Environmental Economics

In Theory and Practice

Second edition

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CHAPTER

3 Market failure

3.1 Introduction

A market is an exchange institution that serves society by organizing economic activity. Markets use prices to communicate the wants and limits of a diffuse and diverse society so as to bring about coordinated economic decisions at the least cost. The power of a perfectly functioning market rests in its decentralized process of decision-making and exchange. No omnipotent central planner is needed to allocate resources. Rather, prices ration resources to those who value them the most, and in doing so, people are swept along by Adam Smith's invisible hand to achieve what is best for society as a collective. Optimal private decisions based on mutually advantageous exchange can lead to optimal social outcomes.

That is the basic idea. For the most part, markets represent one of the greatest human discoveries. Markets work to collect and disseminate information about diverse preferences and constraints in a least cost manner relative to other exchange institutions like collective and government allocation decisions. Markets use prices to communicate both the laws of nature and the laws of humanity. But for many environmental goods and services, markets fail if prices do not communicate society's desires and constraints accurately. Market prices can understate the full range of services provided by the natural environment, or these prices might not exist to send an accurate signal about the total value of the asset (e.g., such as the species living in a local forest). A *market failure* occurs when the market does not allocate scarce resources to generate the greatest social welfare. A *wedge* exists between what a private person does given market prices and what society might want him or her to do to protect the environment. Such a wedge implies *wastefulness* or *economic inefficiency*; resources can be reallocated to make at least one person better off without making anyone else worse off.

One example of a market failure is habitat destruction and threats to biological diversity on Earth. Biological diversity contributes to productivity, acts as insurance, is a warehouse for genetic knowledge, and supplies ecosystem services (e.g., filtration, pollination) (e.g., see Heal, 2000; NRC, 2005). Biodiversity is at risk, however, as the evidence suggests species are in a new wave of extinction, disappearing at rates 10–1000 times greater than natural rates of extinction. In addition, the numbers of invasive species, species introduced from elsewhere, are increasing worldwide. They can change biological structure in an ecosystem; for example, zebra mussels in the US Great Lakes, the giant conifer aphid in Malawi, the water hyacinth in Lake Victoria. If the extinction and invasion problems are due to human action, modifying human behavior should be part of the solution. Economics plays a role in identifying how the market works well and how it can fail to provide the services we desire.

Madagascar is one example. An ecologically rich and economically poor island nation, biologists estimate that nearly 75 percent of the 200,000 species found on Madagascar are unique: 98% of the palm species, 93% of primates, 80% of flowering plants, 95% of reptiles, 99% of frogs, 97% of tenreck and 89% of carnivores (USAID, 1992). But more than 12 million people live on Madagascar (50% under age 15), with an annual income of about US$800 (purchasing power parity). Policymakers have a desire to implement policies that can increase the welfare of the citizens. Agriculture employs over 85 percent of the population, and people are increasing private wealth by converting forest lands to agriculture, which has altered the habitat for many species. Deforestation has occurred at about 200,000 hectares per year, with nearly 80% of the original forest cover already gone. The economic cost of environmental degradation has been estimated at $100–290 million (5–15% Madagascar's GDP), in which three-quarters of these costs arise from deforestation.

Market failure exists here when prices of timber, agriculture, and land do not provide an incentive to curtail habitat destruction because biodiversity is a public good. Biodiversity provides a public good to people because its goods and services are non-rival and non-excludable (e.g., life support, water filtration, pollination). Biodiversity is non-rival in that the public benefits of protection are not diminished for others by a person's use; it is non-exclusive in that it is too costly to exclude people from gaining the benefits of protection. As a result, market prices for timber and agriculture do not capture the social benefits provided by biodiversity. These commodity prices reflect the supply and demand for certain attributes of these market goods, at the expense of biodiversity and social welfare.

This chapter explores the relationship between markets and market failure for environmental goods and services. We begin by defining the theoretically ideal benchmark for the efficient allocation of resources: the perfectly competitive market in which private market decisions match up with the social optimum. Next we consider how this market benchmark can misfire by examining five interrelated cases of market failure: externalities, non-exclusion, non-rival consumption nonconvexities, and asymmetric information. We define each type of market failure as we go along. We do not discuss the classic case of market failure by market power (e.g., monopoly) (see Berg and Tschirhart, 1988).

3.2 Markets: Efficient and otherwise

Ledyard (1987, p. 185) notes, "[t]he best way to understand market failure is to first understand market success." A market system is *successful* when markets allocate scarce resources within an economy to promote the welfare of households. Consumers and producers making independent choices to maximize their own private net benefits through markets do not waste resources, that is, the allocation of resources is efficient (Arrow and Debreu, 1954). By efficiency, we use the classic concept of *Pareto efficiency* (or *Pareto optimality*): one person cannot be made better off by reallocating resources without making another person worse off.

The First Fundamental Theorem of welfare economics summarizes the foremost advantage of competitive markets for social welfare. The theorem says a competitive equilibrium is always Pareto efficient. Formally, if

(i) a complete set of markets with well-defined property rights exists so buyers and sellers can exchange assets freely for all potential transactions and contingencies;
(ii) consumers and producers behave competitively by maximizing benefits and minimizing costs;
(iii) market prices are known by consumers and firms; and
(iv) transaction costs (e.g., DEFN costs to organize a market) are zero so charging prices does not consume resources;

then the decentralized allocation of resources is Pareto efficient, i.e., all gains from trade have been exhausted (Debreu, 1957).

One key requirement for market success is that markets are *complete*. That is, there are enough markets to cover all possible transactions or contingencies so all gains from trade are realized (condition (i)). Resources are free to move from low-valued to high-valued uses. Well-defined property rights for wealth and assets are crucial for market success. A property rights system represents a set of entitlements that define the owner's privileges and obligations for use of an asset or resource. Property rights are considered well-defined if they have the following characteristics:

(a) *Comprehensively assigned.* All assets or resources must be either privately or collectively owned, and all entitlements must be known and enforced effectively.
(b) *Exclusive.* All benefits and costs from use of a resource should accrue to the owner, and only to the owner, either directly or by sale to others. This applies to privately and collectively owned resources.
(c) *Transferable.* All property rights must be transferable from one owner to another in a voluntary exchange. Transferability provides the owner an incentive to conserve the resource beyond the time he or she expects to make use of it.
(d) *Secure.* Property rights to resources should be secure from involuntary seizure or encroachment by other people, firms, or the government. The owner has an incentive to improve and preserve a resource under his or her control.

When a market fails to protect the environment, the problem can usually be traced back to incomplete markets. Markets are incomplete when people fail or are unable to establish well-defined property rights due to high costs (Starrett, 2003). The failure of the market to produce efficient outcomes can also arise from institutional constraints imposed by government action. Such government failure arises when special interests set rules to create financial obstacles to the effective creation of property rights and a market. See Anderson and Leal (1991) for a detailed discussion of government failure; for example, a "race to the bottom" in which local governments are tempted to lower environmental standards to attract industry and jobs into their region (see Cumberland, 1979).

This inability/unwillingness to assign property rights to create a complete set of markets provides a rationale for government intervention. Governments intervene by imposing mandatory pollution-technologies, emission standards, fines, taxes, subsidies, and bans. But Coase (1960) argued if zero transaction costs exist, such government intervention is unnecessary. Rather we can expand the set of markets to include nonmarket goods, provided we remove any institutional constraints that prohibit defining property rights. The key is to give one person property rights to the nonmarket good, for example pollution control. The *Coase theorem* says these two disputing parties can bargain with each other and agree to an allocation of resources that is Pareto efficient, regardless of the party to whom unilateral property rights to the nonmarket asset are initially assigned. As long as these property rights can be freely exchanged, the only role for government intervention is to assign and enforce the property rights. The government does not need to collect information on benefits or costs or damages; this is because each party knows already what is best for him or her. They both use their own private information when they bargain over an acceptable level of the nonmmarket good.

We illustrate the Coase theorem with an example. Suppose two parties, Riley and Ole, disagree about the optimal level of pollution in the Cloquet River. Riley owns a paper mill that produces pulp and paper on the Cloquet River. He can minimize his production costs by discharging the waste water untreated (or after some minimal treatment) into the river. Although more pollution treatment improves water quality downstream, Riley has little incentive to abate the pollution since he earns no direct financial benefits. The "environment as a dump" is a free good for him. Once the wastewater hits the river and flows downstream, two problems emerge – the river now stinks from the discharge, and lignin and a host of hazardous chemicals, including dioxin, begin to accumulate in sediment. The health risks associated with dioxins include greater risk of death from skin and organ cancer, and the increased risk of non–life-threatening diseases due to a reduction in immune response.

Now suppose Ole lives downstream from Riley, and runs a rafting and kayaking business. While both have rights to water quality, Riley's odiferous pollution directly reduces the profitability of Ole's rafting and kayaking business. Ole's business depends on the quality of the water. Fewer people want to raft and kayak when the river smells bad, especially if this gives rise to a general concern for their health. Ole wants Riley to control his pollution.

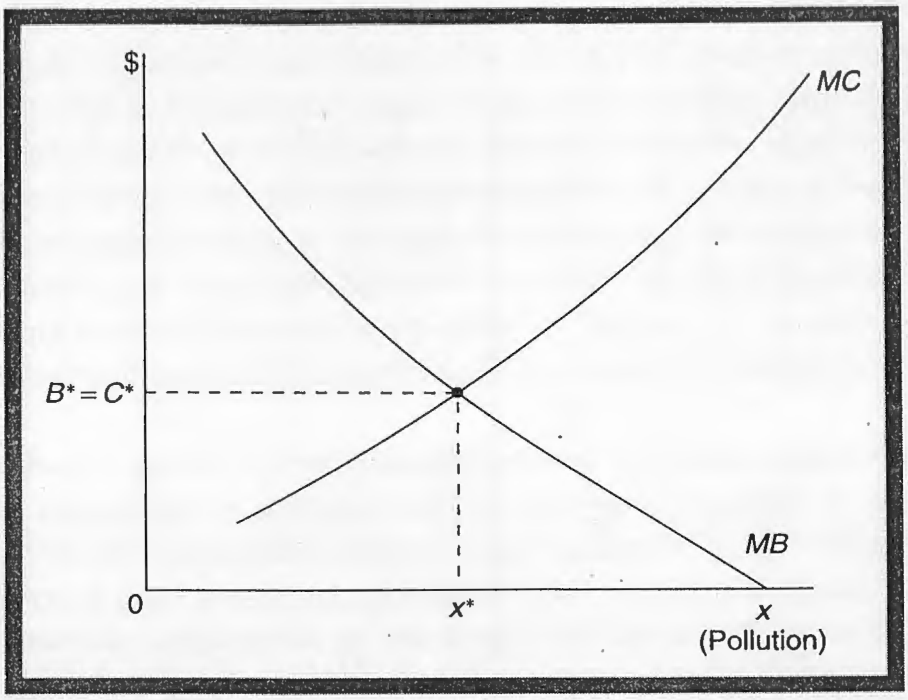


Figure 3.1 Socially optimal level of pollution

Figure 3.1 shows the marginal cost (MC) to Ole from each unit of pollution, and the marginal benefit (MB) to Riley from the pollution via production. Recall that the MCs are the incremental costs (to say more sick days or damaged lost species) associated with another unit of pollution; marginal benefits are the incremental gains to firms or consumers from an extra unit of pollution. The socially optimal level of pollution, x^*, is when society balances the extra gains with the extra costs, that is MB = MC. Pollution levels to the left of the optimal level, x^*, imply too little pollution (the marginal benefits still exceed the marginal costs, MB > MC); pollution levels to the right of x^* imply too much pollution (the marginal costs now exceed the marginal costs, MB < MC).

If markets are incomplete, Riley and Ole have no official auction block to trade for alternative levels of water quality even though they both could be made better off with the trade. Here the Coase theorem steps in. First, suppose a neutral third party creates a market by assigning the property rights to clean water to Ole. The marginal cost curve in Figure 3.1 represents Ole's supply of clean water, while the marginal benefit curve represents Riley's demand for clean water. If Ole has the rights, Riley would compensate Ole by the amount C^* for each unit of pollution. If Ole demands a higher level of compensation, $C > C^*$, then a surplus of clean water exists since Riley does not demand as much as Ole wants to supply. If Ole asks for a lower level of compensation, $C < C^*$, a shortage arises as Riley's demand exceeds Ole's supply. The surplus forces compensation down, while the shortage forces the level up until the market clears at the compensation level C^*; the demand for clean water equals the supply at the socially optimal level of pollution, x^*.

Now suppose the neutral third party assigns the property rights to pollute to Riley. The MC curve presented in Figure 3.1 now represents Ole's demand for pollution control, while the MB curve represents Riley's supply of pollution control. Given Riley has the right to pollute, Ole can offer a bribe to Riley of the amount B^*. If Riley asks for a higher bribe, $B > B^*$, a surplus of pollution control exists. Ole demands less pollution control than Riley would be willing to supply. If Riley asks for a lower bribe, $B < B^*$, a shortage of pollution control arises as Ole demands more than is supplied. The bribe B^* clears the market – the demand for pollution control equals the supply at the socially optimal level of pollution, x^*.

