CHAPTER

4 Incentive design*

4.1 Introduction

Incentives are the key between economics and better environmental policy. People have less incentive to protect the environment today when the social costs fall on others in the future (as we discussed in Chapter 3). A nation might not have incentive to reduce its domestic carbon emissions to curb climate change if it believes other nations will not do likewise. A producer chasing profits may not have incentive to clean up its emissions to the degree desired by the rest of society. A consumer with a tight budget has less incentive to buy "eco-friendly" goods when "cheap and dirty" goods are less expensive. A homeowner might think recycling is a good idea but has no incentive to take the time with a busy family. Landowners who shelter endangered species on private property but fear costly government intervention have an incentive to follow a "shoot, shovel and shut up" strategy, i.e., take actions to harm the species by killing it or destroying its habitat before government intervention.

This chapter addresses how societies can use economic incentives within public policy decisions to align private motives with social objectives to protect the environment. In general, a social regulator has three broad policy tools to help her realign private incentives with environmental goals: legal mandates and technological restrictions (e.g., air and water filtration technology), cooperative institutions to share information between regulators, polluters, and victims (e.g., voluntary agreements, Coasean bargaining), and economic incentive mechanisms to increase the cost of "environmental shirking" on environmental protection (e.g., charges, fees, taxes, tradable permits). This chapter focuses on the third tool, economic incentives.

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Economists have long promoted incentive systems as a cost-effective alternative to inflexible command-and-control environmental regulations (e.g., uniform technological mandates). The basic idea behind incentives is to design an incentive system with private flexibility to achieve desired public objectives. Incentives raise the cost of environmental shirking, while allowing people the flexibility to find the least-cost pollution control strategy. Economic incentive systems can also be used to implement the so-called "polluter-pays principle," in which the entity that causes pollution pays for the clean-up costs and is responsible for any damages suffered.

By increasing the cost of environmental shirking, the producer has an incentive to provide the socially optimal level of pollution control, or some other sub-optimal but socially desirable target (e.g., the precautionary principle). To illustrate, consider the case of Figure 4.1, which shows the marginal cost (MC) and marginal benefit (MB) of an extra unit of pollution control. Producers control pollution before it enters the environment through abatement technologies of their choice (e.g., filters, condensation, oxidation, scrubbers), and producers/governments control pollution after it hits the environment through clean-up and remediation technologies.

Figure 4.1 illustrates the textbook case of optimal pollution control. Here MCs are positively sloped, that is, control costs increase at an increasing rate. This captures the idea that while control costs are low initially, they increase tremendously as society moves toward total pollution control. Achieving a zero-risk/no-pollution society with given technologies implies near infinite opportunity costs. In contrast, marginal benefits are negatively sloped, i.e., the benefits of control increase but at a decreasing rate. Each

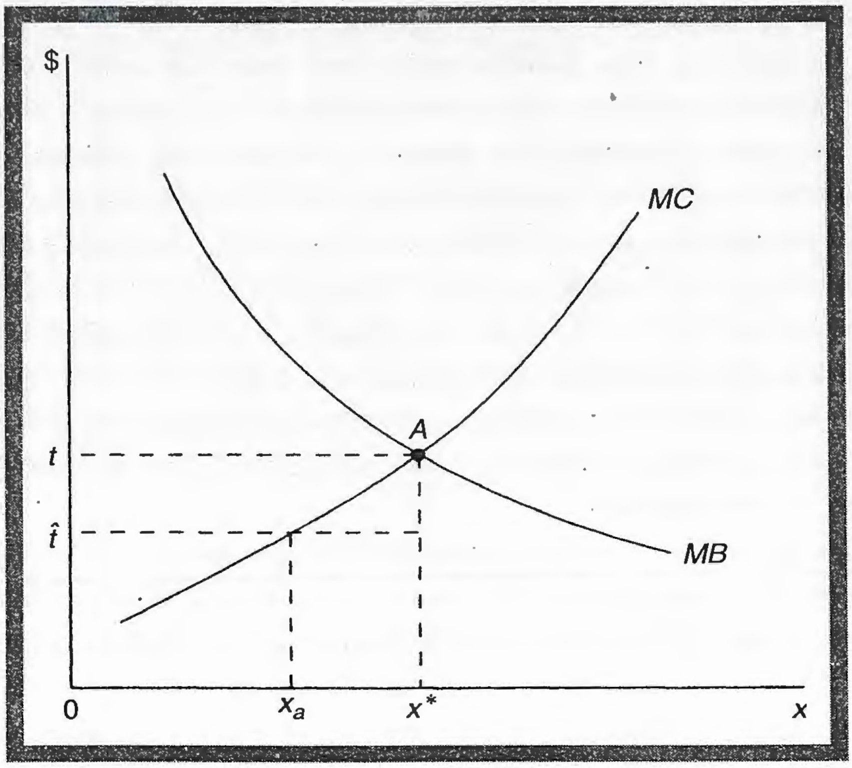

Figure 4.1 Socially optimal level of pollution control

incremental unit of control provides fewer incremental benefits to society since most of the pollution is now already cleaned up. While the exact slopes of these curves are an empirical question, Figure 4.1 is useful to illustrate how economists think about optimal pollution control.

Ideally, society would want a regulator (or firm) to consider both the MBs and the MCs when selecting the optimal level of pollution control. If MB > MC, society should increase pollution control to capture the net benefits; if MB < MC, control should decrease to avoid the net losses. The socially optimal level of pollution control is then achieved at the point in which net benefits or net losses are zero, that is MB = MC (point A in Figure 4.1). If a private firm must pay the marginal costs of pollution control without receiving any of the marginal benefits (which, say, accrue to the entire global population), its private optimum is to set MC = 0 (point B).

Incentive systems are designed to provide an incentive for a firm to move from point B to point A on its own. A regulator assigns a price to not controlling pollution, such that firms now must pay for decisions that damage the environment. In principle, the regulator can affect firm behavior by imposing a tax (or emissions charge) at the level in which marginal benefits and marginal costs are equal, $t = \text{MB} = \text{MC}$. Now the producer either invests in pollution control or pays the tax, t, for each unit of pollution. In Figure 4.1, the tax exceeds the marginal control costs are equal, $t > \text{MC}$, up to point A; therefore it is cheaper for the firm to control pollution rather than pay the tax. This tax provides incentive so the producer increases control until its private level of control equals the social optimum, MC = MB. Such pollution taxes are known famously as *Pigovian taxes*, named after British economist Alfred Pigou. See Baumol and Oates (1988) for a detailed general equilibrium model of Pigovian charges and pollution control.

In this chapter, we discuss incentives by grouping them into three categories: price rationing (i.e., a Pigovian tax), liability rules, and quantity rationing (i.e., tradable permits). Price rationing increases the costs of shirking by setting a Pigovian charge, tax, or subsidy on producer behavior or products. Emission or effluent charges are the most commonly discussed form of price rationing. Liability rules set up a socially acceptable benchmark of behavior so if a producer violates this benchmark he suffers some financial consequence. Non-compliance fees, deposit-refund schemes, and performance bonds represent alternative liability rules (see Khanna, 2001). Quantity rationing uses a tradable permit system. A tradable permit system sets a fixed emission (protection) level and then allows low control cost producers to reduce pollution and sell excess permits to high-cost producers. Chapter 5 looks at two incentive schemes, pollution taxes and tradable permits, in more detail.

In this chapter, we also discuss how asymmetric information affects incentive design. A producer knows more about his own costs of pollution control or choice of control strategies than a regulator. The producer can take advantage of this asymmetry to gain additional rents (Lewis, 1996; Laffont and Martimor, 2001). For example, nonpoint source pollution implies numerous, diffuse sources of emissions, making it too costly to perfectly monitor behavior and enforce pollution control (see Shortle and Dunn, 1986; Horan *et al.*, 2002). Given the inability to monitor action perfectly, moral hazard implies a producer has an incentive to shirk on pollution control since the expected shirking costs are low. Unless the regulator can overcome this barrier of asymmetric information, the end result is too little pollution control and too much pollution. As a consequence, the regulator may have to give up some efficiency gains with an economic incentive scheme to reduce the information rents associated with moral hazard or adverse selection. Recall that moral hazard exists when a regulator cannot observe the actions of a firm or consumer (e.g., high or low abatement); adverse selection exists when she cannot observe the type of firm or consumer (e.g., high or low cost producer). A mixed system of economic incentives and technological restrictions is more likely to be considered by the regulator.

Finally, we consider a set of criteria to evaluate the effectiveness of an incentive system for environmental problems. Some incentive schemes work better than others depending on the environmental issue and the criteria deemed most important by the policymakers. We present five criteria: an adequate information base, a strong legal structure, competitive markets, administrative capacity, and political feasibility.

4.2 Price rationing: Charges and subsidies

4.2.1 Emission charges

Emission charges are Pigovian taxes or fees levied on the discharge of pollutants into air, water, or onto the soil, or on the generation of noise. These charges are designed to reduce the quantity or improve the quality of pollution by making polluters pay at least part of the costs of the harm they do to the environment. Following Pigou, economists favor emission charges over other options because by charging for every unit of pollution released into the environment they induce firms to lower their emissions to account for social damages. Because pollution control costs typically differ among producers (e.g., due to location, age of capital stock, products), those with lower control costs reduce emission levels further than high control cost polluters. This cost differentiation matters because it allows society to achieve its environmental protection at the lowest possible costs, which implies more resources are freed up for other desired collective goods like education and health care. Emission charges give producers an incentive to develop and adopt newer and better pollution control technologies as a means of bringing down the charges they must pay. In doing so, we can achieve more environmental protection at lower costs.

We illustrate the idea behind the emission charge by considering a profit-maximizing producer who produces a valuable good or service, and also generates pollution (e.g., waste water emissions). Let the producer select output, q, to maximize his or her net profits, $\pi = pq - c(q)$, where p is the fixed market price of q and $c(q)$ is the cost function associated with producing q. For simplicity, we are assuming the producer is a price-taker in a perfectly competitive output market. Assume costs increase at an increasing rate, $c' \equiv dc/dq > 0$ and $c'' \equiv d^2c/dq^2 > 0$. The producer's profit-maximizing problem is to maximize profits

$$\max\ [pq - c(q)] \tag{4.1}$$

The producer selects his or her optimal level of output, q^*, to maximize net profits by equating the MB of an extra unit of output, p, to the MC, c',

$$\text{MB} \equiv p = c' \equiv \text{MC} \tag{4.2}$$

Figure 4.2 shows the private optimal level of production.

The production of q also emits a pollutant feared to damage human and environmental health. For simplicity, let the total emissions level of the pollutant be represented by a linear relationship, $\alpha = \beta q$, where β is a fixed emission coefficient, that is as production increases, emissions increase at the constant rate of β. Let $D(\alpha)$ represent the monetary damages associated with the level of emissions. Assume as emissions increase, damages increase, $D' \equiv dD/d\alpha > 0$. The incremental increase in damages represents the marginal social costs (MSC) due to another unit of pollution.

If a producer accounted for the damages to human and environmental health, his problem is

$$\text{Max}\ [pq - c(q) - D(\beta q)] \tag{4.3}$$

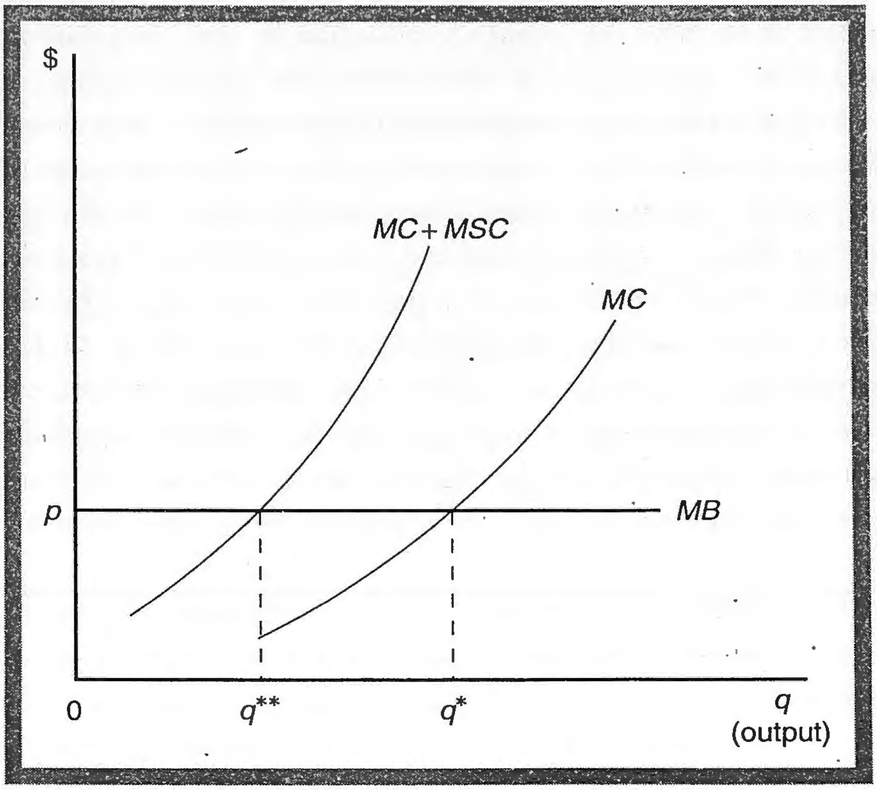

Figure 4.2 Privately and socially optimal levels of output

He selects an optimal level of output, q^{**}, to maximize net profits by equating the marginal benefit, p, to the private marginal cost, c', and the marginal social cost, $\beta D'$, or

$$\mathrm{MB} \equiv p = c' + \beta D' \equiv \mathrm{MC} + \mathrm{MSC} \tag{4.4}$$

The producer accounts for the damages by reducing his output to q^{**} from q^{*}. Figure 4.2 shows if marginal social costs are included in the producer's decision, his optimal response is to decrease output until the marginal benefit equals the sum of the private and social marginal costs.

The open question is how society can induce the producer to internalize the marginal social cost into his decision making. The classic solution is the Pigovian tax. A regulator can set this tax, t (also called an emissions charge), equal to the marginal social costs, $\beta D'$,

$$t = \beta D' \tag{4.5}$$

The producer's problem now becomes

$$\text{Max } [pq - c(q) - tq] \tag{4.6}$$

such that he chooses a level of q to maximize profits

$$p = c' + t \tag{4.7}$$

Since $t = \beta D'$, we see expression (4.7) is identical to (4.4). The implication is that the tax has caused the producer to internalize the external damages of pollution into his decision making, and has *voluntarily* selected society's desired level of output.

But as pointed by Coase (1960) more than four decades ago, if life was this simple, societies would have solved pollution problems long ago through Pigovian taxation. If a regulator could somehow measure the marginal social costs, MSC, that fall on the entire population, he could set the Pigovian tax accordingly. Measuring these social costs, however, is a challenge to say the least (as we will see in the following chapters). Pollution travels through air and water, sometimes in unpredictable ways, and might not affect health for a decade. Assigning a monetary value to an uncertain cause-and-effect relationship requires real resources and effort, which are referred to as transaction costs. In general, the transaction costs to create a Pigovian tax that achieves a social optimum are not trivial.

Let us shift back to the example of pollution control to illustrate this point. If a regulator is absolutely certain as to the marginal costs and benefits of pollution control, achieving the socially optimal level of control with an emission charge is straightforward. The regulator sets the emission charge, t, equal to the level at which marginal benefits, MB, equal the marginal control cost, MC, i.e. $t = \mathrm{MB} = \mathrm{MC}$, as we saw in Figure 4.1. Given this charge, a producer compares the charge to his marginal cost of control. If $t > \mathrm{MC}$, the producer invests in pollution control since it is cheaper than paying the emission charge per unit of emissions. The producer continues to control pollution until

$t = MC = MB$. At this level, the producer's private choice of pollution control matches the regulator's socially optimal level of control.

