7 PIGOVIAN FEES

In the past few chapters we explored the reasons that markets cannot be relied on to provide the right amount of pollution—markets fail when it comes to public bads. Normally, consumer preferences are communicated to producers through the price system. The basic problem in the case of pollution is that without a price system, polluters do not "see" the damage caused by the pollution they emit. In the last chapter, we explored how liability and negotiation could solve the problem. We now consider the alternate approach of the government intervening and sending a signal to polluters—the government prices pollution. Since pollution is a bad, the price is negative. In other words, polluters pay a price for every unit of pollution they generate. This corrects the market failure, at least in theory.

I. PIGOVIAN FEES: SINGLE POLLUTER

Early in the twentieth century the English economist Arthur C. Pigou argued for the imposition of taxes on generators of pollution.[1] Since the social cost of pollution is in excess of the private cost to the polluter (actually, polluters have a negative cost since they save money by polluting), the government should intervene with a tax, making pollution more costly to the polluter. If the pollution is more costly to produce, the polluter will produce less pollution. This tax has come to be called a Pigovian fee or Pigovian tax.

Suppose we have a factory generating pollution in the amount x and goods output in the amount y. Production costs for the factory depend on x and y (as well as input prices) and can be written $C(x,y)$, assuming input prices are constant. For the most part, we can also assume y will be produced where the marginal cost of production of goods is equal to the price of goods. For that reason, and to keep things simple, we will suppress writing y as a determinant of costs. This does not always simplify things, as is demonstrated in Problem 5 at the end of the chapter. The elimination of y and the suppression of input prices results in costs which depend on x only, $C(x)$, with marginal costs $MC(x)$—the additional costs from producing one more unit of pollution, x. Since costs decline as x is increased, marginal costs are actually negative. Another way of thinking about this is in terms of marginal savings—the savings from emitting one more unit of pollution. Of course the marginal savings is the negative of the marginal costs: $MS(x) = -MC(x)$.

Further assume there are N people surrounding the factory and that pollution causes damage. For the time being, assume that people cannot use locational choice to change the amount of pollution they face. Thus there is nothing a person can do to reduce his or her exposure, short of getting the factory to cut back. For person i, the damage from pollution is $D_i(x)$, which is positive and increases in x. There are several other ways of interpreting this damage. We could also say that person i benefits from the pollution in the amount $B_i(x)$ with benefits negative and decreasing in x. Or, we could say that $D_i(x)$ is the willingness to pay to eliminate the pollution. Total damages are given by

$$D(x) = \Sigma_i D_i(x) \tag{7.1}$$

The right amount of pollution is the amount that minimizes total costs and damages:

$$x^* \text{ minimizes } \{C(x) + D(x)\} \tag{7.2a}$$

We know that something is minimized when its marginal is zero. Further, the marginal of a sum is equal to the sum of the marginals. Thus we can set the marginal of the quantity in braces in Eq. (7.2a) to zero:

$$MC(x^*) + MD(x^*) = 0 \tag{7.2b}$$

Substituting the marginal version of Eq. (7.1) into Eq. (7.2b) and recognizing that marginal savings is the negative of marginal cost, we obtain

$$MS(x^*) = \Sigma_i MD_i(x^*) \tag{7.2c}$$

In other words, we seek a level of pollution such that the marginal savings to the firm from pollution ($-MC$) is equal to the marginal damage from pollution over the entire population. Since pollution is a public bad, the aggregate marginal damage (MD) is the vertical sum of the individual marginal damages (MD_i).

A. The Fee Level

We have seen that a market will not spontaneously emerge to supply the right amount of pollution. If it did, each individual would receive compensation equal to $MD_i(x^*)$ per unit of pollution (Lindahl prices) and the firm would pay $MS(x^*)$ per unit of pollution. This would induce the firm to generate the correct amount of pollution. Budgets would balance because of the relationship in Eq. (7.2b). Suppose the firm paid $-MC(x^*)$ per unit of pollution but paid it to the government instead of to the consumers of the pollution. This would result in the correct amount of pollution being generated and, since consumers cannot affect their exposure, the fact that they are not compensated is irrelevant for efficiency. This is the concept of a Pigovian fee.

Definition *A Pigovian fee is a fee paid by the polluter per unit of pollution exactly equal to the aggregate marginal damage caused by the pollution when evaluated at the efficient level of pollution. The fee is generally paid to the government.*

This situation is illustrated in Figure 7.1 for the case of one polluter and two victims of the pollution. Shown in the lower half of the figure is the marginal cost of pollution. Note that this is negative since every extra unit of pollution the factory is allowed to emit lowers total costs for the factory (up to a limit of course). The marginal savings to the factory is the negative of this and is shown in the first (upper) quadrant. As the factory increases pollution from no emissions at all, savings are initially quite high. When emissions are relatively large, the savings from emitting a little more are much smaller. Thus $MS(x)$ is downward sloping.

Also shown in Figure 7.1 are the marginal damage functions for the two victims of the pollution: $MD_i(x)$. Marginal damage is the negative of the demand function for pollution for each of the individuals. Each of the marginal damage schedules is upward sloping. When pollution levels are small, one more unit of pollution causes little damage. When pollution levels are higher, that extra unit causes more damage. Since the pollution is a public bad, aggregate marginal damage, like aggregate demand, is the vertical sum of individual marginal damages. This is also shown in the figure [$MD(x)$]. The optimal amount of pollution is the x for which $MD(x) = MS(x)$, shown as x^* in Figure 7.1. Also shown in Figure 7.1 is the Pigovian fee, p^*. If the polluter is charged p^* per unit of pollution, the polluter basically sees pollution as priced at p^*. Thinking of pollution as an output of the firm, the firm receives $-p^*$ of revenue for each unit of pollution it generates. We know that the firm will produce so that price equals marginal cost:

$$MC(x^*) = -p^* \quad \text{or} \quad MS(x^*) = p^* \tag{7.3}$$

The total amount of money the firm pays for the pollution is p^*x^*.

Another way of viewing this problem is that without the Pigovian fee and without any other markets or regulations to restrict pollution, the firm basically sees a price of zero for pollution. It is optimal (from the firm's point of view) for the firm to respond to a zero price by producing where marginal cost is zero, $\hat{x}$ (see Figure 7.1). To reduce pollution generation, we must increase the cost of pollution by raising the fee. As the fee is

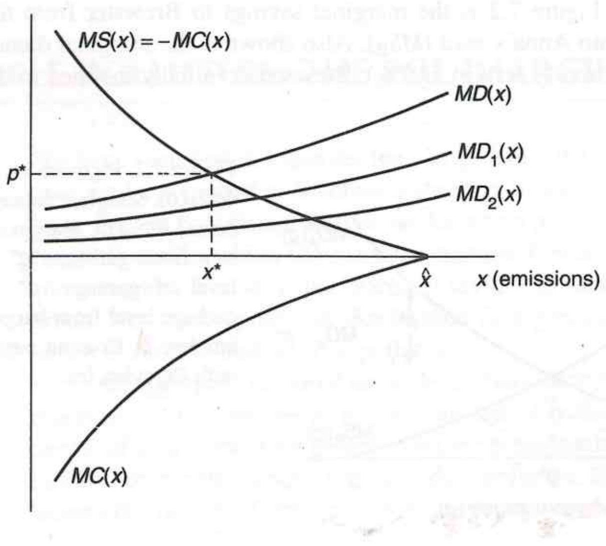

Figure 7.1 Optimal Pigovian fee on pollutant emissions with two victims of pollution. $MD_1(x)$, Marginal damage to victim 1; $MD_2(x)$, marginal damage to victim 2; $MD(x)$, aggregate marginal damage; $MC(x)$, marginal cost of emitting for the polluter; $MS(x)$, marginal savings from emitting for the polluter; $\hat{x}$, pollution levels with no regulation; x^*, efficient amount of emissions; p^*, Pigovian fee.

raised from zero, pollution generation gradually declines until we reach x^* when the fee rises to p^*.

Note that the Pigovian fee is defined as the marginal savings from pollution generation *at the optimal level of pollution*. If we are not at the optimum, the Pigovian fee will be neither the current marginal cost of pollution control nor the marginal damage from pollution. Thus the Pigovian fee is not any emission fee; it is the marginal savings from pollution at the optimal pollution level.

B. Should Victims be Compensated?

One feature of the Pigovian fee is that it is paid to the government and the government keeps it. It is not necessary to pay it out as compensation to the victims of the pollution, although it is not undesirable to do so. Why? Remember that the only thing that matters for efficiency is that the actions of consumers and producers be correct. How much is paid is irrelevant except to the extent that it induces optimal behavior. Since consumers can do nothing to influence how much pollution they are exposed to, payment of compensation will not change their behavior vis-à-vis pollution. Such payment would be only an income transfer. On the other hand, if consumers can change their location, we saw in Chapter 5 that consumers should not be compensated. If they are, they will tend to move toward the pollution. In this case payment of compensation is worse than neutral—it reduces efficiency. Thus in either case, as long as we are dealing with a public bad, the Pigovian fee should be levied and collected but need not be paid out to victims.