The Coase theorem works in this case. Society achieves the optimal level of pollution at the lowest cost. Regardless of the initial assignment of property rights, the optimal bribe equals the optimal compensation, $B^* = C^*$, at the socially optimal level of pollution, x^*. The newly created market allows the two parties to reach the optimal level of pollution. Figure 3.1 is just one case. Figure 3.2 illustrate that the optimal level of pollution depends on the relative magnitude of the MB and MC curves. Figure 3.2a shows how the optimal level of pollution may well be zero if the MCs are extremely high (e.g., DDT);

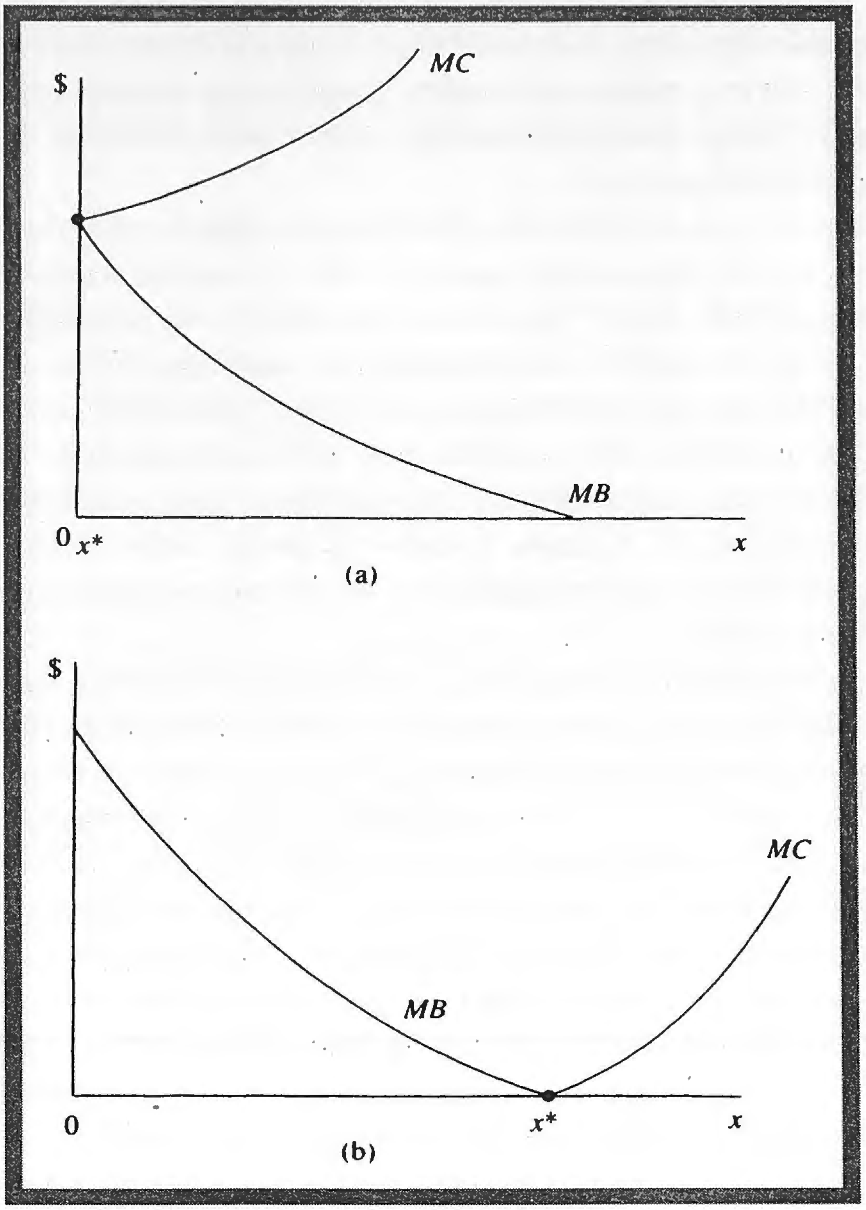


Figure 3.2 Alternative socially optimal levels of pollution

Figure 3.2b illustrates that optimal pollution could be near the private optimum if MCs approach zero.

If one looks at the Coase theorem from a bargaining model perspective (with zero costs of bargaining), we see that efficiency should be the same regardless of whether property rights are assigned to Riley or Ole separately or in common. Either way the pair should negotiate until they reach the efficient bargaining frontier. The only thing that should differ is the final distribution of total wealth. We illustrate with a thought experiment. Suppose the regulator gives Riley the unilateral property rights. Riley can exercise his outside option of full pollution with these secure rights, thereby ending the bargain. Bargaining, however, allows Riley and Ole to achieve a mutually advantageous deal. Assuming equal bargaining ability, the bargaining solution is when Riley and Ole split equally the additional wealth above the outside option, with Riley earning more total wealth than Ole. In contrast, suppose property rights are jointly owned by Riley and Ole, such that the outside option is for them to go to court to determine the final outcome. Given equal bargaining ability, Riley and Ole now share the total wealth equally, which is again on the efficient bargaining frontier. A bargaining solution with unilateral or common property rights, or any combination of these cases, should be equally efficient in this zero transaction cost world.

The Coase theorem is a powerful idea. The theorem suggests when the costs of organizing economic activity are low and people are free to choose, institutional structure does not matter all that much. This notion has caused a lot of commotion over the years. Critics complain that the Coase theorem is a *tautology*, that is, the assumptions prove the result. In this case, two bargainers with zero transaction costs implies that a market can arise instantaneously, in which they have no incentive to quit bargaining until an efficient resource allocation is achieved. Critics then point out the numerous flaws with such an idea. For example, if numerous people are involved in the dispute, the large numbers should make bargaining too costly and complex to find the efficient outcome (Baumol, 1972).

But in fact Coase did not promote a world of zero transaction costs, rather he "pushed the fiction of zero transaction costs reasoning to limit" (Williamson, 1994). His Nobel-prize winning work, twenty-three years earlier, on transaction costs within a firm established that (Coase, 1936). What Coase said was that since a zero transaction costs world does not exist, what we need to study was the world that does – the one with transaction costs (Coase, 1988). He did not champion a zero-transaction-costs world; rather he argued the institutional constraints on defining property rights are immaterial to economics if and only if transaction costs are zero. Since this world does not exist, efficiency is affected by the assignment of property rights. Coase (1988, p. 15) states, "[w]hat my argument does suggest is the need to introduce positive transactions costs explicitly into economic analysis so that we can study the world that does exist." This is the world of incomplete markets. Incomplete markets exist in many different forms throughout the economy. We now consider the concept of the externality as a result of incomplete markets.

3.3 Externalities

Many definitions live in the literature to reflect the idea behind what economists call an *externality*, the classic case of market failure. While the definitions vary by author, the general idea is that an *externality* exists when one person's actions affect other people, who neither receive compensation for harm done nor pay for benefit gained. For instance, Riley's discharge of wastewater into the Cloquet River that affects Ole's well-being (without compensation) is an externality. Riley's choices affect Ole, who receives no compensation for damage done.

Following up on the Coasean argument of incomplete markets, a useful definition is provided by Kenneth Arrow. Arrow (1969) defines an externality as "a situation in which a private economy lacks sufficient incentives to create a potential market in some good, and the nonexistence of this market results in the loss of efficiency." This efficiency loss arises when the action of one person bestows a benefit or imposes a cost on another person with neither consent nor compensation. Without a market, no decentralized mechanism exists to facilitate payment for benefits accrued or compensation for damages incurred (also see Cornes and Sandler, 1986). Negative and positive externality is the common vernacular.

Again consider Riley and Ole and their common Cloquet River. Riley's pollution discharge is an example of a negative externality. His disposal choice has a direct negative impact on Ole's production of enjoyable rafting and kayaking. If transaction costs are too great to define and enforce property rights for clean water or pollution control, a wedge exists between the private and the social level of pollution. Without property rights over the clean water, no decentralized mechanism exists for them to trade to a mutually acceptable level of water quality even though both could be better off with the trade. Of course, Ole could always choose to move elsewhere, nothing prevents him from exiting the conflict. Under the idea of the Coase theorem, this might be the efficient action: Riley bribes Ole to shut down kayaking operations.

To illustrate, consider a formal example. In this chapter we use lower-case Latin for variables, upper-case Latin for functions, lower-case Greek for parameters, and upper-case Greek for specific purposes, and primes represent derivatives. Suppose Riley selects a privately optimal level of pollution, x, to maximize his net profits, Π^R. Write net profits as $\Pi^R = \hat{\Pi}^R - C(\hat{x}^R - x)$, in which $\hat{\Pi}^R$ is the maximum profits in the absence of abatement, $C(\hat{x}^R - x)$ is the cost of abatement, and $\hat{x}^R > 0$ is Riley's privately optimal level of pollution. Reducing pollution to a level x is achieved at cost $C(\hat{x}^R - x)$. Assume $C(\hat{x}^R - x)$ is increasing and convex in abatement $\hat{x}^R - x$, such that $C'(\hat{x}^R - x) > 0$. Also there are no costs $C(0) = 0$ when Riley selects his optimal pollution level, $\hat{x}^R = x$. Ole's net profits Π^O equal his profits $\hat{\Pi}^O$ minus the damage $D(x)$ caused by the pollution, $\Pi^O = \hat{\Pi}^O - D(x)$. Assume damages are increasing and convex in pollution, $D'(x) > 0$, and that no damages arise if pollution is zero, $D(0) = 0$.

We determine whether a market failure exists by comparing the market outcome to the social optimum. If market circumstances induce Riley to choose a level of pollution identical to the level selected at the social optimum, the market works; if not, we have a market failure. The social optimum exists when aggregate profits are maximized: $\Pi^R + \Pi^O = \hat{\Pi}^R - C(\hat{x}^R - x) + \hat{\Pi}^O - D(x)$. The socially optimal level of pollution is determined by equating the marginal benefits from pollution with the marginal damages, $C'(\hat{x}^R - x) = D'(x)$, which is represented by x^* in Figure 3.3.

For the market outcome, however, Riley has no economic incentive to account for how his level of pollution affects Ole. Rather Riley selects a level of pollution that maximizes his net profits, i.e., $C'(\hat{x}^R - x) = 0$. Riley pollutes only accounting for his own private marginal benefit (i.e., avoided abatement costs), which is represented by x' in Figure 3.1. Note the difference between the two conditions which define the social optimum and the market outcome is the marginal damage term, $D'(x)$. Riley ignores these damages, the social optimum does not. Therefore, private pollution levels exceed socially optimal pollution levels, $x' > x^*$, and we have a market failure. The market failed to allocate resources efficiently – Riley releases too much pollution into the Cloquet River. Pollution is the classic example of a negative externality.

Now consider the opposite case, a positive externality. We consider Meade's (1952) famous case of the apple farmer and the beekeeper. Two producers are neighbors: one grows apples; the other raises bees to make honey. The production function for apples is written as $a = A(l^A)$, where a is apple output and l^A is labor devoted to apple production. More labor produces more apples, $A'(l^A) > 0$. The production function for honey is $h = H(l^H, a)$, where h is honey output which depends on labor devoted to honey production, l^H, and apple production, a. More labor leads to more honey, $\partial H(l^H, a)/\partial l^H > 0$. In addition, more apples produces more honey, $\partial H(l^H, a)/\partial a > 0$, that is, the honey producer's bees collect their nectar from the neighboring apple blossoms. This is the positive externality.

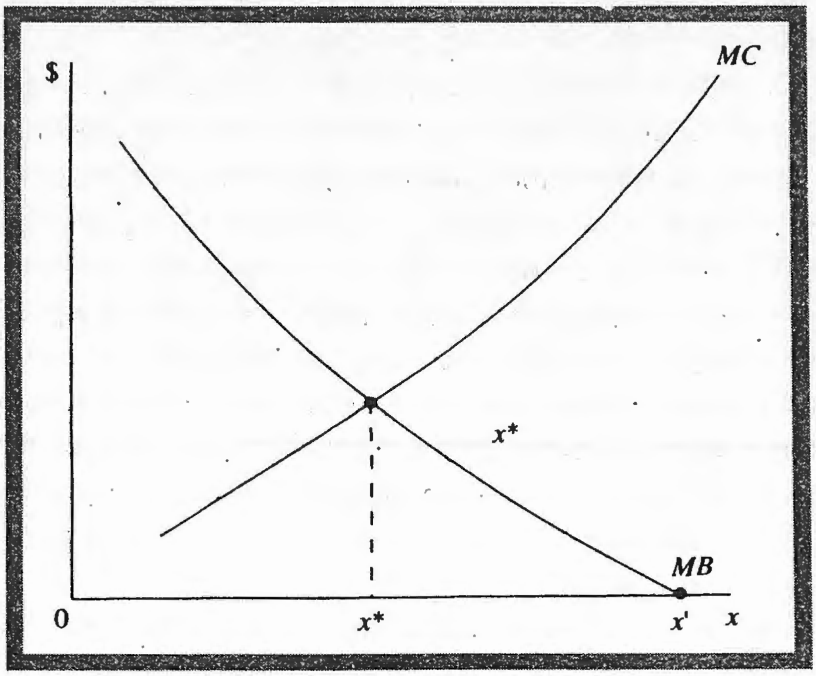


Figure 3.3 Socially and privately optimal level of pollution

Again market failure is determined by comparing the market equilibrium with the social optimum. Assume market prices for apples and honey, p^{A} and p^{H}, are fixed. In the market outcome, each producer considers only his or her own costs and benefits. The apple producer selects labor, l^{A}, to maximize net profits, $\Pi^{\mathrm{A}} = p^{\mathrm{A}}A(l^{\mathrm{A}}) - l^{\mathrm{A}}$ (for simplicity, assume the price of labor is unity). The honey producer selects labor, l^{H}, to maximize net profits, $\Pi^{\mathrm{H}} = p^{\mathrm{H}}H(l^{\mathrm{H}}, a) - l^{\mathrm{H}}$. The market equilibrium of apples and honey production is determined when relative market prices equal relative marginal productivity, $p^{\mathrm{A}}/p^{\mathrm{H}} = (\partial H(l^{\mathrm{H}}, a)/\partial l^{\mathrm{H}})/A'(l^{\mathrm{A}})$.

For the social optimum, we consider aggregate profits, $\Pi^{\mathrm{A}} + \Pi^{\mathrm{H}} = p^{\mathrm{A}}A(l^{\mathrm{A}}) - l^{\mathrm{A}} + p^{\mathrm{H}}H(l^{\mathrm{H}}, a) - l^{\mathrm{H}}$. In contrast to the market equilibrium, the social optimum considers how labor used for apples affects honey production, $h = H(l^{\mathrm{H}}, a) = H(l^{\mathrm{H}}, A(l^{\mathrm{A}}))$. Assuming total labor is fixed, $\bar{l} = l^{\mathrm{A}} + l^{\mathrm{H}}$, the socially optimal equilibrium condition equates relative market prices and how apple labor affects honey production to the relative marginal productivities, $p^{\mathrm{A}}A'(l^{\mathrm{A}}) + p^{\mathrm{H}}(\partial H(l^{\mathrm{H}}, A(l^{\mathrm{A}})/\partial l^{\mathrm{A}})) = p^{\mathrm{H}}\partial H(l^{\mathrm{H}}, a)/\partial l^{\mathrm{H}}$, which can be rewritten as $p^{\mathrm{A}}/p^{\mathrm{H}} + (\partial H(l^{\mathrm{H}}, A(l^{\mathrm{A}})/\partial l^{\mathrm{A}})) = (\partial H(l^{\mathrm{H}}, a)/\partial l^{\mathrm{H}})/A'(l^{\mathrm{A}})$. Comparing the market and social equilibria, we see the positive externality term, $(\partial H(l^{\mathrm{H}}, A(l^{\mathrm{A}})/\partial l^{\mathrm{A}})) > 0$, which implies that the apple producer produces too few apples given current prices relative to the social optimum. Because the apple producer is not compensated by the honey producer, he provides fewer apple trees than society would otherwise desire.

The classic apple–honey story is a market failure in theory. Historical evidence suggests, however, that a Coasean solution to this problem can exist (see Cheung, 1973). Farmers and beekeepers negotiate and write up formal contracts that provide compensation to the apple grower from the honey maker. The compensation, ideally, would be equal to the externality term, $(\partial H(l^{\mathrm{H}}, A(l^{\mathrm{A}})/\partial l^{\mathrm{A}}))$. If so, the compensation would induce the apple grower to hire the socially optimal level of labor. See Baumol and Oates (1988) for further discussion on general equilibrium model of externalities within a market system.

