# Chapter 2

# Market Failure



## 2.1 Introduction

A market is an exchange institution that serves society by organising economic activity. Markets use prices to communicate the wants and limits of a diffuse and diverse society so as to bring about co-ordinated economic decisions in the most efficient manner. The power of a perfectly functioning market rests in its decentralised 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, individuals 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 lead to optimal social outcomes.

But for environmental assets, markets can fail if prices do not communicate society's desires and constraints accurately. Prices often understate the full range of services provided by an asset, or simply do not exist to send a signal to the market-place about the value of the asset. Market failure occurs when private decisions based on these prices, or lack of them, do not generate an efficient allocation of resources. Inefficiency implies that resources could be reallocated to make at least one person better off without making anyone else worse off. A wedge is driven between what individuals want privately and what society wants as a collective.

As an example of market failure, consider habitat destruction and the threat to biodiversity in Madagascar. Madagascar is one of the ecologically richest, but economically poorest, countries in the world. As resource managers and policy makers became more aware of the importance of biodiversity to support and maintain human life locally and globally, international agencies dubbed Madagascar as a prime spot to conserve biodiversity – the totality of genes, species, populations and ecosystems. Biologists estimate that 150 000 of the 200 000 species on the island are unique to Madagascar, the fourth largest island in the world: 98 per cent of





the palm species, 93 per cent of primates, 80 per cent of flowering plants, 95 per cent of reptiles, 99 per cent of frogs, 97 per cent of tenrec and 89 per cent of carnivores (USAID, 1992).

There are also over 12 million human inhabitants on Madagascar (50 per cent under 15 years of age), with a population density of 17.5 people/km$^2$ and a growth rate of 3 per cent per year. Agriculture employs over 85 per cent of the population, with over 70 per cent of farmers engaged in production on two-thirds of the cultivated land. As the locals try to increase or maintain their per capita income of about US$200 a year, habitat destruction through deforestation has increased rapidly over the last few decades. Deforestation is occurring at an estimated rate of 200 000 ha/yr, with nearly 80 per cent of the original forest cover already gone. The economic cost of environmental degradation has been estimated at US$100–290 million (5–15 per cent of GDP) – 75 per cent derived from deforestation.

The factors leading to habitat destruction and the loss of biodiversity originate in several sources of market failure. First, habitat destruction arises from public ownership of large areas of land with open access property right regimes and limited government capacity to manage the land. These economic incentives encourage the overexploitation of wildlife, timber, grazing lands and crop lands. Second, land tenure is often insecure since the locals in remote rural areas have little or no influence over the national laws, policies, social changes and economic forces. Lack of secure land tenure provides little incentive to maintain the habitat necessary for biodiversity conservation. The local residents have little incentive to conserve if they are unsure their kin will have access to the same land.

At the most basic level, the threat to biodiversity exists because many of the services provided are non-rival and non-excludable. A service is non-rival in that, one person's use does not reduce another's use, and it is non-exclusive in that it is extremely costly to exclude anyone from consuming the service. As a result of these characteristics, biodiversity in and of itself has no value reflected by market prices. In contrast, the commodity resources of the habitat (for example, chemicals, minerals, timber, game) are valued on the market, and the supply and demand reflect the relative scarcity of these goods. Therefore, there is pressure to harvest the commodity goods at the expense of biodiversity. This lack of a complete market implies that the unintended effects of private economic decisions can create biodiversity loss, to a socially inefficient level.

This chapter explores the relationship between markets and market failure for environmental assets. We first briefly define the theoretically ideal benchmark for an efficient allocation of resources – the perfectly competitive market where private decisions lead to a social optimum. We then consider how this perfect market benchmark misfires by examining six cases of market failure – incomplete markets, externalities, non-exclusion, non-rival consumption, non-convexities and asymmetric information. We define these terms as we go along, introducing each type of market failure sequentially (though all are related to a certain degree). Note that we do not discuss another common form of market failure, non-competitive behaviour such as monopoly power, that is often not associated with environmental assets.