The astute reader may ask the following: If the Coase Theorem fixes the problem of externalities, why do we need Pigovian fees? Further, won't Pigovian fees exacerbate the problem if the Coase Theorem is also operating?

Consider the case of Anna and Brewster, who this time are neighbors. Brewster generates a lot of garbage and Anna does not. To start with, we have no property rights, so Brewster gets rid of his excess garbage by tossing it over the fence into his neighbor's yard. This situation is represented graphically in Figure 7.2.

Shown in Figure 7.2 is the marginal savings to Brewster from throwing garbage over the fence into Anna's yard (MS_B). Also shown is the marginal damage Anna suffers from this unneighborly activity (MD_A). Brewster is initially inclined to dump $\hat{g}$, the point

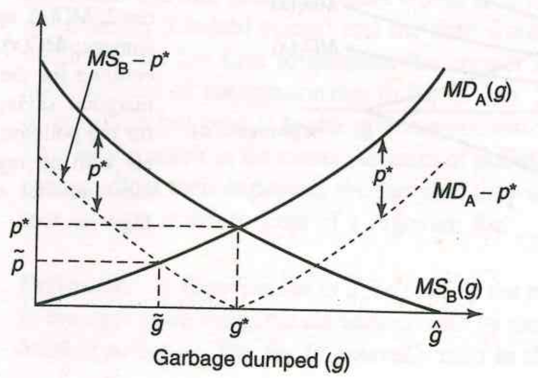

Figure 7.2 Pigovian vs. Coasian solutions. $MD_A(g)$, Marginal damage from garbage to Anna; $MS_B(g)$, marginal savings to Brewster from garbage; g^*, socially efficient level of garbage; p^*, Pigovian fee; $\tilde{g}$, garbage level from bargaining with Pigovian fee; $\tilde{p}$, Coasian payment to Brewster, with Pigovian fee.

8 REGULATING POLLUTION

In previous chapters, we discussed the virtues of markets for allocating goods and services but also the problems markets have in allocating environmental goods, particularly pollution. In the last chapter, we took a first step toward correcting the market failure associated with pollution by introducing the concept of a Pigovian fee, which generally works to correct the efficiency problems associated with pollution. But a Pigovian fee does not spontaneously emerge as markets do for conventional goods. It needs a central authority—a government—to implement the fee.

In this chapter we introduce the government as an active player in solving the problems associated with pollution. In some cases, the government will play a modest role, simply laying down the ground rules for a quasimarket to operate to solve the pollution problem. In other cases, the government will play a much more visible role, directing specific polluters as to what emissions are allowed. Although governments can solve problems that decentralized markets cannot, governments can also fail. Government failure is not a focus here, but we should be aware that government intervention to cure market failure is not always successful.[1] Some ways of intervening to solve pollution problems are better than others.

I. RATIONALE FOR REGULATION

The theory of economic regulation goes far beyond the issues of concern in environmental regulation. In fact, environmental regulation is a special, and relatively recent, example of economic regulation. For that reason, it is appropriate to place it in a larger context.

Economic regulation involves the government intervening, in a variety of ways, in the private actions of firms and individuals. There are two basic theories of regulation, the public interest theory and the interest group theory.[2] The public interest theory of regulation views the purpose of regulation as the promotion of the public interest. In this context there are three general reasons why regulation might exist: imperfect competition, imperfect information, and externalities. The interest group theory of regulation views the purpose of regulation as promoting the narrow interests of particular groups in society, such as individual industries.[3] We consider these in turn.

To a certain extent, the public interest theory of regulation is a normative theory. Recall that normative theory seeks to explain what should happen in an ideal world. In contrast, the interest group theory is a positive theory, attempting to explain why the world works as it does.

Imperfect competition, particularly natural monopoly, is the traditional normative justification for government regulation.[4] In the case of natural monopoly (such as an electricity distribution company), economic efficiency calls for a single firm. It is not a good idea to have multiple sets of poles and wires traveling down streets, connecting residences to sources of power.[5] The role of government is to guarantee a monopoly to a particular firm (restrict the entry of new firms) and, in addition, to control prices in order to protect consumers from monopoly pricing.

A related role of government is to prevent undue concentration of power in markets in which multiple competing firms represent the best organizational structure. In this case, the government attempts to prevent collusion and restricts mergers that will create excessive market power. The array of U.S. antitrust laws, starting with the Sherman Act of 1890, is designed to preserve a competitive environment in the United States, outlawing practices that are deemed anticompetitive. Many other countries have a more laissez-faire attitude toward anticompetitive activities, since such activities often serve to bolster domestic industries in the international marketplace.

The second major rationale for government regulation is the case of imperfect information. Acquiring information is costly. As a consequence, when consumers are about to enter into a transaction, they may not always have complete information on items such as product quality. Furthermore, because of the cost of acquiring information, it may not even be desirable for consumers to acquire complete information—the costs may far exceed the benefits. Imagine that each time we entered a grocery store we had to conduct extensive tests on the safety of each food item. This is a justification for the government to step in to compensate for incomplete information.[6] The role may be a relatively "hands-off" type of intervention such as establishing a set of liability rules to encourage the provision of safety-related quality. If problems occur in consuming a product, a firm can be held liable. Properly designed, such liability rules can induce firms to provide an efficient level of safety-related quality. Of course, government can also more directly intervene in the market, specifying acceptable levels of quality, such as is generally the case with regulations on food additives.

A third rationale for government regulation is in the area of the provision of public goods and bads. Public bads and externalities are of course our focus. As we know from earlier chapters, when there are elements of "publicness" (nonrivalry or nonexcludability), private markets are inefficient. Government intervenes to try to correct the problem. Government may step in to directly provide these goods or bads at efficient levels, effectively eliminating the private market. This is frequently the case with public goods (e.g., national defense) and rarely the case with public bads. In the case of public bads, the usual approach is for government to define a set of institutions and regulations to govern the provision of these public bads, e.g., the government establishes a set of regulations to restrict the production of pollution.

The interest group theory of regulation maintains that rent seeking is the primary rationale for regulation.[7] As will become clear, rent seeking is less a justification for regulation than an explanation of why some regulations exist—a positive theory of regulation. What is meant by rent seeking? Rent seeking involves private individuals or firms using the government to guarantee extra profits (rents) through government-mandated restrictions on economic activity. For instance, U.S. requirements that a certain fraction of clean-fuel gasoline additives be from renewable sources is fundamentally a subsidy to producers of ethanol in the midwest United States (the requirement is largely unrelated to air quality). Groups that benefit from such regulation lobby government for regulations that provide them with rents that would not exist in a competitive market.

II. A POLITICAL ECONOMY MODEL OF REGULATION

The basic problem of environmental regulation involves the government trying to induce a polluter to take socially desirable actions, which ostensibly are not in the best interest of the polluter. But the government may not always be able to precisely control the polluter. To further complicate matters, the government faces a complex problem of determining exactly what level of pollution is best for society. In reality, the government faces pressures from consumers and polluters. Although a full development of this interaction is beyond the scope of this discussion, Figure 8.1 captures some of this complexity. Shown in Figure 8.1 is a highly stylized schematic of the interactions among government, polluting firms, and consumer citizens.

The government is shown in Figure 8.1 as consisting of three branches, the legislature, the judiciary, and the regulators. Although the nomenclature may vary from country to country, this is a reasonably general representation of basic government. In the United States, the legislature would be Congress, the regulators would be the EPA, and the judiciary would be the Federal courts. In the United Kingdom, Parliament would be the legislature. The regulator would be the Department of Environment, Transport and the Regions, although other branches of national and local government also oversee pollution control (as in the United States). The courts and the House of Lords would be the equivalent of the judiciary, though the regulatory process tends to be less litigious in the EU than in the United States. The legislature passes laws defining what the regulators are to do in controlling pollution. The regulators are charged with the detailed implementation of the legislature's laws. The regulator's actions are tempered by the judiciary. Note that the legislature may have difficulty achieving its goals since it does not directly influence the polluter but must act through another part of government. This other part of government—the regulator—may have different goals. For instance, regulators may be interested in job security or the size of the bureaucracy they control as well as in reducing pollution levels. Furthermore, the judiciary may temper the actions of the regulators.