The cause and effect relationship that creates these externalities is fairly evident. Riley's emissions (cause) harm Ole's kayaking business (effect); more apple trees (cause) imply more honey production (effect). But when considering ecosystems and the services they provide to people, the effects of certain actions are not always so obvious and direct. Rather actions affecting an ecosystem at one point can reverberate throughout the ecosystem, ultimately impacting people in some unexpected manner. The pesticide DDT, for instance, was banned not only because it killed birds directly, but because it thinned the shells of bird eggs to unlivable levels, an unpredicted cause–effect relationship. Another example comes from Kern County, California, USA, around the turn of the century. About a hundred years ago, residents of the county killed nearly all the natural predators (e.g., coyotes) to reduce risks to domestic animals and children (see Crocker and Tschirhart, 1992). Unfortunately, the ultimate effect was one of the largest rodent infestations ever witnessed in the United States. Free from natural enemies, rodents invaded the villages and farms, wiping out crops. This is not the traditional case of one person affecting another, i.e., Riley affecting Ole. Rather Kern County residents were imposing a negative externality on themselves. They did not immediately recognize the link since the cause and effect was not obvious. Few citizens probably guessed that killing coyotes and foxes (the cause) would reduce grain and bread production (the effect). The externality emerged from a different point in the ecosystem than from where it started.

Let us consider how the ecosystem externalities work for the case of Kern County. Following Crocker and Tschirhart (1992), we develop their simple general equilibrium model of an *ecosystem externality*, which shows why it is important to understand the links and feedbacks between economic and ecological systems (also see Settle *et al.*, 2002). Again we compare socially optimal choices against those that arise in a market outcome.

We consider a three-species system, people, rodents, and predators, which are linked through the supply of grain. People eat bread produced from grain, rodents eat grain, and predators eat rodents. People are directly affected by grain and predators; rodents do not directly affect them. The key link is how rodents affect people indirectly through grain, that is, the ecosystem externality. We begin by defining the model and the socially optimum level of labor spent on bread production versus predator control.

A Kern County resident gains utility from more bread, b, and more leisure, l^l; he or she loses utility from more predators, d. We can write his or her utility function as

$$u = U(b, d, l^l) \tag{3.1}$$

where b is the level of bread consumed, d is the level of predators, and l^l is the amount of leisure. Assume increased bread and leisure increase utility, $U_b \equiv \partial U/\partial b > 0$ and $U_l \equiv \partial U/\partial l^l > 0$, while more predators decrease utility, $U_d \equiv \partial U/\partial d < 0$.

The ecosystem externality link between killing predators and bread production works in three steps. First, the consumer gives up l^d units of leisure to eliminate the predators

$$d = D(l^d) \tag{3.2}$$

where $D'(l^d) < 0$.

Second, they produce grain by

$$g = G(l^g, d) \tag{3.3}$$

where l^g is the labor units to produce grain, $G_1 = \partial G(l^g, d)/\partial l^g > 0$. Grain production also depends on the predator, $G_2 = \partial G(l^g, d)/\partial d$. This is the key ecosystem externality term, and can be either a negative or positive effect.

Third, the production of bread is represented by

$$b = B(g, l^b) \tag{3.4}$$

where l^b is the labor devoted to bread production, $B_1 \equiv \partial B(g, l^b)/\partial g > 0$ and $B_2 \equiv \partial B(g, l^b)/\partial l^b > 0$. The total amount of available labor is

$$\bar{l} = l^b + l^g + l^d + l^l$$

so available leisure is

$$l^l = \bar{l} - [l^b + l^g + l^d] \tag{3.5}$$

We determine the socially optimal allocation of labor resources by substituting Equations 3.2–3.5 into the resident's utility function (3.1)

$$u = U(b, d, l^l) = U(B(G(l^g, D(l^d)), l^b), D(l^d), \bar{l} - [l^b + l^g + l^d]) \tag{3.6}$$

Solving for the optimal allocation of labor between grain production, bread production and predator control yields the first-order conditions

$$U_b B_1 G_1 - U_l = 0 \tag{3.7}$$

$$U_b B_2 - U_l = 0 \tag{3.8}$$

$$U_b B_1 G_2 D' + U_d D' - U_l = 0 \tag{3.9}$$

Rearranging the conditions (3.7–3.9) yields the social or Pareto Optimal allocation of labor

$$\frac{U_d}{U_b} = \frac{B_2 - B_1 G_2 D'}{D'} \tag{3.10}$$

Here the left-hand side of expression (3.10) represents the marginal rate of substitution between bread production and predator removal, and the right-hand side shows the marginal rate of transformation between bread and predator control. This establishes our optimal benchmark against which we can compare the market outcome.

Now consider the market equilibrium. Here we have to consider two separate labor decisions. The labor demand side decision: the firm's choice over how much labor to hire for grain and bread production; the labor supply side decision; the consumer's decision to sell labor devoted to grain production, or use it for predator control and leisure. Let k and w represent the price of bread and labor; assume one firm produces all bread production (for simplicity).

The firm's profits are

$$\Pi = kB(g, l^b) - w(l^g + l^b) \tag{3.11}$$

The firm maximizes its profits, expression (3.11), by selecting the labor used for bread and grain production. In contrast, the consumer determines how much labor to sell for grain production and predator removal and leisure to maximize (3.1) subject to the budget constraint $kB(g, l^b) \leq w(\bar{l} - l^l - l^d)$. Combining the marginal conditions from two decisions yields the market outcome

$$\frac{U_d}{U_b} = \frac{B_2}{D'} \tag{3.12}$$

Now compare the socially efficient condition (3.10) to the market equilibrium (3.12). We see the market outcome does not include the externality ecosystem term, $B_1 G_2$, which is in the social optimum.

In general, the sign of the ecosystem externality term depends on the links within the ecosystem. If $B_1 G_2 > 0$, the model suggests that the residents of Kern county devoted too much labor to predator control relative to the socially optimal level. Determining the sign and the magnitude of the ecosystem externality is an empirical question. The evidence in Kern County suggest a negative impact from removing predators, too few resources were devoted to bread production and too many resources devoted to predator removal. The consumer neglects how predator removal indirectly affects grain production. The ecosystem externality idea invites economists to think beyond their normal disciplinary bounds, asking them to address cause–effect relationships which are less than obvious and not anticipated.

Finally, consider the idea of a *transferable externality*. The idea of a transferable externality is that people protect themselves from external damages by transferring the threat through space to another location or through time to another generation (Bird, 1987). A transferable externality differs from the traditional view of the pollution externality since transferability is motivated by intentional behaviors, not by the unintentional residuals of production. People select an abatement technology which transfers a risk, thereby creating conflict that induces strategic behavior between people, firms, or countries.

From a materials balance perspective, most environmental programs do not reduce environmental problems since they do not reduce the mass of materials used. While continuing to allow waste masses to flow into the environment, the programs simply transfer these masses through time and across space. Future generations and other jurisdictions then suffer the damages. In the past, Mid western industrial states in the US reduced regional air pollution problems like acid deposition by building tall stacks at emitter sites. For agriculture, air pollution from a coal-fired electric utility can encourage farmers to change how they use land, fertilizers, and pesticides, which in turn could generate more nonpoint pollution downstream. Large present-day use of pesticides accelerates the development of immune insect strains with which future human generations must contend. Some governments forbid the storage of toxins within their jurisdictions, thereby causing the toxins to be stored or dumped elsewhere.

A good example was the operations of the Des Moines (Iowa) Water Works in the early 1990s. The Water Works built the world's largest nitrates removal facility to clean nitrates from the city's Des Moines River drinking water supply. When nitrates exceed 10 parts per million (ppm) for 29 days, it triggered a legally imposed nitrate alert. Nitrate pollution, it is feared, promotes stomach cancer and methaemoglobinaemin (the blue baby syndrome). The removal facility transferred this risk, however, in that once removed, the nitrates were dumped back in the Des Moines River. L.D. McMullen, manager of the Water Works, noted "... [u]nfortunately, the nitrate is not salable so we will just take it out of the water temporarily. We put it back into the water and someone has to worry about it downstream."

Conflict is the inevitable consequence of the transferable externality as people shift the risk to others. The unilateral use of self-protecting technologies creates environmental conflicts which add another layer of inefficiency to the market system: the potential over investment in pollution abatement.

Consider a simple model to illustrate the impact of the transferable externality. Suppose Riley and Ole can select an abatement technology to transfer the risk posed by a hazard to the other player. Riley and Ole select a level of self-protection, s^{R} and s^{O}, to minimize the sum of the damages from the hazard, $D^i(s^{\mathrm{R}}, s^{\mathrm{O}})$, and the cost of the protection, $C^i(s^i)$, where $i = \mathrm{R}$ or O. Riley's cost minimization problem is

$$\hat{C}^{\mathrm{R}}(s^{\mathrm{R}}, s^{\mathrm{O}}) = D^{\mathrm{R}}(s^{\mathrm{R}}, s^{\mathrm{O}}) + C^{\mathrm{R}}(s^{\mathrm{R}}) \tag{3.13}$$

while Ole's problem is symmetric

$$\hat{C}^{\mathrm{O}}(s^{\mathrm{R}}, s^{\mathrm{O}}) = D^{\mathrm{O}}(s^{\mathrm{R}}, s^{\mathrm{O}}) + C^{\mathrm{O}}(s^{\mathrm{O}}) \tag{3.14}$$

Riley's damages decrease when he increases his own self-protection, $D_1^{\mathrm{R}} \equiv \partial D^{\mathrm{R}}/\partial s^{\mathrm{R}} < 0$, and increase when Ole increases his protection, $D_2^{\mathrm{R}} \equiv \partial D^{\mathrm{R}}/\partial s^{\mathrm{O}} > 0$. Ole's damages are similar: decreasing in own protection, $D_1^{\mathrm{O}} \equiv \partial D^{\mathrm{O}}/\partial s^{\mathrm{O}} < 0$, increasing in Riley's effort, $D_2^{\mathrm{O}} \equiv \partial D^{\mathrm{O}}/\partial s^{\mathrm{R}} > 0$. Costs of protection increase with increased effort, $C^{\mathrm{R}'} \equiv \partial C^{\mathrm{R}}/\partial s^{\mathrm{R}} > 0$ and $C^{\mathrm{O}'} \equiv \partial C^{\mathrm{O}}/\partial s^{\mathrm{O}} > 0$.

Consider a simple Nash equilibrium game of transferable externalities. If the players do not coordinate their self-protection efforts, Riley and Ole independently and simultaneously select their optimal level of self-protection to minimize their private costs, expressions (3.13) and (3.14). Each player ignores how he impacts the other player's costs. Assuming an interior minimum exists, these actions yield the following non-cooperative first-order conditions

$$-D_1^{\mathrm{R}} = C^{\mathrm{R}'} \tag{3.15}$$

and

$$-D_1^{\mathrm{O}} = C^{\mathrm{O}'} \tag{3.16}$$

The two non-cooperative conditions imply each player selects the level of self-protection to equate his own MB, $-D_i^i(i = \mathrm{R}, \mathrm{O})$, with MC, $C^{i'}(i = \mathrm{R}, \mathrm{O})$.

Now suppose both players decide to coordinate their actions. The cooperative level of self-protection is determined by minimizing the sum of both costs, $C^{\mathrm{T}} = C^{\mathrm{R}}(s^{\mathrm{R}}, s^{\mathrm{O}}) + C^{\mathrm{O}}(s^{\mathrm{R}}, s^{\mathrm{O}})$, yielding the cooperative first-order conditions of

$$-D_1^{\mathrm{R}} = C^{\mathrm{R}'} + D_2^{\mathrm{O}} \tag{3.17}$$

and

$$-D_1^{\mathrm{O}} = C^{\mathrm{O}'} + D_2^{\mathrm{R}} \tag{3.18}$$

Now these cooperative conditions imply both players select the level of self-protection to equate their MBs, $-D_1^i(i = \mathrm{R}, \mathrm{O})$, with two MCs: their private costs, $C^{i'}(i = \mathrm{R}, \mathrm{O})$, and the external cost they impose on the other player, $D_2^i(i = \mathrm{R}, \mathrm{O})$

Consider a simple model to illustrate the impact of the transferable externality. Suppose Riley and Ole can select an abatement technology to transfer the risk posed by a hazard to the other player. Riley and Ole select a level of self-protection, s^R and s^O, to minimize the sum of the damages from the hazard, $D^i(s^R, s^O)$, and the cost of the protection, $C^i(s^i)$, where $i = \mathrm{R}$ or O. Riley's cost minimization problem is

$$\hat{C}^R(s^R, s^O) = D^R(s^R, s^O) + C^R(s^R) \tag{3.13}$$

while Ole's problem is symmetric

$$\hat{C}^O(s^R, s^O) = D^O(s^R, s^O) + C^O(s^O) \tag{3.14}$$

Riley's damages decrease when he increases his own self-protection, $D_1^R \equiv \partial D^R/\partial s^R < 0$, and increase when Ole increases his protection, $D_2^R \equiv \partial D^R/\partial s^O > 0$. Ole's damages are similar: decreasing in own protection, $D_1^O \equiv \partial D^O/\partial s^O < 0$, increasing in Riley's effort, $D_2^O \equiv \partial D^O/\partial s^R > 0$. Costs of protection increase with increased effort, $C^{R'} \equiv \partial C^R/\partial s^R > 0$ and $C^{O'} \equiv \partial C^O/\partial s^O > 0$.

Consider a simple Nash equilibrium game of transferable externalities. If the players do not coordinate their self-protection efforts, Riley and Ole independently and simultaneously select their optimal level of self-protection to minimize their private costs, expressions (3.13) and (3.14). Each player ignores how he impacts the other player's costs. Assuming an interior minimum exists, these actions yield the following non-cooperative first-order conditions

$$-D_1^R = C^{R'} \tag{3.15}$$

and

$$-D_1^O = C^{O'} \tag{3.16}$$

The two non-cooperative conditions imply each player selects the level of self-protection to equate his own MB, $-D_i^i(i = \mathrm{R}, \mathrm{O})$, with MC, $C^{i'}(i = \mathrm{R}, \mathrm{O})$.