But if the regulator is uncertain about the marginal cost or benefit of pollution control, the effectiveness of price rationing with an emission charge depends on the slopes of the cost and benefit curves and how far expectations deviate from reality (see Weitzman, 1974). The slopes represent how the marginal costs and benefits change given an increase in pollution control. A flat slope implies costs and benefits do not change much as pollution control increases; a steep slope implies the opposite. Suppose the regulator knows the marginal benefits of control, but is uncertain about the marginal costs. The effectiveness of the emissions charge depends on the slope of the marginal benefits curve. If marginal benefits are constant across alternative levels of pollution control, the uncertainty about marginal control costs does not matter – the social optimum can be achieved regardless of the realized cost. Figure 4.3a illustrates the horizontal MB curve representing the constant marginal benefits. The curve EMC represents the regulator's expectation, or best guess, about the producer's marginal control cost. Point A represents the expected social optimum at which the marginal benefits equal the expected marginal costs, $MB = EMC$. The regulator sets the charge at $t = MB = EMC$, and sees if the realized cost deviates from his expectations.

Suppose the realized marginal costs are lower than expected, as represented by MC_L. The social optimum is at $MB = MC_L$ (point B), but this is also equal to the charge $t = MB = MC_L$. The private optimum is the social optimum, $x^* = x_L$. This result holds even if actual marginal costs are higher than expected, $t = MB = MC_H$ (point C), where $x^* = x_H$. The uniform emission charge perfectly matches the marginal benefit of control, so no divergence exists between the social and the private optima.

In the opposite case, in which marginal control benefits are extremely steep as reflected in Figure 4.3b, the results change. If the actual marginal costs are lower than expected, the producer supplies too much pollution control, $x_L > x^*$ (point E vs point F), where $t = MC_L > MB$. If the actual costs are higher, not enough control occurs, $x_H < x^*_H$, where $t = MC_H > MB$ (point G vs point H). The further the realized costs deviate from the expectations, the worse the tax performs, providing either too few or too many incentives to invest in pollution control.

Figure 4.3c shows an intermediately sloped marginal benefit curve. The emission charge provides the incentive to over- or under-invest in pollution control given the divergence between realized and actual costs, but the inefficiency is not as severe as in the case of the extremely steep slope. The flatter the marginal benefits curve the less severe the divergence of costs is on efficiency.

If we reverse the situation so marginal control costs are known with certainty but the benefits are uncertain, the emission charge again provides an incentive to over- or under-invest in pollution control. Figure 4.3d shows an intermediate case in which EMB represents the expected marginal benefits of pollution control. If the actual benefits exceed the expected benefits, the emission charge results in too little pollution control $t = MC < MB_H$. The opposite occurs if the expectations exceed the actual benefit, $t = MC > MB_L$ – too much pollution control. Too much pollution control means that

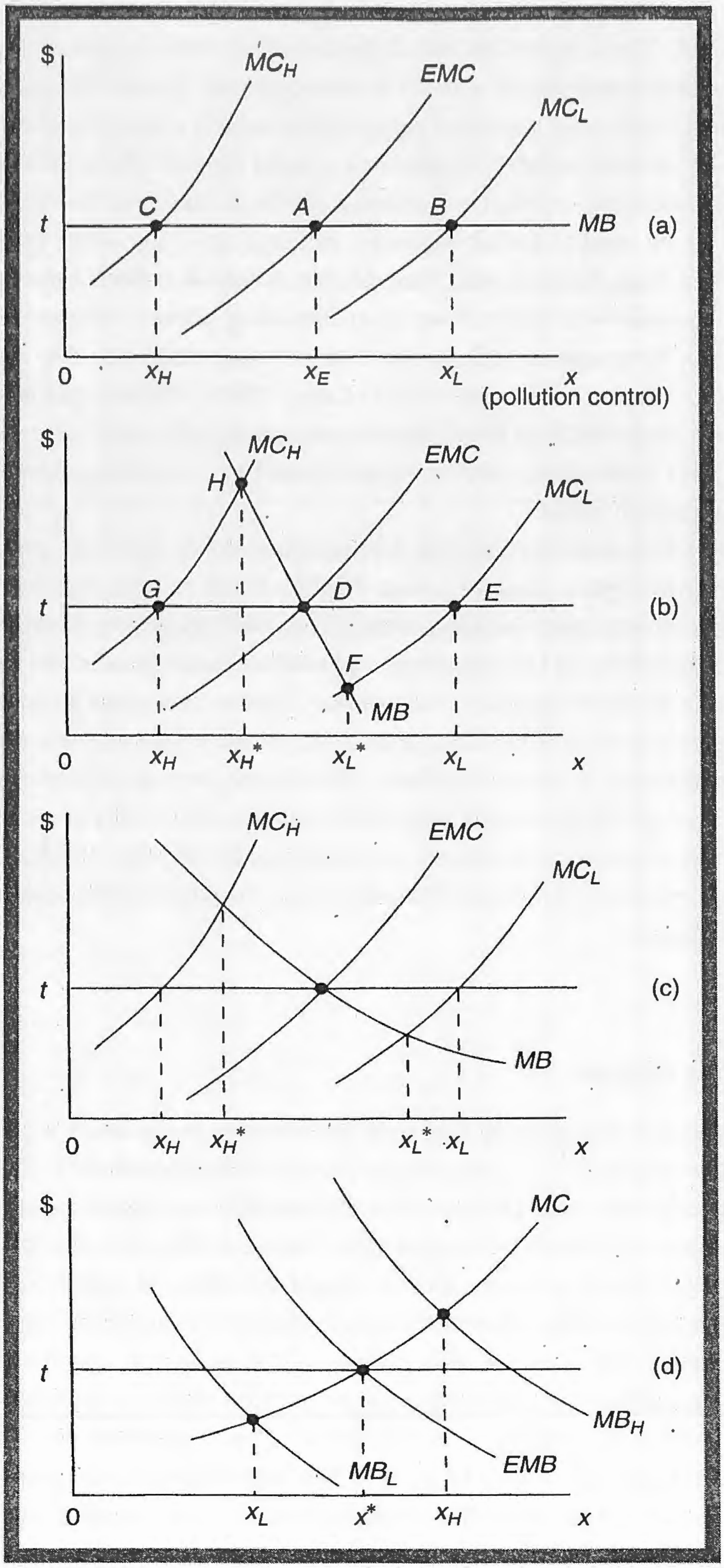

Figure 4.3 Charges given uncertainty

opportunity costs of using scarce resources to create a pristine state of nature exceed the benefits gained. There are other social demands on these scarce resources, such as K–12 public education and health care. This is not to say people do not want a clean environment, rather this says a level of safety exists which allows for some pollution.

Another important topic is what a regulator should do with the revenue raises with a Pigovian tax. Some economists have suggested a *double dividend* exists – the revenues from a Pigovian tax can be used to reduce society's reliance on other taxes that distort labor and capital markets (e.g., income tax). The double dividend is both lower pollution and more incentive to work and invest. Two countervailing effects emerge when swapping environmental tax revenues to reduce the rate of labor taxation: the *revenue-recycling* and *tax-interaction* effects (see Goulder 1995; Parry, 1995). Welfare gains arise from the revenue-recycling effect because lower labor taxes imply increased labor supply, which is a good thing. But these gains can be overwhelmed by the welfare losses that emerge from the tax-interaction effect.

These net losses can arise because the environmental tax increases production costs, which translates into higher product prices. Higher prices reduce real household wages, which then leads to less labor supply, which is a bad thing. Once one considers the general equilibrium effects of tax swapping, the welfare losses exceed the benefits, and in the end the double dividend appears to disappear. This is essentially a classic second-best story: correcting one market failure in the presence of many failures does not necessarily lead to an improvement in overall welfare. The debate over the double dividend is far from over, however, given its potential importance in public policy decisions around the globe. Economic circumstances can be found to generate a double dividend; these conditions usually involve some serious inefficiency (e.g., the total excess burden declines) in the existing tax system.

4.2.2 Ambient charge

In general, an emission charge is limited for many sources of pollution due to the information requirements needed to set an optimal charge to change behavior. Emission charges are likely to be inefficient due to asymmetric information, i.e. moral hazard, the inability to perfectly monitor a producer's control efforts; adverse selection, the inability to know a producer's "type." To reduce the moral hazard problem, Segerson (1988) suggested regulators can design a charge system based on the overall ambient concentration of a pollutant in a region. Following Holmström's (1982) work on incentive structures for labor, Segerson introduced an ambient charge scheme which combines penalties and rewards for exceeding or beating a specific level of total ambient concentrations. The ambient charge scheme has two parts: (1) a per unit charge or subsidy based on the deviation from some ambient standard and (2) a lump sum penalty for not achieving the standard. The charge or subsidy per unit depends on the magnitude of the deviation from the standard, while the lump sum penalty is independent of the magnitude of deviation.

The liability of each polluter depends on the aggregate emissions from the entire group of polluters, not just his own level of emissions since these emissions are unobservable to the regulator. This creates a bubble of total ambient concentration that the entire group of producers must satisfy. If the total ambient concentration of a pollutant is found to exceed the standard, each polluter pays the full incremental social costs of the excessive ambient concentrations. Suppose the marginal damages cost society \$1000, each polluter pays the full \$1000 rather than some share of the damages. The regulator collects $\{n \cdot (\$1000)\}$, where n is the number of polluters. The system is not budget balancing: the regulator collects more money in charges from the polluters than society suffered in damages. The regulator can set the charge/subsidy and penalty in several different combinations to achieve the desired goal of reduced pollutant use. The major advantage of the ambient charge system is that it does not require continual monitoring of emissions; a disadvantage is that one has to be able to define a "reasonable" region in which one has captured only and all of the relevant polluters (e.g., watershed).

Now reconsider the model of the producer to see how the ambient charge system is constructed. Assume there are many producers, $i = 1, 2, \ldots, n$, who are generating some output, q_i, sold at a fixed price, p, and can be produced at a cost, $c_i(q_i)$, where costs increase with increased output, $c_i' \equiv dc_i/dq_i > 0$. As before, a producer's problem absent any incentive scheme is to select a level of output to maximize net profits

$$\text{Max}\,[pq_i - c_i(q_i)]. \tag{4.8}$$

Producer i selects the privately optimal level of output, q_i^*, so the marginal benefits equal the marginal costs of production

$$p = c_i' \tag{4.9}$$

Again the production of q_i generates emissions. Let $\alpha_i = \beta_i q_i$ represent the emission level of output q_i given the fixed emission coefficient, β_i. But suppose the regulator cannot directly monitor how producer i's emissions are transported into a central collection point such as a lake or river. The best the regulator can do is measure the total ambient concentration of the pollutant – the regulator cannot identify which producer contributed the most or the least to the total ambient concentration given a random factor, ε, affects the transport of emissions through the environment. The random factor includes rainfall, soil conditions, and wind direction. Let the ambient concentration of the pollutant be written as $\varphi = \varphi(\alpha; \varepsilon)$, where $\alpha = (\alpha_1, \alpha_2, \ldots, \alpha_n)$. Assume the level of ambient concentration increases with increased emissions, $\varphi' \equiv \partial\varphi/\partial\alpha > 0$.

The ambient charge scheme is implemented by comparing actual ambient levels of the pollutants to a specific ambient standard. The standard is the cutoff beyond which ambient concentrations are perceived to increase the risk to an unacceptable level. Let $\overline{\varphi}$ be the specific ambient standard so if the observed ambient level exceeds this cutoff, $\varphi > \overline{\varphi}$, the producers are penalized; if the level is less than or equal to the cutoff, $\varphi \leq \overline{\varphi}$, the producers may receive a subsidy. Let $F(\overline{\varphi}, \alpha)$ represent the likelihood the ambient concentration does not exceed the cutoff. The ambient charge is written as

$$T_i(\varphi) = \begin{cases} t_i(\varphi - \overline{\varphi}) + k_i & \text{if } \varphi > \overline{\varphi} \\ t_i(\varphi - \overline{\varphi}) & \text{if } \varphi \leq \overline{\varphi} \end{cases}$$

where t_i is the variable charge to producer i and k_i is a fixed penalty imposed on producer i when the ambient cutoff is exceeded. This fixed penalty provides extra incentive to keep the ambient level of the pollutant below the cutoff level.

The level of the ambient charge depends on the perceived benefits of reduced pollution. Suppose the regulator knows the social benefit of reducing ambient concentrations, $B(\varphi(\alpha; \varepsilon) - \varphi(0; \varepsilon))$, which decline with increased ambient concentrations, $B' \equiv (\mathrm{d}B/\mathrm{d}\varphi)(\partial\varphi/\partial\alpha) < 0$. If the regulator selected the optimal level of output as a benchmark, she would maximize

$$\text{Max}\,[pq_i - c_i(q_i) + E[B(\varphi(\alpha; \varepsilon) - \varphi(0; \varepsilon))]]$$

The optimal level of output, q_i^{**}, from the regulator's viewpoint is when the marginal benefits equal the marginal private costs and the expected marginal social costs defined in terms of lost benefits, $E[B']\beta_i$.

$$p = c_i' - E[B']\beta_i \tag{4.10}$$

The ambient charge is an incentive to induce the producer to select this socially optimal level of output. The producer's revised problem is to select a level of output given the ambient charge is included in his net profit calculations.

$$\text{Max}\,[pq_i - c_i(q_i) + E[T_i(\varphi(\alpha; \varepsilon))]]$$

where $E[T_i(\varphi(\alpha; \varepsilon))] = t_i E[\varphi(\alpha; \varepsilon)] - t_i\overline{\varphi} + k_i(1 - F(\overline{\varphi}, \alpha))$. Let E represent the expectation of the random factor, ε, that is, $E[T_i(\varphi(\alpha; \varepsilon))]$ is the expected ambient charge given uncertain weather (e.g., rain or drought). The producer selects q_i so marginal benefits equal the marginal private cost and the expected marginal cost of ambient charge

$$p = c_i' + t_i E[\varphi']\beta_i - k_i(\partial F/\partial\alpha_i)\beta_i \tag{4.11}$$

where $\partial F/\partial\alpha_i < 0$, i.e. increased emissions decrease the likelihood of observed ambient concentrations being lower than the cutoff standard. Comparing Equation (4.11) with Equation (4.10), several ways exist for the regulator to set the ambient charge to achieve the desired level of production. The regulator sets the fixed penalty equal to zero and sets the tax equal to the (negative) ratio of expected marginal benefits over the marginal contribution to ambient concentrations of increased production; set the tax equal to zero and set the fixed penalty equal to the ratio of expected marginal benefits over the marginal likelihood of exceeding the cutoff standard; or the tax is set at an arbitrary level and the fixed penalty is set equal to the ratio of the sum of expected marginal benefits and the tax-weight marginal contribution to ambient concentrations over the marginal likelihood of exceeding the cutoff standard:

(a) $k_i = 0$ and $t_i = -E[B']/E[\varphi']$
(b) $t_i = 0$ and $k_i = E[B']/(\partial F/\partial \alpha_i)$
(c) t_i set arbitrary and $k_i = (E[B'] + t_i E[\varphi'])/(\partial F/\partial \alpha_i)$

All three forms of the ambient charge give the producer an incentive to select the level of output the regulator wants. Since each producer pays the full marginal damage of the total level of ambient pollution, he has no incentive to free ride on the other's actions. Since the regulator collects a tax on marginal damages from all producers, however, the scheme is not budget balancing.

Consider now the drawbacks of the ambient charge. Similar to emission charges, Cabe and Herriges (1992) argue the disadvantage of the ambient charge is the remaining information requirements needed to set the appropriate levels of the tax/subsidy and penalty. The ambient charge requires collecting site-specific data on the complex fate and transport systems associated with pollutant leaching, runoff, and volatilization and the polluter's and regulator's prior beliefs about this transport system. Without this, the ambient charge is incorrectly specified and does not meet its desired goal of socially optimal pollution.