The firm, as shown in Figure 8.1, consists of several pieces. The Board of Directors is the core of the firm, although it is subject to oversight by the owners—the stock and bond holders. The Board issues directives to the managers; the managers issue directives to employees who produce the product of the firm as well as pollution. The key point is that regulators direct the Board to take certain actions, but the Board is removed,

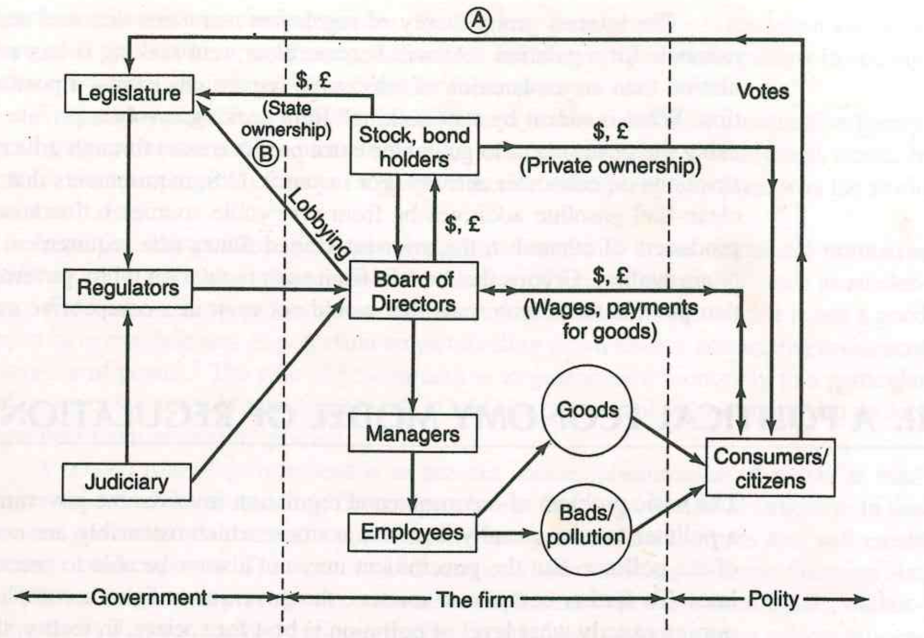

Figure 8.1 Schematic of interactions among government, polluting firms, and consumer citizens.

by several steps, from the employees who actually generate the pollution. Furthermore, the Board has other objectives in addition to pleasing the regulators (such as pleasing the stockholders). Generally, this is termed the principal-agent problem because of the inability of the EPA (the principal) to completely control the polluter (the agent). Note that the firm may not be a passive entity but may in fact influence legislation, through lobbying or financial incentives. These are shown as line B in Figure 8.1.

Finally, it is the consumers who consume the goods produced by the firm as well as the pollution generated by the firm. Consumers in turn are the citizenry whom the legislature is supposedly serving. Thus consumers direct votes and other influence to the legislature (line A), while at the same time sending money to the firm in exchange for the goods consumed.

There is obviously much detail missing from Figure 8.1. We could have employees or stockholders lobbying the legislature, for example, or firms lobbying the citizenry through advertising. Nevertheless, the essence of the process is represented in Figure 8.1.

There are really two important lessons that should be taken from Figure 8.1. The first is that there are many imperfect links between the legislature and the pollution-generating process. Since the legislature cannot physically control pollution directly, it must rely on indirect means to obtain its ends, and often these indirect means may be less than perfect. Regulation may be excessively costly, may result in considerable cheating, may result in excessive time delays, and may result in too much pollution.

The second point to take from Figure 8.1 is that the legislature does not necessarily act as an efficient benevolent maximizer of social well-being. Although we may think it is "best" if the legislature is influenced only by citizen welfare, as represented by line

A in Figure 8.1, the legislature will likely be influenced by other interests, such as the well-being of the polluter, as reflected in line B. This is the distinction between normative theory, what *should* happen (perhaps maximizing citizen welfare with some concern for equity), and positive theory, what *will* happen (a balancing of interests, some "legitimate," some not). This distinction is important. Sometimes we are trying to design a best regulation, in which case we want to know what *should* happen. In other cases, we are trying to understand why a certain regulation is on the books, in which case we should be interested in what *will* happen or why something has happened. Often the inclusion of line B is termed regulation with *endogenous* politics; the omission of line B is termed regulation with *exogenous* politics.

We can also view exogenous politics as coinciding with the public interest theory of regulation. Though it may be quite difficult to induce the firm to do the right thing, the fundamental objective of the regulatory agency is to maximize social welfare (however defined), subject to the regulatory constraints it faces. Typically, the objective of the regulator is viewed as maximizing the sum of producer and consumer surplus, perhaps with a slight bias toward consumer surplus.

The positive interest group theory mentioned earlier is consistent with the endogenous politics model of regulation. With endogenous politics, we are conscious of the ability of interest groups (boxes in Figure 8.1) to influence the regulators, legislators, and perhaps the judiciary. Environmental regulation is particularly susceptible to interest group influence. One interest group is clearly the firms potentially subject to environmental regulation—the polluters, or "browns." Another interest group, however, is the "greens," or environmental interest groups. Understanding how the browns and greens interact with the legislature and regulatory agencies can explain why we see the environmental regulations we do.

III. BASIC REGULATORY INSTRUMENTS

Having just discussed the prevalence of conflicting incentives and private information, this is an appropriate time to introduce the two major types of environmental regulation: economic incentives and command and control.

A. Command and Control

Command-and-control regulation is the dominant form of environmental regulation in the world today. Although it can take many forms, the basic concept of command and control is for the regulator to specify the steps individual polluters must take to solve a pollution problem. The essence of command and control is that the regulator collects the information necessary to decide the physical actions to control pollution; the regulator then commands the polluter to take specific physical steps to control the pollution. The regulator is generally quite specific as to what steps must be taken.

Command-and-control regulations can take many forms. One way of conveying the nature of command and control is by example. For instance, the Clean Air Act in the

United States requires the EPA to determine the minimum pollution control "performance" of new sources of pollution. The EPA is required to specify for each new category of source (e.g., new power plants or new tire factories) what pollution controls and emission rates are deemed acceptable. This means that the EPA must investigate the production process for literally every type of plant or factory in the United States, at least if significant pollution is involved. For instance, in tire manufacture, the EPA has hired engineers to examine the process of tire manufacture, generating a "Control Technology Guideline," which indicates what kinds of pollution control are appropriate for new tire manufacturing plants. In industries that apply surface coatings (e.g., furniture manufacture), regulations may impose limits on the types of coatings that may be used or firms may be required to use a certain type of vent system to recapture vapors that are emitted during painting. Furthermore, products may be banned altogether as is the case with many oil-based paints in urban areas of the United States most severely affected by photochemical smog. Power plants (producing electricity) may be required to use certain technologies to reduce emissions of sulfur dioxide. At one time in the United States, flue-gas desulfurization was required on all new coal-fired power plants, regardless of the uncontrolled emission rate of the plant.

Command-and-control regulations take many specific forms. Specific pollution-control equipment requirements can be specified as in the above example. Alternatively, the regulation may specify an emission limit for particular types of plants and particular pollutants. An example might be the U.S. standards for new automobiles: every new car may emit no more than x grams of carbon monoxide per mile driven.[8] Furthermore, all new cars are required to have a specifically defined system for capturing vapor that might escape from the gasoline tank during refueling. (In the case of automobiles, a major factor that bears on pollution is how much the car is used. There are virtually no regulations in the United States addressing distance driven except for modest taxes on gasoline.) In the case of power plants, fuel quality may be limited (e.g., sulfur content cannot exceed 1%) or emissions per unit of fuel use may be limited (e.g., no more that 1.2 pounds of sulfur dioxide may be emitted per million Btu of fuel used).

Command and control may in fact be combined with significant fines and penalties associated with noncompliance. Such incentives to comply with a command-and-control regulation should not be confused with an economic incentive to abate pollution. Though command and control may take many forms, there are two key features that distinguish command and control from economic incentives: (1) restricted choice for the polluter as to what means will be used to achieve an appropriate environmental target; and (2) a lack of mechanisms for equalizing marginal control costs among several different polluters. For example, if a polluter is told by a regulator that it must use a particular type of equipment, the polluter has little choice in determining emissions. If there is a cheaper way to attain the same level of emissions, such cost savings cannot be pursued. Some command-and-control regulations may afford some discretion to the polluter. Polluters may, for instance, be told that they can emit up to a certain amount per unit of goods output (e.g., grams of SO_2 per kwh sold). This gives more discretion to the polluter, although the polluter is not free to adjust emissions among sources that have different pollution control costs. The one thing that characterizes all command-and-control regulation is a centralization of some of the pollution control decisions that could be made by the polluter.

The best analogy for command and control is the system of central planning that

existed in the former Soviet Union to manage its economy. Rather than let prices signal relative scarcity and thus direct goods around the economy, nearly all decisions on production, investment, and even interplant trade were made centrally, by central planners. In theory this can work as well as any system. The problem is that the informational requirements are enormous. In actuality, planners operate with very incomplete information, which leads to serious inefficiencies. Despite these problems, this is more or less how pollution generation is managed in most countries. Although this approach to running an economy proved too burdensome for the Soviet Union, environmental regulation in most market economies is unlikely to have such a dramatic effect since pollution control is only a modest part of modern economies. On the other hand, one might expect it to be possible to significantly improve on the current system.