Now suppose both players decide to coordinate their actions. The cooperative level of self-protection is determined by minimizing the sum of both costs, $C^T = C^R(s^R, s^O) + C^O(s^R, s^O)$, yielding the cooperative first-order conditions of

$$-D_1^R = C^{R'} + D_2^O \tag{3.17}$$

and

$$-D_1^O = C^{O'} + D_2^R \tag{3.18}$$

Now these cooperative conditions imply both players select the level of self-protection to equate their MBs, $-D_1^i(i = \mathrm{R}, \mathrm{O})$, with two MCs: their private costs, $C^{i'}(i = \mathrm{R}, \mathrm{O})$, and the external cost they impose on the other player, $D_2^i(i = \mathrm{R}, \mathrm{O})$

Figure 3.4 illustrates the basic idea. If one accounts for the external cost, each player should cut back on their level of self-protection as the non-cooperative level exceeds the cooperative level, point A versus point B. Figure 3.5 shows the cooperative solution ($s^* = s^{R*} + s^{O*}$) minimizes the joint cost, whereas the non-cooperative solution ($s' = s^{R'} + s^{O'}$)

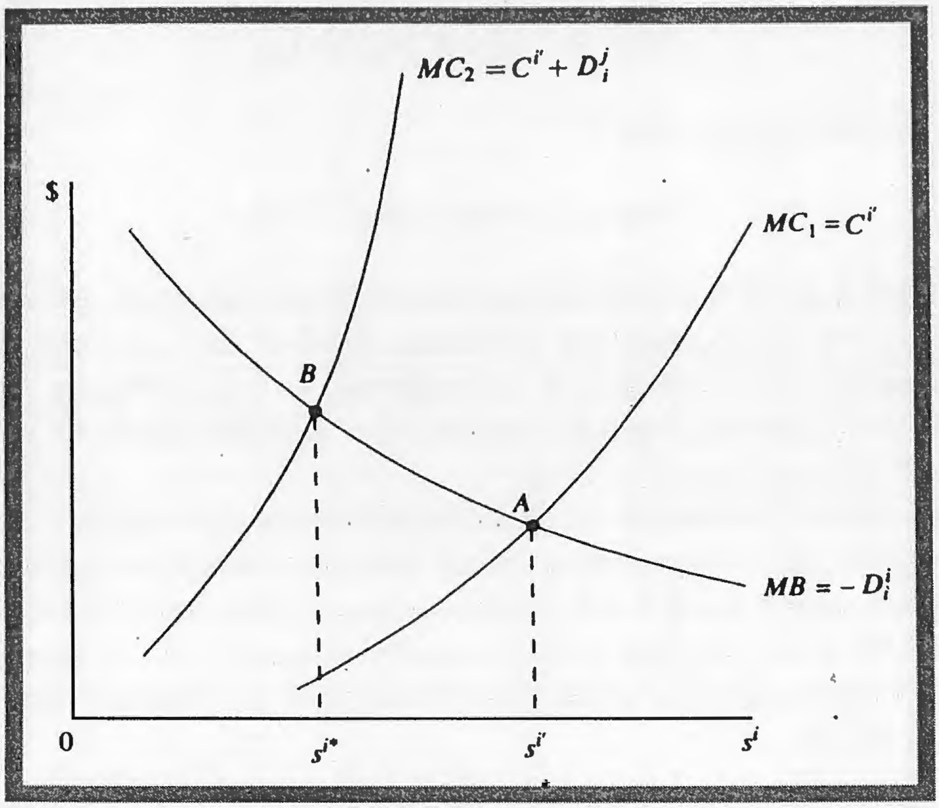


Figure 3.4 Cooperative and non-cooperative self-protection

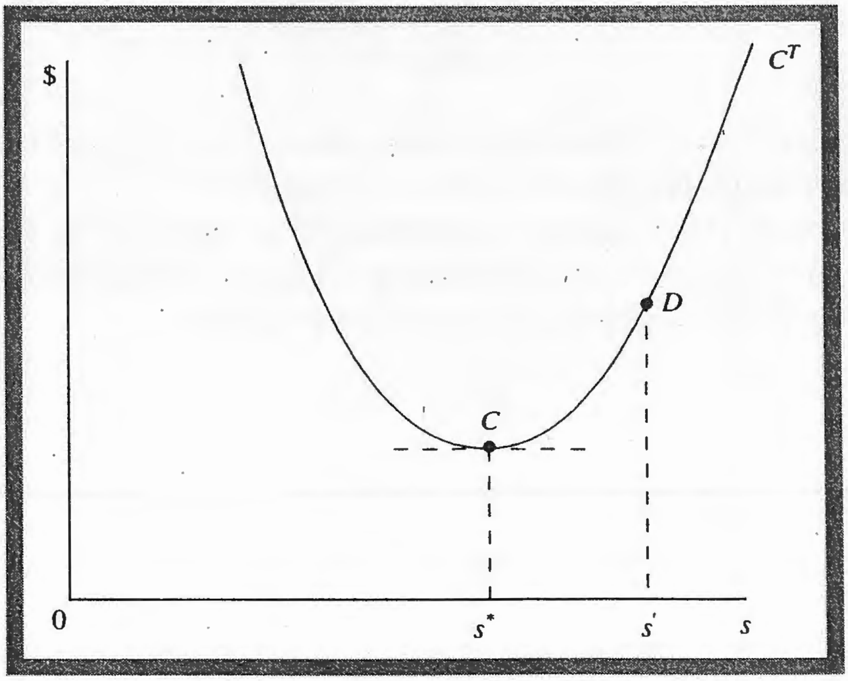


Figure 3.5 Total cost of cooperative and non-cooperative self-protection

implies both players are spending too much on abatement, point C versus point D. One shows this by substituting the non-cooperative solution (Equations 3.15 and 3.16) for self-protection into the cooperative Equations (3.17) and (3.18), thereby yielding the positively sloped external MC. This implies the non-cooperative solution is on the right-hand side of the minimum point on the total cost curve, point D (see Shogren and Crocker 1991).

Environmental policies that allow unilateral transfers of pollution rather than encouraging cooperation result in too much self-protection. Therefore, environmental protection is too expensive relative to the benefits gained. Policy strategies that encourage self-protection should be reconsidered since such strategies intensify the inefficiencies. This type of result also can arise in questions of environmental federalism (i.e., policy set by local versus federal authorities), when one jurisdiction overprotects relative to the social optimum (e.g., see Wellisch, 2000). This is the classic NIMBY problem (Not In My Back Yard), in which no community wants to be the location of the nuclear waste storage facility.

3.4 Non-exclusion and the commons

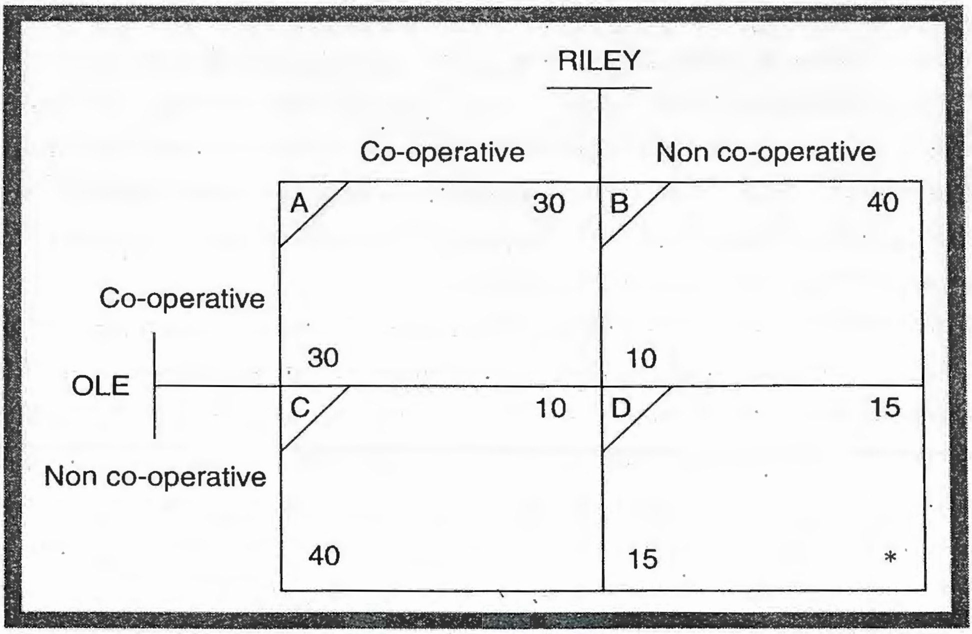
Common property is another classic case in which the market might fail to efficiently allocate resources. If it is technically impossible or too costly to deny open access to an environmental resource, market allocation is likely to be inefficient. If Riley's use of a resource rivals Ole's use and they both have legal (or illegal) access rights, they have the incentive to capture the benefits before the other does. In such cases, they over-exploit the resource relative to what is best for both of them. When overuse occurs due to non-exclusion the market has failed to signal the true scarcity of the asset.

The potential problem associated with common property and non-exclusion has long been recognized, although it was popularized by Hardin's (1968) term the "tragedy of the commons." Before continuing, a few definitions are worth noting – "commons" refers to the environmental asset itself, "common property resource" or "common pool resource" refers to a property right regime that allows for some collective body to devise schemes to exclude others, thereby allowing the capture of future benefit streams and "open-access" implies there is no ownership in the sense that "everybody's property is nobody's property" (see Gordon 1954, p. 124).

Fishing grounds on the oceans provide the best-known examples of open-access commons. More fish caught by one party implies less fish for others. Each fisher therefore has incentive to increase his or her fishing effort to capture the rents. If each fisher ignores how his actions affect others, total effort expended exceeds the socially optimal level determined when MC of harvesting equals the market price. Rather with open access conditions, fishers expend effort until their average cost of production equals the market price. The scarcity value of the resource is ignored. When scarcity value is neglect, it can result in over-fishing and the depletion of the fishing stock to an unsustainable level. Open access conditions, for example, resulted in over-fishing of cod and witch flounder off Canada's Grand Banks in the North Atlantic, once one of the richest fishing grounds. Over-fishing led to a moratorium, which put some 30,000 Newfoundlanders out of work, and triggered a conflict between Canada and Spain, whose fleets were fishing just off Canada's 200-mile limit.

The Black Sea is another commons affected by the weakly coordinated activity of Bulgaria, Georgia, Romania, the Russian Republic, Turkey, and Ukraine. The Sea also serves as a common receptacle for a drainage basin five times the area of the sea itself encompassing 16 countries and 165 million people. The inability to exclude people from using or dumping waste into the commons affected the structure and functioning of the coastal marine ecosystem (see Mee, 1994). The Danube introduces about 60,000 tons of total phosphorous per year, and about 340,000 tons of total inorganic nitrogen per year, about one-half from agricultural sources and half from industrial and domestic sources. In addition, numerous coastal communities directly discharge their sewage and waste into the sea. This increased nutrient load causes overfertilization of the sea leading directly to increased global quantities of phytoplankton and the occasional algae bloom. The impacts include less biological production, disturbed oxygen content leading to fish kills, more sediment, and reductions in the stocks of sturgeon, turbot, mackerel, and the dolphin. Only 6 of 26 species of commercial fish in the 1960s remain in significant quantities to harvest.

Figure 3.6 illustrates another Nash non-cooperative game, in which the incentive is to overharvest an open-access fishery. Suppose Riley and Ole both fish on Big Lake. Riley and Ole have a choice: they can cooperate by limiting their fishing fleet to one ship per day or they can act non-cooperatively by sending out three ships every day. If both cooperate, they each earn net profits of 30 (Box A in Figure 3.6). If Riley sends out three ships and Ole only sends out one, Riley increases his net profits to 40. He captures a greater share of the rents. Ole would only earn net profits of 10 (Box B).



		RILEY	
		Co-operative	Non co-operative
OLE	Co-operative	A 30 30	B 40 10
	Non co-operative	C 10 40	D 15 15 *

Figure 3.6 Open access and the prisoners' dilemma

Since net profit of 40 exceeds 30, Riley has an incentive to send out three ships. Ole has the identical incentive. If Riley cooperates and Ole does not, then Ole earns 40 and Riley earns 10 (Box C). If both players decide to act non-cooperatively by sending out three ships each, they over-fish Big Lake and their net profits fall to 15 each (Box D). The end result is both fishermen only earn total net profits of $30(15+15)$, while the social optimum is total net profits of $60(30+30)$ when both cooperate.

The dominant strategy for each player is to not cooperate. A dominant strategy means a player can earn more payoffs regardless of the other player's actions. In our example, the non-cooperative strategy dominates the cooperative one since $40 > 30$ and $15 > 10$. This outcome is called a Nash equilibrium. A Nash equilibrium exists when neither player has a unilateral incentive to change his strategy. A unilateral action here leaves a player worse off without a reciprocal move by the other player. Our example of both players falling into the non-cooperative solution is the classic "prisoner's dilemma" game – each prisoner has an incentive to fink on his fellow partner in crime to secure a milder punishment for himself, even though both are better off if they both keep their mouths shut.

Consider a static model to illustrate the basic structure of the commons problem (see Cornes and Sandler, 1986; see Mason and Polasky, 1997, for a dynamic model). Suppose n producers have access to a commons. Total harvest, y (e.g., fish, timber), from the commons is determined by total effort expended, $\hat{x}$, by all the users (e.g., fishing fleet). Let the production function be $y = F(\hat{x})$, where $F'(\hat{x}) > 0$ and $F''(\hat{x}) < 0$. Assume harvest is sold on a competitive world market, so we can normalize the market price at unity. For simplicity, assume each producer is identical, so his share of the total harvest (y) is determined by his effort (x) relative to total effort, $y = \{x/\hat{x}\}F(\hat{x})$, where $\hat{x} = x + \tilde{x}$, where $\tilde{x}$ is the total effort of all other producers.

The social optimum level of effort is determined by maximizing the profits of all the users, $\Pi(\hat{x}) = F(\hat{x}) - p\hat{x}$, where p is the opportunity cost of harvest effort (e.g., rental rate of boats, logging equipment). The socially optimal level of harvest, $\hat{x}^*$, is determined by the first-order condition which equates the value of marginal product to the opportunity cost of effort, $F'(\hat{x}) = p$. In contrast, the market outcome is set by the profit maximizing behavior of each user, $\Pi(x) = \{x/\hat{x}\}F(\hat{x}) - px = \{x/(x+\tilde{x})\}F(x+\tilde{x}) - px$. Assuming $\tilde{x}$ is an exogenous parameter, the first-order conditions now equates each user's marginal benefits and costs, $\{x/\hat{x}\}F'(\hat{x}) + \{\tilde{x}/\hat{x}\}[F(\hat{x})/\hat{x}] = p$. Here the marginal benefits are a weighted average of marginal product, $F'(\hat{x})$, and average product, $[F(\hat{x})/\hat{x}]$. The weighting scheme depends on the number of users, n. Assuming a symmetric Nash equilibrium for the n users (i.e., all players are identical), we write $(1/n) = \{x/\hat{x}\}$ and $(n-1)/n = \{\tilde{x}/\hat{x}\}$, such that the private optimum condition is $\{1/n\}F'(\hat{x}) + \{n - 1/n\}[F(\hat{x})/\hat{x}] = p$. If we consider the case of a signal producer (a monopoly, $n = 1$), the market optimum corresponds with the social optimum, $F'(\hat{x}) = p$. The monopolist producer selects the social optimal level of harvest because he captures the scarcity rents associated with the commons. But if the number of producers is very large (i.e., $n \to \infty$), the producer now equates the value of average product with MCs, $F(\hat{x})/\tilde{x} = p$, and economic profits disappear toward zero. This implies he and all other producers using the commons expend too much effort; they all ignore the scarcity value of the resource. This is the "tragedy of the commons," a similar incentive problem as in the classic prisoner's dilemma.

