Externalities: Problems and Solutions

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In December 1997, representatives from over 170 nations met in Kyoto, Japan, to attempt one of the most ambitious international negotiations ever: an international pact to limit the emissions of carbon dioxide worldwide. The motivation for this international gathering was increasing concern over the problem of global warming. As Figure 5-1 on p. 116 shows, there has been a steady rise in global temperatures over the twentieth century. A growing scientific consensus suggests that the cause of this warming trend is human activity, in particular the use of fossil fuels. The burning of fossil fuels such as coal, oil, natural gas, and gasoline produces carbon dioxide, which, in turn, traps the heat from the sun in the earth's atmosphere. Many scientists predict that, over the next century, global temperatures could rise by as much as ten degrees Fahrenheit.[1]

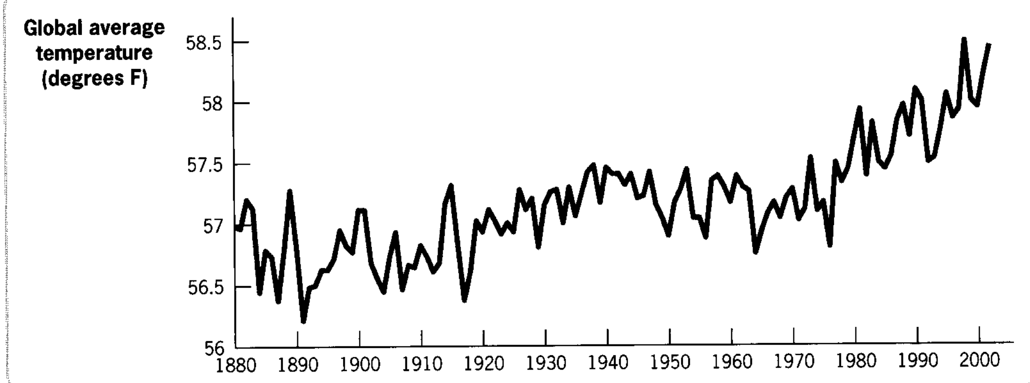
If you are reading this in North Dakota, that may sound like good news. Indeed, for much of the United States, this increase in temperatures will improve agricultural output as well as quality of life. In most areas around the world, however, the impacts of global warming would be unwelcome, and in many cases, disastrous. The global sea level could rise by almost three feet, increasing risks of flooding and submersion of low-lying coastal areas. Some scientists project, for example, that 20–40% of the entire country of Bangladesh will be flooded due to global warming over the next century, with much of this nation being under more than five feet of water![2]

Despite this dire forecast, the nations gathered in Kyoto faced a daunting task. The cost of reducing use of fossil fuels, particularly in the major industrialized nations, is enormous. Fossil fuels are central to heating our homes, transporting us to our jobs, and lighting our places of work. Replacing these fossil fuels with alternatives would significantly raise the costs of living in developed countries. To end the problem of global warming, some predict

[1] International Panel on Climate Change (2001). Global warming is produced not just by carbon dioxide but by other gasses, such as methane, as well, but carbon dioxide is the main cause and for ease we use carbon dioxide as shorthand for the full set of "greenhouse gasses."

[2] Mirza et al. (2003).

▪ **FIGURE 5-1**



Average Global Temperature, 1880 to 2002 • There has been a steady upward trend in global temperatures throughout the twentieth century.

Source: Figure adapted from NASA's Goddard Institute for Space Studies, "Global Annual Mean Surface Air Temperature Change," located at http:/www.giss.nasa.gov/data/update/gistemp/graphs/Fig.A.pdf

that we will have to reduce our use of fossil fuels to nineteenth-century (preindustrial) levels. Yet, even to reduce fossil fuel use to the level ultimately mandated by this Kyoto conference (7% below 1990 levels) could cost the United States \$1.1 trillion, or about 10% of GDP.[3] Thus, it is perhaps not surprising that the United States has yet to ratify the treaty agreed to at Kyoto.

Global warming due to emissions of fossil fuels is a classic example of what economists call an **externality.** An externality occurs whenever the actions of one party make another party worse or better off, yet the first party neither bears the costs nor receives the benefits of doing so. Thus, when we drive cars in the United States we increase emissions of carbon dioxide, raise world temperatures, and thereby increase the likelihood that in 100 years Bangladesh will be flooded out of existence. Did you know this when you drove to class today? Not unless you are a very interested student of environmental policy. Your enjoyment of your driving experience is in no way diminished by the damage that your emissions are causing.

Externalities occur in many everyday interactions. Sometimes they are localized and small, such as the impact on your roommate if you play your stereo too loud or the impact on your neighbors if your dog uses their garden as a bathroom. Externalities also exist on a much larger scale, such as global warming or *acid rain.* When utilities in the Midwest produce electricity using coal, a by-product of that production is the emission of sulfur dioxide and nitrogen oxides into the atmosphere, where they form sulfuric and nitric acids. These acids may fall back to earth hundreds of miles away, in the process destroying trees, causing billions of dollars of property damage, and increasing

externality Externalities arise whenever the actions of one party make another party worse or better off, yet the first party neither bears the costs nor receives the benefits of doing so.

[3] Nordhaus and Boyer (2000), Table 8.6 (updated to 2,000 dollars).

respiratory problems in the population. Without government intervention, the utilities in the Midwest bear none of the cost for the polluting effects of their production activities.

market failure A problem that causes the market economy to deliver an outcome that does not maximize efficiency.

Externalities are a classic example of the type of **market failures** discussed in Chapter 1. Recall that the most important of our four questions of public finance is *When* is it appropriate for the government to intervene? As we will show in this chapter, externalities present a classic justification for government intervention. Indeed, 135,000 federal employees, or 5% of the federal workforce, are ostensibly charged with dealing with environmental externalities in agencies such as the Environmental Protection Agency and the Department of the Interior.[4]

This chapter begins with a discussion of the nature of externalities. We focus primarily throughout the chapter on environmental externalities, although we briefly discuss other applications as well. We then ask whether government intervention is necessary to combat externalities, and under what conditions the private market may be able to solve the problem. We discuss the set of government tools available to address externalities, comparing their costs and benefits under various assumptions about the markets in which the government is intervening. In the next chapter, we apply these theories to the study of some of the most important externality issues facing the United States and other nations today: acid rain, global warming, and smoking.

5.1 Externality Theory

In this section, we develop the basic theory of externalities. As we emphasize next, externalities can arise from either the production of goods or from their consumption and can be negative (as in the examples discussed above) or positive. We begin with the classic case of a negative production externality.

Economics of Negative Production Externalities

Somewhere in the United States there is a steel plant located next to a river. This plant produces steel products, but it also produces "sludge," a by-product useless to the plant owners. To get rid of this unwanted by-product, the owners build a pipe out the back of the plant and dump the sludge into the river. The sludge produced is directly proportional to the production of steel; each additional unit of steel creates one more unit of sludge as well.

The steel plant is not the only producer using the river, however. Farther downstream is a traditional fishing area where fishermen catch fish for sale to local restaurants. Since the steel plant has begun dumping sludge into the river, the fishing has become much less profitable because there are many fewer fish left alive to catch.

[4] This estimate is from the U.S. Office of Personnel Management (2003), p. 90, as well as Web pages of agencies and departments.

negative production externality When a firm's production reduces the well-being of others who are not compensated by the firm.

private marginal cost The direct cost to producers of producing an additional unit of a good.

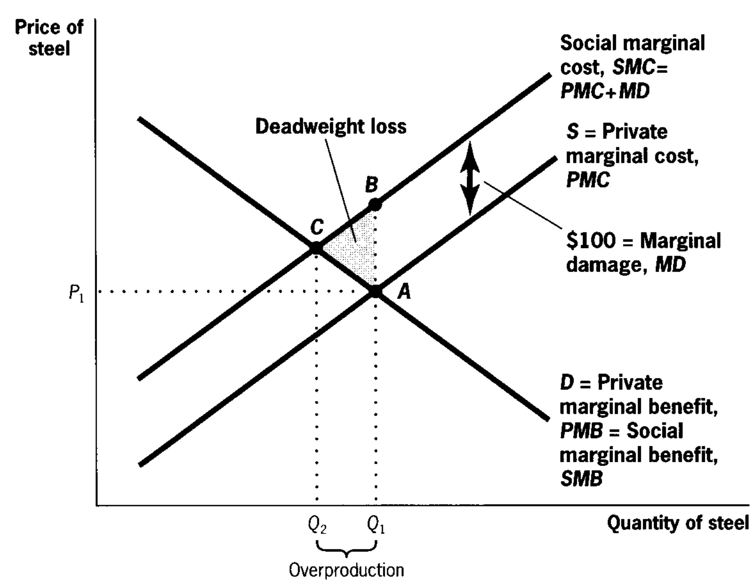
social marginal cost The private marginal cost to producers plus any costs associated with the production of the good that are imposed on others.

This scenario is a classic example of what we mean by an externality. The steel plant is exerting a **negative production externality** on the fishermen, since its production adversely affects the well-being of the fishermen but it does not compensate the fishermen for their loss.

One way to see this externality is to graph the market for the steel produced by this plant (Figure 5-2) and to compare the private benefits and costs of production to the social benefits and costs. *Private benefits and costs* are the benefits and costs borne directly by the actors in the steel market (the producers and consumers of the steel products). *Social benefits and costs* are the private benefits and costs *plus* the benefits and costs to any actors outside this steel market who are affected by the steel plant's production process (the fishermen).