What are the pros and cons of command and control? Command-and-control regulations have one major advantage: more flexibility in regulating complex environmental processes and thus much greater certainty in how much pollution will result from regulations. In an urban area with factories at different locations contributing differently to overall levels of urban pollution, it can be difficult to fashion a workable set of emission taxes or other incentives to ensure a certain level of pollution. Furthermore, in an atmosphere of uncertainty, where it is unclear how a polluter might respond to an economic incentive, command and control gives greater certainty on how much pollution will actually be emitted.[9] Another advantage of command and control is in simplifying monitoring of compliance with a regulation. If a regulation states that a particular piece of pollution control equipment must be used, monitoring simply involves seeing whether that equipment has been installed. This is easier than measuring pollution emissions.

There are of course disadvantages to command and control. Because the informational costs are high for command and control, such a regulatory system can be very costly to administer. Each plant, or at least each industry, must be analyzed in detail to determine the appropriate level of emission control. This is very costly, not to mention fraught with errors. There is also the potential for fundamental information problems. The regulator often needs to rely on information from the polluter, either in terms of emissions or costs of control. Because of this, the polluter has an incentive to distort information provided to the regulator. (Though this problem often applies to other forms of regulation as well.)

A very significant problem with command and control is reduced incentives to find better ways to control pollution. This may be purely a static issue, finding process changes or other means to reduce pollution. Or it might involve investing in research into better ways of controlling pollution. In either case, many types of command and control provide weak incentives for innovation (see Jaffe and Stavins, 1995).

Perhaps one of the biggest problems with command and control is difficulty in satisfying the equimarginal principle. It is almost impossible for command-and-control regulations to ensure that the marginal costs of pollution control are equalized among different polluters generating the same pollution. This could occur only if regulators are completely correct in their assessment of each firm's control costs. If the marginal costs of pollution are not equalized, costs of pollution control will be unnecessarily high.

This failure of the equimarginal principle is illustrated in Table 8.1, which shows the marginal cost of controlling biological oxygen demand (BOD), a measure of water pollution in rivers and lakes. Table 8.1 is drawn from an analysis (Magat et al., 1986) of

TABLE 8.1 Marginal Treatment Costs of BOD Removal, U.S. Regulations

Industry	Subcategory	Marginal cost[a]
Poultry	Duck—small plants	3.15
Meat packing	Simple slaughterhouse	2.19
	Low processing packinghouse	1.65
Cane sugar	Crystalline refining	1.40
Leather tanning	Hair previously removed/chromium	1.40
Poultry	Duck—large plants	1.04
Leather	Save hair/vegetable	1.02
	Hair previously removed	1.02
Meat packing	High processing packinghouse	0.92
	Complex slaughterhouse	0.90
Paper	Unbleached kraft	0.86
Leather tanning	Save hair/chromium	0.75
	Pulp hair/chromium	0.63
Poultry	Turkey	0.60
Cane sugar	Liquid refining	0.51
Paper	Paperboard	0.50
	Kraft—NSSC	0.42
Leather	Pulp or save hair/no finish	0.39
Poultry	Further processing only—large plants	0.35
	Chicken—small plants	0.25
Paper	NSSC—ammonia process	0.22
Raw sugar processing	Louisiana	0.21
Poultry	Fowl—small plants	0.20
	Chicken—medium plants	0.16
Raw sugar processing	Puerto Rico	0.16
Paper	NSSC—sodium process	0.12
Poultry	Fowl—large plants	0.10
	Chicken—large plants	0.10

[a]*Units: U.S. dollars per kilogram of BOD removed.*
Source: Magat et al. (1986), p. 136.

how the USEPA translates legislative mandates regarding water quality into regulations to apply to individual firms. Clearly, the equimarginal principle is violated. It would be much more cost effective, without hurting the environment, to relax regulations on some of the high cost industries and tighten regulations on some of the lower cost industries.[10]

As another example, Table 8.2 is a listing of a number of U.S. command-and-control regulations that are designed to protect health and save lives. Interpreting lives saved as the only goal of the regulation, the equimarginal principle also fails to hold. Some regulations save lives at very low cost, whereas some are extremely costly (e.g., formaldehyde in the workplace, at $72 billion per life saved).

A final problem is that with command-and-control, the polluter pays only for pollution control, not residual damage from the pollution that is still emitted even after controls are in place. This effectively provides a subsidy to the polluter, which may create a variety of distortions. As an example of this consider paper manufacture with pulp (the raw material) either coming from recycled paper (assumed pollution free) or virgin wood

TABLE 8.2 Average Cost of US Regulations to Reduce Risk of Death

Regulation	Initial annual risk	Expected annual lives saved	Cost per expected life saved (millions of 1984 $)
Unvented space heaters	2.7 in 10^5	63.000	0.10
Airplane cabin fire protection	6.5 in 10^8	15.000	0.20
Auto passive restraints/belts	9.1 in 10^5	1,850.000	0.30
Underground construction	1.6 in 10^3	8.100	0.30
Servicing wheel rims	1.4 in 10^5	2.300	0.50
Aircraft seat cushion flammability	1.6 in 10^7	37.000	0.60
Aircraft floor emergency lighting	2.2 in 10^8	5.000	0.70
Crane suspended personnel platform	1.8 in 10^3	5.000	1.20
Concrete and masonry construction	1.4 in 10^5	6.500	1.40
Benzene/fugitive emissions	2.1 in 10^5	0.310	2.80
Grain dust	2.1 in 10^4	4.000	5.30
Radionuclides/uranium mines	1.4 in 10^4	1.100	6.90
Benzene in workplace	8.8 in 10^4	3.800	17.10
Ethylene oxide in workplace	4.4 in 10^5	2.800	25.60
Arsenic/copper smelter	9.0 in 10^4	0.060	26.50
Uranium mill tailings, active	4.3 in 10^4	2.100	53.00
Asbestos in workplace	6.7 in 10^5	74.700	89.30
Arsenic/glass manufacturing	3.8 in 10^5	0.250	142.00
Radionuclides/DOE facilities	4.3 in 10^6	0.001	210.00
Benzene/ethylbenzenol styrene	2.0 in 10^6	0.006	483.00
Formaldehyde in workplace	6.8 in 10^7	0.010	72,000.00

Source: Viscusi (1996), pp. 124–125.

(with associated pollution). Efficiently regulating the manufacture of virgin wood pulp involves seeing that the proper pollution control is achieved and that the damage from any remaining pollution is included in the price of pulp. This way the price of pulp reflects pollution control costs and residual damage. However, if command-and-control regulations require only pollution control and not the payment of residual damage, the resulting price of virgin pulp will be lower. Why is this undesirable? It is easy to see that with a lower price of virgin pulp, paper manufacturers are more likely to choose virgin pulp over recycled pulp, because it is cheaper. As a result, there will be more pollution than is efficient.

B. Economic Incentives

Economic incentives, in contrast to command-and-control regulation, provide rewards for polluters to do what is perceived to be in the public interest. We are all familiar with incentives. Instead of closely monitoring a child's homework activity, a parent may provide a substantial reward for good grades (or a disincentive for bad grades). The idea is to align public and private incentives. In the context of pollution, there are three basic types of economic incentives: fees, marketable permits, and liability.

Pollution fees involve the payment of a charge per unit of pollution emitted. If the fee is at the right level, this would be an example of a Pigovian fee. When a polluter must pay for every unit of pollution emitted, it becomes in the polluter's interest to reduce emissions.

A marketable permit allows polluters to buy and sell the right to pollute. Thus what starts as something akin to command and control (a permit to pollute) turns into an economic incentive by allowing trading. Trading induces a price or value on a permit to pollute, thus causing firms to see polluting as an expensive activity; less pollution means fewer permits need be bought. There is an opportunity cost of emitting; by not emitting, the firm can sell more permits.

This is illustrated in Figure 8.2, which corresponds to the situation in which there are two polluters. We are interested in allowing 100 units of pollution in total. We start by giving each firm 50 permits. The marginal savings from polluting functions are shown in Figure 8.2 for the two firms. They have been drawn so that any point along the horizontal axis gives the number of permits each firm holds: read from the left for firm 1 and from the right for firm 2. Note that trading will occur until firm 1 holds e^* and firm 2 holds $100 - e^*$. The equilibrium price of a permit is p^*.

It is important to note that an emission fee of p^* would achieve exactly the same outcome. Suppose there is a little uncertainty. With an emission fee, we know precisely what the marginal cost of control will be; we are less sure about the quantity of pollution. With a marketable permit, we know exactly how much pollution there will be; we are less sure of the marginal cost of control.