Not all non-excludable resources are defined by the prisoner's dilemma style tragedy of the commons game. Commons can also be categorized as a coordination problem (Schelling, 1960). In Figure 3.7, we have a coordination game with two Nash equilibria, one in which both players act non-cooperatively as before and another in which they cooperate. Both outcomes are a Nash equilibrium since neither have a unilateral incentive to deviate from the strategy. Cooperation is a Nash equilibrium since a player receives 50 if both cooperate and only 40 if he unilaterally cheats. Non-cooperation is still a Nash equilibrium because a player receives 15 if he cheats and only 10 if he cooperates while the other player does not. Obviously, both players would prefer the cooperative Nash equilibrium since the payoffs are the greatest, 50 each; society also prefers the cooperative outcome since the joint profits are the greatest, $100 = 50 + 50$.

Though no guarantee exists the players can coordinate their strategies to achieve the preferred cooperative solution, Ostrom (1990) and colleagues have documented several examples of actual common property resources in which players achieve a cooperative outcome. These groups establish self-governing common property regimes without strict private property rules or government intervention. Successful self-coordination of strategies in actual common property regimes appears to depend, among other things, on the information and transaction costs of achieving a credible commitment to the collective, active rules to self-monitor and sanction violators, and the presence of boundary rules that define who can appropriate resources from the commons.

Market failure need not occur with commons, provided rules exist to exclude others and to share the gains. Recent work stresses the role that political institutions play as exchange and enforcement mechanisms for common property. Evidence from the field

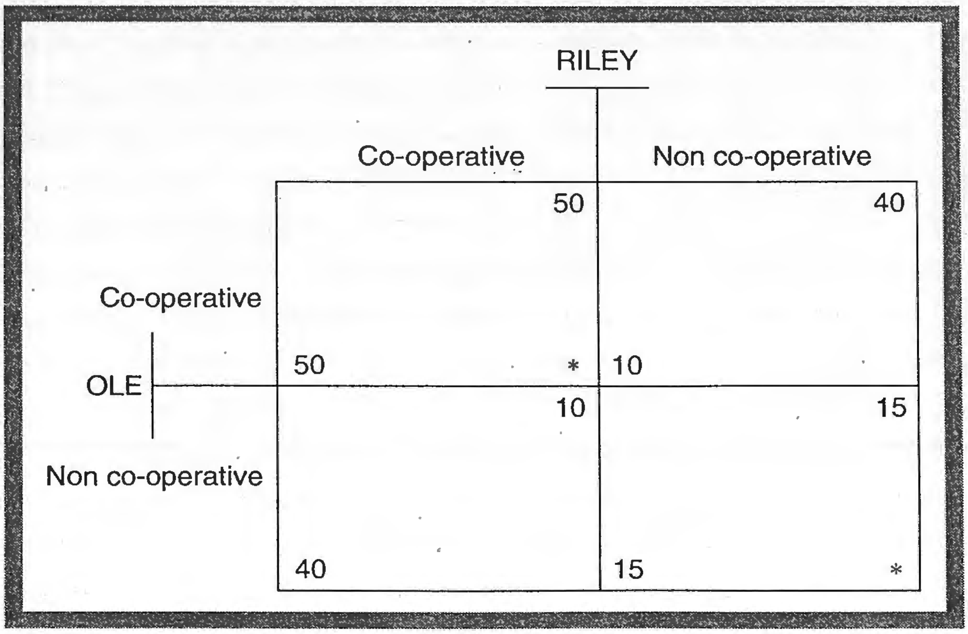


Figure 3.7 Coordination game

suggests an incentive scheme works better if it is designed and enforced by the people inside the collective. Ostrom (1990, p. 94), for instance, notes that "[i]n these robust institutions, monitoring and sanctions are undertaken not by an external authority but rather by the participants themselves." She reviewed 15 self-organized collectives from around the world, finding that sanctions are a necessary condition for robust institutional performance for common property management (Ostrom, 1990, Table 5.2, p. 180). Formal or informal social sanctions defined by the collective can help enforce the agreed sharing rules (e.g., a small financial penalty coupled with reputation loss). It is crucial to understand better how a "community" chooses to design its political institutions that structure how people relate and interact with each of them (e.g., see Agrawal and Gibson, 1999; Baland and Platteau, 2003; Vyrastekova and van Soest, 2003).

3.5 Non-rivalry and public goods

Public goods represent another form of market failure. An environmental good like climate protection is a pure public good because its provision is both non-rival and non-excludable. Recall that non-rival means climate protection provided to one person does not reduce the level of protection to anyone else; non-excludable means it is too costly to exclude any one from receiving climate protection. Countries have a common interest in responding to the global risk of climate change, and yet some are reluctant to reduce their own greenhouse gas emissions voluntarily because no nation can be prevented from enjoying climate protection, regardless of whether it participates in some international treaty. Each nation's incentive to reduce emissions is limited because it cannot be prevented from enjoying the gains provided by other nations' efforts. This incentive to free ride reflects the divergence between national actions and global interests. Since no global police organization exists to enforce an international climate agreement, sovereign parties have incentive to deviate unilaterally from the terms of the agreement. The ideas behind a public good versus an externality are related, though still a bit different. A public good is usually provided or exists for a purpose, for example national defense, climate protection, biological diversity, whereas an externality is generally an unintended consequence of some action started for a different reason (e.g., pollution). An externality can generate a "public bad" like climate change. A pure public good is available to all; one person's consumption does not reduce another person's consumption (Samuelson, 1954, 1955). Non-rivalry implies the marginal social cost of supplying the good to an additional person is zero. It is not Pareto efficient to set prices to exclude anyone who derives positive marginal benefits from the public good – a market failure exists since a private firm cannot profit by providing a pure public good to everyone as dictated by Pareto efficiency. In addition, since everyone benefits from the services provided by a pure public good and no one can be excluded from these benefits, there is a general concern that people will "free ride." Recognized early on by Swedish economist Knut Wicksell (1896), a free rider is someone who conceals his or her preferences for the good and then enjoys the benefits without paying for them. Free riding implies the market provides less public good than is socially desired, thereby misallocating resources away from the environment toward private goods in which the conditions of rivalry and exclusion hold.

For example, forests provide local public goods by managing such ecosystem services like water flow, soil erosion, and nutrient recycling. Forests provide global public goods through contributions to the non-rival benefits of biodiversity, ecosystem linkages, and carbon sequestration (see Myers, 1992, pp. 261–266). Wetlands act as a local public good by buffering the economy from natural and man-made shocks by adjusting to fluctuating water levels from tides, precipitation, and runoff, and by providing water purification and habitat services. An ecosystem, in general, provides public services given its ability to underpin and buffer the market economy from the external shocks of production and consumption activities (see Chapter 2). There are also public goods that reduce utility or profits such as pollution or noise. The loss suffered by one person from the pollution of air or from climate change, for example, does not reduce the loss suffered by another. This "public bad" is oversupplied by the market.

We illustrate the market failure associated with a pure public good by considering a case in which Riley and Ole contribute voluntarily to the provision of a public good. This public good could be a local public good, abatement effort to clean up the Cloquet River, or a global public good, abatement effort to reduce carbon emissions feared to induce climate change. The aggregate level of the public good is represented by $\bar{q} = q^{R} + q^{O}$, where q^{R} and q^{O} represent Riley and Ole's respective private contributions. Given non-rivalry and non-exclusion, both Riley and Ole benefit from the aggregate level of the public good, $\bar{q} = q^{R} + q^{O}$. This is the "summation" representation of a public good, that is all contributes summed together create the public good. See Cornes and Sandler (1986) for a discussion of alternative representations of public goods, for example best shot, weak link public goods.

Write each contributor's utility function as

$$U^{i}(z^{i}, \bar{q}) \qquad \text{for } i = \text{R, O}$$

where z^{i} represents consumption of a private good. A person's utility is increasing in both the private good and the public good

$$U_{z}^{i} \equiv \partial U^{i}/\partial z^{i} > 0$$

and

$$u_{q}^{i} \equiv \partial U^{i}/\partial \bar{q} > 0 \qquad i = \text{R, O}$$

Riley and Ole each choose their level of private good consumption and public good contributions given each has his own budget constraint

$$m = z^{i} + pq^{i} \qquad i = \text{R, O}$$

where m is a person's monetary income and p is the per unit cost of providing the public good. For simplicity, assume the price of the private good, z^{i}, equals unity.

Riley selects a level of the private and public goods to maximize his utility subject to his budget constraint

$$\operatorname*{Max}_{z^R, q^R}\left[U^R(z^R, \bar{q}) | m = z^R + pq^R; \bar{q} = q^R + q^O\right]$$

We simplify Riley's problem by substituting the budget constraint into his utility function given $z^R = m - pq^R$

$$\operatorname*{Max}_{q^R}\left[U^R(m - pq^R, q^R + q^O)\right]$$

Riley selects his optimal contribution to the public good yielding

$$p = \frac{U_q^R}{U_z^R} = \mathrm{MRS}_{qz}^R$$

This condition says the per unit cost of the public good, p, equals the marginal benefits from the public good defined in terms of the private good foregone, i.e., the MC equals the marginal rate of substitution between the public and the private good, $\frac{U_q^R}{U_z^R} = \mathrm{MRS}_{qz}^R$

Ole makes a similar decision to determine his optimal level of contributions to the public good

$$\operatorname*{Max}_{q^O}\left[u^O(M - pq^O,\ q^R + q^O)\right]$$

and his optimal level is determined by

$$p = \frac{U_q^O}{U_z^O} = \mathrm{MRS}_{qz}^O$$

Ole balances the MC of his contribution with the MB from the public good, in terms of the private good. Both Riley and Ole contribute without concern for how their contribution affects the other person.

Now consider the socially optimal allocation of resources for the public good. We determine the efficient level of the aggregate public good by selecting the levels of q^R and q^O to maximize one person's utility, say Riley, subject to the constraint that Ole achieves a utility level of $\bar{v}$

$$\operatorname*{Max}_{q^R, q^O}\left\lfloor U^R(m - pq^R,\ q^R + q^O) | \bar{v} = U^O(m - pq^O,\ q^R + q^O)\right\rfloor$$

yielding

$$-U_z^R p + U_q^R - \lambda U_q^O = 0 \tag{3.19}$$

and

$$U_q^R - \lambda\left[U_z^O(-p) + U_q^O\right] = 0 \tag{3.20}$$

where λ is the Lagrangian multiplier representing the shadow price of the utility constraint. Solving for λ in Equation (3.19) and substituting it into Equation (3.20) yields the condition for optimal provision of the public good

$$p = \frac{U_q^R}{U_z^R} + \frac{U_q^O}{U_z^O}$$

or

$$p = \mathrm{MRS}_{qz}^R + \mathrm{MRS}_{qz}^O$$

This term is the classic *Samuelson public good condition* (Samuelson, 1954). The efficient level of the public good exists when the summation of marginal benefit for the public good, in terms of the private good, equals its marginal cost. The intuition behind the aggregation of marginal benefits rests in the assumptions of non-rival and non-excludable consumption. The benefits of the public good are all inclusive. The inefficiency from the private provision of the public good derives from Riley ignoring his impact on Ole and vice versa. Neither person accounts for the extra benefit passed on to the other as each increases his contribution to the supply of the public good.

Figure 3.8 illustrates the socially optimal level of the public good for Riley and Ole. Let RR′ and OO′ represent Riley and Ole's demand curves for the public good assuming a given distribution of income. Let MC represent the marginal cost of providing the public good. If Q′ is supplied, Riley's marginal willingness to pay is wtp^R. Riley's willingness to

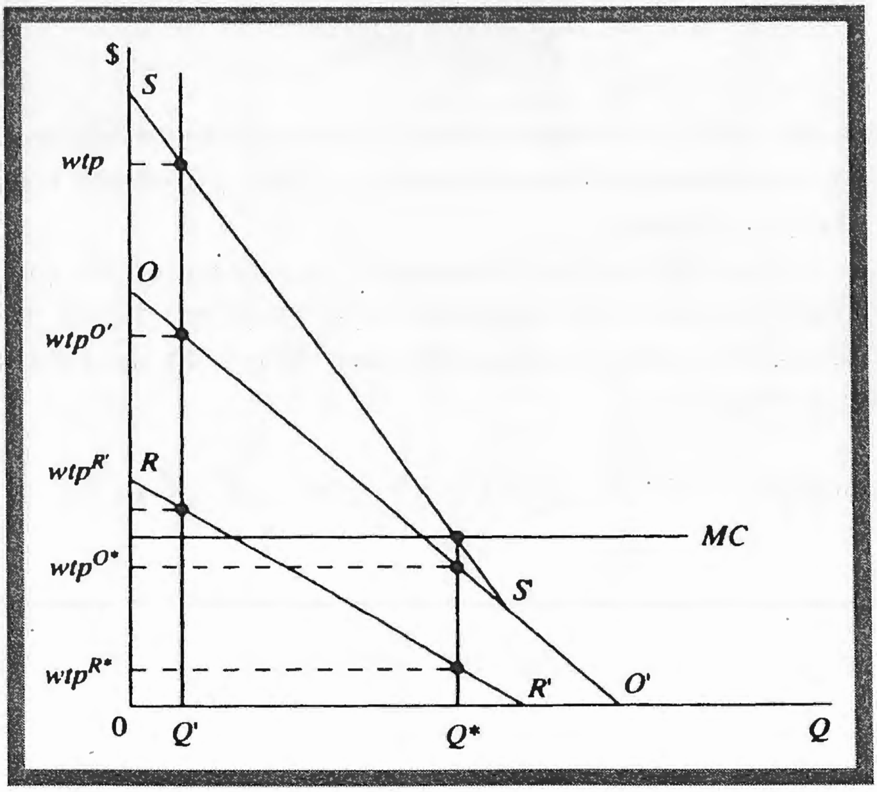


Figure 3.8 Pure public goods

pay represents the maximum he would pay for one unit of the good given his preferences and budget constraint. Ole's marginal willingness to pay is wtp^{O}, which then implies a total demand of $\text{wtp}' = \text{wtp}^{R} + \text{wtp}^{O}$. Because there are no rivalries with the public good, marginal social value is the vertical summation of the two values, so summing the marginal private values at every level of the public good would yield line SS′. The optimal level of the public good, Q*, is where the marginal social value equals the MC. At this optimal level, each person would pay a personalized price – Riley would pay wtp^{R*} and Ole would pay wtp^{O*}. Revealing these personalized prices for pure public goods, however, is difficult in practice as we see in the chapter on non-market valuation (see Chapter 9).

3.6 Nonconvexities

We have assumed the marginal benefit and cost functions associated with increased pollution are well behaved – marginal benefits are decreasing, while marginal costs are increasing (recall Figure 3.1). These well-behaved curves guarantee that if an equilibrium level of pollution exists then it is unique. If a set of complete markets exists for clean water or pollution control, the market sends the correct signal about the socially optimal level of pollution. Figure 3.9 shows the net benefit curve is "single-peaked," implying there is one efficient level of pollution.