Figure 4.4 illustrates the information problem with the ambient charge for pollutant control. The horizontal axis represents the level of production, q, which influences ambient concentration levels; the top vertical axis represents the net benefit to society which depends on production and emissions, B, while the bottom axis represents the level of the ambient charge, t. The social optimal production is when the net social benefits are maximized, B^*, at production level q^*. Points to the left of q^* represent too little production from society's viewpoint, while points right imply too much production. If the producer does not perceive his actions affect pollution, he believes his tax burden is independent of production and is determined by the solid line in the lower half of Figure 4.4. The production level remains at q_1 and the producer stays in business as long as the ambient charge does not exceed some economic threshold, $t \leq t_1$. If the charge exceeds this threshold, the producer shuts down and leaves the industry. Here the ambient charge is a discrete policy tool: the firm either does what it normally does without the charge or it shuts down, $B = 0$. The reason is that the producer's beliefs influence the perceived impact of the charge. If the producer thinks its actions do not impact ambient concentrations, the ambient charge does not change its behavior. If $q_1 < Z$, the regulator allows production and pollution to continue; otherwise, if $q_1 > Z$, it shuts down the firm, since net social welfare is negative, $B < 0$.

The information problems with ambient charges exist any time the producer's beliefs about the relationship between production and pollution are small relative to the true value or the regulator's belief. Figure 4.4 shows if the producer believes some relationship

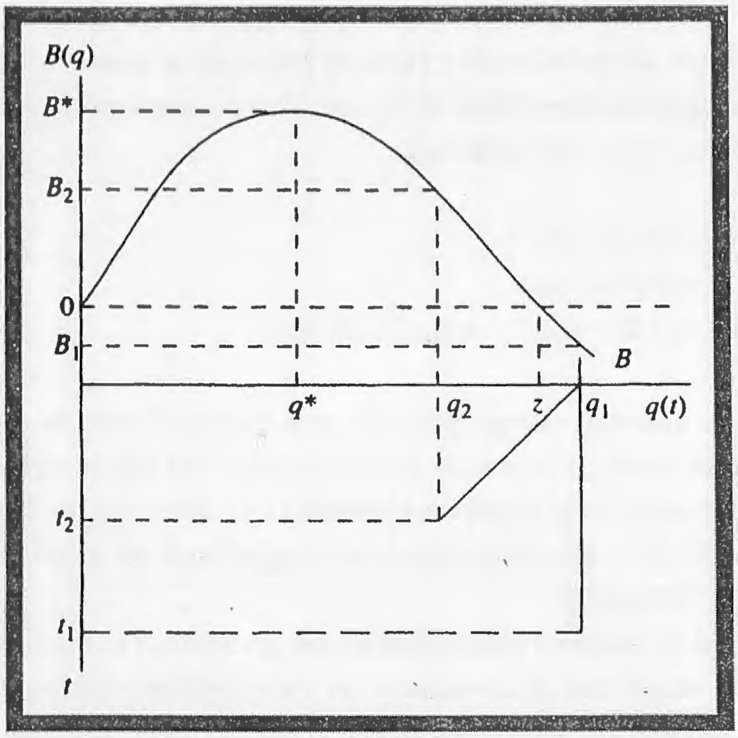

Figure 4.4 Optimal levels of output drive given ambient charge (adapted from Cabe and Herriges, 1992)

exists between his tax burden and his level of production, production changes little given an increase in the charge. The level of production still exceeds the socially optimal level, q^*. Again the charge can be set high enough to shut the producer down, but this depends on the level of q_2 relative to Z. In the case illustrated in Figure 4.4, the regulator wants the producer to stay in operation, even though the production level is more than is socially optimal. Given the regulator's ability or inability to determine and alter the producer's belief about the fate and transport system, quantity rationing in the form of traditional emission standards or technology restrictions may be the more attractive policy tool relative to the ambient charge.

The problems with the ambient standard become even thornier when producers can make more decisions than just abatement. Horan *et al.* (1998) show how Segerson's ambient tax is efficient if firms had one choice, abatement. They show the ambient tax is inefficient when firms have multiple input choices, that is combinations of pesticides, nutrients, tillage. Rather, an efficient tax must be state-dependent to account for the risk-effects of the various choices. They also examine the Cabe and Herriges model of asymmetric expectations, and find again that the ambient tax, even if adjusted to efficiently account for asymmetric expectations, is only possible when firms make a single choice (Horan *et al.*, 2002). They show this is impossible when firms have multiple input combinations and when polluters are risk-averse. Here efficiency is unattainable, in part because the tax itself is a source of risk. Their results suggest the ambient tax could be severely limited in actual practice. (See Box 4.1 for a discussion on a testbed experiment designed to understand the efficiency properties of an auction to address asymmetric information in a nonpoint pollution problem.)

BOX 4.1

Bush tender and experimental economics

Asymmetric information complicates the design of incentive schemes used to protect nature on private lands. Nonpoint source pollution is a prime example – pollution comes from diffuse sources making it too costly to monitor private behavior perfectly. Property owners know more about their land, production choices, disposal methods and preferences than does a regulator; providing landowners an opportunity to exploit their hidden information for personal gain. The ongoing theoretical challenge is to construct incentive schemes to overcome this IC problem. While elegant, the question is whether the mechanisms work in practice for people who frequently fall short of the hyper-rational game-theoretic ideal.

Experimental economic methods can be used to *testbed* incentive schemes designed to address asymmetric information between a private landowner and a regulator. Like a wind tunnel to test airplane design, lab experiments provide a testbed for what is called *economic design* – the process of constructing institutions and mechanisms to examine efficient resource allocation. Classic testbed experiments run by Charles Plott and colleagues helped guide the design of the multi-billion dollar spectrum auction run by the Federal Communications Commission in 1994. The power and limits of testbedding rests in whether lab behavior is a reliable guide to how people act in the wilds. Consider the following example of such a testbed nonpoint pollution experiments. Bohm (2003) also has a useful survey on experimental methods to evaluate incentive systems for environmental policy.

Bush Tender is a program designed to improve the management of native vegetation on private land in Victoria, Australia, given nonpoint pollution problems. Better land management in Victoria translates into less nonpoint pollution from nutrient runoff, which can help improve regional water quality. Introduced by the Victorian Department of Natural Resources and Environment, Bush Tender is an auction-based approach designed to induce private landowners to reveal asymmetric information about their land management practices. Landowners submit bids that specify both the land they will retire for a specific cost. The Department then ranks the land's quality through a *biodiversity benefits index*, the ranking of which is only partially revealed to the landowner.

Cason *et al.* (2003) designed a lab testbed to examine how information about public benefits and the market clearing mechanism affect the efficiency of auctions designed to conserve land. Their work illustrates how one can use the lab to look for empirical patterns of behavior. In contrast to testing a specific theoretical prediction, pattern recognition explores how people react to economic environments which cannot be tractably modeled to generate testable hypotheses. They use a *discriminative price auction*: the regulator discriminates based on both the offer and the estimated environmental benefits. They also ran the auction over many rounds so each seller could learn about how profitable his or her own bidding strategy in earlier rounds actually turned out.

The lab evidence revealed an interesting pattern: bidders who did not know the environmental benefits of their own land were less likely to bid strategically in a conservation auction.

▶

Private ignorance reduced public expenditures. This result suggests a provocative policy. A regulator might continue to restrict the biological information publicly provided to landowners prior to running the auction. The downside with the experiment is that a rational landowner probably would not rely on the government for his sole source of information. Rather he has incentive to hire a private biologist to appraise the environmental benefits on his land. The landowner has an outside option, one not addressed in their experiment. Landowners know or will pay to learn about the public benefits of their own lands. Australia policymakers guided by these experimental results for conservation auctions might also consider how such a realistic outside option might affect auction behavior.

4.2.3 Product charges

Given the information problems associated with the theoretically first-best schemes such as the emission and ambient charges, the regulator's alternative form of price rationing is product charges – an indirect attempt to influence behavior by putting a charge directly on the product or input perceived to cause the problem. Product charges are fees or taxes levied on outputs or inputs potentially hazardous to humans or the environment when used in production, or when they or the containers become waste. By increasing the cost of hazardous materials, product charges encourage producers and consumers to substitute toward more environmentally safe products or inputs. Product charges promote a life-cycle approach to pollutant control by focusing attention on potential environmental costs at each stage of the product cycle: production, use, and disposal. In principle, product charges can be used to exercise control at any point in the pollutant product cycle. In addition, these charges may also be levied on input characteristics, such as the persistence of a pollutant. Product charges have many variations and are applied extensively (see Box 4.2 on the product charges in the European Union).

BOX 4.2

European product charges

The Netherlands uses a product charge with its general fuel charge in the form of surtax on oil excise duties. Its rationale is that while many of the individual inputs to a production process may not be environmentally friendly, the administrative cost to apply charges to inputs is too high. A tax on the energy required to process a set of inputs offers a straightforward alternative which is administratively efficient. Experience in European countries suggests product charges applied to identifiable intermediate or finished products are more difficult to use than when they are applied to inputs or post-consumption wastes. Nevertheless, some European countries have instituted product charges on a limited range of products. Norway and Sweden, for example, apply product charges to batteries, fertilizers and pesticides, while Italy levies a tax on plastic bags which is paid by manufactures and importers. Norway places a flat surcharge of 13 percent on wholesale pesticide prices. Between 1986 and 1992, Sweden imposed a 20 percent charge on the price of pesticides. The administrative efficiency of product charges has been found to be high, mainly because they can be incorporated into existing tax systems.

A common feature of almost all reported product charges, however, is their apparent lack of impact on the behavior of producers [OECD (1994)]. Little evidence exists that product charges significantly reduce the use of targeted inputs or final products. The evidence suggests product charges have been set at relatively low levels, so it is more cost effective for producers and consumers to pay these charges than to seek alternative inputs or finished products, or to vary their practices with respect to waste disposal. While product charges may not induce the "optimal" behavioral changes, the funds raised could be used to support other environmental policies and programs (i.e., information programs). These funds would have to be earmarked for this specific purpose, which is not always the rule.

4.2.4 Subsidies

Subsidies are financial assistance offered to a producer by regulators. Subsidies can be used as an incentive to encourage pollution control or to mitigate the economic impact of regulations by helping firms meet compliance costs. Subsidies normally take the form of grants, loans, and tax allowances. Subsidies are widely applied in many countries, and are usually funded by environmental charges rather than from general tax revenues.

Suppose our producer receives a subsidy for selecting an output level below some fixed output level set by the regulator to achieve a specific level of ambient concentrations. Let the subsidy equal $S = \gamma(\overline{q} - q)$, where $\gamma = D'\beta$ represents the marginal external social cost of producing q. If $q = \overline{q}$, the producer receives no subsidy, $S = 0$. If the producer shuts down operations, $q = 0$, he gets the full subsidy $S = \gamma\overline{q}$.

The producer's problem including the subsidy is written as

$$\text{Max}\,[pq - c(q) + \gamma(\overline{q} - q)]$$

The producer selects a level of output to maximize net profits so marginal benefit, p, equals the marginal private cost, c', and the marginal opportunity cost of lost subsidy, γ,

$$p = c' + \gamma$$

Every unit of output results in a lost unit of the subsidy, γ. The producer has incentive to reduce his output to the socially desired level, identical to the case of the emission charge.

But a difference exists between a subsidy and a charge viewed from a long-run perspective that allows for entry and exit in the industry. Without entry and exit, a subsidy and a charge lead to symmetric results, but with entry and exit the aggregate impacts differ – the charge reduces aggregate pollution, while the subsidy increases aggregate pollution. Figures 4.5 and 4.6 illustrate how charges and subsidies differ. We first define producer behavior given the charge. Figure 4.5 shows the case of the charge with entry and exit. Figure 4.5a represents the behavior of a representative producer;

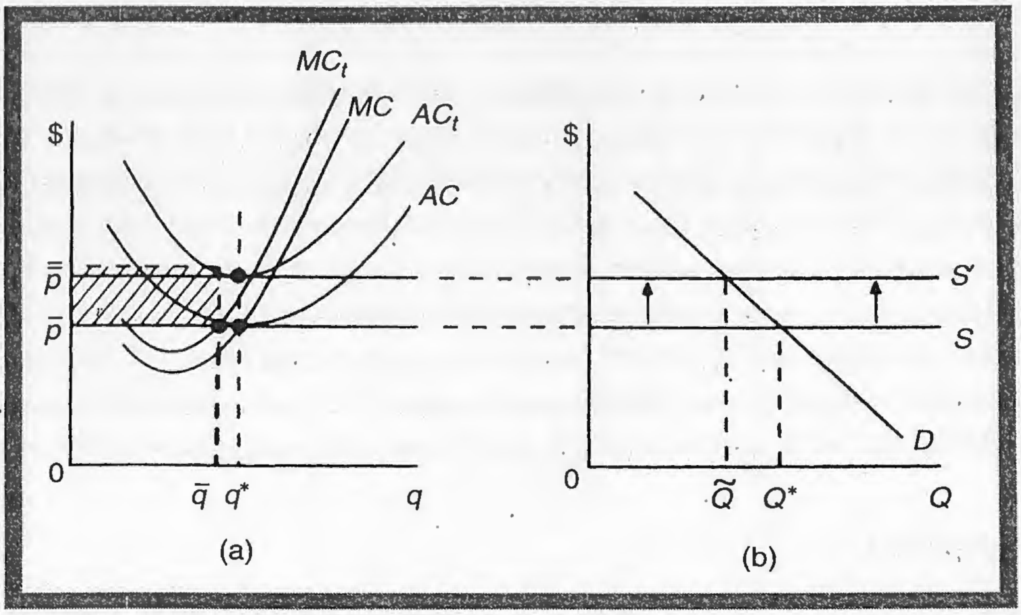

Figure 4.5 Short and long run impacts of a pollution tax

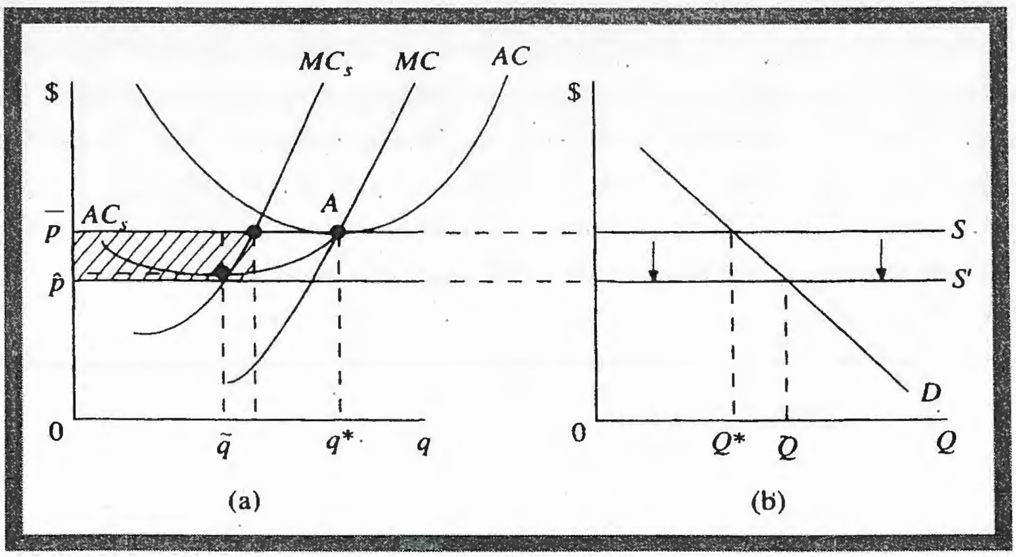

Figure 4.6 Short and long run impacts of a pollution subsidy

Figure 4.5b represents the industry. The average cost curve and marginal cost curve without the tax are written as

$$AC = c(q)/q \quad \text{and} \quad MC = c'$$

The producer operates at output level q^* in which his economic profits are zero. Assume a perfectly competitive market so the producer does not earn positive economic profits. Recall that economic profits include the opportunity cost of the next best alternative, implying the producer earns the market rate of return, no more or no less. Positive economic profits imply the producer is earning more than the going market rate of return, while negative economic profits imply the producer's opportunity cost are too high, and he invests his resources elsewhere. Given perfect competition, this implies a perfectly elastic aggregate supply curve as shown in Figure 4.5b and the market price, $\bar{p}$. Assuming the aggregate demand curve for the industry is downward sloping, the aggregate level of output is set at Q^*, where Q^* equals the sum of all the output, q^*, from every producer in the industry.