Liability is a third type of economic incentive. The basic idea is that if you harm someone, you must compensate that person for damage. In theory, this means that when you undertake a risky activity (such as polluting or storing hazardous wastes), you will take all potential damage from your activity into account when deciding how carefully to perform your activity. The important issue is that the government is not telling you what to do, just that you will be responsible for any consequences. This creates an incentive to be careful when undertaking risky activity and, in fact, to take the socially desirable amount of precaution in undertaking such risky activity.

To illustrate liability, suppose we have a hazardous waste storage facility (a "dump"). The dump can do things to minimize the risk of hazardous wastes leaking into the envi-

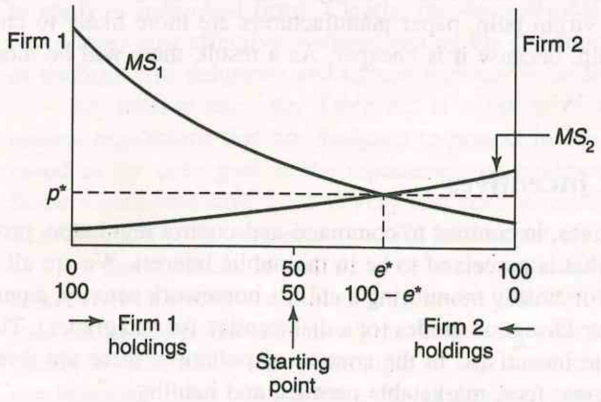

Figure 8.2 Marginal savings from polluting functions for two firms. MS_1, Marginal savings from emitting, firm 1; MS_2, marginal savings from emitting, firm 2; e^*, equilibrium holding of permits; p^*, equilibrium price of permits.

ronment. We can lump all of those risk-reducing activities into one term, "precaution." If the dump takes a great deal of precaution, the risk of a leak will be low. If the dump takes little precaution, the risk will be high. Precaution is of course expensive for the dump to undertake. All other things being equal, the dump would prefer to take little precaution. Damage to society also depends on the level of precaution. This is illustrated in Figure 8.3, which shows both costs to the dump and damage to society as functions of the level of precaution. There is some socially desirable level of precaution, x^*, at which the marginal costs of taking more precaution are just offset by the reduction in marginal damage from taking more precaution. Liability works by saying to the dump: "Do whatever you wish but should an accident occur, we will find the socially desirable level of precaution; if you were not taking that level of precaution, you will be responsible for all of the environmental damage from the accident." This is how negligence liability works, although other types of liability work in a similar fashion. This threat of being held responsible for accident damages is often a sufficient incentive for firms to take the socially desirable amount of precaution.

One of the dominant questions in environmental economics and regulation over the past three decades is why command and control dominates environmental regulation worldwide when most economists believe economic incentives are much better.

Clearly, economic incentives have a number of advantages over command and control. First, informational requirements are less significant. It is not necessary to know what it going on within a firm to use an emission fee. Furthermore, economic incentives will provide an incentive for a polluter to innovate, finding cheaper ways of controlling pollution.[11] Also, in contrast to command and control, economic incentives involve the polluter paying for control costs as well as pollution damage. Thus there is no implicit subsidy to the industry. As we will see, the fee payments approximate the damage associated with the pollution. Consequently the cost (and thus the price) of the product manufactured in association with pollution will reflect control costs as well as residual pollution damage. In the previous section, in the example of paper manufacture, we saw the importance of reflecting environmental damage in product price, something that command and control fails to achieve.

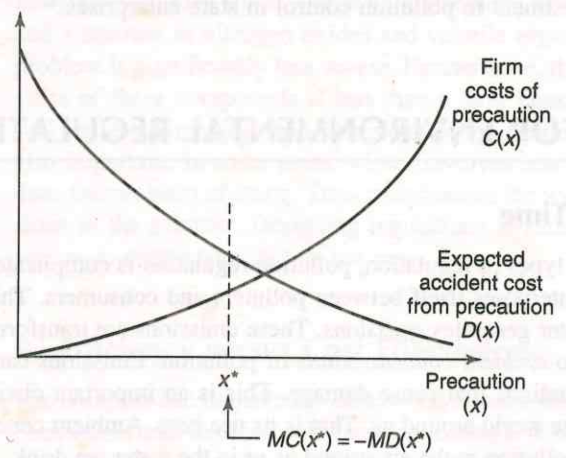

Figure 8.3 An illustration of precaution and liability.

Probably the biggest advantage of economic incentives is that the equimarginal principle will automatically hold for most types of economic incentives. For instance, with an emission fee, all firms set their marginal cost of pollution control equal to the fee. The equimarginal principle is trivially satisfied. When firms trade pollution permits, the price of the permit that will be determined by the permit market sends the same signal to all polluters regarding the opportunity cost of emitting. The equimarginal principle will hold. As we will see in Chapter 12, liability effectively has the polluter setting its marginal abatement cost equal to marginal damage. Thus the equimarginal principle will also hold. Why is meeting the equimarginal principle so important? Basically because the costs of regulation will be higher if the equimarginal principle does not hold, perhaps much higher. Thus economic incentives have this cost-saving advantage.

There are disadvantages to economic incentives. One problem is forging a set of economic incentives that can accommodate the complexities of environmental transformation without being excessively complex and impractical. Just think of urban air pollution in which the damage from a unit of emissions can vary considerably in both space and time. Developing an economic incentive that efficiently and perfectly takes these complexities into account can be very difficult.

A second problem with economic incentives is largely political. If there is a great deal of uncertainty associated with the environmental problem being controlled, it may be necessary to adjust the level of the incentive (level of the fee, number of marketable permits issued) over time, as information becomes available. This may be very difficult in many practical situations. For instance such an adjustment in the United States might require Congressional action. It took over 10 years of debate in Congress before the U.S. Clean Air Act was amended in 1990 to include acid rain control.

A third problem, also political, is that many economic incentives involve massive transfers from firms to the government. An emissions tax generates a tremendous amount of revenue for the government administering the tax. This may be good for the government, but instituting such a tax may be very difficult politically, precisely because of these wealth transfers. This explains in large part why substantial emission fees have gone nowhere in most market economies. In contrast, emission fees have been widely used in the former Soviet Union and Eastern Europe because of the traditional dedication of the fee revenue to investment in pollution control in state enterprises.[12]

IV. COMPLICATIONS FOR ENVIRONMENTAL REGULATION

A. Space and Time

In contrast to most types of regulation, pollution regulation is complicated by the physical environment that interposes itself between polluters and consumers. This is illustrated in Figure 8.4. A polluter generates *emissions*. These emissions are transformed, possibly in a complex fashion, to *ambient concentrations* of pollution. Emissions cause no damage; it is ambient concentrations that cause damage. This is an important distinction. The word ambient refers to the world around us. That is its use here. Ambient concentrations are the concentrations of pollution in the air around us or in the water we drink. It is ambient con-

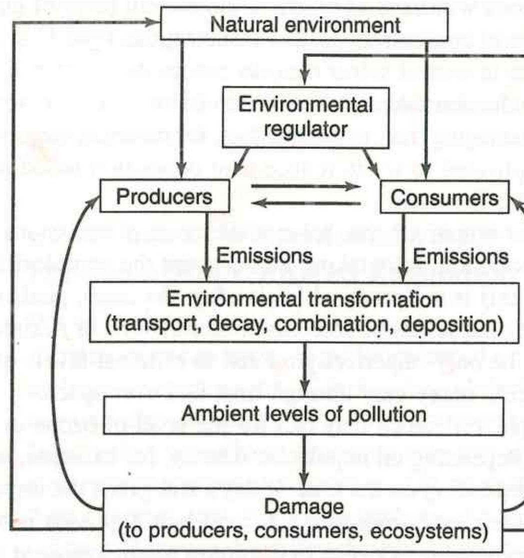

Figure 8.4 Environmental regulators face a complex task.

centrations, not emissions, that should be of concern when we discuss environmental damage. The regulator, too, is interested in ambient concentrations because that is the source of damage. However, ambient concentrations are imperfectly connected to emissions and emissions are what firms emit and what needs to be regulated. This creates a complexity that is not present in other forms of regulation, such as monopoly or occupational safety.

Space is a major player in environmental transformation. If we are interested in pollution levels in central Tokyo, sources nearby will generate more damage than sources located in distant suburbs. Or if we are interested in acid rain damage in the Black Forest, emissions from German power plants will be more damaging than emissions from more distant English power plants. We take this issue up in more detail in the next chapter.

Time is also a significant factor in environmental transformation, though probably less important than space. Urban photochemical smog (primarily ozone) involves sunlight and a mixture of nitrogen oxides and volatile organic compounds. Without sunlight, the problem is significantly less severe. Furthermore, the residence time in the atmosphere of some of these compounds is less than a day. Thus emissions in the evening or at night will be less damaging than emissions in the morning or mid-day. Seasonal variation is also important. In some areas, winter involves less heat and sunshine, which tends to reduce the problem of smog. Thus emissions in the winter may be less damaging than emissions in the summer. Designing regulations to reflect this hour-to-hour, day-to-day, and season-to-season variation is not easy.