Recall from Chapter 2 that each point on the market supply curve for a good (steel in our example) represents the market's marginal cost of producing that unit of the good—that is, the **private marginal cost (*PMC*)** of that unit of steel. What determines the welfare consequences of production, however, is the **social marginal cost (*SMC*),** which equals the private marginal cost to the producers of producing that next unit of a good *plus any costs associated with the production of that good that are imposed on others.* This distinction was not made in Chapter 2, because without market failures *SMC* = *PMC:* the social costs of producing steel are equal to the costs to steel producers. Thus, when we computed social welfare in Chapter 2 we did so with reference to the supply curve.

■ **FIGURE 5-2**



Market Failure Due to Negative Production Externalities in the Steel Market • A negative production externality of $100 per unit of steel produced (marginal damage, *MD*) leads to a social marginal cost that is above the private marginal cost, and a social optimum quantity (Q_2) that is lower than the competitive market equilibrium quantity (Q_1). There is overproduction of $Q_1 - Q_2$, with an associated deadweight loss of area *BCA*.

This approach is not correct in the presence of externalities, however. When there are externalities, $SMC = PMC + MD$, where MD is the marginal damage done to others, such as the fishermen, from each unit of production (marginal because it is the damage associated with that particular unit of production, not total production). Suppose, for example, that each unit of steel production creates sludge that kills \$100 worth of fish. In Figure 5-2, the *SMC* curve is therefore the *PMC* (supply) curve, shifted upward by the marginal damage of \$100.[5] That is, at Q_1 units of production (point *A*), the social marginal cost is the private marginal cost at that point (which is equal to P_1), plus \$100 (point *B*). For every level of production, social costs are \$100 higher than private costs, since each unit of production imposes \$100 of costs on the fishermen for which they are not compensated.

private marginal benefit The direct benefit to consumers of consuming an additional unit of a good by the consumer.

social marginal benefit The private marginal benefit to consumers plus any costs associated with the consumption of the good that are imposed on others.

Recall also from Chapter 2 that each point on the market demand curve for steel represents the sum of individual willingnesses to pay for that unit of steel, or the **private marginal benefit (*PMB*)** of that unit of steel. Once again, however, the welfare consequences of consumption are defined relative to the **social marginal benefit (*SMB*),** which equals the private marginal benefit to the consumers *plus any costs associated with the consumption of the good that are imposed on others.* In our example, there are no such costs imposed by the consumption of steel, so $SMB = PMB$ in Figure 5-2.

In Chapter 2, we showed that the private market competitive equilibrium is at point *A* in Figure 5-2, with a level of production Q_1 and a price of P_1. We also showed that this was the social-efficiency-maximizing level of consumption for the private market. In the presence of externalities, this relationship no longer holds true. Social efficiency is defined relative to social marginal benefit and cost curves, not to private marginal benefit and cost curves. Because of the negative externality of sludge dumping, the social curves (*SMB* and *SMC*) intersect at point *C*, with a level of consumption Q_2. Since the steel plant owner doesn't account for the fact that each unit of steel production kills fish downstream, the supply curve understates the costs of producing Q_1 to be at point *A*, rather than at point *B*. As a result, too much steel is produced ($Q_1 > Q_2$), and the private market equilibrium no longer maximizes social efficiency.

When we move away from the social-efficiency-maximizing quantity, we create a *deadweight loss* for society because units are produced and consumed for which the cost to society (summarized by curve *SMC*) exceeds the social benefits (summarized by curve $D = SMB$). In our example, the deadweight loss is equal to the area *BCA*. The width of the deadweight loss triangle is determined by the number of units for which social costs exceed social benefits ($Q_1 - Q_2$). The height of the triangle is the difference between the marginal social cost and the marginal social benefit, the marginal damage.

[5] This example assumes that the damage from each unit of steel production is constant, but in reality the damage can rise or fall as production changes. Whether the damage changes or remains the same affects the shape of the social marginal cost curve, relative to the private marginal cost curve.

negative consumption externality When an individual's consumption reduces the well-being of others who are not compensated by the individual.

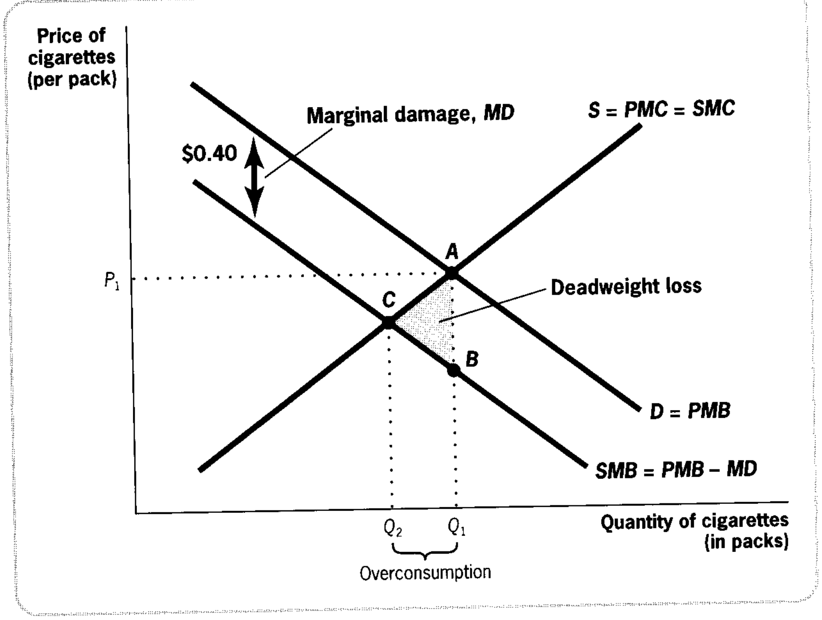
Negative Consumption Externalities

It is important to note that externalities do not arise solely from the production side of a market. Consider the case of cigarette smoke. In a restaurant that allows smoking, your consumption of cigarettes may have a negative effect on my enjoyment of a restaurant meal. Yet you do not in any way pay for this negative effect on me. This is an example of a **negative consumption externality,** whereby consumption of a good reduces the well-being of others, a loss for which they are not compensated. When there is a negative consumption externality, $SMB = PMB - MD$, where MD is the marginal damage done to others by your consumption of that unit. For example, if MD is 40¢ a pack, the marginal damage done to others by your smoking is 40¢ for every pack you smoke.

Figure 5-3 shows supply and demand in the market for cigarettes. The supply and demand curves represent the *PMC* and *PMB*. The private equilibrium is at point *A*, where supply (*PMC*) equals demand (*PMB*), with cigarette consumption of Q_1 and price of P_1. The *SMC* equals the *PMC* because there are no externalities associated with the production of cigarettes in this example. Note, however, that the *SMB* is now below the *PMB* by 40¢ per pack; every pack consumed has a social benefit that is 40¢ below its private benefit. That is, at Q_1 units of production (point *A*), the social marginal benefit is the private marginal benefit at that point (which is equal to P_1), minus 40¢, (point *B*). For each pack of cigarettes, social benefits are 40¢ lower than private, since each pack consumed imposes 40¢ of costs on others for which they are not compensated.

The social-welfare-maximizing level of consumption, Q_2, is identified by point *C*, the point at which $SMB = SMC$. There is overconsumption of ciga-

▪ **FIGURE 5-3**



Market Failure Due to Negative Consumption Externalities in the Cigarette Market • A negative consumption externality of 40¢ per pack of cigarettes consumed leads to a social marginal benefit that is below the private marginal benefit, and a social optimum quantity (Q_2) that is lower than the competitive market equilibrium quantity (Q_1). There is overconsumption $Q_1 - Q_2$, with an associated deadweight loss of area ACB.

rettes by $Q_1 - Q_2$: the social costs (point A on the SMC curve) exceed social benefits (on the SMB curve) for all units between Q_1 and Q_2. As a result, there is a deadweight loss (area ACB) in the market for cigarettes.

APPLICATION

The Externality of SUVs[6]

In 1985, the typical driver sat behind the wheel of a car that weighed about 3,200 pounds, and the largest cars on the road weighed 4,600 pounds. Today, the typical driver is in a car that weighs almost 4,000 pounds (an increase of 25%) and the largest cars on the road weigh 7,150 pounds. The major culprits in this evolution of car size are sport utility vehicles (SUVs), a term originally reserved for large vehicles intended for off-road driving, but which now refers to any large passenger vehicle marketed as an SUV, even if it lacks off-road capabilities. SUVs, with an average weight of 4,500 pounds, represented only 6.4% of vehicle sales as recently as 1988, but fifteen years later, in 2003, they accounted for 23.4% of the new vehicles sold each year.

The consumption of large cars such as SUVs produces three types of negative externalities:

Environmental Externalities The contribution of driving to global warming is directly proportional to the amount of fossil fuel a vehicle requires to travel a mile. The typical compact or mid-size car gets roughly 25 miles to the gallon but the typical SUV gets only 18 miles to the gallon. This means that SUV drivers use more gas to go to work or run their errands, increasing fossil fuel emissions. This increased environmental cost is not paid by those who drive SUVs.

Wear and Tear on Roads Each year, federal, state, and local governments in the United States spend $30.6 billion repairing our roadways. Damage to roadways comes from many sources, but a major culprit is the passenger vehicle, and the damage it does to the roads is proportional to vehicle weight. When individuals drive SUVs they increase the cost to government of repairing the roads. SUV drivers bear some of these costs through gasoline taxes (which fund highway repair), since the SUV uses more gas, but it is unclear if these extra taxes are enough to compensate for the extra damage done to roads.