If the regulator imposes a charge, as in Equation (4.5), the average and marginal cost curves are rewritten as

$$AC_t = \frac{c(q)}{q} + t$$

$$MC_t = c' + t$$

Figure 4.5a shows the charge results in a parallel shift up of both average and marginal cost. If the market price stays at $\bar{p}$, the producer operates until marginal benefit, $\bar{p}$, equals the new marginal cost, MC_t. This means he produces at $\tilde{q}$, which implies negative profits, $\pi < 0$. The hashed area in Figure 4.5a represents the negative profits. These negative profits force some producers to exit the industry, thereby shifting back the aggregate supply curve, as shown in Figure 4.5b. The supply curve shifts back until a new market price is reached, $\widehat{p}$, so the remaining producers are once again making zero economic profits given the charge. This results in a decrease in the aggregate level of output to $\tilde{Q}$ from Q^*, thereby reducing the level of aggregate pollution. The producers who remained in the industry produce again at q^*, but because there are fewer producers, aggregate output and pollution is reduced. The charge achieved the desired long-term objective – less aggregate pollution.

Consider now the subsidy. With the subsidy, the average and marginal cost curves are rewritten as

$$AC_s = \frac{c(q)}{q} - \frac{\gamma\bar{q}}{q} + \gamma$$

$$MC_s = c' + \gamma$$

While the effect of a subsidy on marginal cost is the same as the charge ($t = \gamma = D'\beta$), the effect on average cost is different. Instead of a parallel shift up in average costs as with the charge, the subsidy causes average cost to shift down and to the left. Figure 4.6a shows the impact of a subsidy on the individual producer. Again, if the producer initially was earning zero economic profits (point A), the subsidy causes him to reduce output to $\tilde{q}$ and earn positive economic profits given the market price stays at $\bar{p}$, as shown by the hashed area in Figure 4.6a. But positive profits attract new producers to enter into the industry, thereby shifting the aggregate supply curve out resulting in a lower market price, $\hat{p}$, and a higher level of aggregate output, an increase to $\tilde{Q}$ from Q^* (Figure 4.6b). Even though each producer is generating less output, $\hat{q}$, and less individual pollution, there are more producers in the industry so aggregate pollution actually increases. With unrestricted entry, the subsidy attracts more producers who produce less pollution individually but end up increasing aggregate pollution. The charge and subsidy schemes no longer lead to symmetric results in the long run given free entry and exit into the industry (see Box 4.3, which discusses subsidies in Europe).

BOX 4.3

European subsidies

France provides loans to industry to control water pollution. Italy provides subsidies for solid waste recycling and recuperation, favoring industries which commit themselves to altering manufacturing processes. The Netherlands has a financial assistance program that provides incentive to industries to promote compliance with regulation and promote technology research and the introduction of pollution control equipment. The German subsidy system assists small producers which experience cash flow problems due to additional capital requirements for pollution control, and to speed up the implementation of environmental programs. Sweden used subsidies to reduce pesticide loadings by providing funds to test the efficacy of pesticide spraying equipment, to provide pest forecasts and warning services, to supply financial assistance and technical advice on organic farming, to increase training of applicators, and to increase the level of research and technical training on low-dose sulfonylurea herbicides. The United States subsidized the construction of municipal water treatment plants and has spent billions assisting farmers pay the costs of soil conservation and preventing erosion-induced losses of soil productivity.

Lewis (1996) provides another useful example of how a subsidy can be inefficient even if the regulator can perfectly measure the monetary damages to human and environmental health. A subsidy scheme can lead to inefficiencies if the polluter has private information about the profitability of his production of output. If the regulator does not know the type of producer – high profitability or low profitability – this private information leads to an "information rent." The low-profit producers receive a subsidy even though they should not, that is, they would never be in operation since their expected profits are negative. For example, agricultural producers who own unproductive land might receive a subsidy to idle the land even though it is unprofitable to produce on that land in the first place (see the work on incentive compatibility (IC) and agricultural subsidies in Smith, 1995; also see Weersink *et al.*, 1998).

Consider a group of producers who supply an output sold at a fixed price. The producers are indexed by θ, where the least profitable producer is indexed by $\underline{\theta}$ and the most profitable producer is indexed by $\overline{\theta}$, $\theta \in [\underline{\theta}, \overline{\theta}]$. Let $\pi(\theta)$ represent the expected economic profits of producer type θ, where $\pi(\overline{\theta}) > \pi(\underline{\theta})$ and $\pi'(\theta) \equiv \mathrm{d}\pi/\mathrm{d}\theta > 0$. Assume a producer type exists, $\tilde{\theta}$, who has zero economic profits, $\pi(\tilde{\theta}) = 0$, where $\underline{\theta} < \tilde{\theta} < \overline{\theta}$. Assume the regulator knows the distribution of producer types, but does not know the profitability of any specific producer. For simplicity, assume the distribution of types is uniform, that is, an equal likelihood for each producer type.

Each producer emits a pollutant which imposes an external cost on society. Let $w > 0$ represent the social cost generated by each producer who operates in the economy. For simplicity, assume w is the same for all producers. The net social surplus from production is $\pi(\theta) - w$. The socially optimal size of the industry is, when the net social surplus is zero (i.e., no more gains from trade), $\pi(\hat{\theta}) - w = 0$, where $\hat{\theta}$ is the *threshold* producer who separates producers who should stay in business from those who should not.

Figure 4.7 shows the size of the industry without accounting for social costs is the group of producers with positive expected profits, $\pi(\theta) \geq 0$, which are all the producers of types $\tilde{\theta}$ through $\overline{\theta}$. Those producer types between $\underline{\theta}$ and $\tilde{\theta}$ have negative expected profits, $\pi(\theta) < 0$, and do not enter the industry. If we accounted for the social costs, $\pi(\theta) - w$, the size of the industry declines to the producers where $\pi(\theta) - w > 0$, which are

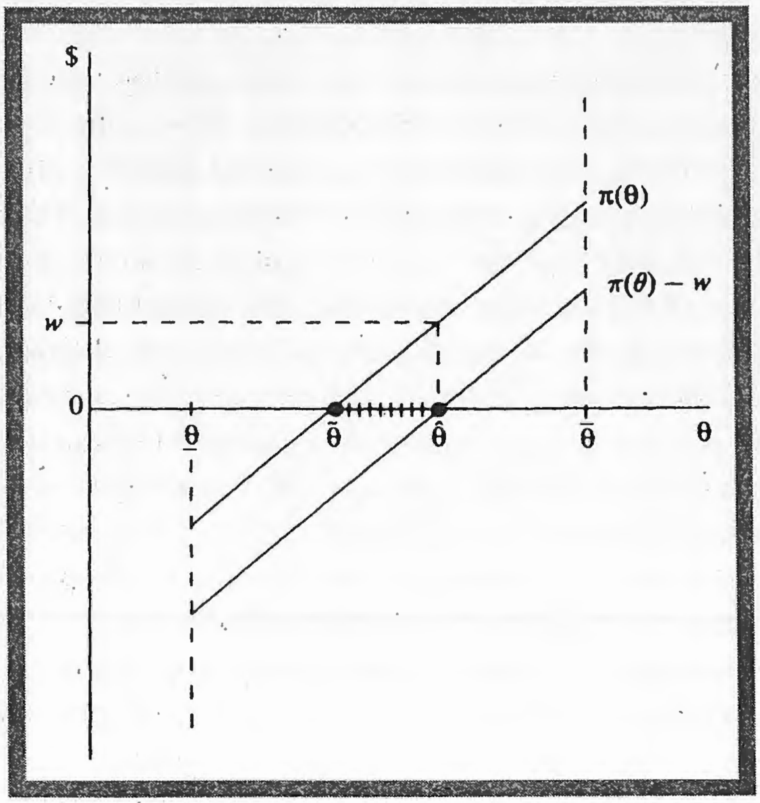

Figure 4.7 Asymmetric information and an environmental subsidy (adapted from Lewis, 1996)

the types between $\hat{\theta}$ and $\bar{\theta}$. The industry should eliminate the producer types between $\tilde{\theta}$ and $\hat{\theta}$ for whom the net expected profits are negative, $\pi(\theta) - w < 0$. If these producers between $\tilde{\theta}$ and $\hat{\theta}$ exit the industry, pollution is reduced to the socially optimal level.

The producer types between $\tilde{\theta}$ and $\hat{\theta}$, however, need an incentive to exit the industry. They are not going to leave on their own since their private expected profits are positive. The regulator needs to provide an incentive to the producers to exit. Let this incentive be in the form of a subsidy equal to the unit social cost, w. Producers who receive the subsidy halt production and exit the industry. Only producers with profits which exceed or equal the social cost (types $\hat{\theta}$ and $\bar{\theta}$) enter the market, resulting in the efficient allocation of resources.

The regulator's inability to determine a producer's type, however, imposes a potential financing problem. If the regulator must balance the budget so the subsidy comes from a tax on the benefits received by society for less pollution (i.e., no deficit), the regulator cannot use the subsidy to reduce pollution to the socially acceptable level without violating the balanced-budget constraint. The reason is since the regulator cannot determine the producer types, he cannot identify which producers would not have entered into production in the absence of the subsidy, that is, those producer types in which $\pi(\theta) < 0$, types between $\underline{\theta}$ and $\tilde{\theta}$. These producer types are entitled to the subsidy since the regulator cannot discriminate between producers, the regulator has to pay more in subsidies than he receives in taxes equaling the gains in environmental quality. The low profitability producers can capture an information rent. It is an open question as to whether a regulator wants these incentive schemes to be budget balancing or not; there are advantages to having more flexibility to either spend more or raise more revenue (see Laffont and Martimor, 2001).

Figure 4.8 shows the divergence between the total subsidy paid out and the total benefits received given the exit of low-profit producers. The regulator's subsidy is paid to all producer types $\underline{\theta}$ to $\tilde{\theta}$ who have negative expected net profits, $\pi(\theta) - w < 0$. The total subsidy equals w times the number of producers between $\underline{\theta}$ and $\tilde{\theta}$. This is areas A + B in Figure 4.8. The total benefit to society from this subsidy, however, is only area B – the group of producer types $\tilde{\theta}$ to $\hat{\theta}$ who operated without the subsidy but have exited with the subsidy, $\pi(\theta) - w < 0 < \pi(\theta)$. By setting the subsidy to accurately reflect the social costs of pollution, the regulator cannot balance his budget and efficiently allocate resources.

The regulator can get around this problem by relaxing the budget-balancing requirement or by offering a subsidy that does not perfectly capture the level of social damages. Figure 4.9 shows what happens if the regulator offers a lower subsidy, $\hat{w} < w$, to the producers. Fewer firms exit the industry so the benefits of improved environmental quality are smaller, areas B + C but the total subsidy outlay is smaller as well, areas B + A. The lower subsidy attempts to curtail the information rent of the privately informed producers. If area A equals area C, the subsidies paid out equals the benefits gained, and the budget is balanced. Here is the point – even if the regulator could accurately set a subsidy to reflect true social cost of pollution, producers with private information can exploit the incentive system to their own benefit, thereby leading to inefficient resource

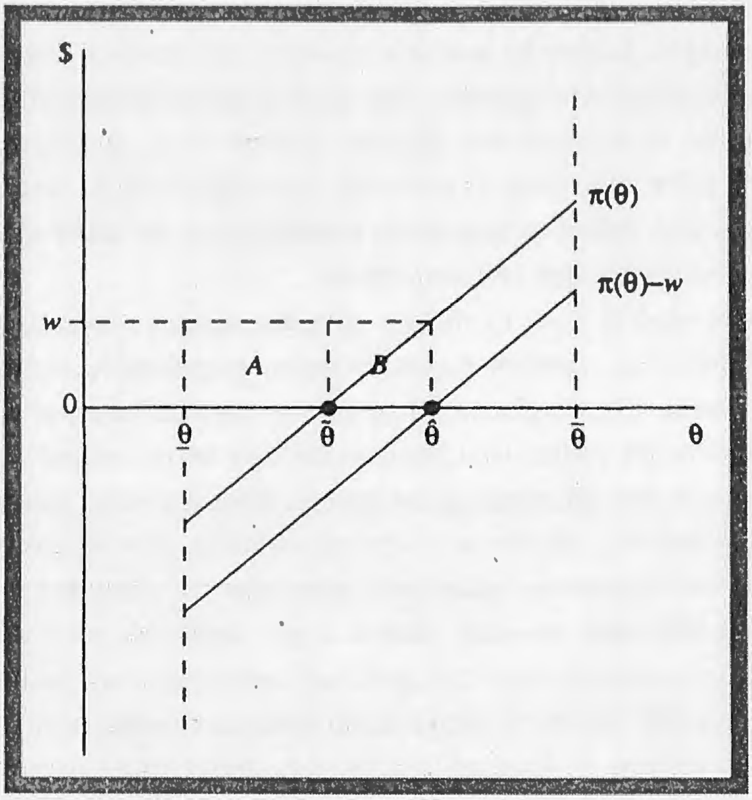

Figure 4.8 Subsidy paid ignoring information rents

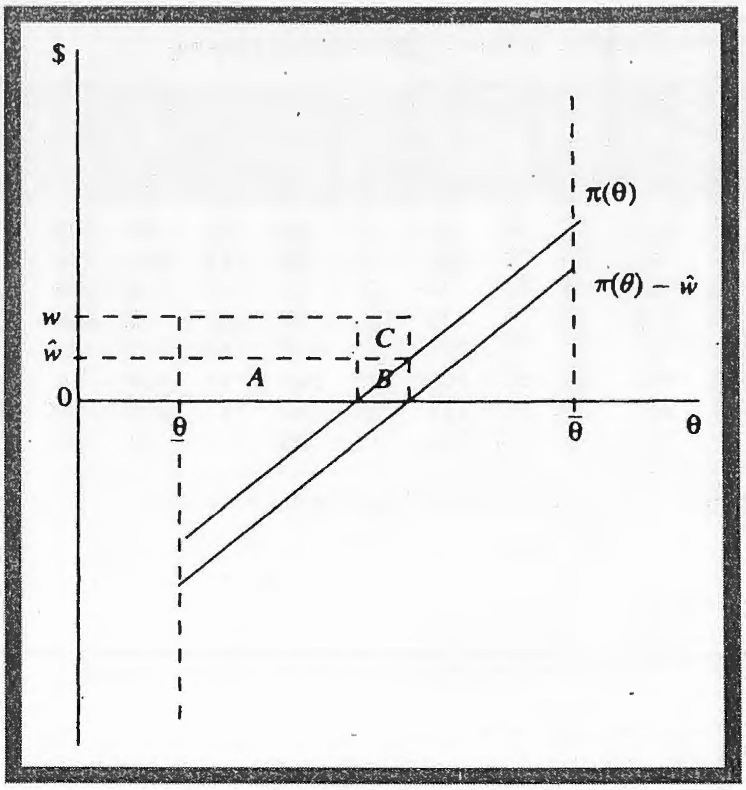

Figure 4.9 Subsidy paid accounting for information rents

allocation. The regulator does not set the subsidy, or a tax for that matter, at the level of marginal social damages. Rather he sets it to balance the costs of the information rents with the gains in environmental quality. This again implies economic instruments alone may not be sufficient to achieve the socially desired level of environmental quality. A mixed system of price rationing or quantity constraints (e.g., tradable permits with "safety value" upper end prices to buy more permits) may be more appropriate to align private and social incentives (see Laffont, 1994).

