The marginal fish catch MFC in each zone can be represented as

$$MFC_1 = 200 - 4(X_1)$$

$$MFC_2 = 100 - 2(X_2)$$

There are 100 boats now licensed by the U.S. government to fish in these two zones. The fish are sold at \$100 per ton. Total cost (capital and operating) per boat is constant at \$1000 per day. Answer the following questions about this situation:

a. If the boats are allowed to fish where they want, with no government restriction, how many will fish in each zone? What will be the gross value of the catch?

b. If the U.S. government can restrict the number and distribution of the boats, how many should be allocated to each zone? What will be the gross value of the catch? Assume the total number of boats remains at 100.

c. If additional fishermen want to buy boats and join the fishing fleet, should a government wishing to maximize the net value of the catch grant them licenses? Why or why not?