Safety Externalities One major appeal of SUVs is that they provide a feeling of security because they are so much larger than other cars on the road. Offsetting this feeling of security is the added *insecurity* imposed on other cars on the road. For a car of average weight, the odds of having a fatal accident rise by four times if the accident is with a typical SUV and not with a car of the same size. Thus, SUV drivers impose a negative externality on other drivers because they don't compensate those other drivers for the increased risk of a dangerous accident. ◄

[6] All data in this application are from *Public Citizen* (2003).

positive production externality When a firm's production increases the well-being of others but the firm is not compensated by those others.

positive consumption externality When an individual's consumption increases the well-being of others but the individual is not compensated by those others.

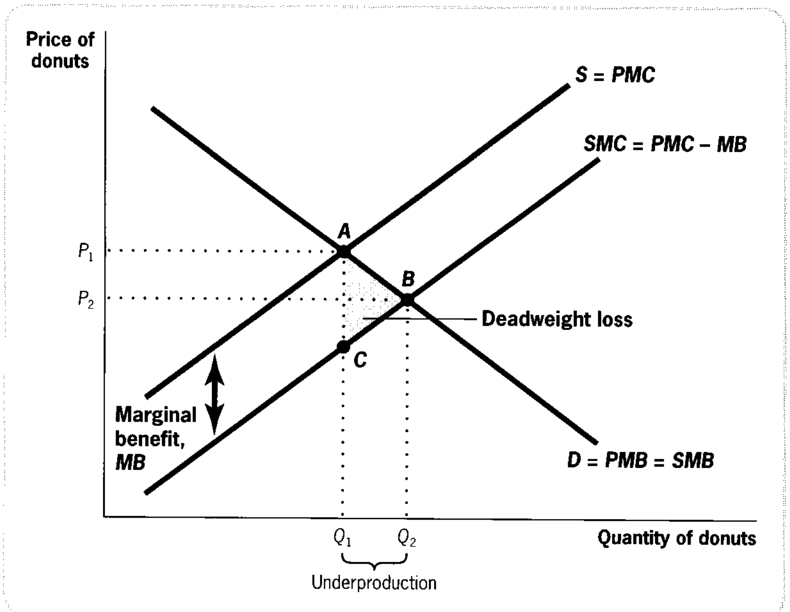
Positive Externalities

When economists think about externalities, they tend to focus on negative externalities, but not all externalities are bad. There may also be **positive production externalities** associated with a market, whereby production benefits parties other than the producer and yet the producer is not compensated. For example, suppose that policemen like to eat donuts when they are on duty. The more donuts that are produced near your house, the more likely a policeman is to be around, which has the positive benefit of making your neighborhood safer. Thus the production of donuts exerts a *positive production externality* on you: each donut produced raises the chance that a policeman will be nearby when you need him.

Figure 5-4 shows the market for donuts to illustrate that there is thus a positive externality to the production of donuts: the social marginal cost of donut production is actually *lower* than the private marginal cost because the production of donuts has a positive effect on neighborhood safety. Assume that the marginal benefit to the neighborhood of each donut produced, through increased police presence and improved neighborhood safety, is a constant amount *MB*. As a result, the *SMC* is below the *PMC* by the amount *MB*. Thus, the private equilibrium in the donut market (point *A*, quantity Q_1) leads to *underproduction* relative to the optimal level (point *B*, quantity Q_2) because the donut shop's owner doesn't recognize the benefit to the neighborhood (since he is not compensated for it).

Note also that there can be **positive consumption externalities.** Imagine, for example, that my neighbor is considering improving the landscaping around his house. The improved landscaping will cost him $1,000, but it is only worth $800 to him. My bedroom faces his house, and I would like to

▪ FIGURE 5-4



Market Failure Due to Positive Production Externality in the Donut Market • The production of donuts has a positive externality because it attracts policemen and thus makes neighborhoods safer. This leads to a social marginal cost that is below the private marginal cost, and a social optimum quantity (Q_2) that is greater than the competitive market equilibrium quantity (Q_1). There is underproduction of $Q_2 - Q_1$, with an associated deadweight loss of area *ABC*.

have nicer landscaping to look at. This better view would be worth $300 to me. That is, the total social marginal benefit of the improved landscaping is $1,100, even though the private marginal benefit to my neighbor is only $800. Since this social marginal benefit ($1,100) is larger than the social marginal costs ($1,000), it would be socially efficient for my neighbor to do the landscaping. My neighbor won't do the landscaping, however, since his private costs ($1,000) exceed his private benefits. His landscaping improvements would have a positive effect on me for which he will not be compensated, thus leading to an underconsumption of landscaping.

Quick Hint One confusing aspect of the graphical analysis of externalities is knowing which curve to shift, and in which direction. To review, there are four possibilities:

- Negative production externality: *SMC* curve lies above *PMC* curve
- Positive production externality: *SMC* curve lies below *PMC* curve
- Negative consumption externality: *SMB* curve lies below *PMB* curve
- Positive consumption externality: *SMB* curve lies above *PMB* curve

Armed with these facts, the key is assessing into what category a particular example fits, which is done in two steps. First, you must assess whether the externality is associated with producing or consuming a good. Then, you must assess whether the externality is positive or negative.

The steel plant example is a negative production externality because the externality is associated with the production of steel, not its consumption; the sludge doesn't come from using steel, but rather from making it. Likewise, our cigarette example is a negative consumption externality because the externality is associated with the consumption of cigarettes; secondhand smoke doesn't come from making cigarettes, it comes from smoking them.

5.2 Private-sector Solutions to Negative Externalities

In microeconomics, the market is innocent until proven guilty (and, similarly, the government is often guilty until proven innocent!). An excellent application of this principle can be found in a classic work by Ronald Coase, a professor at the Law School at the University of Chicago, who asked in 1960: Why won't the market simply compensate the affected parties for externalities?[7]

The Solution

To see how a market might compensate those affected by the externality, let's look at what would happen if the fishermen owned the river in the steel plant example. They would march up to the steel plant and demand an end to the

[7] For the original paper, see Coase (1960).

internalizing the externality When either private negotiations or government action lead the price to the party to fully reflect the external costs or benefits of that party's actions.

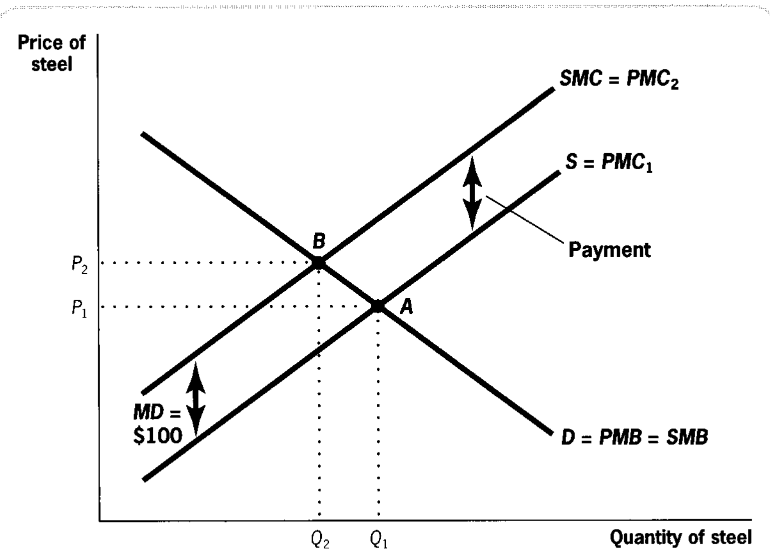
sludge dumping that was hurting their livelihood. They would have the right to do so because they have *property rights* over the river; their ownership confers to them the ability to control the use of the river.

Suppose for the moment that when this conversation takes place there is no pollution-control technology to reduce the sludge damage; the only way to reduce sludge is to reduce production. So ending sludge dumping would mean shutting down the steel plant. In this case, the steel plant might propose a compromise: the steel plant would pay the fishermen $100 for each unit of steel produced, so that they were fully compensated for the damage to their fishing grounds. As long as the steel plant can make a profit with this extra $100 payment per unit, then this is a better deal for the plant than shutting down, and the fishermen are fully compensated for the damage done to them.

This type of resolution is called **internalizing the externality.** Because the fishermen now have property rights to the river, they have used the market to obtain compensation from the steel plant for its pollution. The fishermen have implicitly created a market for pollution, by pricing the bad behavior of the steel plant. From the steel plant's perspective, the damage to the fish becomes just another input cost, since it has to be paid in order to produce.

This point is illustrated in Figure 5-5. Initially, the steel market is in equilibrium at point *A*, with quantity Q_1 and price P_1, where $PMB = PMC_1$ The socially optimal level of steel production is at point *B*, with quantity Q_2 and price P_2, where $SMB = SMC = PMC_1 + MD$. Because the marginal cost of producing each unit of steel has increased by $100 (the payment to the fisherman), the private marginal cost curve shifts upward from PMC_1 to PMC_2, which equals *SMC*. That is, social marginal costs are private marginal costs plus $100, so by adding $100 to private marginal costs, we raise the *PMC* to equal

▪ **FIGURE 5-5**



A Coasian Solution to Negative Production Externalities in the Steel Market • If the fishermen charge the steel plant $100 per unit of steel produced, this increases the plant's private marginal cost curve from PMC_1 to PMC_2, which coincides with the *SMC* curve. The quantity produced falls from Q_1 to Q_2, the socially optimal level of production. The charge internalizes the externality and removes the inefficiency of the negative externality.

the *SMC*. There is no longer overproduction because the social marginal costs and benefits of each unit of production are equalized. This example illustrates **Part I of the Coase Theorem:** when there are well-defined property rights and costless bargaining, then negotiations between the party creating the externality and the party affected by the externality can bring about the socially optimal market quantity. This theorem states that externalities do not necessarily create market failures, because negotiations between the parties can lead the offending producers (or consumers) to *internalize the externality*, or account for the external effects in their production (or consumption).