B. Efficiency versus Cost Effectiveness

The complex and imperfectly understood relationship between emissions and ambient concentrations and, in turn, environmental damage, presents a conundrum for regulators. Ideally, regulations would target damage and ambient concentrations, but that is often too difficult. Often, regulations will have as a goal some overall level of emissions, with no clear connection to ambient concentrations. For instance, the 1990 U.S. acid rain legislation calls for a reduction in annual sulfur dioxide emissions of 10 million tons, without regard for where that reduction takes place. But emissions close to sensitive lakes and forests are much more damaging than emissions that, for instance, largely blow out to sea. However, it is too complicated to try to reduce acid deposition based on variable emission reductions at specific locations.

Efficiency calls for emissions that balance the costs of emissions control with the damage from ambient pollution, fully taking into account the complexities relating emissions to damage. When this is not practical (as is often the case), goals or targets will be established regarding desired levels of ambient concentrations or desired levels of emissions. These goals may be only imperfectly related to efficient levels of pollution, since efficient levels of pollution many vary through time and over space.

As another example, efficiency may call for the level of ozone in the Los Angeles basin to vary spatially (depending on population density, for example, and control costs) as well as temporally (depending on the time of day). But given the imperfect knowledge of ozone damage, formation, and transport, a second-best approach is to establish a target upper bound on concentration of ozone in the entire basin, averaged over an hour. But even such a simplified target may be impractically complex. Because of the imperfect knowledge of the ozone problem, regulations may establish targets for emissions that may be only imperfectly related to ambient concentrations. For instance, goals or targets are established for overall emissions of precursors of ozone (those pollutants that lead to ozone). Regulations apply to individual polluters and are designed to achieve approximately the emission targets for the basin.

This example illustrates the compromises that are often (though not always) necessary in actually regulating polluters. If regulators are unable to control emissions from individual polluters to balance costs and damage, a fall-back position may be to establish ambient pollution targets and regulate polluters in such a way as to achieve the ambient pollution target in the best way possible. But even this may not always be possible, in which case a target is established for emissions and this target may be only approximately related to the target for ambient concentrations. The goal of regulation then is to control individual polluters in such as way as to achieve the emission target in the best way possible.

Establishing emission targets or ambient targets is usually a compromise that sacrifices efficiency in pollution control. But even with an emission target, there are both good ways and less desirable ways of regulating emissions to achieve the target. Different polluters have different costs of pollution control. The least-costly way of achieving a given emission target involves controlling pollution from various sources in a way that reflects different costs of pollution control. If a set of environmental regulations achieves the emission target at least cost, we say the regulation is *cost effective*. If the regulation is cumbersome and poorly matches emission cutbacks with control costs, then it is likely the regulation will not be cost effective.

This is an important concept. Even though efficiency is not attainable for many regulations, cost effectiveness is attainable. Unfortunately many environmental regulations around the world are far from cost effective in achieving either emission targets or ambient targets. In some cases this lack of cost effectiveness is for very real and understandable reasons, particularly concerns about equity. Cost effectiveness may call for most of the damages or costs of emission control to fall on a few individuals or firms.[13] Society may deem this inequitable and consciously move away from cost effectiveness. However, it is just as common that regulations are poorly designed, leading to excessive costs for no particular reason.

C. Ambient-Differentiated versus Emission-Differentiated Regulation

We have already concluded that targets may be ambient targets or emission targets. Regulations, too, can apply to polluters based on their emissions or on their contribution to ambient concentrations. This is a bit subtle but actually relatively simple. Suppose we have an ambient target. Typically, a unit of pollution from one polluter will have a different effect on ambient concentrations than a unit of pollution from another polluter. An ambient-differentiated regulation will control these two polluters differently, based on their different contributions to ambient concentrations. An emissions-differentiated regulation will ignore the differences between the two polluters, though the overall level of emissions will still be controlled in such a way as to achieve the ambient target.

Using the example of ozone in Los Angeles again, regulation is driven by ambient targets on maximum concentrations of ozone at any point in the air basin. However, sources are regulated without much regard for their contribution to ambient concentrations. A source of a particular type (e.g., furniture manufacture) will be subject to the same emissions regulation regardless of its location in the basin. This is an example of emission-differentiated regulation. Contrast this with regulations applying to new sources of pollution in the Los Angeles basin. A new source seeking to locate in the basin must arrange for emission reductions from existing sources and demonstrate that the ambient concentrations resulting from the new source combined with the arranged reductions in existing sources will be better than the previous status quo. This is an example of an ambient-differentiated regulation.

This concept of ambient-differentiated regulations will be explored more fully in the next chapter.

V. BASIC ISSUES IN ENVIRONMENTAL REGULATION

This chapter has served as an introduction to environmental regulation. Lest the reader be seduced into thinking that designing good environmental regulation involves a simple application of economic theory, it may be instructive to briefly mention some of the major issues in environmental regulation. In the succeeding chapters, we will examine many of these issues in more detail.

The debate over command-and-control regulations vs. economic incentives is still as lively as ever. Although there have been some recent major inroads of economic incentives into actual environmental regulation, the verdict is still out on how well these incentives work. Furthermore, some of the more vexing environmental problems, such as

9 EMISSION FEES AND MARKETABLE PERMITS

By now you should be relatively familiar with the concepts of emission fees and marketable emission permits as economic incentives for controlling pollution. Our goal in this chapter is to discuss this topic in more detail, looking at how these incentives might work and exploring some of the potential problems.

Several issues complicate using incentives to control pollution. One is space—pollution transport is often highly dependent on location. Another is time—primarily accumulation over time, such as the multidecade accumulation of greenhouse gases (but also including daily and seasonal variation). A third is imperfect competition. We consider these issues here. We will also examine the question of just how much more efficient economic incentives are than the alternative—command and control.

I. SPACE

A. Sources, Receptors, and Transfer Coefficients

The problem of dealing with spatial effects is very real for pollution control. At the simplest level, Figure 9.1 shows a river with two factories discharging organic waste (such as sewage) into the river and a municipal water supply taking water out of the river (yuk!). For the time being, ignore the fact that the river may be useful for many purposes (such as fishing, swimming, and ecosystem services) and focus on its use as a water source for the town.

The problem of course is that the two factories are upstream of the municipal water supply. Consequently, what these factories do is of importance to the municipality. Fortunately, the river is able to clean itself somewhat. As the river flows, bacteria will work on organic material that the factories have discharged into the river. So the further one goes downstream, the smaller the effects from the pollution. Although this is good for the environment, unfortunately it complicates our analysis. To correctly regulate the two factories, we must take into account their individual effects on the municipality.[1]

To take space into account, we will introduce two terms: *sources* and *receptors*. A source is a point of discharge of pollution. Each factory in our example is a source. A re-

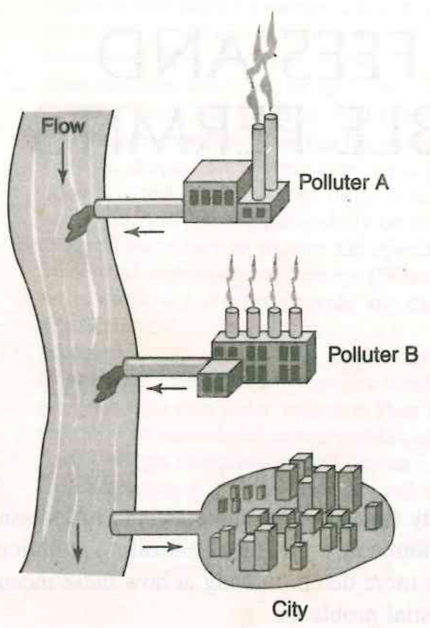

Figure 9.1 River with two factories discharging organic waste into it and a municipal water supply taking water out of it.

ceptor is a point at which we care about the level of ambient pollution. (Recall that ambient pollution refers to the level of pollution in the surrounding environment.) In our example, a logical receptor is the intake point for the municipal water supply. If we are concerned about the health of the river at other points, we might have several receptors located at different points along the river. It might seem that we care about pollution everywhere, not just at a few receptors. While this may be true, in practice we usually identify a small set of receptors where pollution levels will be measured. Typically, these receptors are scattered over space and serve as good proxies for the overall level of pollution.