But for many physical systems the marginal benefit or cost curve need not be so well behaved. The costs of marginal damages, for instance, may initially increase with

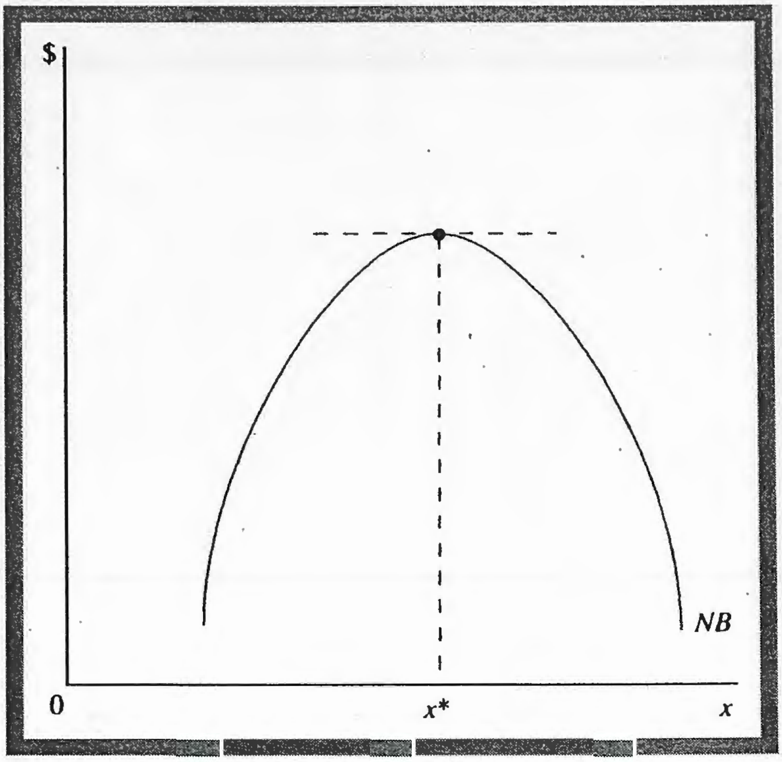


Figure 3.9 Single-peaked net benefit curve

increased pollution but then may actually decrease or go to zero as the physical system is destroyed and there are no additional marginal costs even as pollution continues to increase. The system is destroyed; more pollution cannot make it any more dead. This is a nonconvexity, and it implies that more than one optimal level of pollution might exist.

To better understand the implications of a nonconvexity, let us go back to the example of Riley and Ole on the Cloquet River. Figure 3.10 shows Ole's marginal cost with increased pollution initially increasing. But at a threshold level of pollution, x^+, the marginal cost associated with increased pollution actually starts to decline and eventually reaches zero at level x_C. This implies the damage to Ole is complete – more pollution does not raise his marginal costs because his business is gone.

Figure 3.11 adds Riley's marginal benefits curve back into the picture. We see three points in which marginal benefit equals marginal cost: points A and C represent local maximums of net benefits, while point B is a local minimum of net benefits. We no longer have a "single-peaked" net benefit curve, rather we have two local maximum points where one of the points is the global optimum. Whether point A with a low level of pollution or point C with a high level of pollution is the global maximum depends on the relative magnitude of the two hashed areas marked D and E. Area D represents the net marginal costs of increasing pollution to point A, while area E is the net marginal benefits of moving to point C. If the net marginal costs exceed the net marginal benefits of increasing pollution to point C (area D > area E), point A is the global maximum; otherwise point C is the global maximum and the socially optimal level of pollution is when MB equals zero.

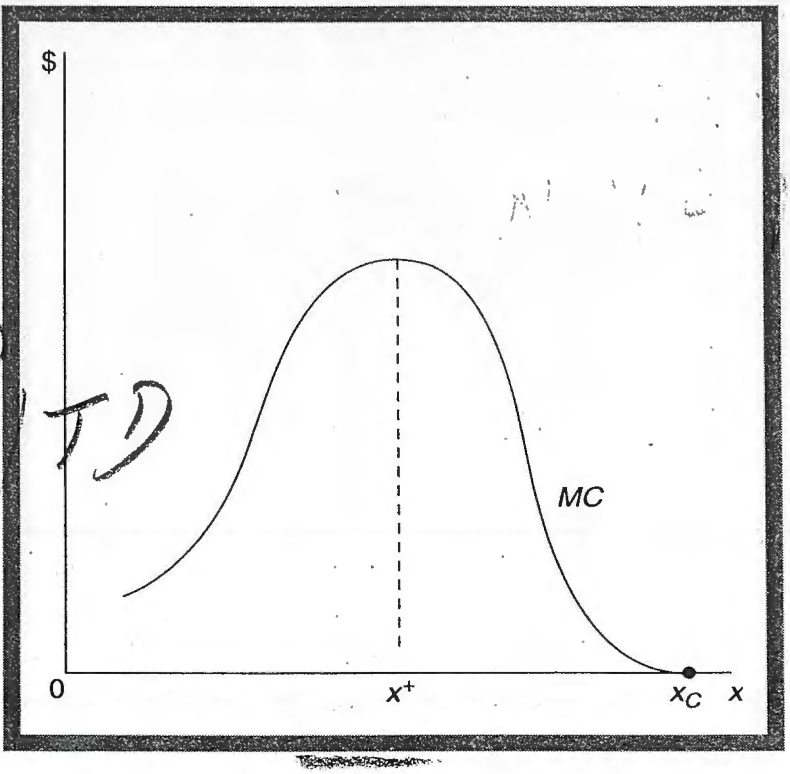


Figure 3.10 Non-convex marginal costs

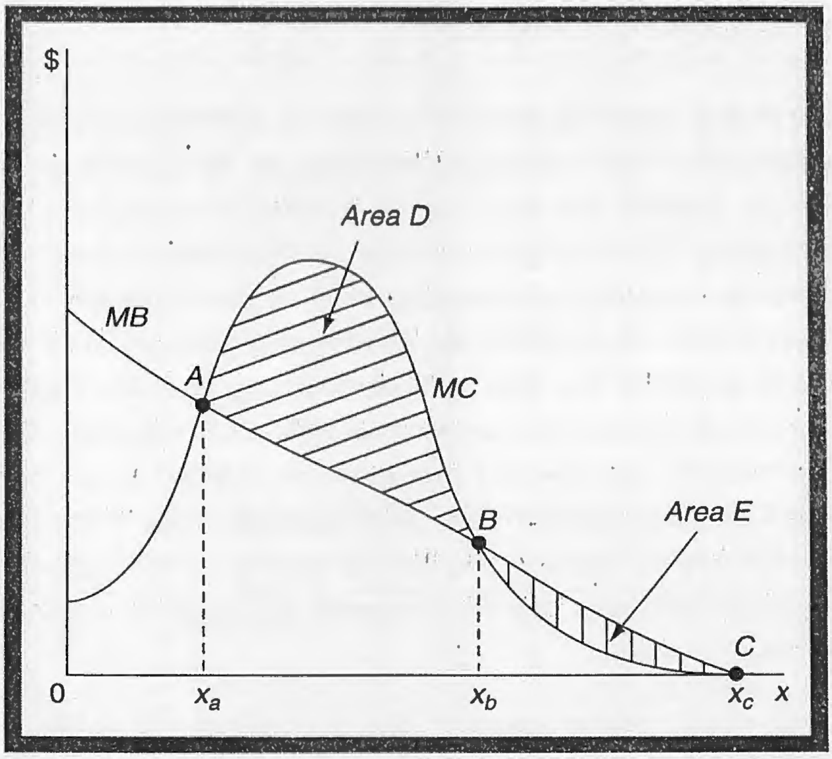


Figure 3.11 Non-convexity and the optimal level of pollution

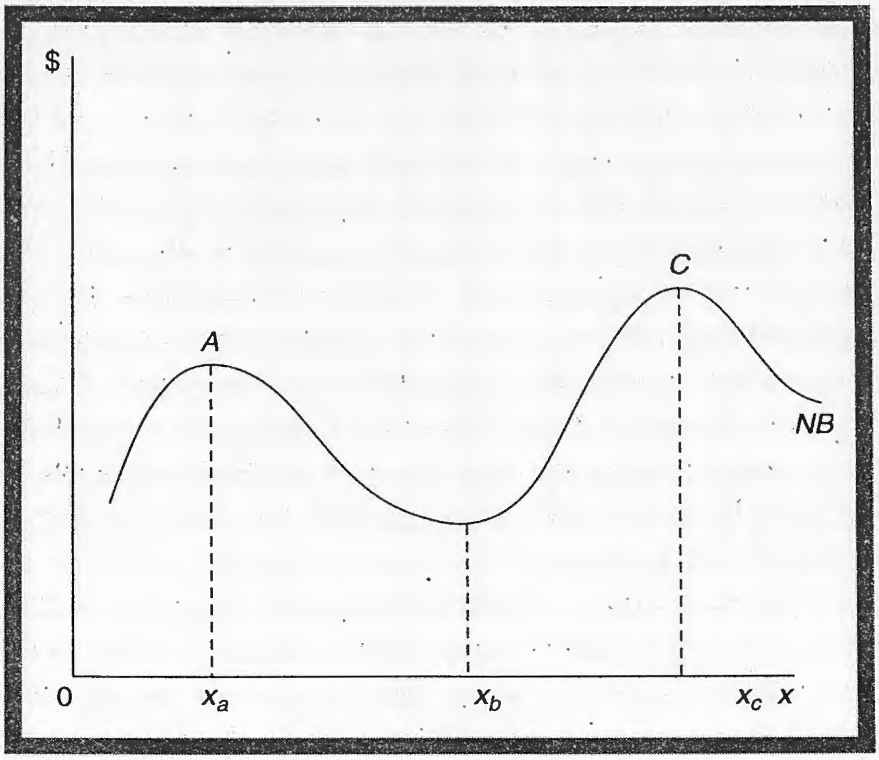


Figure 3.12 Multi-peaked net benefit curve

Figure 3.12 shows the multi-peaked net benefit curve in which the highest level of pollution is the global optimum. With a nonconvexity (even if markets are complete), the market price might send an incorrect signal, such that the local maximum (say point A) is selected rather than a global maximum (point C). Market has failed to allocate resources efficiently in this case.

3.7 Asymmetric information

Market failure can also occur when one person in a transaction does not have full information about either the actions or the "type" of the second person. "Type" can imply the unknown quality of a good or the hidden characteristics of an agent such as inherent intelligence. For example, asymmetric information exists when the person buying the insurance knows more about his level of precautionary behavior than the insurer, or a seller knows more about the quality of a product than a buyer. Without complete information due to the high costs of collecting and distributing data, markets are incomplete and can fail to allocate resources efficiently (also see Stiglitz, 1994). The two types of asymmetric information problems are referred to as moral hazard and adverse selection. The *moral hazard* or incentive problem arises when the actions of one person are unobservable to another person. The *adverse selection* problem exists when one person cannot identify the type or character of the other person (see Rasmusen, 1989). Consider each in turn.

3.7.1 Moral hazard

Moral hazard creates two related problems for environmental assets. First, when the regulators cannot monitor actions, a person has incentive to shirk on pollution abatement since he bears all the costs of such abatement and receives only a share of the benefits. Environmental shirking is likely to occur when a person pays all the costs of abatement but only receives a share of the total benefits to society. The person has an economic incentive to reduce his or her effort to control pollution below the standard set by regulators, resulting in too few resources devoted to abatement, and too much pollution relative to the social optimum. Figure 3.13 illustrates the incentive effects of environmental shirking. The top curve, BB, represents the aggregate net benefits to society from a firm's level of pollution abatement. The lower curve, bb, shows the firm's benefit from his own abatement action. The cost of abatement to the firm is represented by curve cc. Now society prefers the firm to invest in abatement level, s^*, since this is where marginal social benefits equals marginal costs. But since the firm only receives a fraction of the total benefits generated and pays all the cost, it sets its abatement level at s'. Since $s^* > s'$, the market has not allocated enough resources toward abatement.

Second, when the private market cannot monitor actions, an insurer might withdraw from or limit the pollution liability market. They do so when the provision of insurance affects a person's incentives to take precautions. Regular discharges, accidental spills or storage can create potential financial liabilities (e.g., clean-up costs, medical expenses). Therefore, a firm will pay to pass these risks on to a less risk averse agent such as an insurer. But since there is a trade-off between risk-bearing and incentives, the market for pollution liability insurance is incomplete as insurers attempt to reduce the information rents of the better-informed person. The market provides an inefficient allocation of risk.

We use the analytical framework of Arnott and Stiglitz (1988) to illustrate the inefficient risk-bearing problem associated with moral hazard. Consider a representative

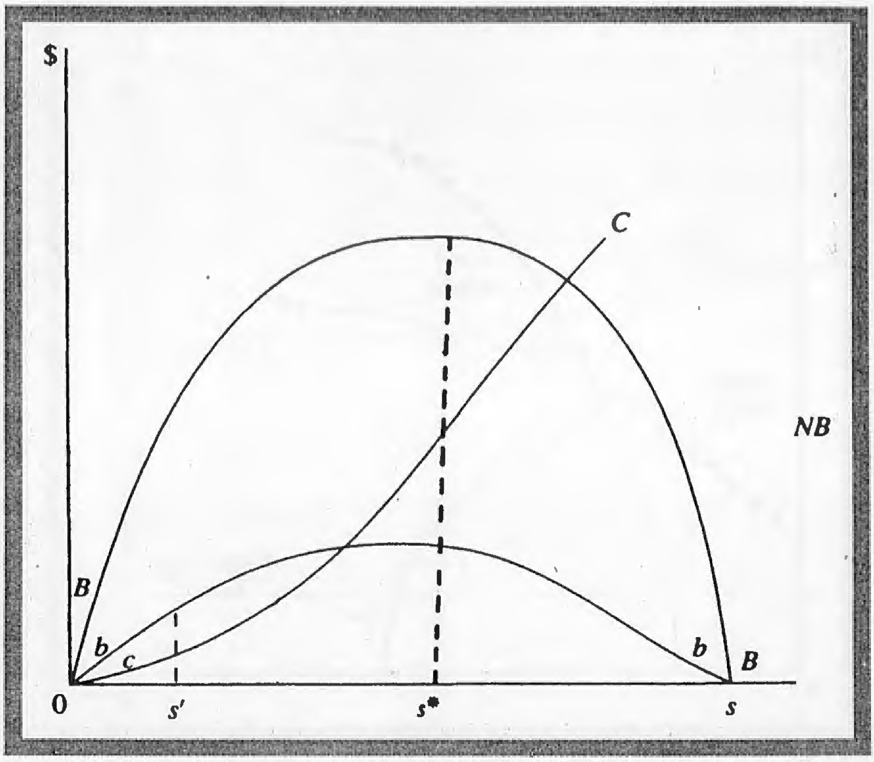


Figure 3.13 Environmental shirking

person who confronts two mutually exclusive and jointly exhaustive states of nature. Let $\hat{u} = \hat{U}(m - \beta)$ represent the utility received under the good state of nature, in which m represents monetary wealth and β is the insurance premium paid by the person. Assume $\hat{U}' > 0$ and $\hat{U}'' < 0$, where primes denote derivatives. Let $\tilde{u} = \tilde{U}(m - D + \alpha)$ represent the utility received under the bad state, where D is the monetary damages suffered and α is the insurance payment net of the premium. Assume $\tilde{U}' > 0$ and $\tilde{U}'' < 0$.