Part I of the Coase Theorem When there are well-defined property rights and costless bargaining, then negotiations between the party creating the externality and the party affected by the externality can bring about the socially optimal market quantity.

Part II of the Coase Theorem The efficient solution to an externality does not depend on which party is assigned the property rights, as long as someone is assigned those rights.

The Coase theorem suggests a very particular and limited role for the government in dealing with externalities: establishing property rights. In Coase's view, the fundamental limitation to implementing private-sector solutions to externalities is poorly established property rights. If the government can establish and enforce those property rights, then the private market will do the rest.

The Coase theorem also has an important **Part II:** The efficient solution to an externality does not depend on which party is assigned the property rights, as long as someone is assigned those rights. We can illustrate the intuition behind Part II using the steel plant example. Suppose that the steel plant, rather than the fishermen, owned the river. In this case, the fishermen would have no right to make the plant owner pay a $100 compensation fee for each unit of steel produced. The fishermen, however, would find it in their interest to pay the steel plant to produce less. If the fishermen promised the steel plant owner a payment of $100 for each unit he did not produce, then the steel plant owner would rationally consider there to be an extra $100 cost to each unit he did produce. Remember that in economics opportunity costs are included in a firm's calculation of costs; thus, forgoing a payment from the fishermen of $100 for each unit of steel not produced has the same effect on production decisions as being forced to pay $100 extra for each unit of steel produced. Once again, the private marginal cost curve would incorporate this extra (opportunity) cost and shift out to the social marginal cost curve, and there would no longer be overproduction of steel.

Quick Hint You may wonder why the fishermen would ever engage in either of these transactions: they receive $100 for each $100 of damage to fish, or pay $100 for each $100 reduction in damage to fish. So what is in it for them? The answer is that this is a convenient shorthand economics modelers use for saying, "The fishermen would charge at least $100 for sludge dumping" or "The fishermen would pay up to $100 to remove sludge dumping." By assuming that the payments are exactly $100, we can convieniently model private and social marginal costs as equal. It may be useful for you to think of the payment to the fishermen as $101 and the payment from the fishermen as $99, so that the fishermen make some money and private and social costs are approximately equal. In reality, the payments to or from the fishermen will depend on the negotiating power and skill of both parties to this transaction, highlighting the importance of the issues raised next.

The Problems with Coasian Solutions

This elegant theory would appear to rescue the standard competitive model from this important cause of market failures and make government intervention unnecessary (other than to ensure property rights). In practice, however, the Coase theorem is unlikely to solve many of the types of externalities that cause market failures. We can see this by considering realistically the problems involved in achieving a "Coasian solution" to the problem of river pollution.

The Assignment Problem The first problem involves assigning blame. Rivers can be very long, and there may be other pollution sources along the way that are doing some of the damage to the fish. The fish may also be dwindling for natural reasons, such as disease or a rise in natural predators. In many cases, it is impossible to assign blame for externalities to one specific entity.

Assigning damage is another side to the assignment problem. We have assumed that the damage was a fixed dollar amount, $100. Where does this figure come from in practice? Can we trust the fishermen to tell us the right amount of damage that they suffer? It would be in their interest in any Coasian negotiation to overstate their damage in order to ensure the largest possible payment. And how will the payment be distributed among the fishermen? When a number of individuals are fishing the same area, it is difficult to say whose catch is most affected by the reduction in the stock of available fish.

The significance of the assignment problem as a barrier to internalizing the externality depends on the nature of the externality. If my loud stereo playing disturbs your studying, then assignment of blame and damages is clear. In the case of global warming, however, how can we assign blame clearly when carbon emissions from any source in the world contribute to this problem? And how can we assign damages clearly when some individuals would like the world to be hotter, while others would not? Because of assignment problems, Coasian solutions are likely to be more effective for small, localized externalities than for larger, more global externalities.

The Holdout Problem Imagine that we have surmounted the assignment problem and that by careful scientific analysis we have determined that each unit of sludge from the steel plant kills $1 worth of fish for each of 100 fishermen, for a total damage of $100 per unit of steel produced.

Now, suppose that the fishermen have property rights to the river, and the steel plant can't produce unless all 100 fishermen say it can. The Coasian solution is that each of the 100 fishermen gets paid $1 per unit of steel production, and the plant continues to produce steel. Each fisherman walks up to the plant and collects his check for $1 per unit. As the last fisherman is walking up, he realizes that he suddenly has been imbued with incredible power: the steel plant cannot produce without his permission since he is a part owner of the river. So, why should he settle for only $1 per unit? Having already paid out $99 per unit, the steel plant would probably be willing to pay more than $1 per unit to remove this last obstacle to their production. Why not ask for $2 per unit? Or even more?

This is an illustration of the **holdout problem,** which can arise when the property rights in question are held by more than one party: the shared property rights give each party power over all others. If the other fishermen are thinking ahead they will realize this might be a problem, and they will all try to be the last one to go to the plant. The result could very well be a breakdown of the negotiations and an inability to negotiate a Coasian solution. As with the assignment problem, the holdout problem would be amplified with a huge externality like global warming, where billions of persons are potentially damaged.

holdout problem Shared ownership of property rights gives each owner power over all the others.

free rider problem When an investment has a personal cost but a common benefit, individuals will underinvest.

The Free Rider Problem Can we solve the holdout problem by simply assigning the property rights to the side with only one negotiator, in this case the steel plant? Unfortunately, doing so creates a new problem.

Suppose that the steel plant has property rights to the river, and it agrees to reduce production by 1 unit for each $100 received from fishermen. Then the Coasian solution would be for the fishermen to pay $100, and for the plant to then move to the optimal level of production. Suppose that the optimal reduction in steel production (where social marginal benefits and costs are equal) is 100 units, so that each fisherman pays $100 for a total of $10,000, and the plant reduces production by 100 units.

Suppose, once again, that you are the last fisherman to pay. The plant has already received $9,900 to reduce its production, and will reduce its production as a result by 99 units. The 99 units will benefit all fishermen equally since they all share the river. Thus, as a result, if you don't pay your $100, you will still be almost as well off in terms of fishing as if you do. That is, the damage avoided by that last unit of reduction will be shared equally among all 100 fishermen who use the river, yet you will pay the full $100 to buy that last unit of reduction. Thought of that way, why would you pay? This is an example of the **free rider problem:** when an investment has a personal cost but a common benefit, individuals will underinvest. Understanding this incentive, your fellow fishermen will also not pay their $100, and the externality will remain unsolved; if the other fishermen realize that someone is going to grab a free ride, they have little incentive to pay in the first place.

Transaction Costs and Negotiating Problems Finally, the Coasian approach ignores the fundamental problem that it is hard to negotiate when there are large numbers of individuals on one or both sides of the negotiation. How can the 100 fishermen effectively get together and figure out how much to charge or pay the steel plant? This problem is amplified for an externality such as global warming, where the potentially divergent interests of billions of parties on one side must be somehow aggregated for a negotiation.

Moreover, these problems can be significant even for the small-scale, localized externalities for which Coase's theory seems best designed. In theory, my neighbor and I can work out an appropriate compensation for my loud music disturbing his studying. In practice, this may be a socially awkward conversation that is more likely to result in tension than in a financial payment. Similarly, if the person next to me in the restaurant is smoking, it would be far outside the norm, and probably considered insulting, to lean over and offer him $5 to stop smoking. Alas, the world does not always operate in the rational way economists wish it would!

Bottom Line Ronald Coase's insight that externalities can sometimes be internalized was a brilliant one. It provides the competitive market model with a defense against the onslaught of market failures that we will bring to bear on it throughout this course. It is also an excellent reason to suspect that the market may be able to internalize some small-scale, localized externalities. Where it won't help, as we've seen, is with large-scale, global externalities that are the focus of, for example, environmental policy in the United States. The government may therefore have a role to play in addressing larger externalities.

5.3 Public-sector Remedies for Externalities

In the United States, public policy makers do not think that Coasian solutions are sufficient to deal with large-scale externalities. The Environmental Protection Agency (EPA) was formed in 1970 to provide public-sector solutions to the problems of externalities in the environment. The agency regulates a wide variety of environmental issues, in areas ranging from clean air to clean water to land management.[8]

Public policy makers employ three types of remedies to resolve the problems associated with negative externalities.

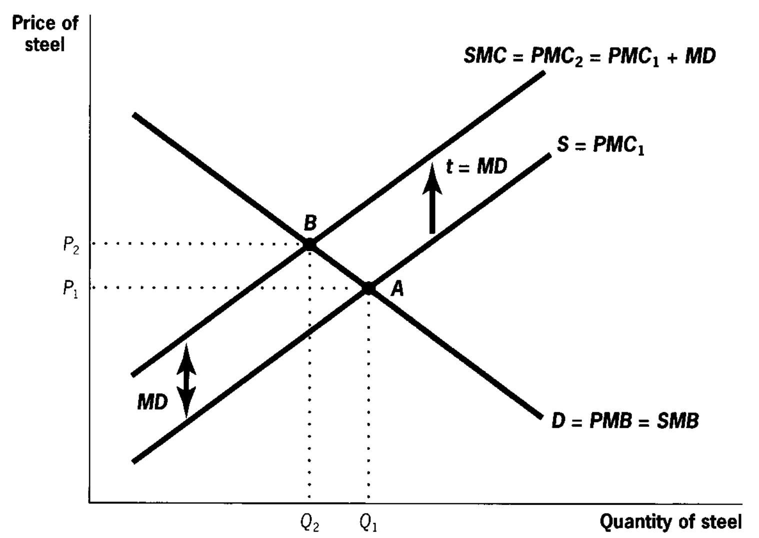
Corrective Taxation

We have seen that the Coasian goal of "internalizing the externality" may be difficult to achieve in practice in the private market. The government can achieve this same outcome in a straightforward way, however, by taxing the steel producer an amount *MD* for each unit of steel produced.