Generally speaking, there is some relationship between emissions at the various sources, $e_1, e_2, \ldots, e_I$ (where I is the number of sources) and concentrations of pollution at any receptor j:

$$p_j = f_j(e_1, e_2, \ldots, e_I) + B_j \tag{9.1}$$

where B_j is the background level of pollution at j (perhaps zero). Fortunately, in many environmental problems the physical environment is linear[2]; that is, Eq. (9.1) can be written as

$$p_j = \Sigma_i\, a_{ij}\, e_i + B_j \tag{9.2}$$

The coefficient a_{ij} is called the *transfer coefficient*. Typically, we assume $B_j = 0$. Note that in Eq. (9.2), if we change emissions at some source i by a little (Δe_i), pollution will change by $a_{ij}\, \Delta e_i$. This brings us to a definition of the transfer coefficient:

Definition *Suppose a change in emissions from source* i *(Δ e$_i$) results in a change in pollution at receptor* j *(Δp$_j$). The transfer coefficient between the source* i *and the receptor* j *is defined as the ratio of the change in pollution at* j *to the change in emissions at* i*:*

$$a_{ij} = \Delta p_j \,/\, \Delta e_i \tag{9.3}$$

The concept of a transfer coefficient is really useful only when the relationship between emissions and pollution is linear, such as in Eq. (9.2). In general, for our analysis, we will make the linearity assumption. Equation (9.3) in essence gives the conversion rate for emissions to ambient concentrations. For instance, if a_{ij} is equal to 2, then every unit of emissions at i yields two units of ambient pollution at j.

B. How Much Pollution Do We Want?

We first turn to the question of what is the efficient amount of pollution. As we know, efficiency involves equating marginal damage with the marginal savings to the firm from pollution generation. But marginal savings is relative to emissions and marginal damage is relative to ambient pollution. To link these, we must either convert a firm's marginal savings function to marginal savings *per unit of ambient pollution* or express marginal damages as marginal damage *per unit of emissions*. We take the second course. Let us term marginal damages per unit of emissions from source i as the function $MDE_i\,(e_i)$, which is in contrast to marginal damages per unit of ambient pollution, $MD(p)$. For now we will work with one receptor. We know that MDE_i is the ratio of the change in damages $[D(p)]$ to the change in emissions at source i:

$$\begin{aligned} MDE_i\,(e_i) &= \{D(p+\Delta p) - D(p)\} \,/\, \Delta e_i \\ &= MD(p)\, \Delta p \,/\, \Delta e_i \\ &= a_i\, MD(p) \end{aligned} \tag{9.4}$$

This relationship between MDE and MD is intuitive. If, as was mentioned in the previous paragraph, a_i is 2, one more unit of emissions yields two units of pollution and thus twice as much damage as one more unit of ambient pollution. Thus MDE is twice as big as MD.

What is the efficient amount of pollution? As before, efficiency calls for equating the marginal savings from emissions with the marginal damage, and this must apply to all sources (from the equimarginal principle). So if there are $i = 1, \ldots, I$ sources, the following must hold:

$$-MC_i\,(e_i) = MDE_i\,(e_i) = a_i\, MD(p), \qquad \text{for all } i = 1, \ldots, I \tag{9.5}$$

Eq. (9.5) is really a set of I equations, one for each source, setting that source's marginal savings from emissions equal to marginal damage. Since all of the $MD(p)$ terms in Eq. (9.5) are the same, this implies that for any two sources, m and n,

$$MC_m\,(e_m) \,/\, a_m = MC_n\,(e_n) \,/\, a_n = -MD(p) \tag{9.6}$$

The MC/a terms can be interpreted as the marginal cost per unit of ambient pollution. Thus Eq. (9.6) says that marginal cost in terms of ambient pollution must be equal to the negative of marginal damage. In other words, efficiency calls for all sources to have the same marginal costs of emissions, normalized by the source's transfer coefficient. Thus if a source has a larger impact on ambient pollution (a is larger), its marginal cost of pollution control (marginal cost of emissions) must be larger. This is the equimarginal principle, modified for ambient pollution.

To summarize, two conditions are necessary for efficiency. First, the marginal cost of emissions, normalized by the transfer coefficient, must be equalized for all sources. Second, that normalized marginal cost must equal the negative of marginal damage.

Example: Suppose that in our problem with the river and the municipality in Figure 9.1 the basic conditions are

$$\begin{aligned} a_1 &= 2 \\ a_2 &= 3 \\ MC_i(e_i) &= -14 + 7e_i,\ i = 1, 2 \\ MD(p) &= p \end{aligned} \tag{9.7}$$

Also assume the background pollution level is zero. How much should each source efficiently emit?

Note that we have assumed that both sources share the same marginal cost function. This of course need not be the case. Note also that marginal costs of emissions are negative. Recall that firm costs decrease as emissions increase, yielding negative marginal costs. Marginal savings from emissions are, in contrast, positive.

Applying Eq. (9.6) to this example yields the following efficiency conditions:

$$MC_1(e_1) / a_1 = (-14 + 7e_1)/2 = MC_2(e_2) / a_2 = (-14 + 7e_2)/3 \tag{9.8a}$$

$$\begin{aligned} MC_1(e_1) / a_1 &= (-14 + 7e_1)/2 = -MD(p) \\ &= -MD(2e_1 + 3e_2) = -(2e_1 + 3e_2) \end{aligned} \tag{9.8b}$$

We have two equations in two unknowns that we know can be solved. First, simplify, rewriting Eq. (9.8) as

$$-42 + 21e_1 = -28 + 14e_2 \tag{9.9a}$$

$$-14 + 7e_1 = -4e_1 - 6e_2 \tag{9.9b}$$

which can be solved for $e_1 = 1$ and $e_2 = 0.5$. The marginal cost for firm 1 is -7 and the marginal cost for firm 2 is -10.5. The total ambient pollution is 3.5, which yields marginal damage of 3.5. Check that the marginal cost, normalized by the transfer coefficient, is equal to the marginal damage.

C. Emission Fees

Having set up the framework for dealing with space, it is relatively straightforward to see how emission fees should be structured to yield efficiency. We seek emission fees, t_i, one for each firm i, that yield efficiency, defined by Eq. (9.6). These will be ambient-differentiated emission fees. We know that whatever fee is used, the firms will respond by minimizing direct costs plus fee payments. This is equivalent to setting marginal cost equal to the negative of the fee:

$$MC_i(e_i) = -t_i, \quad \text{for all sources } i \tag{9.10}$$

This means we can rewrite the conditions for efficiency in Eq. (9.6) as

$$t_n / a_n = t_m / a_m, \quad \text{for all firms } n \text{ and } m \tag{9.11a}$$

and

$$t_n = a_n\, MD(p), \quad \text{for any firm } n \tag{9.11b}$$

Thus the emission fees levied on the firms must be equal, after normalizing by the transfer coefficient. The second condition says that for any firm, marginal damage in emission units (*MDE*) must be equal to the emission fee. The first condition equalizes control costs across firms; the second condition equalizes marginal pollution damage and control costs. An alternative interpretation is that all firms face the same emission fee per unit of ambient pollution, but to convert it to emission units, it must be multiplied by the appropriate transfer coefficient.

Thus we see that ambient-differentiated emission fees can achieve efficiency. Sometimes, however, it is too complicated to let emission fees vary from location to location. For instance, there may be too much uncertainty about the level of the transfer coefficients; or it may be considered unfair to levy different fees on different firms. Most emission fees do not depend on location, even though damages do. How inefficient is applying a uniform emission fee when damages depend on location? Figure 9.2a is a graphic representation of Eq. (9.5). Shown is the marginal savings curve, assumed the same for each firm as well as marginal damages, normalized by the transfer coefficient. We know that efficient taxes are set so that Eq. (9.11a) holds. Thus for efficient taxes (t_1^*, t_2^*), emissions from the two firms will be as shown in Figure 9.2 (e_1^* and e_2^*). But suppose we use

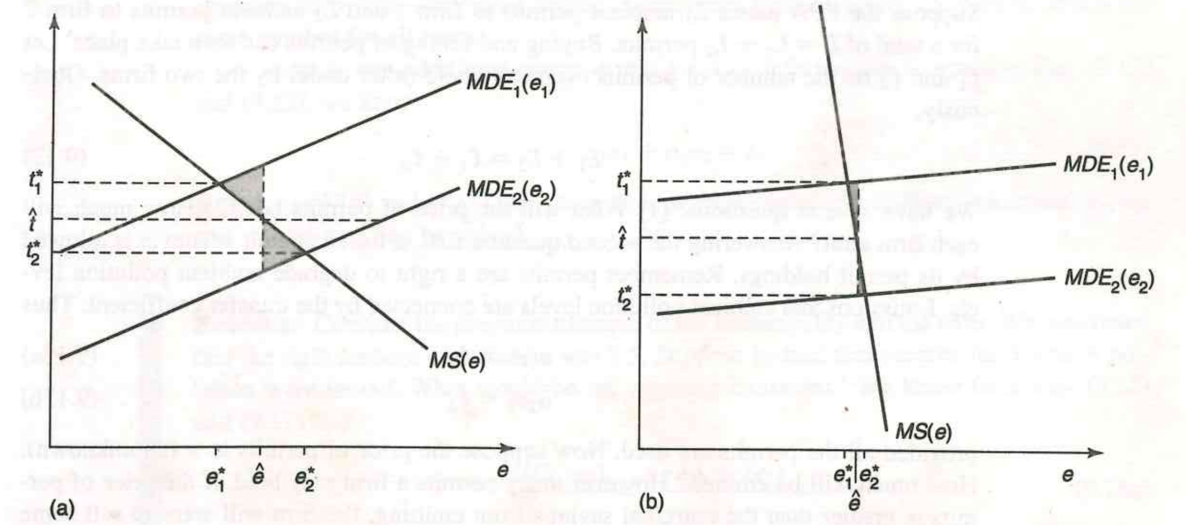

Figure 9.2 (a,b) Illustration of inefficiencies of uniform emission fee. MDE_1, Marginal damage per unit emissions, firm 1; MDE_2, marginal damage per unit emissions, firm 2; *MS*, marginal savings from emitting, firm 1, firm 2; t_1^*, efficient Pigouvian fee, firm 1; t_2^*, efficient Pigouvian fee, firm 2; efficient emissions firm 1; e_2^*, efficient emissions, firm 2; $\hat{t}$, uniform emission fee; $\hat{e}$, emissions from firm 1 or firm 2, uniform emission fee.