Another open question is how to design subsidy schemes to satisfy both economic and biological criteria (e.g., habitat fragmentation, population viability). One idea is the *agglomeration bonus*. The agglomeration bonus mechanism pays an extra subsidy for every acre a landowner retires that borders on any other retired acre (see Parkhurst *et al.*, 2002). The idea is that an endangered species have a greater probability of survival within a contiguous habitat, relative to fragmented lands. The bonus payment works as follows: the landowner receives an additional payment for each of his retired acres that share a common border with another retired acre – both his own and his neighbor's retired acres. The bonus creates a positive network externality across landholdings. Each landowner has an explicit incentive to set aside their acres voluntarily to be adjacent to his neighbor's retired acres. As long as landowners prefer more money to less, government compulsion is unnecessary to create a contiguous habitat across landholdings.

Parkhurst *et al.* (2002) explore the robustness of the agglomeration bonus in a game-theoretic experiment. Landowner payoffs are translated into an 8×8 payoff matrix (see Table 4.1). Each cell in the matrix shows the expected payoff to each player (e.g., what

Table 4.1 Payoff matrix: Transfers with an agglomeration bonus

Actions	*Player 2*															
Player 1	*1*		*2*		*3*		*4*		*5*		*6*		*7*		*8*	
1	60	60	60	105	60	95	60	85	60	111	60	109	60	101	60	99
2	105	60	105	105	105	95	105	85	105	111	105	109	105	101	105	99
3	95	60	95	105	95	95	95	85	95	111	95	109	95	101	95	99
4	85	60	85	105	85	95	**135**	**135**	85	111	85	109	105	121	115	129
5	111	60	111	105	111	95	111	85	**111**	**111**	111	109	111	101	111	99
6	109	60	109	105	109	95	109	85	109	111	109	109	109	101	109	99
7	101	60	101	105	101	95	121	105	101	111	101	109	**121**	**121**	121	119
8	99	60	99	105	99	95	129	115	99	111	99	109	119	121	**129**	**129**

The numbers in this figure were reproduced from Parkhurst *et al.* (2002).

Conservation Action
1: No acres retired.
2: Retired acrés results in fragmented habitat reserve.
3: Retired acres results in fragmented habitat reserve.
4: Retired acres results in biologically preferred habitat corridor on common border.
5: Retired acres results in fragmented habitat reserve.
6: Retired acres results in fragmented habitat reserve.
7: Retired acres result in smaller habitat reserve on common border.
8: Retired acres result in smaller habitat reserve on common border.

Note: When both players choose conservation strategy **4**, they create the *first best* biologically preferred habitat corridor. When both players choose conservation strategies **7** or **8**, they create a smaller *second best* habitat reserve. When both players choose conservation strategy **5**, this is the *safe bet* Nash equilibrium, which creates *fragmented* habitat.

each player expects to earn given both his action and the other player's action). Looking at the matrix we see that the agglomeration bonus creates a coordination game with four Nash equilibria that can be Pareto-ranked, cells (4,4), (5,5), (7,7) and (8,8). Recall that a Nash equilibrium exists when neither party has a unilateral incentive to change his conservation strategy. By assumption, the Pareto-dominant Nash equilibrium in this game, the outcome which yields the greatest social benefit, is when both players retire their most productive land (4,4). If both players select (4,4), both the joint biological and economic payoffs are the greatest. The other three Nash cells lead to sub-optimal biological and economic decisions, that is, fragmented habitat and lower monetary payoffs. The agglomeration bonus can work in the lab. If players communicate at least once with each other, they found the first-best bioeconomic outcome in about nine of every ten games (see Parkhurst *et al.*, 2002). This agglomeration bonus example shows that incentive mechanisms can be designed to induce landowners to voluntarily conserve land to satisfy a species' biological needs. The open question is whether it could work in the field for an actual conservation program.

4.3 Liability rules, non-compliance fees, bonds, and deposit-refunds

Liability rules are set so a producer has an incentive to follow a prescribed mandate, technological restriction or acceptable behavior. Liability rules can be set so the producer pays a bond up-front and is reimbursed if no environmental harm occurs or he pays a non-compliance fee after the harm has occurred. Liability rules attempt to reduce the level of shirking on environmental pollution control by raising the expected costs of misbehavior. One important liability rule is the non-compliance fee. A producer is fined if his actions lead to a level of pollution which exceeds some set standard. But given the moral hazard problems associated with many types of pollution, identifying the exact culprit may not be straightforward since ambient concentrations cannot be perfectly assigned to the responsible producer.

Xepapadeas (1991) recognized the possibility of moral hazard, proposing a theoretically plausible incentive scheme with questionable political appeal. Drawing again on Holmström's (1982) work on behavioral incentives within the firm, Xepapadeas developed an incentive mechanism to induce polluters to supply the targeted level of pollution control. Relying on a combination of subsidies and random fines, the mechanism works as follows. If total ambient concentration exceeds the targeted standard at a common site, the regulator selects at least one producer at random and fines him. The regulator redistributes a portion of this fine minus the damages to society from non-compliance back to the other producers. The random penalty mechanism increases the expected costs of shirking, and if designed properly, induces the targeted control level without actually having to monitor the actions of any producer. Of course, the downside of the random penalty scheme is that a producer who invested in the optimal level of abatement could still be fined if the others did not.

The random penalty mechanism is attractive relative to the systems of emission or ambient charges for two reasons. First, the information required to implement the mechanism is less than that required for charges or subsidies. By only requiring monitoring at the receptor site, the random fine mechanism needs data on the total level of ambient concentration; knowledge of each polluter's actual level of pollution control is unnecessary. In contrast, the charge approaches require data on the actual control efforts of each and every producer, information attainable at a significant cost. Second, the mechanism is budget balancing, and does not require additional revenues beyond the welfare gains generated by abatement. This contrasts with the charges in which each producer incurs the full marginal damage associated with the targeted level of pollution, resulting in a multiple of damage costs collected or distributed when taxes or subsidies are used.

Herriges *et al.* (1994) demonstrate the random penalty scheme works only if all the producers are risk averse. The reason is the balance budget requirement makes producers interdependent, that is, one producer's loss is another's gain. A producer's incentive depends both on his own expected penalty and on the expected penalty suffered by the other producers since he could potentially receive a share of their penalty to keep the budget balanced. By increasing the magnitude of the penalty, the regulator increases both the costs and benefits of shirking. Increasing the penalty given balanced-budgeting increases the variability of a producer's profits from shirking. If the producers are risk neutral, the increased variability does not influence their tendency to shirk since they receive the full marginal benefit of shirking and only pay a fraction of the marginal cost. The expected rewards from shirking still exceed the reward from compliances. But if the producers are risk averse, they are more afraid about losing profits than they are happy about receiving extra profits. This serves to magnify the perceived consequences of being caught shirking. And if producers are sufficiently risk averse, they magnify the fraction of marginal costs enough to offset the full marginal benefits of shirking. Consequently, the expected rewards from compliance exceed the expected rewards from shirking and the random penalty scheme has achieved its objective – private decisions match social objectives.

Consider how the random penalty scheme works to reduce environmental shirking. Suppose we have our group of producers, $i = 1, 2, \ldots, n$, who select a level of pollution control, x_i. The regulator wants each producer to select the socially optimal level of control, x_i^{**}, but given the inability to monitor the control of each producer she constructs the following random penalty scheme. Let $\overline{\varphi}$ represent the critical threshold of the ambient level of aggregate pollution. If the observed ambient pollution concentration does not exceed this cutoff, $\varphi \leq \overline{\varphi}$, each producer receives a subsidy, b_i, equal to a share, ϕ_i, of the social benefit, $B(a(x))$, where $x = (x_1, x_2, \ldots, x_n)$. But if the observed ambient level exceeds the cutoff, $\varphi > \overline{\varphi}$, the producer faces two states of the world: either he is randomly selected and fined, F_i, with probability, σ_i, or another producer is selected and fined with likelihood $(\sigma_j, j \neq i)$ and the remaining producers share the subsidy and the fine minus the damages to society from non-compliance.

Formally defined, the random penalty scheme is

$$S_i(x) = \begin{cases} b_i = \phi_i B(a(x)) & \text{if } \Gamma(a(x)) = 0 \text{ (or } \varphi \leq \overline{\varphi}) \\ -F_i & \text{if } \Gamma(a(x)) < 0 \text{ (or } \varphi > \overline{\varphi}), \text{ with probability } \sigma_i \\ b_i + \phi_{ij}[b_j + F_j + \Gamma(a(x))] & \text{if } \Gamma(a(x)) < 0 \text{ (or } \varphi > \overline{\varphi}), \text{ with probability } \sigma_j, j \neq i \end{cases}$$

where $\phi_{ij} \equiv \phi_i / \sum_{k \neq j} \phi_k$ denotes the share of producer j's penalty allocated to producer i, and $\Gamma(a(x)) \equiv B(a(x)) - \overline{B}$ represents the change in social benefits from the level targeted by the regulator, with $\Gamma(a(x)) = 0$ for $\varphi \leq \overline{\varphi}$ and $\Gamma(a(x)) < 0$ for $\varphi > \overline{\varphi}$.

Given this incentive scheme the risk-averse producer must select a level of abatement to maximize his expected utility received from profits, $\pi_i = \pi_i^0 - c_i(x_i) + S_i(x)$, where π_i^0 represents fixed profits from a given output. The producer's level of expected utility from complying with the socially optimal level of control, provided all other producers comply, is

$$\text{EU}(\pi_i(x_i^{**}, x_{-i}^{**})) = \text{U}(\pi_i^0 - c_i(x_i^{**}) + b_i),$$

where $x_{-i}^{**} = (x_1^{**}, x_2^{**}, \ldots, x_{i-1}^{**}, x_{i+1}^{**}, \ldots, x_n^{**})$. If the producer decides to shirk, given he believes all the other producers comply, his expected utility from cheating on abatement is

$$\begin{aligned} \text{EU}(\pi_i(x_i^{*}, x_{-i}^{**})) = {} & \sigma_i \text{U}(\pi_i^0 - c_i(x_i^{*}) - F_i) \\ & + \sum_{j \neq i} \sigma_j U(\pi_i^0 - c_i(x_i^{*}) + b_i + \phi_{ij}[b_j + F_j + \Gamma(a(x))]) \end{aligned}$$

The incentive system of subsidies and random penalties yields the socially optimal level of pollution control if the expected utility from shirking is less than the expected utility from complying with the optimal level of pollution control.

$$\Omega_i \equiv \text{EU}(\pi_i(x_i^{*}, x_{-i}^{**})) - \text{EU}(\pi_i(x_i^{**}, x_{-i}^{**})) < 0$$

Herriges *et al.* (1994) show how simultaneously increasing the fines for all producers increases the variability of the expected profits from shirking. If all producers are risk-averse, the expected utility losses from the fined exceed the utility gains from cheating and not being caught, $\Omega_i < 0$. A set of risk-neutral producers are unaffected by the increased variability since they capture the full marginal benefit from shirking but suffer only a fraction of the marginal cost. But with risk aversion, this fraction of marginal costs is magnified by the producers' fear of losing wealth, and the net rewards from shirking relative to compliance become negative.

An alternative incentive scheme that tries to bridge the information requirements of the ambient charge and the potential political unattractiveness of the random penalty scheme is an environmental rank-order tournament (see Govindasamy *et al.*, 1994). The environmental tournament uses available information on input use or pollution control effort to construct an ordinal ranking of the set of producers. An advantage of the tournament is that the ordinal ranking of producers by some proxy of actual pollution control provides information typically less costly to obtain than the cardinal rankings required by ambient charges. The tournament approach also ranks producers by actions rather than by a random assignment of blame as required by the random penalty scheme. With nitrate pollution, for example, a regulator monitors surface water contamination for the entire area, ranks producers based on their input use or pollution control effort, and penalizes one or more of the lowest ranking producers if the ambient concentrations for the area exceed the prescribed standard. Alternatively, the regulator might reward the highest ranking producers if the ambient concentration is better than the prescribed standard. Rewards or penalties depend on the relative rank of the producers, not on the absolute level of pollution emissions. In addition, the environmental tournament does not require information on common disturbances such as weather effects. A regulator who cannot observe a common shock to all producers (e.g., rain) does no worse than a regulator who can observe the shock. A regulator who can administer an emissions or ambient charge can reduce costs by using a tournament structure which requires less information. The disadvantage to the nonpoint tournament is if the information used to construct the ordinal ranking is biased due to a heterogeneous fate-and-transport system, the tournament may send incorrect signals to the polluters so the wrong producers are punished or rewarded.

Suppose the regulator wants to set up an environmental rank-order tournament between two producers ($i=1,2$). A producer's actual level of pollution control, x_i, cannot be perfectly observed by the regulator. Rather the regulator can observe a proxy variable, z_i, for pollution control constructed from one or more observable actions such as technology choice. We assume the relation between the actual control, x_i, and the proxy measure, z_i, takes the form

$$x_i = f(z_i) + \varepsilon_i \tag{4.12}$$

where $f(z_i)$ represents the transformation of effort to pollution control, with $f'(z_i) \equiv df/dz_i > 0$, and ε_i is a random factor like weather or unknown characteristics of the producer.

The regulator sets up a tournament with a fixed-reward scheme so the winner's reward equals R, while the loser's reward is r, $R > r$. The regulator ranks the two producers based on their observable proxy measures of pollution control, and determines the winner and loser. To maintain a balanced-budget, the regulator sets the total rewards equal to the economic value of the socially optimal level of pollution control, $R + r = Vx^*$, where V is the per unit social benefit of control and $x^* = x_1^* + x_2^*$ is the socially optimal level of control.

Operating within the fixed-reward tournament system, the risk-neutral producer i selects a level of effort, z_i, to maximize his expected profits given the cost of effort, $c_i(z_i)$

$$\begin{aligned} E\pi_i = \pi_i^0 &+ \sigma_i(x_1, x_2)[R - c_i(z_i)] \quad i = 1, 2 \\ &+ (1 - \sigma_i(x_1, x_2))[r - c_i(z_i)] \end{aligned} \tag{4.13}$$

where π_i^0 represents profits without any expenditures on pollution control and without any punishments or rewards, and $\sigma_i(x_1, x_2)$ is the likelihood of producer i winning the large reward, R,

$$\sigma_i(x_1, x_2) = \text{Probability } (x_i > x_j).$$

Assume the likelihood of producer i winning R increases as his actual abatement increases or as producer j's abatement decreases, $\partial\sigma_i/\partial x_i > 0$ and $\partial\sigma_i/\partial x_j < 0$.

Substituting Equation (4.12) into (4.13), producer i's problem of selecting a level of proxy pollution control to maximize expected profits yields

$$(R - r)(\partial\sigma_i/\partial x_i)(f'(z_i)) = c_i'(z_i) \quad i = 1, 2 \tag{4.14}$$

The marginal benefits of increased control are represented by the left-hand side of Equation (4.14): $(R - r)$ in the spread between the large and the small reward, $(\partial\sigma_i/\partial x_i)$ is the increased likelihood of winning the large reward, and $f'(z_i)$ is the marginal increase in actual control given effort increases. The marginal costs are represented by the right-hand side of Equation (4.14), $c_i'(z_i) \equiv dc_i/dz_i > 0$.

If the regulator sets the spread of the rewards equal to the per unit social benefit divided by the marginal likelihood of winning the large reward,

$$(R - r) = V/(\partial\sigma_i/\partial x_i) \tag{4.15}$$

the producer's have an incentive to select the socially optimal level of pollution control, z_i^{**}. To see this, substitute Equation (4.15) into Equation (4.14), which yields

$$Vf'(z_i^{**}) = c_i'(z_i^{**}) \quad i = 1, 2$$

The producer equates his marginal private cost of pollution control to the marginal social benefit $(Vf'(z_i^{**}))$ of control. The tournament scheme rewards producers for increasing their control effort to the socially optimal level. The tournament subsidy idea could be subject to the same problems of entry into the industry, which might lead to greater aggregate pollution. This remains to be established.