Figure 5-6 illustrates the impact of such a tax. The steel market is initially in equilibrium at point *A*, where supply ($=PMC_1$) equals demand ($= PMB = SMB$), and Q_1 units of steel are produced at price P_1. Given the externality with a cost of *MD*, the socially optimal production is at point *B*, where social marginal costs and benefits are equal. Suppose that the government levies a tax per unit of steel produced at an amount $t = MD$. This tax would act as another input cost for the steel producer, and would shift its private marginal cost up by *MD* for each unit produced. This will result in a new *PMC* curve, PMC_2, which is identical to the *SMC* curve. As a result, the tax effectively internalizes the externality and leads to the socially optimal outcome (point *B*, quantity Q_2). The government per-unit tax on steel production acts in the

[8] See http://www.epa.gov/epahome/aboutepa.htm for more information. There are government resources devoted to environmental regulation in other agencies as well, and this number also doesn't count the millions of hours of work by the private sector in complying with environmental regulation.

■ **FIGURE 5-6**



Taxation as a Solution to Negative Production Externalities in the Steel Market • A tax of $100 per unit (equal to the marginal damage of pollution) increases the firm's private marginal cost curve from PMC_1 to PMC_2, which coincides with the *SMC* curve. The quantity produced falls from Q_1 to Q_2, the socially optimal level of production. Just as with the Coasian payment, this tax internalizes the externality and removes the inefficiency of the negative externality.

same way as if the fishermen owned the river. This type of corrective taxation is often called "Pigouvian taxation," after the economist A. C. Pigou, who first suggested this approach to solving externalities.[9]

Subsidies

As noted earlier, not all externalities are negative; in cases such as the donut shop in a neighborhood or nice landscaping by your neighbors, externalities can be positive.

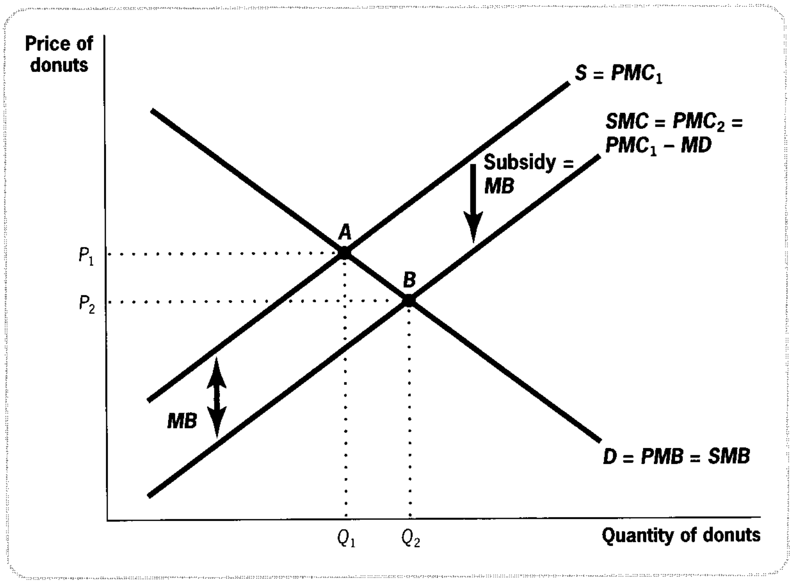
The Coasian solution to cases such as the donut shop would be for the neighborhood to take up a collection to pay the donut shop to produce more donuts (in order to attract more policemen). But, as we discussed, this may not be feasible. The government can achieve the same outcome by making a payment, or a **subsidy,** to the donut shop owner to produce more donuts. The amount of this subsidy would exactly equal the benefit to the neighborhood and would cause the store owner to produce more donuts, since his cost per donut has been lowered.

The impact of such a subsidy is illustrated in Figure 5-7 (page 130), which shows once again the market for donuts. The market is initially in equilibrium at point *A* where PMC_1 equals *PMB*, and Q_1 donuts are produced at price P_1. Given the positive externality with a benefit of *MB*, the socially optimal production is at point *B*, where social marginal costs and benefits are equal. Suppose that

subsidy Government payment to an individual or firm that lowers the cost of consumption or production respectively.

[9] See, for example, Pigou (1947).

▪ **FIGURE 5-7**



Subsidies as a Solution to Positive Production Externalities in the Donut Market • A subsidy that is equal to the marginal benefit from donut production reduces the donut producer's marginal cost curve from PMC_1 to PMC_2, which coincides with the *SMC* curve. The quantity produced rises from Q_1 to Q_2, the socially optimal level of production.

the government pays a subsidy per donut produced of $S = MB$. The subsidy would lower the private marginal cost of donut production, shifting the private marginal cost curve down by *MB* for each unit produced. This will result in a new *PMC* curve, PMC_2, which is identical to the *SMC* curve. The subsidy has caused the donut shop to internalize the positive externality, and the market moves from a situation of underproduction to one of optimal production.

Regulation

Throughout this discussion, you may have been asking yourself: Why this fascination with prices, taxes, and subsidies? If the government knows where the socially optimal level of production is, why doesn't it just mandate that production take place at that level, and forget about trying to give private actors incentives to produce at the optimal point? Using Figure 5-6 as an example, why not just mandate a level of steel production of Q_2 and be done with it?

In an ideal world, Pigouvian taxation and regulation would be identical. Because regulation appears much more straightforward, however, it has been the traditional choice for addressing environmental externalities in the United States and around the world. When the U.S. government wanted to reduce emissions of sulfur dioxide (SO_2) in the 1970s, for example, it did so by putting a limit or cap on the amount of sulfur dioxide that producers could emit, not by a tax on emissions. In 1987, when the nations of the world wanted to phase out the use of chlorofluorocarbons (CFCs), which were damaging the ozone layer, they banned the use of CFCs rather than impose a large tax on products that used CFCs.

Given this governmental preference for quantity regulation, why are economists so keen on taxes and subsidies? In practice, there are complications that may make taxes a more effective means of addressing externalities. In the next section, we discuss two of the most important complications. In doing so, we illustrate the reasons that policy makers might prefer regulation, or the "quantity approach" in some situations, and taxation, or the "price approach" in others.

▶ APPLICATION

Taxes and Regulation in Practice: The Case of the Baltic Sea[10]

The Baltic Sea is the world's largest brackish sea, a mixture of salt and fresh water. Considered a healthy ecosystem until the 1950s, the Baltic is now one of the most polluted bodies of water on earth. The pollution comes now largely from the former communist countries of Eastern Europe, whose inefficient industries and municipalities continue to send pollutants into the sea and the areas that surround and drain into it. Chemical plants in Poland release toxins into nearby soil, while the Russian city of St. Petersburg sends its untreated sewage directly into the Neva River, which in turn flows to the Baltic. The Western European nations are, however, not blameless. Swedish agriculture uses harmful fertilizers that leach into the Baltic's waters, and highly polluting factories in various Western European nations, though now largely closed, were responsible for some of the chemicals that remain in the sea to this day.

This pollution threatens human health, because some species of fish caught in the Baltic Sea now contain dangerously high levels of dioxin, a cancer-causing substance released when plastics and fuels are burned. Moreover, it also weakens the viability of the local fishing industry on which the livelihoods of many Baltic Sea residents depend. Thus, this is a classic negative externality.

The fall of communism in 1989 opened up possibilities for international cooperation that the countries of the Baltic region were quick to seize upon. In 1990, Sweden coordinated the creation of the Baltic Sea Joint Comprehensive Environmental Action Programme (JCP), an agreement to begin a massive cleanup effort among 14 nations close to the Baltic Sea. The JCP identified 132 hot spots, particularly large sources of pollution, and agreed to spend about $1 billion a year for 20 years to clean them up. Funding comes from the wealthier parties to the agreement, as well as from international institutions like the World Bank and European Union. The agreement thus allowed wealthier countries like Sweden and Finland to begin protecting their fishing industries and gave poorer countries funds to modernize industrial and municipal systems.

After the agreement was signed, a further set of questions arose. When trying to clean up a pollution hot spot, should governments use regulation (like forbidding the dumping of untreated sewage) or taxation (a charge per unit of

[10] Helsinki Commission (2003).

sewage dumped)? Under the JCP, as it turns out, both regulation and taxation have been used, often simultaneously. Some examples:

- Poland recently succeeded in having ten hot spots wiped off the list by quintupling (since 1990) investment in technology for environmental protection. Poland spent hundreds of millions of dollars ensuring that the vast majority of its industrial and municipal wastewater was being treated before entering the Baltic system. Surprisingly, only 6% of these funds came from external sources. The remaining 94% was raised by Poland itself, in the form of fines and fees levied on domestic polluters. A tax on pollution was thus being used to fund compliance with regulations demanding the treatment of wastewater.
- The Swedish city of Käppala now runs its own treatment plant through which industrial and municipal wastewater must flow before entering the Baltic system. Industries are forbidden from discharging wastewater that is corrosive or toxic (regulation) and are charged a fee by the city for the volume of wastewater and for each kilogram of pollutant present in the water sent to the treatment plant (taxation). The fees, which range from $0.50 to $10 per kilogram depending on the pollutant, reflect the cost to the city of treating the water.
- In 2002, the JCP was asked to develop ways of dealing with particular hot spots in Ukraine and Belarus that had arisen because of overloaded and obsolete wastewater treatment systems. The JCP noted that most European countries levy significant charges for water usage on households and industry. Belarus and Ukraine charge only 2¢ per cubic meter of water used, much lower than other countries, resulting in a daily consumption of nearly 100 gallons per person, twice the European average! The JCP thus recommended that those countries raise their water fees to accurately reflect the cost of treating water being discharged into the Baltic system.