Let σ^i be the probability the bad state occurs, and $(1 - \sigma^i)$ be the probability the good state is realized. Assume the person affects these likelihoods by his self-protection, s^i, where $i = \text{H, L}$ represent high (H) and low (L) levels of self-protection, $s^{\text{H}} > s^{\text{L}}$ and $\sigma^{\text{H}} < \sigma^{\text{L}}$. Recall that self-protection comprises investments to lower the probability that bad events occur. Self-protection actions include voluntary restraint on forest development or the reduction in wetland drainage. For this model assume the levels of self-protection are fixed, and separable and measurable in utility terms.

Let the person's expected utility, V^{H} and V^{L}, given the high and low levels of self-protection be written as

$$V^{\text{H}} \equiv (1 - \sigma^{\text{H}})\hat{U}(w - \beta) + \sigma^{\text{H}}\tilde{U}(w - D + \alpha) - s^{\text{H}} \tag{3.21}$$

and

$$V^{\text{L}} \equiv (1 - \sigma^{\text{L}})\hat{U}(w - \beta) + \sigma^{\text{L}}\tilde{U}(w - D + \alpha) - s^{\text{L}} \tag{3.22}$$

Self-protection is defined as investments that increase the probabilities that a good outcome happens and a bad outcome does not. Self-protection differs from

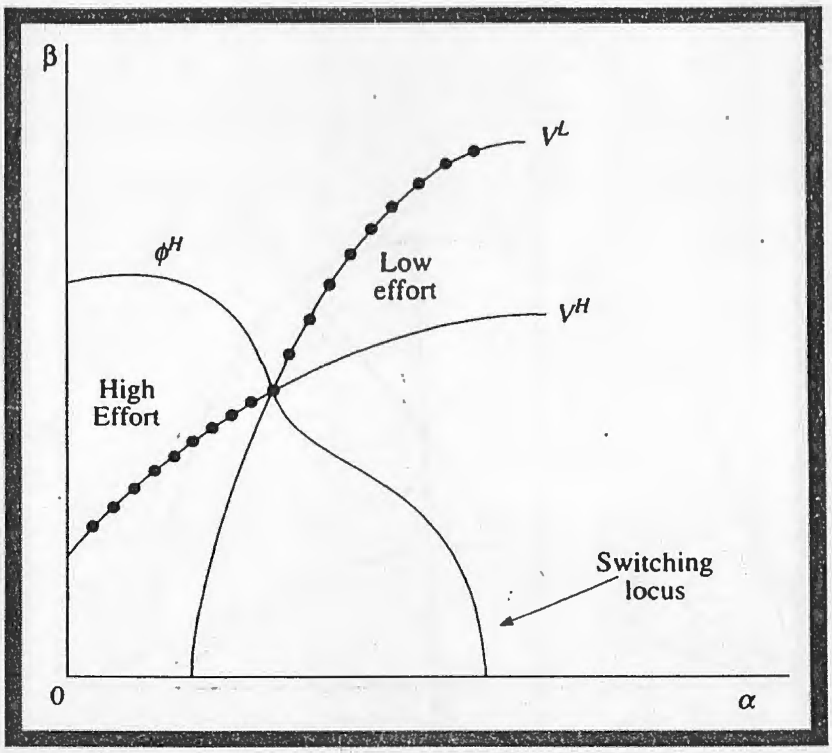


Figure 3.14 Moral hazard (Arnott and Stiglitz, 1988)

self-insurance, which are expenditures that transfer wealth from good to bad states to reduce the financial impact if a bad outcome does occur (see Ehrlich and Becker, 1972).

Figure 3.14 shows the person's indifference curves in premium-net payoff space for the high-effort self-protection. The slope or marginal rate of substitution between α and β is given by

$$\left.\frac{d\beta}{d\alpha}\right|_{V^i} = \frac{\sigma^i}{(1-\sigma^i)}\frac{\tilde{U}'}{\hat{U}'} > 0 \qquad i = \mathrm{H, L}$$

The curvature of the indifference curves, which reflects a person's aversion to risk, is

$$\left.\frac{d^2\beta}{d\alpha^2}\right|_{V^i} = -\frac{\sigma^i}{(1-\sigma^i)}\frac{\tilde{U}'}{\hat{U}'}\left[\frac{\tilde{U}''}{\tilde{U}'} + \frac{\sigma^i}{(1-\sigma^i)}\frac{\hat{U}''}{\hat{U}'}\right] < 0 \qquad i = \mathrm{H, L}$$

At any point in $\alpha - \beta$ space, the slope of the high effort indifference curve is flatter than the slope of the low effort indifference curve

$$\left.\frac{d\beta}{d\alpha}\right|_{V^{\mathrm{H}}} = \frac{\sigma^{\mathrm{H}}}{(1-\sigma^{\mathrm{H}})}\frac{\tilde{U}'}{\hat{U}'} < \frac{\sigma^{\mathrm{L}}}{(1-\sigma^{\mathrm{L}})}\frac{\tilde{U}'}{\hat{U}'} = \left.\frac{d\beta}{d\alpha}\right|_{V^{\mathrm{L}}} \qquad (3.23)$$

This is because high effort decreases the probability of an accident and consequently requires a larger increase in payout to compensate for a given increase in the premium, holding the level of utility constant.

Manipulating expressions (3.21) and (3.22), we see the comparative levels of expected utility depend on the relative magnitudes of the benefits $(\hat{U}-\tilde{U})$ and costs $[(s^{\mathrm{H}}-s^{\mathrm{L}})/(p^{\mathrm{L}}-p^{\mathrm{H}})]$ of self-protection

$$V^{\mathrm{H}} \gtreqless V^{\mathrm{L}} \text{ as } \hat{U}-\tilde{U} \gtreqless \frac{s^{\mathrm{H}}-s^{\mathrm{L}}}{\sigma^{\mathrm{L}}-\sigma^{\mathrm{H}}} = \phi^{\mathrm{HL}} \tag{3.24}$$

The expected utility of high effort equals the expected utility of low effort if the difference in utility between the good and the bad states, $(\hat{U}-\tilde{U})$, equals the difference in cost of effort, $(s^{\mathrm{H}}-s^{\mathrm{L}})$, divided by the difference in the benefits derived from a lower chance of realizing the bad state $(\sigma^{\mathrm{L}}-\sigma^{\mathrm{H}})$. For a given level of wealth, if the person believes his or her self-protection causes a trivial reduction in the likelihood of damages, it is likely that $V^{\mathrm{L}} > V^{\mathrm{H}}$. Alternatively, if the person perceives his or her self-protection has a significant impact on the likelihood of a bad state, the opposite holds, $V^{\mathrm{H}} > V^{\mathrm{L}}$.

In Figure 3.14, the point where expected utilities are equal, $V^{\mathrm{H}} = V^{\mathrm{L}}$, represents a switching point between low and high self-protection. At low levels of insurance, people choose high effort, while at high levels the person picks low effort. The person switches effort levels to increase his or her expected utility. The downward sloping line, ϕ^{HL}, represents the entire switching line between low and high self-protection. Below the switching line high effort is used, above the line low effort is used. Therefore, the person's complete indifference curve is determined by the person selecting the highest level of utility given the level of insurance offered, $\max\{V^{\mathrm{H}}, V^{\mathrm{L}}\}$ – the scalloped-shaped utility curve marked with dots in Figure 3.14 represents the person's indifference curve in premium and net payoffs space, i.e., the indifference curve is nonconvex.

Figure 3.15 shows the set of feasible contracts between the insurer and the insurance buyer is also nonconvex. A feasible contract is one where the insurer's profit is non-negative, $\pi \geq 0$. The shape of the outer boundary of the set of feasible contracts is represented by the two zero-profit loci for high and low effort. For high effort, the zero profit locus is

$$\beta(1-\sigma^{\mathrm{H}})-\alpha\sigma^{\mathrm{H}}=0$$

This locus is a ray from the origin with slope $\sigma^{\mathrm{H}}/(1-\sigma^{\mathrm{H}})$. The insurer earns zero profits when the price of insurance – the ratio of the premium to the net payoffs – equals the ratio of the probability of an accident to the probability of no accident $\beta/\alpha=\sigma^{\mathrm{H}}/(1-\sigma^{\mathrm{H}})$. For low effort, the probability of an accident is higher and therefore the insurer needs a higher price to break even, as shown in Figure 3.15. The hashed line represents the set of feasible contracts for the low and high self-protection – this set is also nonconvex.

Finally, Figure 3.16 shows the competitive equilibrium with moral hazard leads to the inefficient rationing of insurance. Assuming the case where the insurer can observe all insurance purchases by the person and can therefore restrict the quantity of insurance sold, the equilibrium is characterized by an exclusive contract in which the person buys all his insurance from one insurer. Point A in Figure 3.16 represents one exclusive contract given high effort. Though this is an optimal contract (marginal benefits = marginal costs), the contract is infeasible. The contract is infeasible since at this low

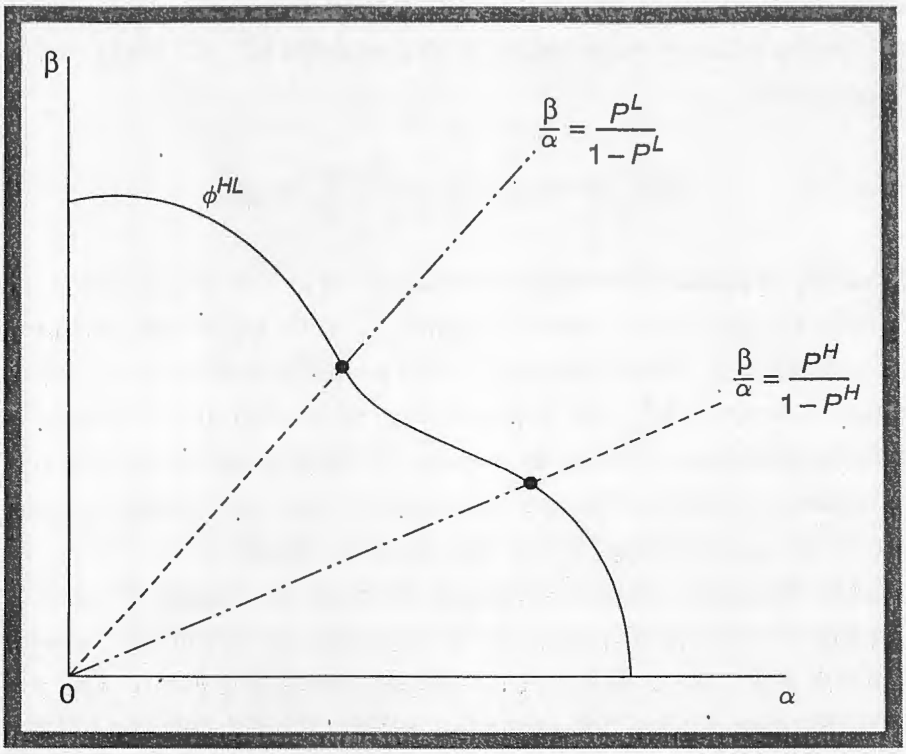


Figure 3.15 Feasible insurance contracts given moral hazard

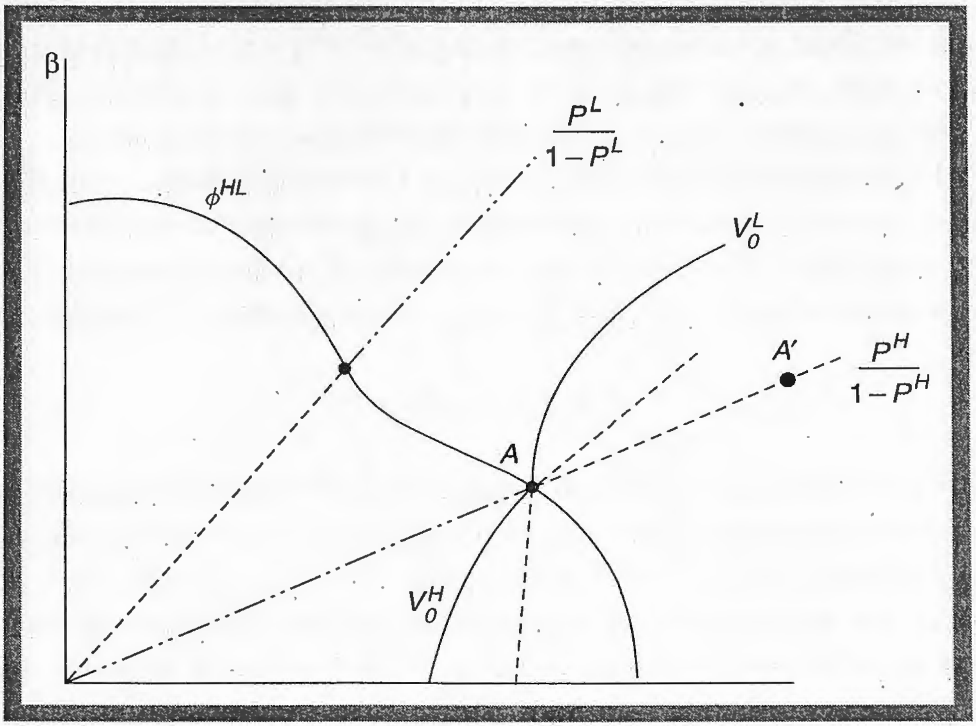


Figure 3.16 Quantity rationing of insurance

price the person wants to buy more insurance since his private marginal benefit exceeds the costs. But if the insurer supplies more insurance at this price, the person switches to the low effort level (point A′) and the contract generates negative profits. Negative profits imply the contract is infeasible, and there is quantity rationing with an excess demand, i.e., a market failure.

3.7.2 Adverse selection

Recall that *adverse selection* exists when one person cannot identify the type or character of another person or firm. Adverse selection may well be a problem for the development of eco-products which are produced with practices less harmful to the environment. Sustainable production of products from tropical forests, for instance, is a commonly promoted alternative to clear-felling activities. The basic problem with eco-products is that while they may be of perceived higher quality and more ethically desirable to some consumers given the production process, these products may also be more expensive due to scale economies and the fact that the environment is not subsidizing its production. Now if the buyer cannot distinguish the eco-product from the same product produced from standard practices, he has no incentive to pay the extra premium. If the high quality/high price producers do not think consumers will pay the premium, they withdraw from the market. This process continues until the market for the eco-product collapses. This is the classic "lemons problem" (see Akerlof's classic 1970 paper) – a "lemon" is a colloquialism for a consistently defective car or truck. The lemons problem exists only when the poorest cars or trucks remain for sale in the used market. A market failure exists when the owners of high-quality cars do not participate in the market because they cannot receive the high price if the buyer cannot verify its quality *ex ante*.