4.3.1 Deposit-refund systems

Under deposit-refund systems purchasers of potentially polluting products pay a surcharge, which is refunded to them when they return the product or its container to an approved center for recycling or proper disposal. This instrument rewards good environmental behavior. Deposit-refund systems have been in place worldwide for many years to control the disposal of beverage containers. India, Syria, Lebanon, Egypt, Cyprus, Australia, Canada, France, Germany, Switzerland, and the US, among others, all have deposit-refund systems for particular kinds of beverage containers. Deposit-refund systems can also help to prevent the release of toxic substances into the environment from the disposal of batteries, the incineration of plastics or residuals from pesticide containers. Other nations have either implemented or studied such systems for other articles such as batteries with a high content of mercury and cadmium. Well functioning deposit-refund systems may also stimulate the emergence of markets in safe waste disposal. Such systems pay people to look for opportunities to return waste back into the economy. If some people throw cans out, other people have incentives to find and return them.

From an economic point of view, deposit-refund systems can be cost-effective. They provide economic benefits for good environmental behavior and impose costs for bad behavior. These systems are also efficient from an administrative point of view because once the deposit is paid, no further significant involvement by authorities is needed (see Bohm (1981) for the definitive study). The downside with deposit-refund systems is the extra administrative costs and the personal costs imposed on citizens as reflected by time costs, travel costs, cleaning costs, and so on to get the products into the proper bins. Ackerman *et al.* (1995), for example, estimate administrative costs average about 2.3 cents per container, which is more than $300 per ton for steel containers and $1300 per ton for aluminum cans. Again these costs would have to be balanced against the benefits gained from participating in the program, that is the warm glow associated with "doing the right" thing.

4.3.2 Performance bonds

A performance bond is a mechanism argued to induce socially desirable incentives in a producer (see Bohm and Russell, 1985). With a performance bond, a producer posts a bond before operations begin, forfeiting the bond if his activities cause environmental harm or if he pollutes in excess of acceptable levels. The bond increases the costs of shirking, thereby reducing the incentive for malfeasance. Performance bonds are less common than non-compliance fees, and are applied primarily in cases of clear-cut environmental damage, for example with surface mining of coal in Wyoming. The administrative efficiency of non-compliance fees is low because of the high proportion of cases that must be settled in court.

Bonds can reduce the incentive to shirk. With perfect monitoring, the value of the bond equals or exceeds the value of damages. With imperfect monitoring, the value of the bond reflects both the damages and the probability of detection and damage. Any combination of the detection probability and magnitude of the bond yields the desired result. Since the regulator expends real resources in monitoring behavior but does not in collecting the bond, his efficient strategy is to set the detection probability as low as possible while setting the bond as high as possible. This is the classic economic solution to shirking. A regulator who requires a producer to post a bond imposes an actual cost for environmental shirking. The producer must take this cost into account when deciding whether or not to shirk, recognizing any identified violation may result in the loss of the bond. The producer internalizes his impact on social welfare. He has a greater incentive to work toward a socially optimal level of pollution control or safety precautions, given the positive cost for shirking.

Perrings (1989) identifies several benefits of environmental bonds. Value registration requires an explicit registration of the potential damages to the environment. By requiring producers to post bonds, the costs of the environmental damage are registered, and open to public debate and scrutiny. Value registration acts as a benchmark to guide the environmental costs of future innovative activities. Forcing the producer to post a bond shifts the burden of proof to the producer from society. Rather than taking the producer to court to prove the producer was liable for damages, the producer must prove no environmental effects occurred to avoid forfeiting the bond.

The value of the bond is determined by the potential environmental impact of the producer's actions. If a producer shows the cost of environmental damages is less than the cost of their posted bond, the value of the bond can be reduced. The firm has incentive to invest resources in R&D to discover the true value of environmental damage or increase the use of inputs more benign to the environment. Perrings (1989) suggests once the bond is posted, the interest income could be used for further research into the damaging effects of production.

Bonds are commonly used in the mining industry for reclamation of lands; they are less popular for general environmental policy. Environmental bonds have three major limitations: moral hazard, liquidity constraints, and legal restrictions on contracting (see Shogren *et al.*, 1993). First, moral hazard exists when the actions of the regulator are unobservable by the producer. If the regulator is interested in maximizing his own private welfare rather than social welfare, the government could label the producer as a shirker, thereby confiscating the value of the bond. When the regulator is the sole seller of bonds, the producer has no choice but to either post the bond or not go into business in the country. The regulator might have the incentive to capture the producer's bond by arguing the producer has shirked, regardless of whether he has or not. The producer has the option of challenging the regulator, reposting the bond, or starting a new business. Given legal action is costly, the producer may search for new opportunities. A producer who wants to do business in a foreign country faces the risk a government takes the bond unjustifiably. Appeals to third parties may be ineffective, unless an effective international court exists. Unless an impartial third party exists, the producer has no incentive to post a bond to a regulator whose trust-worthiness is uncertain.

The second factor that limits the use of bonds is liquidity constraints. Liquidity constraints exist when a producer is forced to post a bond *ex ante*, but he cannot acquire the capital necessary for the bond. When a large bond is required, the producer may have insufficient liquid assets to deposit up front. If the producer cannot post the bond, the project might be dropped even though from the social welfare viewpoint the proposal may be beneficial. A possible solution is for insurance markets to spread the risk of the firm defaulting on borrowed assets used to post the bond. The size of bonds needed for environmental issues, however, suggests insurance markets bear a significantly higher risk of a major multi-million dollar claim. The cost of a policy backing an environmental bond is significant, increasing the possibility of default on the loan.

Third, imperfect contract enforcement can effect bond performance due to a variety of reasons including performance excuses, formation defenses, illegalities, and the inability of the enforcer to do the job. Suppose a producer has its performance bond confiscated because of some perceived non-compliance in pollution control. The producer may argue that the breach was caused by an act of God which was not explicitly identified in the contract. Alternatively, the producer may argue that there was some form of imperfection in the procedures to define the contract such as unilateral or mutual mistake, misrepresentation, or threats, bargaining incompetence, and asymmetric information.

When should a producer post an environmental bond? Bonds will work for environmental problems if they can satisfy several key conditions: well-understood costs of environmental damages, observable producer actions (i.e., no moral hazard), few agents to administer, fixed time horizon for remittance issues, well-defined states of the world and their likelihood of occurrence, no irreversible effects, and a relatively small bond value (Shogren *et al.*, 1993). Many forms of pollution such as nonpoint pollution do not satisfy these conditions. Rather here the long-term health costs are still debated, the actions of the producers are unobservable, there are numerous agents to monitor, the time horizon associated with environmental contamination and other impacts on ecosystem functions is ambiguous, the states of nature are still being identified, and liquidity constraints may pinch the ability to post the value of the bond.

4.4 Quantity rationing – tradable permits

Crocker (1966) and Dales (1968) introduced the idea of quantity rationing through tradable permits. Tradable permits specify a pre-determined total level of emissions or emission concentrations within a specified region. Permits equal to the permissible total emissions are distributed among producers in the region. The permits can be traded among plants of a single producer as well as among producers. Producers that keep their emissions levels below their allotted permit level can sell or lease their surplus permits to other producers or use them to offset emissions in other parts of their own facilities. To ensure that such permits serve their purpose as incentives to change pollution control to socially desired levels, total emission levels within a given region are limited such that the permits are valuable to producers. This scarcity value creates an incentive to trade to permits. The US makes limited use of tradable permits for pollution control.

The main feature of quantity rationing through tradable permits is the shift of decision-making from regulators to producers about the design and location of pollution control strategies. In the US, evidence suggests permit systems reduce emissions similar to standard regulatory systems at lower costs; sometimes at half the costs (see Chapter 5; also Hahn, 1987; Klarer, 1994; Stavins, 1998). Whether tradable permits have stimulated any more innovation in pollution control technology relative to the command-and-control technological restrictions is unclear at this time. Tradable permits have sometimes proven to be administratively cumbersome. Their application has been hindered by debates about baseline emission levels, the need for government approval at all stages of policy formulation, and the process in which producers must engage as they exchange proposals for carrying out a permit trade. In addition, the permit trading process has technical, financial, and legal dimensions which have to be addressed before each trade in permits occurs.

Regulators must have sufficient knowledge to design the market. This includes knowing (a) how to establish the time frame of the permits, such as weekly or monthly; (b) the kinds of information required to allocate permits quickly and fairly; (c) how monitoring data is obtained and tested; and (d) the inspection schedule. The producers also need information to make better decisions about buying or selling permits. Tradable permits need a legal structure to define the property rights to trade permits, and to assure that these rights are well defined and enforceable. The nature of the permits and the terms of exchange have to be carefully specified; these issues are taken up in more detail in Chapter 5.

Hahn and Noll (1990) identify several criteria to help make a tradable permit system function more efficiently. First, permits are limited and well-defined to give them a value that can be accurately estimated. Second, permits are be freely tradable with limited restrictions on the scope of trading, thereby guaranteeing those producers who value the permits the most either buy or hold them. Third, permits are *storable* or *bankable* to maintain their usefulness in times of thin buying and selling. Fourth, the trading of permits is not bottled up due to transaction costs, thereby opening up entry into the market and promoting efficiency. Fifth, penalties for violating a permit are greater than the permit price to give incentive for producers to play within the rules of the market. Sixth, permits can only be expropriated in extreme circumstance to maintain the stability of the market. Finally, producers keep any profits they earn from the trade of permits.

If the regulator knows the marginal costs and benefits of pollution control with certainty, the level of tradable permits can be set such that they lead to a socially optimal reduction in emissions. The number of permits is set at the control level so marginal benefits equal marginal cost, as in Figure 4.1. Given the permits can be freely traded, supply and demand sets the permit market price equal to when marginal costs equal marginal benefits of control, $m = \mathrm{MB} = \mathrm{MC}$. With complete certainty the permit market price equals the optimal emission charge, $m = t = \mathrm{MB} = \mathrm{MC}$.

But suppose control costs are uncertain. Figures 4.10a,b, and c show the effectiveness of a tradable permit system given the three cases of marginal benefits considered earlier in the emission charge section – flat, extremely steep, and intermediate slope. In the case in which the slope of the marginal benefits curve is flat (Figure 4.10a), the emission charge works well, but the permit system works poorly. The regulator sets the number of tradable permits, x_m, at the level in which marginal benefits, MB, equal the expected marginal costs, EMC. If realized marginal costs are lower than expected, the permit scheme provides too little pollution control, $x_m < x_L^*$. The permit scheme cannot adjust to the lower realized costs if the number of permits is fixed, thereby leading to an

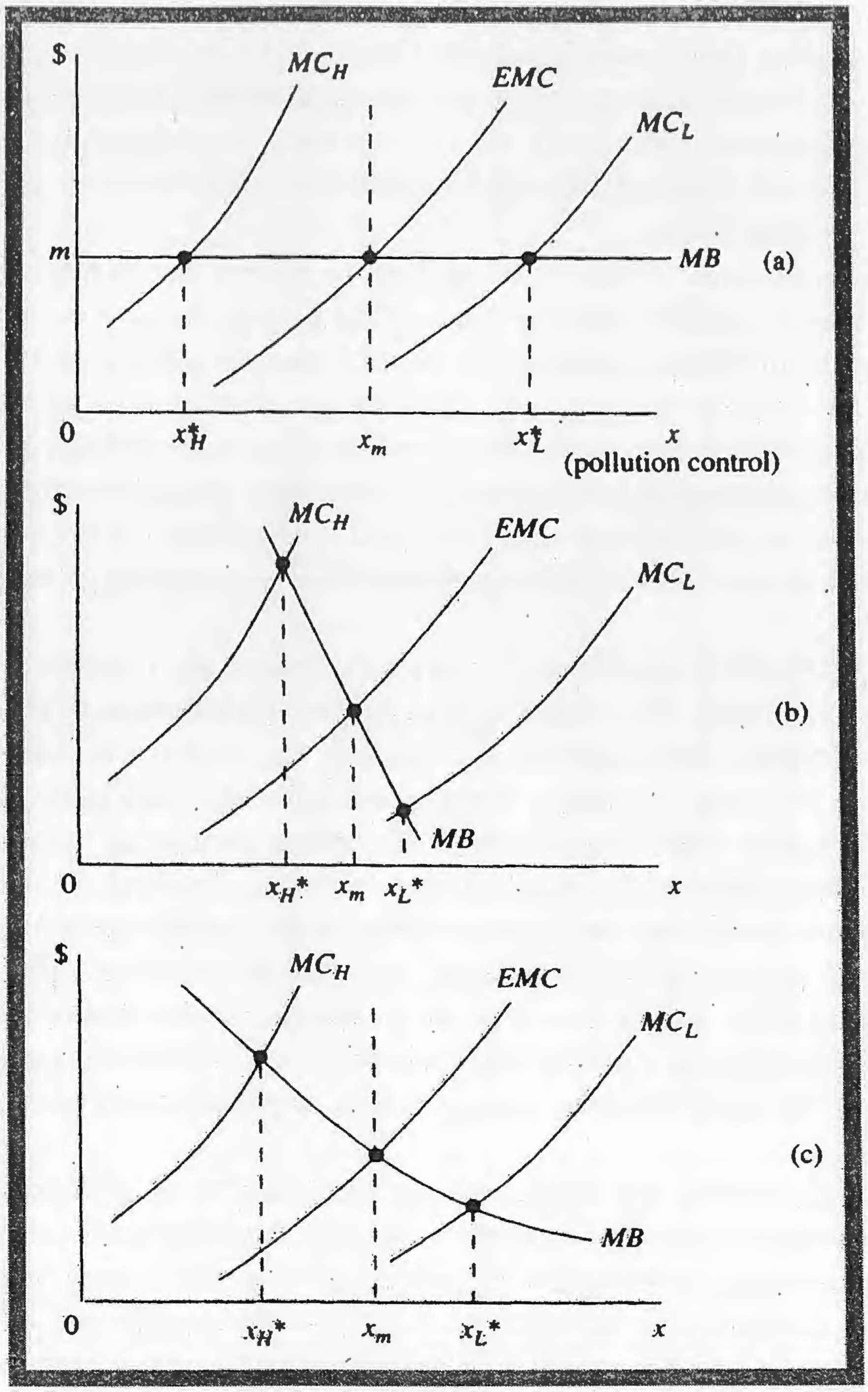

Figure 4.10 Quantity rationing under uncertainty

inefficiently low level of control. Alternatively, if realized costs exceed expectations, too much pollution control is used, $x_m > x^*_H$. Again the quantity of permits does not adjust to the realized control costs. In the case of a flat marginal benefits curve, an emission charge system appears preferable to the tradable permit system.

At the other extreme, if the slope of marginal benefit curve is very steep, the tradable permit system performs well. Figure 4.10b shows regardless of whether realized marginal control costs exceed or are less than expected costs, the socially optimal level of pollution control is nearly achieved, $x_m \cong x_L^* \cong x_H^*$. In this situation, the permit system is preferred to the emission charge scheme.

Figure 4.10c presents the intermediate case in which permits lead to inefficiencies, although the size of the loss is reduced relative to the flat marginal benefit curve. In general, if costs are higher than expected, the permits lead to too much pollution control; if costs are lower than expected, we see too little pollution control. It is unclear whether a permit scheme is preferred to the emission charge. The preferred scheme ultimately depends on the slopes of the marginal cost and benefits curves and the divergence between expected and actual costs and benefits. One can construct alternative scenarios in which either the charge or the permit scheme is preferred depending on the relative slopes of the marginal benefits and cost curves.

Roberts and Spence (1976), however, note a mixed permit-charge system can be more effective than either a charge or permit alone. The idea with the mixed system is it combines the relative strengths of the charge and permit schemes. The strength of the permit system is it protects against the possibility of extremely high levels of environmental damage by providing incentives for too much pollution control when control costs are higher than expected; the strength of the charge is it provides incentive to control more pollution than the permits require when control costs are lower than expected. Combined, the two schemes give the producer more flexibility to respond to changes in market conditions.