The challenges to the Baltic Sea are hardly over. To date, around 80 of the original 132 hot spots still remain heavily polluting. The main challenge, unsurprisingly, is to find the funding to deal with such spots. St. Petersburg, for example, continues as the Baltic's single largest polluter because it cannot raise the funds necessary to complete a partially built sewage treatment plant. The JCP nevertheless provides an interesting example of how to use both regulation and taxation to accomplish environmental goals. ◀

5.4 Distinctions Between Price and Quantity Approaches to Addressing Externalities

In this section, we compare price (taxation) and quantity (regulation) approaches to addressing externalities, using more complicated models in which the social efficiency implications of intervention might differ between the two approaches. The goal in comparing these approaches is to find the most efficient path to environmental targets. That is, for any reduction in pollution, the goal is to find the least-cost means of achieving that reduction.[11]

Basic Model

To illustrate the important differences between the price and quantity approaches, we have to add one additional complication to the basic competitive market that we have worked with thus far. In that model, the only way to reduce pollution was to cut back on production. In reality, there are many *other* technologies available for reducing pollution besides simply scaling back production. For example, to reduce sulfur dioxide emissions from coal-fired power plants, utilities can install smokestack scrubbers that remove SO_2 from the emissions and sequester it, often in the form of liquid or solid sludge that can be disposed of safely. Passenger cars can also be made less polluting by installing "catalytic converters," which turn dangerous nitrogen oxide into compounds that are not harmful to public health.

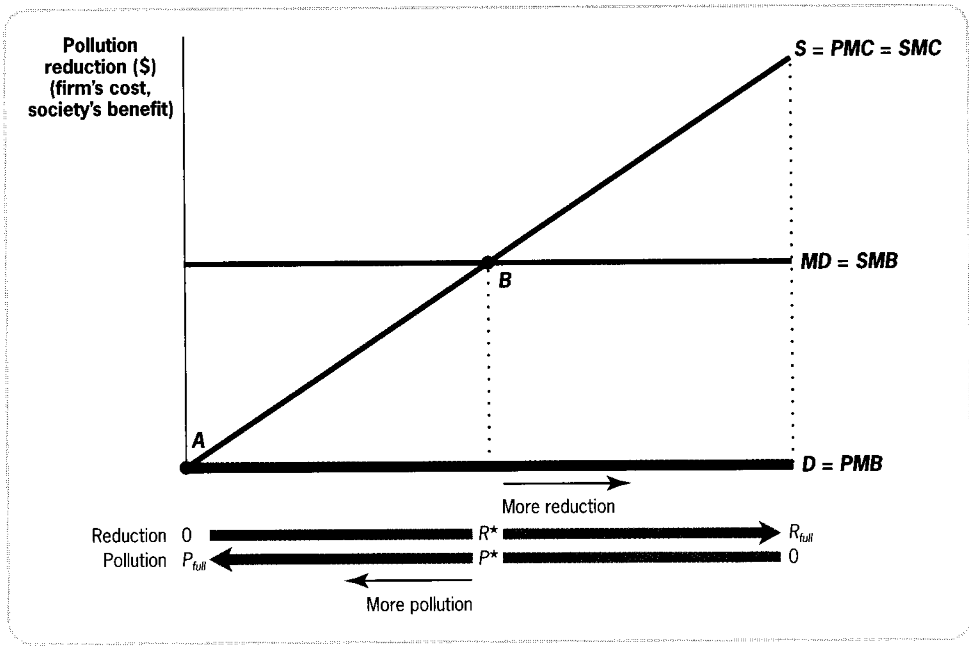
To understand the differences between price and quantity approaches to pollution reduction it is useful to shift our focus from the market for a good (e.g., steel) to the "market" for pollution reduction, as illustrated in Figure 5-8 (page 134). In this diagram, the horizontal axis measures the extent of pollution reduction undertaken by a plant; a value of zero indicates that the plant is not engaging in any pollution reduction. Thus, the horizontal axis also measures the amount of pollution: as you move to the right, there is more pollution reduction and less pollution. We show this by denoting *more reduction* as you move to the right on the horizontal axis; R_{full} indicates that pollution has been reduced to zero. *More pollution* is indicated as you move to the left on the horizontal axis; at P_{full}, the maximum amount of pollution is being produced. The vertical axis represents the cost of pollution reduction to the plant, or the benefit of pollution reduction to society (that is, the benefit to other producers and consumers who are not compensated for the negative externality).

The *MD* curve represents the marginal damage that is averted by additional pollution reduction. This measures the social marginal benefit of pollution reduction. Marginal damage is drawn flat at $100 for simplicity, but it could be downward-sloping due to diminishing returns. The private marginal benefit of pollution reduction is zero, so it is represented by the horizontal axis; there is no gain to the plant's private interests from reducing dumping.

The *PMC* curve represents the plant's private marginal cost of reducing pollution. The *PMC* curve slopes upward because of diminishing marginal productivity of this input. The first units of pollution are cheap to reduce: just tighten a few screws or put a cheap filter on the sludge pipe. Additional units

[11] The discussion of this section focuses entirely on the efficiency consequences of tax vs. regulatory approaches to addressing externalities. There may be important equity considerations as well, however, which affect the government's decision over policy instruments. We will discuss the equity properties of taxation in Chapter 19.

■ FIGURE 5-8



The Market for Pollution Reduction • The marginal cost of pollution reduction (*PMC* = *SMC*) is a rising function, while the marginal benefit of pollution reduction (*SMB*) is (by assumption) a flat marginal damage curve. Moving from left to right, the amount of pollution reduction increases, while the amount of pollution falls. The optimal level of pollution reduction is R^*, the point at which these curves intersect. Since pollution is the complement of reduction, the optimal amount of pollution is P^*.

of reduction become more expensive, until it is incredibly expensive to have a completely pollution-free production process. Because there are no externalities from the production of pollution reduction (the externalities come from the end product, reduced pollution, as reflected in the *SMB* curve, not from the process involved in actually reducing the pollution), the *PMC* is also the *SMC* of pollution reduction.

The free market outcome in any market would be zero pollution reduction. Since the cost of pollution is not borne by the plant, it has no incentive to reduce pollution. The plant will choose zero reduction and a full amount of pollution P_{full} (point *A*, at which the *PMC* of zero equals the *PMB* of zero).

What is the optimal level of pollution reduction? The optimum is *always* found at the point at which social marginal benefits and costs are equal, here point *B*. The optimal quantity of pollution reduction is R^*: at that quantity, the marginal benefits of reduction (the damage done by pollution) and the marginal costs of reduction are equal. Note that setting the optimal amount of pollution reduction is the same as setting the optimal amount of pollution. If the free market outcome is pollution reduction of 0 and pollution of P_{full}, then the optimum is pollution reduction of R^* and pollution of P^*.

Price Regulation (Taxes) vs. Quantity Regulation in This Model

Now, contrast the operation of taxation and regulation in this framework. The optimal tax, as before, is equal to the marginal damage done by pollution, $100. In this situation, the government would set a tax of $100 on each unit of pollution. Consider the plant's decision under this tax. For each unit of pollution the plant makes, it pays a tax of $100. If there is any pollution reduction that the plant can do that costs less than $100, it will be cost-effective to make that reduction: the plant will pay some amount less than $100 to get rid of the pollution, and avoid paying a tax of $100. With this plan in place, plants will have an incentive to reduce pollution up to the point at which the cost of that reduction is equal to the tax of $100. That is, plants will "walk up" their marginal cost curves, reducing pollution up to a reduction of $R^\star$ at point B. Beyond that point, the cost of reducing pollution exceeds the $100 that they pay in tax, so they will just choose to pay taxes on any additional units of pollution rather than to reduce pollution further. Thus, a Pigouvian (corrective) tax equal to $100 achieves the socially optimal level of pollution reduction, just as in the earlier analysis.