only one tax. If a uniform tax ($\hat{t}$) is used, both firms will emit the same ($\hat{e}$). The deadweight loss associated with this uniform emission fee is the shaded area in Figure 9.2. The "optimal" uniform tax is one that minimizes the total area of the two triangles.

The loss from a uniform fee depends on the nature of the marginal cost and damage functions. Figure 9.2b shows the same thing as 9.2a except with different slopes for marginal costs and benefits. Clearly, the deadweight loss is much lower. In fact, the steeper the marginal cost functions and the flatter the marginal damage, the smaller the deadweight loss.[3]

D. Marketable Ambient Permits

Marketable emission permits that take into account the effect of ambient pollution concentrations are somewhat more complicated, but in theory can work just as well as ambient-differentiated emission fees.

First we need to define what we mean by an ambient pollution permit.

Definition *An ambient pollution permit for a receptor j gives the holder the right to emit at any location, provided the incremental pollution at receptor j does not exceed the permitted amount.*

An ambient pollution permit system is a set of permits, distributed to sources in a region, a well-defined way of computing the effects of emissions on ambient pollution at receptors, along with a right to buy and sell these permits.

1. Two Firms. First consider the case of two firms and one receptor (this is easiest). Suppose the EPA issues L_1 ambient permits to firm 1 and L_2 ambient permits to firm 2 for a total of $L = L_1 + L_2$ permits. Buying and selling of permits can then take place. Let ℓ_1 and ℓ_2 be the number of permits eventually held (after trade) by the two firms. Obviously,

$$L_1 + L_2 = \ell_1 + \ell_2 \tag{9.12}$$

We have several questions: (1) What will the price of permits be? (2) How much will each firm emit? Answering the second question first, a firm can emit whatever is allowed by its permit holdings. Remember permits are a right to degrade ambient pollution levels. Emissions and ambient pollution levels are connected by the transfer coefficient. Thus

$$a_1 e_1 = \ell_1 \tag{9.13a}$$

$$a_2 e_2 = \ell_2 \tag{9.13b}$$

provided all the permits are used. Now suppose the price of permits is π (an unknown). How much will be emitted? However many permits a firm may hold, if the price of permits is greater than the marginal savings from emitting, the firm will want to sell some permits and emit less. In contrast, if the permit price is lower than the firm's marginal savings from polluting, buying permits is easier than controlling emissions: the firm will buy permits and increase emissions. We seek a price for which the desired emission levels for each of the two firms corresponds to the number of permits issued.

Total costs (TC) for each firm are

$$\begin{aligned} TC_1(e_1) &= C_1(e_1) + \pi(\ell_1 - L_1) \\ &= C_1(e_1) + \pi(a_1 e_1 - L_1) \end{aligned} \tag{9.14a}$$

and

$$\begin{aligned} TC_2(e_2) &= C_2(e_2) + \pi(\ell_2 - L_2) \\ &= C_2(e_2) + \pi(a_2 e_2 - L_2) \end{aligned} \tag{9.14b}$$

where $C_i(e_i)$ is the direct cost to firm i, excluding permit costs. To minimize total costs, each firm sets the marginal total costs (MTC) to zero:

$$MTC_1(e_1) = MC_1(e_1) + a_1\pi = 0 \tag{9.15a}$$

$$MTC_2(e_2) = MC_2(e_2) + a_2\pi = 0 \tag{9.15b}$$

which implies

$$\frac{MC_1(e_1)}{a_1} = \frac{MC_2(e_2)}{a_2} = -\pi$$

or

$$\frac{MS_1(e_1)}{a_1} = \frac{MS_2(e_2)}{a_2} = \pi \tag{9.16}$$

Equation (9.16) should look familiar. It says that marginal savings, normalized by the transfer coefficient, should equal the permit price. This is analogous to how an ambient emission fee works—marginal savings, normalized by the transfer coefficient, equals the same number for all firms.

There is one additional equation that gives us information. Combining Eqs. (9.12) and (9.13), we know

$$a_1 e_1 + a_2 e_2 = L \tag{9.17}$$

Equations (9.16) and (9.17) constitute three separate equations in three unknowns (e_1, e_2, and π) and thus can be solved.

Example: Consider the previous example of the municipality and the river. We concluded that the right amount of pollution was 3.5. Suppose instead that permits for 5 tons of pollution were issued. What would be the resulting emissions? We know from Eqs. (9.16) and (9.17) that

$$\frac{MC_1(e_1)}{a_1} = \frac{(-14 + 7e_1)}{2} = -\pi \tag{9.18a}$$

$$\frac{MC_2(e_2)}{a_2} = \frac{(-14 + 7e_2)}{3} = -\pi \tag{9.18b}$$

$$a_1 e_1 + a_2 e_2 = 2e_1 + 3e_2 = 5 \tag{9.18c}$$

Equations (9.18a) and (9.18b) indicate that whatever the price of permits might be, the two firms will emit so that marginal costs, adjusted by the transfer coefficient, are equal to the permit price. A high price will result in fewer emissions than a low price. Equation (9.18c) indicates that not just any emissions will do; additional pollution concentrations must be exactly 5 units. The price of permits, as well as emission levels, are unknowns in Eq. (9.18). These three equations can be solved for $(e_1, e_2, \pi) = (1.23, 0.85, 2.69)$.

2. Multiple Sources and Receptors. Suppose we have $e = 1, \ldots, I$ polluters and $j = 1, \ldots, J$ receptors. Suppose the government determines that the efficient pollution level is $\bar{s}$ at each receptor and thus distributes $L_j = \bar{s}$ ambient pollution permits for each receptor, j. How will firms buy and sell these permits? Let ℓ_i^j be the number of permits held by source i for polluting receptor j. Because of buying and selling, ℓ_i^j need not equal the number of permits it initially received. But because permits cannot be created (legally), we know that the "law of conservation of permits" applies:

$$\bar{s} = L_j \geq \Sigma_i \, \ell_i^j \tag{9.19}$$

If all permits are used and none is lost or destroyed, we would have equality in Eq. (9.19). Equation (9.19) simply states that after trading has occurred, the number of permits held by various firms for polluting each receptor j must be less than or equal to the number of permits initially issued for that receptor.

How much then can source i emit, assuming it has a portfolio of permits? Basically, the set of permits the firm has allows certain pollution levels at the various receptors. If the firm emits e_i, its pollution at receptor j will be $a_{ij}\, e_i$. The permit holdings require that

$$a_{ij}\, e_i \leq \ell_i^j \quad \text{for all } j \tag{9.20a}$$

or

$$e_i \leq \ell_i^j / a_{ij} \quad \text{for all } j \tag{9.20b}$$

This means that allowed emissions for source i are given by

$$e_i{}^* = \min_j \{\ell_i^j / a_{ij}\} \tag{9.21}$$

This probably seems more complicated than it really is. Consider Figure 9.1 again but suppose there is a swimming area between the city and polluter B. Call the swimming area receptor S and the city receptor C. Each polluter has permits to degrade river quality at C and permits to degrade quality at S. Emissions are governed by whichever receptor is most sensitive, taking into account permits held. This is Eq. (9.21).

With some receptors being more sensitive than others, it is entirely possible that some receptors will have less pollution than is allowed. For instance, if we are regulating a large region that contains an urban area, some receptors will be in the urban area and some in the surrounding countryside. It is entirely possible that pollution will be at the limit at the urban receptors and below the limit at the rural receptors. If the pollution is below the limit, it means not all of the initially issued permits are being used and thus the price of those permits must be zero.

This brings us to the question of what prices will result from trading. The permits are rights to trade the ambient environment. There will be a different price for this at each