Figure 4.11 illustrates the mixed permit-charge scheme. The regulator uses the mixed scheme to approximate the marginal benefit function by setting a charge, t, subsidy, s, and a level of permits, x_m. Suppose the realized marginal control costs, MC_H, are

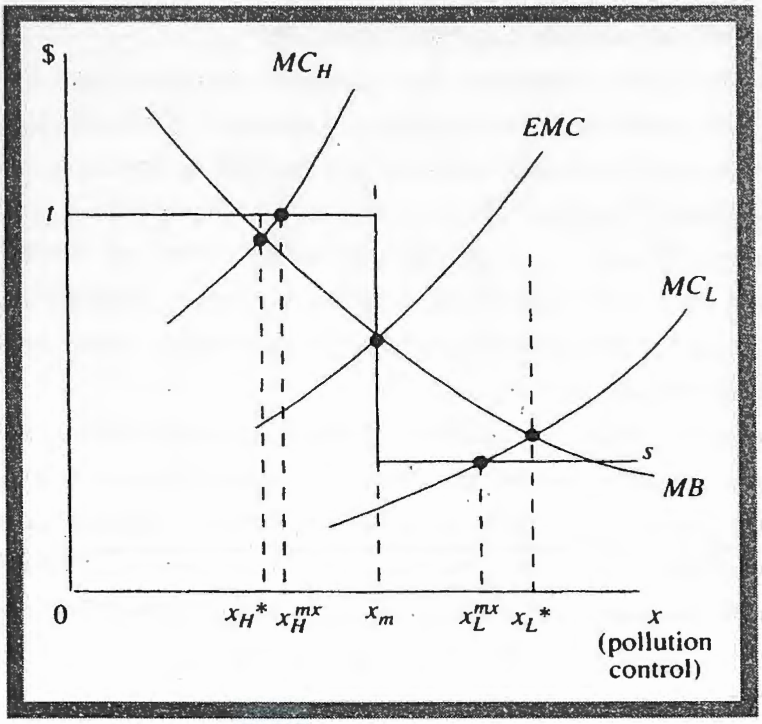

Figure 4.11 Mixed incentive system

higher than expected. The mixed scheme results in a level of pollution control higher than optimal, $x_{\mathrm{H}}^{mx} > x_{\mathrm{H}}^{*}$, but not as high as if the permit system were operating alone, $x_m > x_{\mathrm{H}}^{mx} > x_{\mathrm{H}}^{*}$. If the realized marginal control costs, $\mathrm{MC_L}$, are lower than expected, the mixed system results in too little control, $x_{\mathrm{L}}^{mx} < x_{\mathrm{L}}^{*}$, but more than if the permit system operated alone, $x_m < x_{\mathrm{L}}^{mx} < x_{\mathrm{L}}^{*}$. The charges work to dampen the inefficiencies associated with large deviations between actual and expected marginal costs. If the costs fall within the range $t > m > s$, the private optimum equals the social optimum. Ideally, the mixed system has numerous levels in this step-function so it more closely approximates the marginal benefit curve. If you break down the steps, the scheme approaches a theoretically feasible but challenging variable charge scheme that allows the regulator to achieve the social optimum with a decentralized system. (See Box 4.4, which discusses the use of economic incentives in developing and transitional economies; also see Russell and Vaughan, 2004.)

BOX 4.4

Economic incentives in developing and transition economies

Over the last two decades, several developing and transitional economies have turned to economic incentive systems to help in environmental regulation. China, for example, has used pollution levy or tax system for over two decades. Industrial firms that exceed pollution standards pay emission taxes, which accrued to an estimated $4 billion from 1979 to 1995. Emission levels are self-reported, although monitored through government spot checks (see Bluffstone, 2003). The open question is to whether these levies are designed to change firm behavior or to raise revenues for other social goals. Another example is the Philippines, in which an environmental user fee was implemented in 1997.

Some industries pay a fee based on their assessed pollution load from discharging wastewater, that is a fee for every unit of pollution. In the early 1990s, the Singapore government introduced an auction mechanism to trade the permits for the consumption of ozone-depleting substances (see O' Connor, 1993; World Bank, 1997). Poland introduced pollution fees for over sixty air pollutants, by their potential risks. During the 1990s, the fees have increased dramatically (i.e., some by a factor of 20) from the low levels initially set the 1980s (Blackman and Harrington, 1999). Similar to China, emission levels are self-reported with local government responsibility for monitoring.

Interestingly, many economic incentives in developing countries have not been to add new Pigovian taxes or tradable permits, but rather have altered basic incentives by working to eliminate perverse subsidies. China began removing energy subsidies for coal during the 1980s, in which subsidy rates for coal decreased to 11 percent in 1995 from 61 percent in 1984; Indonesia phased out subsidies for pesticide use from about $180 million per year (1995 dollars), which was about 0.2% of the national GDP. Again since the 1980s, Brazil has worked to removed subsidies for land conversation to agriculture from forests (World Bank, 1997).

4.5 Incentive compatibility

Frustration with the inability of Pigovian taxes and Coasean bargaining to address the question of asymmetric information (e.g., moral hazard, adverse selection) has led to the development of mechanisms that are *incentive compatible.* The idea behind these mechanisms is a principal (a regulator) offers up a payment contract to an agent (a firm) to induce the agent to reveal his or her private information.

For instance, suppose two regulated firms have either high or low pollution abatement costs. If information was perfect, a regulator could set abatement levels corresponding to actual marginal abatement costs, and would set external damages to socially accepted limits. Under asymmetric information, however, each firm knows its own abatement cost structure and the regulator does not. Now the regulator must rely on each firm to report its cost as high or low. Herein is the rub. A high cost firm reports its abatement cost as high, but a low cost firm might not report its cost as low. By reporting its cost is high, the low cost firm is allowed to abate less, giving it excess profits. The regulator's challenge is to devise a mechanism that provides incentives for the low cost firm to admit to being *low cost,* and thus to abate more. Simultaneously, the mechanism should give incentives for a high cost firm to abate less. A mechanism to implement efficient or "close to efficient" outcomes is to announce a menu of prices and rewards/penalties combinations to the firm (see Lewis, 1996; Maskin and Baliga, 2003). The firm examines the menu and chooses the price/reward pair in its best interest. Given we have two firm types, the menu is straightforward. Two contracts are offered: one targeted at the low cost firm, the other at the high cost firm.

We illustrate this point by considering Laffont's (1995) model on optimal regulation of a project that could cause a catastrophe. Suppose a regulator hires a firm to run a project, which has some likelihood of environmental damages (e.g., Yucca Mountain storage of nuclear waste in the US). Let the social value of the project be written as S. The project costs are $c = \beta - e_1$, where β is a technical efficiency characteristic of the monopoly running the project and e_1 is an effort variable to reduce costs. These costs are observed ex post by the regulator. Let $0 < (1 - \pi) < 1$ be the probability an environmental catastrophe occurs which causes damages, E. The expected value of the project is $S - (1 - \pi)E$. Assume the monopoly can engage in self-protection, e_2, to reduce the probability of a catastrophe, $(1 - \pi(e_2))$, where $\pi'(e_2) > 0$. For simplicity, assume either no or full self-protection (0 or 1), such that $\pi(1) > \pi(0)$. Let t be the monetary (net) transfer from the regulator to the firm on completion of the project.

The firm's ex post utility on successful completion of the project is $U = t - \eta(e_1 + e_2)$, where $\eta(e_1 + e_2)$ is the cost function of effort, such that $\eta'(e_1 + e_2) > 0$ and $\eta''(e_1 + e_2) > 0$. Consumers' expected value of the project is $V = S - (1 - \pi(e_2))E - (1 + \lambda)(c + t)$, where λ is the shadow (social) value of the public funds used by the regulator to compensate the firm. This shadow value represents the social opportunity cost of spending money on environmental protection relative to other public goods like education and health care.

The regulator's objective function then is to maximize social welfare, $W = U + V$, which after some substitution we write as

$$W = S - (1 - \pi(e_2))E - (1 + \lambda)(\beta - e_1 + \eta(e_1 + e_2)) - \lambda U$$

As a comparative benchmark, we first look at the regulator's problem under complete information about β, e_1 and e_2. To define the social optimum target, suppose the regulator selects e_1, e_2 and U to maximize social welfare, W, subject to the constraint that the firm's ex post utility is non-negative, $U \geq 0$. The interior solution for optimal regulation implies (i) full self-protection should be employed given damages (E) are sufficiently large, so that $e_2 = 1$; (ii) costs should be reduced so marginal benefits equal marginal costs, $\eta'(e_1 + 1) = 1$ and (iii) zero rents for the firm given the shadow costs of public funds, $U = 0$.

Now consider the problem of optimal regulation under incomplete information. Suppose the regulator cannot observe β, e_1, and e_2 ex ante, but can observe the costs and if a catastrophe occurs ex post. Let there be two types of firms, low or high cost, $\beta \in (\underline{\beta}, \overline{\beta})$, where ω is the probability the firm is low cost ($\beta = \underline{\beta}$) and $(1 - \omega)$ is the probability the firm is high cost ($\beta = \overline{\beta}$).

The revelation principle says the regulator can offer a direct mechanism $\{c(\tilde{\beta}),\ t^c(\tilde{\beta}),\ t^{nc}(\tilde{\beta})\}$ to the firm. If the firm accepts this mechanism, the firm announces its characteristics, $\tilde{\beta}$. The firm is required to produce at cost level $c(\tilde{\beta})$ and it receives transfer $t^c(\tilde{\beta})$ if a catastrophe occurs, and $t^{nc}(\tilde{\beta})$ otherwise. For an announced characteristic $(\tilde{\beta})$, the firm's expected utility is

$$U(\beta, \tilde{\beta}, e_2) = \pi(e_2)t^{nc}(\tilde{\beta}) + (1 - \pi(e_2))t^c(\tilde{\beta}) - \phi(\beta - c(\tilde{\beta}) + e_2)$$

Again assume the E is large enough such that $e_2 = 1$.

The regulator considers six incentive compatibility (IC) constraints that say each firm type should not deviate in the truthful announcement of β, and self-protection. For the low type, we have three IC constraints:

$$\begin{cases} U(\underline{\beta}, \underline{\beta}, 1) \geq U(\underline{\beta}, \overline{\beta}, 1) & \text{(L1)} \\ U(\underline{\beta}, \underline{\beta}, 1) \geq U(\underline{\beta}, \underline{\beta}, 0) & \text{(L2)} \\ U(\underline{\beta}, \underline{\beta}, 1) \geq U(\underline{\beta}, \overline{\beta}, 0) & \text{(L3)} \end{cases}$$

Similarly, for the high type

$$\begin{cases} U(\overline{\beta}, \overline{\beta}, 1) \geq U(\overline{\beta}, \underline{\beta}, 1) & \text{(H1)} \\ U(\overline{\beta}, \overline{\beta}, 1) \geq U(\overline{\beta}, \overline{\beta}, 0) & \text{(H2)} \\ U(\overline{\beta}, \overline{\beta}, 1) \geq U(\overline{\beta}, \underline{\beta}, 0) & \text{(H3)} \end{cases}$$

The regulator also considers two participation or individual rationality (IR) constraints

$$U(\underline{\beta}) \equiv U(\underline{\beta}, \underline{\beta}, 1) \geq 0 \qquad \text{(L4)}$$

$$U(\overline{\beta}) \equiv U(\overline{\beta}, \overline{\beta}, 1) \geq 0 \qquad \text{(H4)}$$

The regulator's objective function is now to select $\{\underline{e}_1, \overline{e}_1, U(\underline{\beta}), U(\overline{\beta})\}$ to maximize

$$W = \omega[S - (1-\pi(1))E - (1+\lambda)(\underline{\beta} - \underline{e}_1 + \eta(\underline{e}_1 + 1)) - \lambda U(\underline{\beta})]$$
$$+ (1-\omega)[S - (1-\pi(1))E - (1+\lambda)(\overline{\beta} - \overline{e}_1 + \eta(\overline{e}_1 + 1)) - \lambda U(\overline{\beta})]$$

subject to (L1)–(L4) and (H1)–(H4).

Setting aside (L2), (L3), (H2) and (H3) (which can be shown to be satisfied at no additional welfare costs), we focus on the IC constraint for the low type (L1) and the individual rationality constraint for the high type (H4) as the only binding constraints. After some algebraic manipulation, one can show (L1) is equivalent to $U(\underline{\beta}, \underline{\beta}, 1) \geq U(\overline{\beta}) + \Phi(\overline{e}_1 + 1)$, where $\Phi(\overline{e}_1 + 1) = \eta(\overline{e}_1 + 1) - \eta(\overline{e}_1 - (\overline{\beta} - \underline{\beta}))$. Since rents to firms ($U(\underline{\beta})$) are costly ($\lambda$) to the regulator, the constraints (L1) and (H4) are binding at the optimum, which implies (H4′) is $U(\overline{\beta}) = 0$ and (L1′) is $U(\underline{\beta}) = \Phi(\overline{e}_1 + 1)$. Now substitute these two constraints into the regulator's objective function and solve for the optimal level of self-protection for the two types. This yields the first order conditions:

$$\eta'(\underline{e}_1 + 1) = 1$$

and

$$\eta'(\overline{e}_1 + 1) = 1 + \frac{\lambda}{(1+\lambda)} \frac{\omega}{(1+\omega)} \Phi'(\overline{e}_1 + 1)$$

Recalling the full information comparative benchmark, these conditions imply the following. The low cost firm invests the optimal level of effort, $\underline{e}_1 = e^*$, and captures some information rents, $U(\underline{\beta}) = \Phi(\overline{e}_1 + 1)$. The high cost firm under-invests in effort, $\overline{e}_1 < e^*$, and captures no information rents, $U(\overline{\beta}) = 0$. The ability of the efficient type (low cost) to mimic the inefficient type (high cost) forces the regulator to give up a rent to the low cost producer – provided the regulator wants to keep the high cost type active. This rent is a function of the inefficient type's effort, $\overline{e}_1$. If the regulator was to insist on a first-best level of effort for the high cost type, it would result in a greater information rent for the low cost type. To reduce the costly rents, the regulator lowers the effort requested by the inefficient type. (Box 4.5 discusses the use of incentive design for endangered species management.)

BOX 4.5

Incentive design for endangered species protection

Smith and Shogren (2002) examine the properties of two types of voluntary incentive mechanisms to protect endangered species on private land given private information. One mechanism, loosely referred to as an ex ante mechanism, offers each landholder a set of contracts that are independent of other landholders' types. The other mechanism, called an ex post mechanism, offers contracts that are type-contingent: a landholder's actual payment and retirement levels depend on both his own type and the other landholders' types. They presume the government has selected a probabilistic safe minimum standard for species survival, a so-called *Minimum Acceptable Probability of Survival* (MAPS) constraint that serves as a safety net on the minimum number of acres to set aside to guarantee survival of the species.

Their model suggests several results worth considering. First, if the MAPS constraint binds because social gains for less-known and less-favored species fall below the MAPS constraint (e.g., historical pests like the black tailed prairie dog), then the habitats created by both ex ante and ex post mechanisms will be of the same size. In addition, the same ex ante mechanism "bunches" landholders – a regulator asks each landholder to retire the same number of acres and pays each landowner the same amount for each acre retired. In this case each landowner receives an amount equal to the lost rent of the landholder with the most expensive land. Landowners with less-known but protected species capture top dollar irrespective of their type.