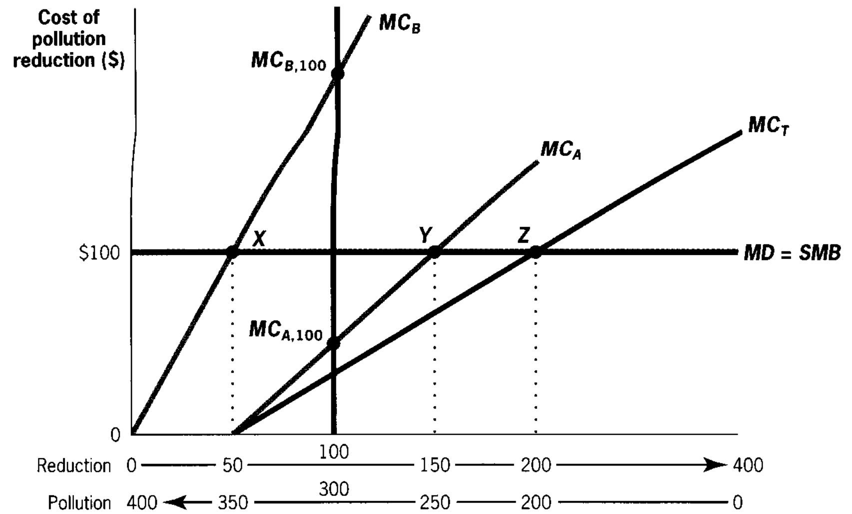
Regulation is even more straightforward to analyze in this framework. The government simply mandates that the plant reduce pollution by an amount $R^\star$, to get to the optimal pollution level $P^\star$. Regulation seems more difficult than taxation because, in this case, the government needs to know not only *MD* but also the shape of the *MC* curve as well. This difficulty is, however, just a feature of our assumption of constant *MD;* for the more general case of a falling *MD,* the government needs to know the shapes of both *MC* and *MD* curves in order to set either the optimal tax or the optimal regulation.

Multiple Plants with Different Reduction Costs

Now, let's add two wrinkles to the basic model. First, suppose there are now two steel plants doing the dumping, with each plant dumping 200 units of sludge into the river each day. The marginal damage done by each unit of sludge is $100, as before. Second, suppose that technology is now available to reduce sludge associated with production, but this technology has different costs at the two different plants. For plant *A* reducing sludge is cheaper at any level of reduction, since it has a newer production process. For the second plant, *B,* reducing sludge is much more expensive for any level of reduction.

Figure 5-9 (page 136) summarizes the market for pollution reduction in this case. In this figure, there are separate marginal cost curves for the plant *A* (MC_A) and for plant *B* (MC_B). At every level of reduction, the marginal cost to plant *A* is lower than the marginal cost to plant *B,* since plant *A* has a newer and more efficient production process available. The total marginal cost of reduction in the market, the horizontal sum of these two curves, is MC_T: for any total reduction in pollution, this curve indicates the cost of that reduction if it is distributed most efficiently across the two plants. For example, the total marginal cost of a reduction of 50 units is zero, since plant *A* can reduce 50 units for free; so the efficient combination is to have plant *A* do all the reducing. The socially efficient level of pollution reduction (and of pollution)

■ FIGURE 5-9



Pollution Reduction with Multiple Firms • Plant *A* has a lower marginal cost of pollution reduction at each level of reduction than does Plant *B*. The optimal level of reduction for the market is the point at which the sum of marginal costs equals marginal damage (at point *Z*, with a reduction of 200 units). An equal reduction of 100 units for each plant is inefficient since the marginal cost to plant *B* (MC_B) is so much higher than the marginal cost to plant *A* (MC_A). The optimal division of this reduction is where each plant's marginal cost is equal to the social marginal benefit (which is equal to marginal damage). This occurs when plant *A* reduces by 150 units and plant *B* reduces by 50 units, at a marginal cost to each of $100.

is the intersection of this MC_T curve with the marginal damage curve, *MD,* at point *Z,* indicating a reduction of 200 units (and pollution of 200 units).

Policy Option 1: Quantity Regulation Let's now examine the government's policy options within the context of this example. The first option is regulation: the government can demand a total reduction of 200 units of sludge from the market. The question then becomes: How does the government decide how much reduction to demand from each plant? The typical regulatory solution to this problem in the past was to ask the plants to split the burden: each plant reduces pollution by 100 units to get to the desired total reduction of 200 units.

This is not an efficient solution, however, because it ignores the fact that the plants have different marginal costs of pollution reduction. At an equal level of pollution reduction (and pollution), each unit of reduction costs less for plant *A* (MC_A) than for plant *B* (MC_B). If, instead, we got more reduction from plant *A* than from plant *B,* we could lower the total social costs of pollution reduction by taking advantage of reduction at the low-cost option (plant *A*). So society as a whole is worse off if plant *A* and plant *B* have to make equal reduction than if they share the reduction burden more efficiently.

This point is illustrated in Figure 5-9. The efficient solution is one where, for each plant, the marginal cost of reducing pollution is set equal to the social marginal benefit of that reduction; that is, where each plant's marginal cost curve intersects with the marginal benefit curve. This occurs at a reduction of 50 units for plant *B* (point *X*), and 150 units for plant *A* (point *Y*). Thus, mandating a reduction of 100 units from each plant is inefficient; total costs of achieving a reduction of 200 units will be lower if plant *A* reduces by a larger amount.

Policy Option 2: Price Regulation Through a Corrective Tax The second approach is to use a Pigouvian corrective tax, set equal to the marginal damage, so each plant would face a tax of $100 on each unit of sludge dumped. Faced with this tax, what will each plant do? For plant *A*, any unit of sludge reduction up to 150 units costs less than $100, so Plant *A* will reduce its pollution by 150 units. For plant *B*, any unit of sludge reduction up to 50 units costs less than $100, so it will reduce pollution by 50 units. Note that these are exactly the efficient levels of reduction! Just as in our earlier analysis, Pigouvian taxes cause efficient production by raising the cost of the input by the size of its external damage, thereby raising private marginal costs to social marginal costs. Taxes are preferred to quantity regulation, with an equal distribution of reductions across the plants, because taxes give plants more flexibility in choosing their optimal amount of reduction, allowing them to choose the efficient level.

Policy Option 3: Quantity Regulation with Tradable Permits Does this mean that taxes *always* dominate quantity regulation with multiple plants? Not necessarily. If the government had mandated the appropriate reduction from each plant (150 units from *A* and 50 units from *B*), then quantity regulation would have achieved the same outcome as the tax. Such a solution would, however, require much more information. Instead of just knowing the marginal damage and the total marginal cost, the government would also have to know the marginal cost curves of each individual plant. Such detailed information would be hard to obtain.

Quantity regulation can be rescued, however, by adding a key flexibility: issue permits that allow a certain amount of pollution and let the plants trade. Suppose the government announces the following system: it will issue 200 permits that entitle the bearer to produce one unit of pollution. It will initially provide 100 permits to each plant. Thus, in the absence of trading, each plant would be allowed to produce only 100 units of sludge, which would in turn require each plant to reduce its pollution by half (the inefficient solution previously described).

If the government allows the plants to trade these permits to each other, however, plant *B* would have an interest in buying permits from plant *A*. For plant *B*, reducing sludge by 100 units costs $MC_{B,100}$, a marginal cost much greater than plant *A*'s marginal cost of reducing pollution by 100 units, which is $MC_{A,100}$. Thus, plants *A* and *B* can be made better off if plant *B* buys a permit from plant *A* for some amount between $MC_{A,100}$ and $MC_{B,100}$, so that plant *B* would pollute 101 units (reducing only 99 units) and plant *A* would pollute 99 units (reducing 101 units). This transaction is beneficial for plant *B* because as long as the cost of a permit is below $MC_{B,100}$, plant *B* pays less than the amount it would cost plant B to reduce the pollution on its own. The trade is beneficial for plant A as long as it receives for a permit at least $MC_{A,100}$, since it can reduce the sludge for a cost of only $MC_{A,100}$, and make money on the difference.

By the same logic, a trade would be beneficial for a second permit, so that plant B could reduce by only 98, and plant A would reduce by 102. In fact, any trade will be beneficial until plant B is reducing by 50 units and plant A is reducing by 150 units. At that point, the marginal costs of reduction across the two producers are equal (to $100), so that there are no more gains from trading permits.

What is going on here? We have simply returned to the intuition of the Coasian solution: we have *internalized the externality by providing property rights to pollution.* So, like Pigouvian taxes, trading allows the market to incorporate differences in the cost of pollution reduction across firms. In Chapter 6, we discuss a successful application of trading to the problem of environmental externalities.