Consider the case of a set of products produced with technologies "friendly to the environment." Figure 3.17 shows a uniform distribution of quality or "environmental

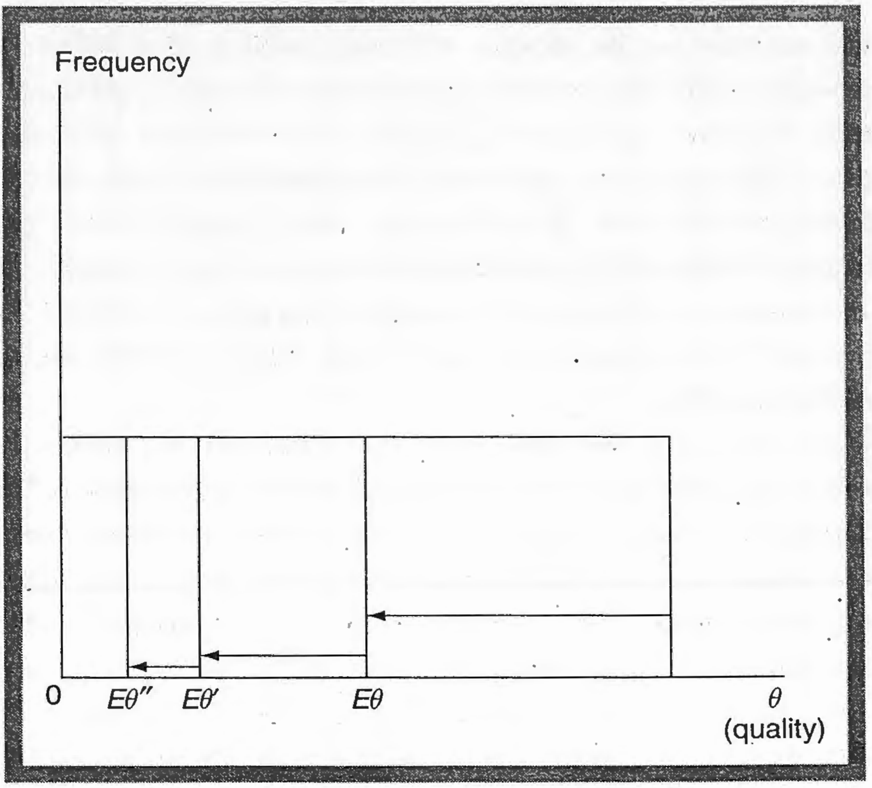


Figure 3.17 Adverse selection

friendliness," θ_i, for this product set with different quality as defined by perceived eco-friendly practices. High quality products are assumed to cost more to produce, and should command higher prices. Low quality products cost less to produce, so if they can sell for a high price, the producer gets the "information rents." Information rents imply that a seller gets economic rents above and beyond his opportunity costs simply because he knows more about the production process and costs than the buyer. The seller can claim high quality and ask for a high price; the buyer, however, has difficultly assessing whether this is the case.

But if a consumer cannot identify the true level of quality by the eco-label (e.g., they all say "environmental friendly" or "organic" or "natural"), he or she has no incentive to pay anymore than the price of the average quality product, $E\theta$. Why should he or she pay more than average if he or she cannot distinguish high quality from low quality products? If all consumers behave this way, the producers with an "environmental friendly" quality above the market average, $\theta_i > E\theta$, have no incentive to sell their product because they earn profits lower than their opportunity cost. When the above-average producers exit the market, the distribution of goods is now truncated at the mean, $E\theta$.

But the story does not end here. If a consumer realizes the above-average producers have left the market, the new average quality is at $E\theta'$. Again consumers should not pay more than the price implied by new average quality level. In response, the remaining producers whose quality exceeds $E\theta'$ exit the market themselves since they cannot receive enough revenue to cover their opportunity cost. The market is again truncated at an even lower quality $E\theta''$. This pattern continues until either (a) only the lowest quality producers are left in the market or (b) the market collapses all together.

One potential solution to the adverse selection problem is if either the market or a government agency provides credible certification to verify a good as coming from "environmentally friendly" production practices. If consumers believe the warranty scheme is credible, the market for eco-products is more likely to be efficient and avoid the problem of adverse selection. The warranty sends a signal to the consumers about quality, which should allow for high-quality producers to capture their costs. Eco-labels are currently used in several countries, including the Japanese "Eco-Mark," German "Blue Angel" and Swedish "Environmental Choice" and "Nordic Swan" programs (OECD, 1997; Cole and Harris, 2003).

Eco-labeling is a fine idea, but has its limits. Labels are not a sure bet due to the reality of imperfect monitoring. With imperfect monitoring, a signal is "noisy", in that here noisy means some low-quality producers have incentive to claim more quality than they can deliver. Mason (2005) builds a model of green and brown firms, with costly monitoring and noisy signals for eco-labels. He finds that the price achieved through certification and labeling is not necessarily sufficient to induce all firms to pick the green "environmental friendly" technology; rather some still find it worth the risk to select the brown technology and say the opposite. It remains an open question whether the welfare gains from improving information outweigh the costs of providing the information.

3.8 Concluding remarks

Adam Smith said in *The Wealth of Nations*

> [e]very man endeavours to supply by his own industry his own occasional wants as they occur. When he is hungry, he goes to the forest to hunt; when his coat is worn out, he clothes himself with the skin of the first large animal he kills; and when his hut begins to go to ruin, he repairs it, as well as he can, with the trees and the turf that are nearest to it.

People use markets to help organize this economic activity efficiently. But limits exist on the effectiveness of market allocation when we are considering environmental protection. Prices do not exist or they undervalue an asset. Decentralized decisions based on these prices, or lack of them, do not generate an efficient allocation of resources, and this is implied by market failure. This chapter has explored the five cases of market failure for environmental assets – externalities, non-exclusion, non-rival consumption, nonconvexities, and asymmetric information. How society reduces these forms of failure through privatization, collective action, or government intervention remains an ongoing debate in environmental economics. In the Chapter 4, we explore some alternative economic incentive schemes designed to address the problem of market failure.

BOX 3.1

Experimental evaluations of the Coase theorem

Beginning with the work of Hoffman and Spitzer (1982), researchers have used laboratory experiments to test the robustness of the Coase theorem. Lab experiments are designed based on seven key assumptions behind the Coase theorem: (i) zero transaction costs, (ii) two agents to each bargain, (iii) perfect knowledge of each other's well-defined profit or utility functions, (iv) competitive markets for legal entitlements, (v) costless court system to uphold all legal contracts, (vi) profit-maximizing producers and expected utility-maximizing consumers, and (vii) no wealth effects. Hoffman and Spitzer's initial results supported the Coase theorem in that bargains were highly efficient (about 90 percent). Expected wealth, however, was frequently divided equally (e.g., a 50–50% split) rather than what the rational choice model would predict (the person with property rights gets his opportunity costs, e.g., a 90–10% split). In response to this unpredicted finding, Harrison and McKee (1985) retested the Coasean bargaining under unilateral and joint property rights regimes. They found evidence

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to support the Coase theorem and a rational split of wealth under the unilateral system, as predicted.

Critics of the Coase theorem question the plausibility of one or more assumptions, arguing the theorem will falter when these restrictions are relaxed. Researchers have examined the robustness of the theorem by adding differing forms of transaction costs into the experimental design. The theorem remained relatively robust to incomplete information and large group sizes (Hoffman and Spitzer, 1986); and uncertain payoff streams and imperfect contract enforcement (Shogren, 1992). The theorem was less than robust, however, with the introduction of certain serious transaction costs like delay costs, uncertain final authority, and insecure property right claims (see Cherry and Shogren, 2005). Further explorations on the boundaries of the Coase theorem with transaction costs seem worthwhile.

BOX 3.2

Property rights and the efficiency of resource use: A Scottish history lesson

The management of the Scottish Highlands over the last 1000 years offers an interesting example of problems associated with alternative property rights regimes, and an illustration of how the phrase "tragedy of the commons" can mislead. The Scottish Highlands are characterized by relatively high rainfall, low temperatures, and poor soils. Until the Act of Union with England at the beginning of the 18th century, however, the majority of the Scottish population was resident there, settling in the glens (valleys), and surviving on livestock production, the growing of oats and bere (a type of barley), and timber exploitation, amongst other activities. From early times, the system of land ownership was a complex one. The Highlands were divided up amongst separate clans (from the Gaelic meaning "children"). Land was owned by all members of the clan, but control was often exercised by the clan chief. Until about the mid-18th century, land was managed on a "runrig" system. This seems to have had an equitable use of land (as opposed to an efficient use of land) as its major objective. The more fertile areas around villages were divided into narrow strips. The productivity of land varied greatly across these strips, but all individuals were each given a turn at growing crops on the best land. This set up serious disincentive problems: there was little reward for hauling rocks off your strip of land this year, since next year someone else would get to farm it. The system was also very inefficient, since your farming area for a year could consist of strips at opposite ends of the glen. Indications suggest output was sufficient, however, to keep the population well above starvation levels in most years (Grant, 1965).

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This all changed after the Act of Union, and as a consequence of the aftermath of the unsuccessful Jacobite uprising in 1745 (led by Bonnie Prince Charlie). To minimize the likelihood of a similar uprising reoccurring, the English government destroyed as much of the old clan system as it could. This included the banning of the wearing of tartan and the speaking of Gaelic, for example. Many powers of the clan chiefs, such as the power to enforce the law and adjudicate in legal disputes, were removed. The clan chiefs responded by effectively privatizing the clan lands, taking them into their ownership. Increasingly, a cash economy replaced the former barter system, with tenants having to pay money rents for their holdings. Landowners sought to increase their incomes by turning to a number of ventures, including sheep ranching (which led to the wholesale clearance of people from the glens, and their partly subsidized emigration to North America and Australia) and kelp gathering. Tenure rules again prevented the efficient use of land, for tenants could be evicted at the end of each year. Any improvements made to a tenant's land resulted in rises in real rents, as landlords used their monopoly power to extract all the profits.

This situation persisted into the mid-1800s, when a Royal Commission of enquiry found the conditions of most of the rural poor in the Highlands to be a desperate one. Pressure from Scottish MPs, and accompanying riots in places such as Skye, led eventually to the Crofting Reform Act of 1883. This set up the system of land holding that largely exists today in the "crofting counties" of the Highlands (Argyll, Ross-shire, Caithness and Sutherland). A "croft" is legally defined as a parcel of land below a certain maximum size. The crofter (who farms the croft) was given lifetime security of tenure, with the right to pass on the croft to one of his or her children. Any improvements made in the value of the croft could be realized by the crofter (who is *not* the landowner, but essentially a tenant) if the croft is transferred to another crofter. Transfers are supervised by the Crofting Commission, a government body.

The incentives for improvement being made to crofting land were substantially increased. But given the small size of the crofts, access to grazing land was essential. This was provided for by a system of common grazing on the hillsides and mountainsides. This might sound like the classic Hardin open-access problem of overgrazing on common land. In this case, however, the commons are not open access resources – only registered crofters could graze their livestock there. What is more, the maximum number of cattle and sheep that may be put on the hill by any one crofter is set by a crofter council which exists for each small geographic grouping of crofts (known as a "township"). A community thus enforces its own code of practices on the management of a common access (but not common property since the land is not actually owned by the crofters, but by other people who, for example, own the deer stalking rights too); with strict limits on the number of animals each person can put on the hill. While this might have led to ecological overgrazing, due partly to the nature of agricultural policy in the sheep and beef sectors, it is not an example of the over-use portrayed by Hardin (1968).

BOX 3.3

Climate change and the public good

Scientists warn that our daily actions could influence the global climate to its detriment: developing land, raising livestock and burning fossil fuels might be disrupting the planet's atmosphere – and that the consequences could be devastating. Their argument is based on two trends. First, the Earth has warmed 0.5 °C, or 1 °F, over the past 100 years. At the same time, atmospheric concentrations of GHGs have increased by about 30 percent over the last 200 years. A connection between these trends has been suggested, and the United Nations Intergovernmental Panel on Climate Change (IPCC, 1996) has concluded, "the balance of evidence suggests that there is a discernible human influence on global climate." Many scientists now advocate a worldwide reduction in greenhouse gas emissions to reduce the risks to human and environmental health posed by climate change. Scientists warn that such changes could affect agricultural yields, timber harvests and water resource productivity. Results might include a rise in sea level, contamination of drinking water by salt water and more storms and floods. Human health could be threatened by more heat waves and spreading tropical diseases. Accurately defining the risk of such outcomes is crucial for good climate policy (see the literature review in Shogren and Toman, 2000).

Climate change is the classic example of a market failure: the flow of GHG emissions accumulates into a global carbon stock that poses the risks to humanity. These GHGs remain in the atmosphere for hundreds of years. GHG concentrations reflect long-term emissions; changes in any one year's emissions have a trivial effect on current overall concentrations. Even significant reductions in emissions made today will not be evident in atmospheric concentrations for decades or more. Economics asks one to distinguish a *stock* from a *flow* pollutant. Stock pollution is concentration – the accumulated carbon in the atmosphere, like water in a bathtub. Flow pollution is emissions – the annual rate of emission, like water flowing into the tub. Because risk comes from the total stock of carbon, our focus should be on projected concentration levels. GHGs remain in the atmosphere decades before they dissipate, so different rates of emission could generate the same concentrations by a given year; policymakers therefore have options regarding how they hit a given concentration target.

The public-good nature of climate protection suggests it is the sum of all the carbon emitted around the globe that matters. This is crucial because the major emitters of GHGs will probably change over the next few decades. Today the industrialized world accounts for the largest portion of emissions, but soon developing countries such as China and India will be the world's largest emitters. Defining and enforcing an international treaty (e.g., the Kyoto Protocol of 1997) is critical for effective abatement. But achieving meaningful international cooperation is a challenge for several reasons. First, although nations have a common interest in climate change, many are reluctant to reduce carbon voluntarily since climate protection is a public good. They recognize others can "free ride" off their efforts: everyone gains from a less volatile climate whether they pay for reduced emissions or not. Second, the agreement should be self-enforcing

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given there is no global police force to punish violators (see Barrett, 2003). The problem of achieving effective and lasting agreements can be stated simply: A self-enforcing deal is easiest to close when the stakes are small, or when no other option exists (a clear and present risk). Otherwise, a country needs a domestic rationale to participate. Third, developing nations see carbon-based fossil fuels as the key input to economic growth and prosperity; their answer to grow their economy right now. The people in these nations have pressing needs, such as potable water and health care, and less financial and technical capacity than rich countries to mitigate or adapt to climate change. These nations have less incentive to agree to a policy that they see as imposing unacceptable costs today. The international policy objective is clear but elusive: find incentives to motivate nations with strong and diverse self-interests to move voluntarily toward a collective goal of reduced carbon emissions.

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