If the MAPS constraint does not bind, the choice of mechanism leads to different habitat sizes. Non-binding MAPS constraints are more likely when the regulator confronts more well-known and charismatic species like the bald eagle and the grizzly bear. People will support programs for species they understand. They also note that the social welfare associated with an ex post allocation is greater than the social welfare associated with the corresponding ex ante allocation. This is because the ex post mechanism makes use of more information than the ex ante mechanism, linking contracts to type-combinations. This suggests that policymakers should seek ways to address the feasibility of the more efficient ex post compensation plans for those species that surpass the minimum level of survival as specified by the MAPS constraint. These results suggest it is reasonable to expect the ex-post habitat to be smaller than the size of the corresponding ex ante habitat. This is especially true if the deadweight losses associated with raising tax revenues are relatively small. Environmentalists might prefer that the government implement the simpler ex ante mechanism.

Now consider Varian's (1994) IC model in which two parties are well informed about each others' tastes and technologies, but a regulator is not. Varian developed a two-stage *compensation* mechanism in which a regulator can be used to induce one party to account for external damages it imposes on another party. The mechanism works off the condition that both parties are well informed about each others' tastes and technologies, but the regulator is not. For example, two disputing neighbors who share a fence line might know a lot about each other, while the intervening regulator only knows that an externality exists.

Suppose person 1 selects output x to maximize his profits, $\pi_1 = rx - c(x)$, where r is the fixed price of output and $c(x)$ is the costs of producing x. Assume $c' > 0$ and $c'' > 0$. Person 1's choice of output, however, imposes external damages, $e(x)$, on person 2, so her profits are $\pi_2 = -e(x)$, where $e' > 0$ and $e'' > 0$. A regulator enters the picture and offers up the compensation mechanism. The scheme has two stages: an announcement stage and a choice stage. In the announcement stage, person 1 announces the compensation (p_1) that he will pay to person 2 for marginal damages; likewise, person 2 announces the compensation (p_2) person 1 should pay her for marginal damages. In the choice stage, person 1 then selects his level of output given the compensation mechanism.

Now person 1's and 2's profits become

$$\pi_1 = rx - c(x) - p_2 x - \alpha_1 [p_1 - p_2]^2$$

and

$$\pi_2 = p_1 x - e(x)$$

where $\alpha_1 [p_1 - p_2]^2$ is a quadratic penalty scheme for any differences in stated compensation levels and $\alpha_1 > 0$ is a parameter. Person 1 pays both the compensation to person 2 (as reported by 2) and a penalty if he reports a different marginal damage than person 2. Person 2 receives compensation based on what marginal damage person 1 reports.

Working backwards, we see the unique subgame perfect equilibrium of this two stage game is for each person to offer the identical compensation and for person 1 to select the efficient level of output, i.e. x^* such that $r - c' - e' = 0$. Recall that a subgame perfect equilibrium exists when a Nash equilibrium exists for each subgame, including the entire game (see, e.g. Osborne, 2003). We show this by solving the choice stage first. Person 1 chooses output to maximize his profits conditional on the compensation scheme, which yields the first-order condition

$$r - c'(x) - p_2 = 0$$

which determines the optimal output level, denoted as $x(p_2)$. Assume the higher compensation demanded by person 2, the less person 1 will produce, $x'(p_2) < 0$.

Consider the announcement stage next. The logic works as follows. If person 1 believes person 2 will announce p_2, he should announce $p_1 = p_2$ to minimize the potential penalty, i.e. $\alpha_1 [p_1 - p_2]^2 = 0$. Now consider person 2's choice of compensation, p_2. Her choice indirectly affects person 1 through his output decision in the choice stage. Her profits are now $\pi_2 = p_1 x(p_2) - e(x(p_2))$, so selecting p_2 to maximize profits yields the first-order condition

$$[p_1 - e'(x)]\, x'(p_2) = 0$$

Since $x'(p_2) < 0$, it must be $p_1 - e'(x) = 0$. Therefore, combining the three optimization problems $\{r - c'(x) = p_2, p_1 = p_2, \text{and } p_1 = e'(x)\}$, we have recaptured the desired efficiency condition, $r - c'(x) - e'(x) = 0$. The intuition is straightforward. Person 2 effectively sets person 1's output by setting the price that person 1 faces. Person 1 selects $p_1 = p_2$ to minimize the penalty. Together they generate the efficient level of output. Varian shows this result holds for a class of problems including reciprocal externalities, public good provision, and common property prisoner's dilemmas.

4.6 Evaluative criteria

Judgments about the usefulness and practicality of the economic incentives we have discussed can be based on the extent to which they meet four criteria: effectiveness, efficiency, equity, and flexibility. Regardless of theoretical appeal, an incentive scheme falls short if it is ineffective in reducing pollution damage, unacceptably inefficient in accomplishing these goals, violates social norms of equity, or lacks the flexibility to change with shifting economic, technological, and environmental conditions.

4.6.1 Effectiveness

The effectiveness of an incentive system depends on the success in achieving the regulator's objective in pollution control. If the objective is to secure a given level of emissions, quantity rationing through tradable permits appears to be the preferred incentive scheme. Permits establish a fixed quantity of emissions within a specific region, and offer more predictability and control over the decline in emissions. If the risks associated with small increases in emissions are assessed to be high, the prudent strategy is to use a tradable permit system to narrow the potential difference between actual emissions and the prescribed emission standard.

But if the regulator's objective is to maintain more certainty over the costs of pollution control, quantity rationing is not as effective as price rationing through a charge scheme. Charges set a specific cost for emissions; the level of pollution control is uncertain, however, which is the opposite of the tradable permit system. If the regulator believes significant uncertainty exists about the control costs and the risks change slowly as emissions increase, the strategy is to design a charge system that offers more predictability in costs and accept the variability in the level of pollution control. This is especially true if the charge is not set sufficiently high to motivate producers to increase their pollution control. Producers may simply pay the charge and not reduce emissions.

Effectiveness debates are usually based on theory, not experience, since no incentive system has been used enough to make detailed statements of support for or against. It is unclear the effectiveness advantage of emission charges are realized in connection with practical applications of this instrument. The use of incentives within market economies have found little evidence any system stimulates innovative behavior in pollution control technology. Given most charges are not sufficiently high to motivate producers to change their behavior, regulators need to consider increasing emission charges and reducing allowable emission levels to increase pollution control.

4.6.2 Efficiency

Efficiency is desirable because it implies the regulator's objectives are achieved at the lowest possible cost. In principle, quantity rationing with tradable permits and price rationing with emission charges are equally efficient. In practice, however, the efficiency of the two systems can differ significantly, depending on the characteristics and source of the pollution. The critical issue is the cost of monitoring and enforcement. An emission charge requires continuous data on the quantities of emissions from sources to be controlled. Regulators must also have the administrative capacity to use the data to set appropriate charges and to collect them. Regulators using tradable permit systems, in contrast, need to establish the rules and organization rules of the permit market, must monitor the trades among producers, and must determine if the producers selling permits reduce their emissions appropriately. With a large number of producers, continuous monitoring and enforcement requirements can be expensive. If too few producers exist, the permit market is "thin," and inefficiencies can arise.

Again, the lack of long-term experience with these incentive systems makes judgments about their relative efficiency speculative. The US experience provides some evidence that there are more cost savings with tradable permits than with emission charges. In developing and transition economies, however, the restricted technical and administrative capacity in regulatory agencies, the shortage of financial resources, and limited institutional and administrative resources to monitor and enforce emission controls strengthen the case for price rationing with product charges, over quantity rationing through tradable permits. Price rationing probably does not require the establishment of new administrative systems since most countries already have institutions for taxing relevant commodities. Most countries need to create new institutional apparatus to implement and manage a quantity rationing system of tradable permits. (See Parkhurst and Shogren (2003) for a discussion on eight different incentive schemes and their potential efficiency to protect endangered species.)

4.6.3 Equity

Economic incentives can influence the distribution of costs and benefits among members of society. These distribution effects raise the issue of equity and fairness, both within and across generations. Regulators can identify the winners who capture the benefits of the cleaner environment and losers who bear the financial burden of a system. For example, a regulator can implicitly assign the rights to pollute by using either a charge or a subsidy. The popular polluter-pays-principle used in western Europe forces the producer to pay the control costs, the emissions charge, or the compensation to any victims who are harmed by his emissions. The producer does not have the right to pollute, and must pay for his emissions or damage. Alternatively, the regulator can assign the producer the right to pollute, and society provides a subsidy to increase pollution control. The regulator keeps the producer in operation, protecting jobs and promoting economic growth. Equity and efficiency can be in conflict – protecting jobs of inefficient producers does not necessarily increase the size of the economic pie.

The producer's burden within an incentive system is lower profits and less industry-wide competitiveness, both domestically and internationally. If a charge raises costs so a producer is no longer competitive in national or world markets, profits fall and some producers exit the industry or move to other countries. In the case of emission charges, some firms pollute less than others because of different local conditions or because of differences in the relative availability of low versus high-polluting inputs. If all are charged according to their emissions, producers in low-charge areas have an cost advantage over firms in high-cost areas. Location also affects the environmental damage caused by a given level of emission, so uniform emission charges, in some cases, may be perceived as inequitable.

Equity also involves the relative burden placed on consumers, businesses, and workers. Understanding equity requires knowing how the costs of an incentive scheme can be shifted forward to consumers from producers through higher prices, or backward to workers through lower wages or lower prices paid for raw materials. The ease with which a producer can shift the cost burden depends on competitive conditions in input, labor, and product markets. A large number of consumers with limited substitution opportunities and only a few producers suggest the costs are passed forward to consumers who face higher prices. But, a few consumers with readily available substitutes buying from a large number of producers creates a case in which each producer has to accept lower profits or try to pass the costs to workers or suppliers. The burden of the incentive system follows the path of least economic resistance.

4.6.4 Flexibility to achieve objectives

A useful economic incentive system adapts to changes in markets, technology, knowledge, social, political, and environmental conditions. Given the difficulty in achieving a social objective, the system is sufficiently flexible to accommodate several iterations of use. For example, the flexibility in an emission charge depends on the ability of the regulator to respond to changes in emissions or abatement costs. If altering a charge requires several levels of authority, the change might be too late to be effective. Flexibility also requires a charge system be indexed to inflation. If a country has a high inflation rate (e.g., 50–1000% every year), a fixed emission charge loses its effectiveness to reduce pollution or generate revenue. An inflation-indexed charge system is more flexible than one in which the administering agency is required to obtain authority to adjust the charge each year (see Zylicz, 1994 for a discussion of indexation in the charge system in Poland).

A tradable permit system allows the price of the permits to be set by transactions among producers participating in the market. These prices adjust to changing economic, technological, and inflationary conditions insofar as these changing conditions affect the decisions of participating producers and their emission rates. For example, if a new technology to reduce emissions is developed, the permit market reflects this change through shifts in the supply and demand for permits. This, in turn, affects permit prices. Tradable permit systems are more flexible in price and less flexible in the total level of emissions relative to emission charges.

4.7 Practical conditions for use of economic incentives

Certain conditions are required before economic incentives can be used effectively to promote environmental protection. One set of necessary conditions include an adequate information base and administrative capacity, a strong legal structure, competitive markets, administrative capacity, and political feasibility. Since conditions in market, transition, and developing countries differ significantly, no attempt is made to determine which alternatives are most useful (see King *et al.*, 1993). We highlight questions regulators might want to consider before attempting to develop and apply any of the incentive systems we have discussed.

4.7.1 Information base and administrative capacity

Effective use of economic incentives requires information on the costs and benefits of alternative incentive systems and recognition of the winners and losers. Moreover, useful information includes the technological and institutional opportunities and constraints in pollution control, and the substitution possibilities allow both the regulators and the producers to assess potential trade-offs between pollution control and production processes. This information needs to be collected, stored, and disseminated to provide an adequate knowledge base to implement an economic incentive scheme. Economic incentives are likely to be ineffective when the expected policy objectives are unclear or when the legal structure is not established through environmental legislation. Legislation must specify the chain of authority, the range and assignment of jurisdiction, and the legal standing of the affected parties. Regulators also need to specify which indicators of improvement in environmental quality and human welfare is used to judge success, which provides a yardstick to measure progress.

Regulators who want to achieve the socially optimal level of pollution control are constrained by their own administrative capacity to implement the economic incentive system. Regulators need staff and funding to effectively implement, monitor, and enforce the system, just as producers need staff and funding to determine the consequences of the system on their operations. As a consequence, regulators combine the efficiency gains of economic incentives with the strict standards of command-and-control to promote pollution control.

4.7.2 Legal structure

The effective use of an economic incentive system requires the legal structure to define property rights clearly, provide the legislative authority to issue the incentives, and specify who has legal standing and jurisdiction in the use of the system. An effective property rights scheme requires the rights holder be able to transfer the rights, control access to the resource, receive all the benefits, and bear all the costs associated with its management (see Chapter 3). Under this definition, ill-defined or conflicting property rights structures do not produce the set of access claims necessary to allow economic incentives to work effectively. In many developing and transition economies, property rights may be unfavorable for the effective use of economic incentives. In particular, incentives based on private property may not be effective under conditions of open access, common property, or centralized property systems. Under centralized property regimes the condition that the rights holder alone receives the benefits and bears the costs is frequently violated. Evidence from transition economies indicates that regulators operating under centralized property regimes do not pay the costs of poor management. The tenure of regulators depends on both political connections and merits, and consequently they do not always receive or send the correct sets of incentives and have lower incentives to manage pollution control efficiently.

4.7.3 Competitive markets

Economic incentives are more effective if competition plays a meaningful role in the economy and in the decisions of the regulators. If competitive markets exist, developing a robust permit market is more likely to be relative to if a potential monopoly seller exists, for example Russia in carbon emission trading (see Godby, 2002). Economic incentives are most advantageous, relative to direct regulations, in markets with many buyers and sellers. Credit, liability, and insurance markets also play an important role in the use of economic incentives. Producers short of capital find it difficult to post a performance bond unless they have access to credit markets. Without these markets, economic incentives that require cash outlays give a competitive advantage to large producers over small or rural producers who cannot cross-subsidize products that require more pollution control.

4.7.4 Political feasibility

While economists can promote economic incentives as a cost-effective tool to increase pollution control, it is the regulator who must face the winners and losers of any proposed incentive system. These winners and losers include other regulators, producers, and individuals impacted by the emissions and by organizations who represent the victims of pollution. The push and pull of these countervailing forces help determine the political feasibility of the proposed incentive system. For example, the random penalty scheme may not be politically feasible given a well-behaved producer might be penalized due to the shirking of others. The performance bond raises political challenges given the thin capital and insurance markets associated with pollution control. Producers can claim the bonds impose unnecessary hardships (e.g., lost jobs), a factor sure to interest any politician up for re-election.

4.8 Concluding remarks

Economists offer up incentive schemes to help correct environmental problems for nearly a century now, their collective voice growing louder in variety and reach over the last four decades. This chapter has reviewed some key issues in incentive design and application. We have examined the general principles at work: balancing the incremental private costs of pollution control against the incremental social gains given different degrees of information. As long stressed by my mentor and colleague Tom Crocker, the lesson worth remembering about all this is "no universally preferred incentive system exists." Incentive design depends on the economic circumstances, environmental conditions, funding sources, habitat and land quality and quantity, the mix of pollutants, land values, human capital, and so on. Some pragmatic circumstances warrant the use of price rationing (e.g., carbon emission reductions); others the use of quantity rationing (e.g., acid deposition control).

But also remember as you read deeper into the incentives literature you will find that different schemes can be just different sides of the same coin. From the perspective of complete contracting and the revelation principle, any regulation is equivalent to a revelation mechanism, which means all agents truthfully report their private information to the regulator. The regulator then recommends proper action, that is, a command and control option. Since the command and control option is optimal in this case, discussion over whether price rationing or quantity rationing are mute since they implement the same allocation as the command and control approach. But when contracts are incomplete, which is more likely realistic scenario, the choice of incentive tool can matter. Here aligning private and social choices requires serious information about values, costs, preferences, both at absolute and relative levels. The less we know about what drives private choices, the more political realities and rationalizations play a role, which means nearly all the time. Readers interested in learning more about the nature of incentives for environmental policy within this political web can find numerous theoretical, empirical, and practical applications in the economics literature and in government publications.

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