Uncertainty About Costs of Reduction

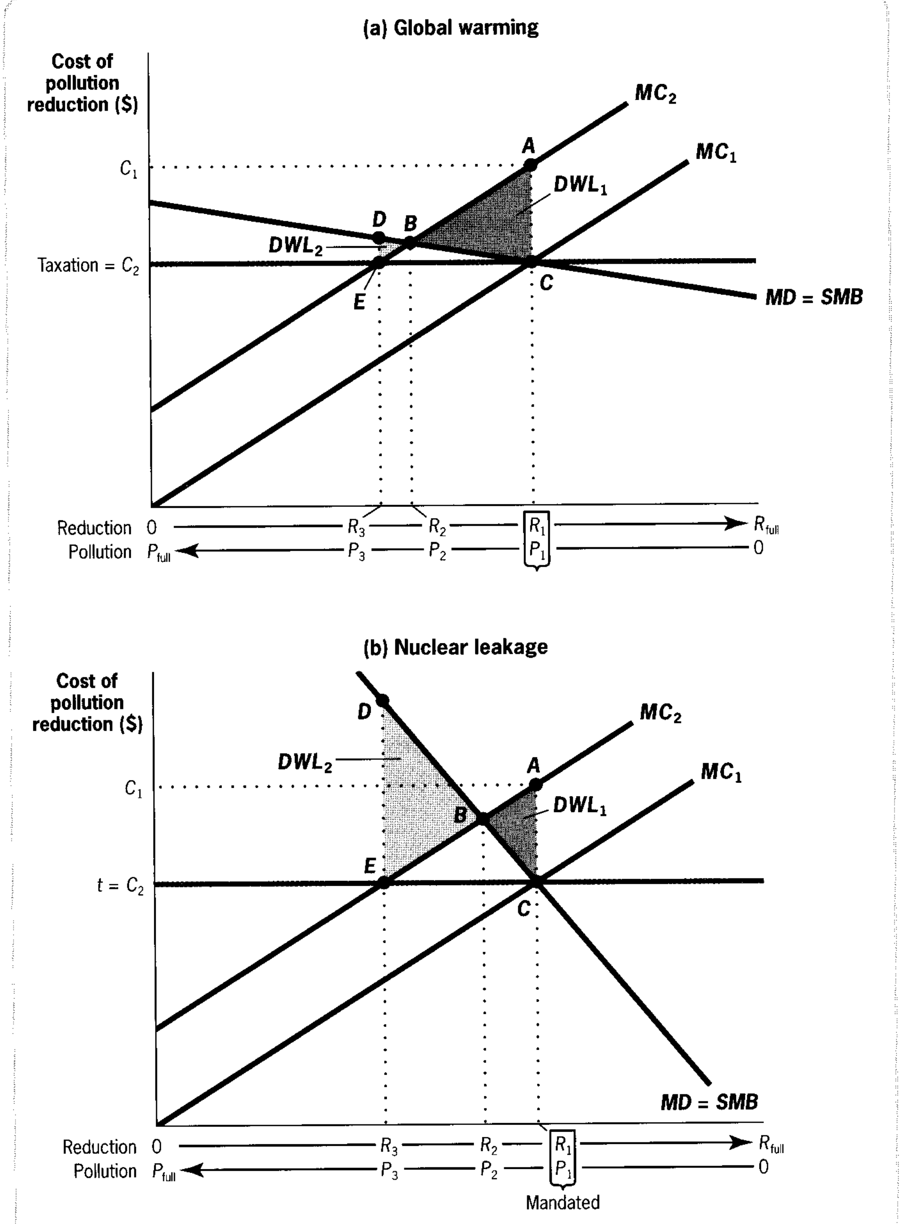
Differences in reduction costs across firms are not the only reason that taxes or regulation might be preferred. Another reason is that the costs or benefits of regulation could be uncertain. Consider two extreme examples of externalities: global warming and nuclear leakage. Figure 5-10 extends the pollution reduction framework from Figure 5-8 to the situation in which the marginal damage (which is equal to the marginal social benefit of pollution reduction) is now no longer constant, but falling. That is, the benefit of the first unit of pollution reduction is quite high, but once the production process is relatively pollution-free, additional reductions are less important (that is, there are diminishing marginal returns to reduction).

Panel (a) of Figure 5-10 considers the case of global warming. In this case, the exact amount of pollution reduction is not so critical for the environment. Since what determines the extent of global warming is the total accumulated stock of carbon dioxide in the air, which accumulates over many years from sources all over the world, even fairly large shifts in carbon dioxide pollution in one country today will have little impact on global warming. In that case, we say that the social marginal benefit curve (which is equal to the marginal damage from global warming) is *very flat:* that is, there is little benefit to society from modest additional reductions in carbon dioxide emissions.

Panel (b) of Figure 5-10 considers the case of radiation leakage from a nuclear power plant. In this case, a very small difference in the amount of nuclear leakage can make a huge difference in terms of lives saved. Indeed, it is possible that the marginal damage curve (which is once again equal to the marginal social benefits of pollution reduction) for nuclear leakage is almost vertical, with each reduction in leakage being equally important in terms of saving lives. Thus, the social marginal benefit curve in this case is *very steep.*

Now, in both cases, imagine that we don't know the true costs of pollution reduction on the part of firms or individuals. The government's best guess is that the true marginal cost of pollution reduction is represented by curve

▪ FIGURE 5-10



Market for Pollution Reduction with Uncertain Costs • In the case of global warming (panel (a)), the marginal damage is fairly constant over large ranges of emissions (and thus emission reductions). If costs are uncertain, then taxation at level $t = C_2$ leads to a much lower deadweight loss (*DBE*) than does regulation of R_1 (*ABC*). In the case of nuclear leakage (panel (b)), the marginal damage is very steep. If costs are uncertain, then taxation leads to a much larger deadweight loss (*DBE*) than does regulation (*ABC*).

MC_1 in both panels. There is a chance, however, that the marginal cost of pollution reduction could be the much higher, as represented by the curve MC_2. This uncertainty could arise because the government has an imperfect understanding of the costs of pollution reduction to the firm, or it could arise because both the government and the firms are uncertain about the ultimate costs of pollution reduction.

Implications for Effect of Price and Quantity Interventions This uncertainty over costs has important implications for the type of intervention that reduces pollution most efficiently in each of these cases. Consider regulation first. Suppose that the government mandates a reduction, R_1, which is the optimum if costs turn out to be given by MC_1: this is where social marginal benefits equal social marginal costs of reduction if marginal cost equals MC_1. Suppose now that the marginal costs actually turn out to be MC_2, so that the optimal reduction should instead be R_2, where $SMB = MC_2$. That is, regulation is mandating a reduction in pollution that is too large, with the marginal benefits of the reduction being below the marginal costs. What are the efficiency implications of this mistake?

In the case of global warming (panel (a)), these efficiency costs are quite high. With a mandated reduction of R_1, firms will face a cost of reduction of C_1, the cost of reducing by amount R_1 if marginal costs are described by MC_2. The social marginal benefit of reduction of R_1 is equal to C_2, the point where R_1 intersects the *SMB* curve. Since the cost to firms (C_1) is so much higher than the benefit of reduction (C_2), there is a large deadweight loss (DWL_1) of area *ABC* (the triangle that incorporates all units where cost of reduction exceeds benefits of reduction).

In the case of nuclear leakage (panel (b)), the costs of regulation are very low. Once again, with a mandated reduction of R_1, firms will face a cost of reduction of C_1, the cost of reducing by amount R_1 if marginal costs are described by MC_2. The social marginal benefit of reduction at R_1 is once again equal to C_2. In this case, however, the associated deadweight loss triangle *ABC* (DWL_1) is much smaller than in panel (a), so the inefficiency from regulation is much lower.

Now, contrast the use of corrective taxation in these two markets. Suppose that the government levies a tax designed to achieve the optimal level of reduction if marginal costs are described in both cases by MC_1, which is R_1. As discussed earlier, the way to do this is to choose a tax level, *t*, such that the firm chooses a reduction of R_1. In both panels, the tax level that will cause firms to choose reduction R_1 is a tax equal to C_2, where MC_1 intersects *MD*. A tax of this amount would cause firms to do exactly R_1 worth of reduction, if marginal costs are truly determined by MC_1.

If the true marginal cost ends up being MC_2, however, the tax causes firms to choose a reduction of R_3, where their true marginal cost is equal to the tax (where $t = MC_2$ at point *E*), so that there is *too little* reduction. In the case of global warming in panel (a), the deadweight loss (DWL_2) from reducing by R_3 instead of R_2 is only the small area *DBE*, representing the units where social marginal benefits exceed social marginal costs. In the case of nuclear leakage in panel (b), however, the deadweight loss (DWL_2) from reducing by R_3 instead of R_2 is a much larger area, *DBE*, once again representing the units where social marginal benefits exceed social marginal costs.

Implications for Instrument Choice The central intuition here is that *the instrument choice depends on whether the government wants to get the amount of pollution reduction right or whether it wants to minimize costs.* Quantity regulation assures there is as much reduction as desired, regardless of the cost. So, if it is critical to get the amount exactly right, quantity regulation is the best way to go. This is why the efficiency cost of quantity regulation under uncertainty is so much lower with the nuclear leakage case in panel (b). In this case, it is critical to get the reduction close to optimal: so if we end up costing firms extra money in the process, so be it. For global warming, getting the reduction exactly right isn't very important; so it is inefficient in this case to mandate a very costly option for firms.

Price regulation through taxes, on the other hand, assures that the cost of reductions never exceeds the level of the tax, but leaves the amount of reduction uncertain. That is, firms will never reduce pollution beyond the point at which reductions cost more than the tax they must pay (the point at which the tax intersects their true marginal cost curve, MC_2). If marginal costs turn out to be higher than anticipated, then firms will just do less pollution reduction. This is why the deadweight loss of price regulation in the case of global warming is so small in panel (a): the more efficient outcome is to get the exact reduction wrong but protect firms against very high costs of reduction. This is clearly not true in panel (b): for nuclear leakage, it is most important to get the quantity close to right (almost) regardless of the cost to firms.

In summary, quantity regulations ensure environmental protection, but at a variable cost to firms, while price regulations ensure the cost to the firms, but at a variable level of environmental protection. So, if the value of getting the environmental protection close to right is high, then quantity regulations will be preferred; but if getting the protection close to right is not so important, then price regulations are a preferred option.

5.5 Conclusion

Externalities are the classic answer to the "when" question of public finance: when one party's actions affect another party, and the first party doesn't fully compensate (or get compensated by) the other for this effect, then the market has failed and government intervention is potentially justified. In some cases, the market is likely to find a Coasian solution whereby negotiations between the affected parties lead to the "internalization" of the externality. For many cases, however, only government intervention can solve the market failure.

This point naturally leads to the "how" question of public finance. There are two classes of tools in the government's arsenal for dealing with externalities: price-based measures (taxes and subsidies) and quantity-based measures (regulation). Which of these methods will lead to the most efficient regulatory outcome depends on factors such as the heterogeneity of the firms being regulated, the flexibility embedded in quantity regulation, and the uncertainty over the costs of externality reduction. In the next chapter, we take these somewhat abstract principles and apply them to some of the most important externalities facing the United States (and the world) today.