## 2.2 Incomplete markets

Ledyard (1987, p. 185) notes that 'the best way to understand market failure is to first understand market success'. The market system is considered successful when a set of competitive markets generates an efficient allocation of resources between and within economies. Efficiency is defined as Pareto optimality – the impossibility of reallocating resources to make one person in the economy better off without making someone else worse off. If consumers and producers are rational such that they maximise their private net benefits, a set of markets where each person has the opportunity to exchange every good with every other person will generate a socially optimal allocation of resources.

The theorems of welfare economics summarise the major benefits of markets on social welfare, of which the first fundamental theorem is of most concern for market failure. The first theorem says that if: (1) a complete set of markets with well-defined property rights exists such that buyers and sellers can exchange assets freely for all potential transactions and contingencies; (2) consumers and producers behave competitively by maximising benefits and minimising costs; (3) market prices are known by all consumers and firms; and (4) transaction costs are zero so that charging prices does not consume resources; then the allocation of resources will be a Pareto optimum. A market failure occurs when the conclusions of this theorem do not hold, and the allocation of resources is inefficient (Bator, 1958).

A key requirement to avoid a market failure is that markets are complete – enough markets exist to cover each and every possible transaction or contingency so that resources can move to their highest valued use (condition 1). Markets will be complete when traders can costlessly create a well-defined property rights system such that a market will exist to cover any exchange necessary. This well-defined property rights system represents a set of entitlements that define the owner's privileges and obligations for use of a resource or asset and have the following general 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 resources that are owned in common as well as to resources for which private property rights have been assigned.

(c) *Transferable.* All property rights must be transferable from one owner to another in a voluntary exchange. Transferability provides the owner with an incentive to conserve the resource beyond the time he or she expects to make use of it.

(d) *Secure.* Property rights to natural resources should be secure from involuntary seizure or encroachment by other individuals, firms or the government. The owner has an incentive to improve and preserve a resource while it is in his or her control rather than exploit the assets.

But most market failures with environmental assets can be linked, in one way or another, to incomplete markets. Markets are incomplete because of the failure or inability of institutions to establish well-defined property rights. For example, many people own land and are able to take action when damage is done to it, but they do not generally own the rivers or the air, through which significant amounts of pollution travel. The lack of clear and well-defined property rights for clean air thus makes it difficult for a market to exist such that people who live downwind from a coal-fired power plant can halt the harm that the plant does to them or to successfully demand a fee, equivalent to the costs they bear, from the operator of the upwind plant. The plant operator does not bear the downwind costs, so he ignores them. With incomplete markets, he lacks any economic incentive to control emissions or to switch to less polluting practices. Similarly, there may be no legal or institutional basis that allows the downstream users of polluted river water to receive compensation from upstream farmers whose sediments, pesticides or fertilisers impose downstream costs in the form of contaminated drinking water, poor fishing or reduced recreational opportunities.

This inability or unwillingness to assign property rights such that a complete set of markets can be created has provided the rationale for governments to intervene as an advocate of proper management of environmental resources. But Coase (1960) pointed out that if the assumption of zero transaction costs (condition 4) is maintained, the set of markets can be expanded beyond normal private goods to include many non-market assets as long as institutional constraints to assigning well-defined property rights are removed. The so-called Coase theorem posits that disputing parties will work out a private agreement that is Pareto efficient, regardless of the party to whom unilateral property rights to the non-market asset are assigned initially. As long as these legal entitlements can be freely exchanged, government intervention is relegated to designating and enforcing well-defined property rights.

reason

suggest

lower importance

Consider an example to illustrate the Coase theorem. Suppose there are two parties, Riley and Ole, who disagree about the optimal level of pollution in the Cloquet river. Riley produces pulp and paper, and discharges the waste water back into the Cloquet River. Ole lives downstream and uses the river for his rafting and kayaking business. While both have rights to the water, Riley's emissions reduce the profitability of Ole's rafting and kayaking business. Figure 2.1 shows the marginal cost ($MC$) to Ole from the pollution, and the marginal benefit ($MB$) to Riley from the pollution. The socially optimal level of pollution, $x^*$, is where $MB$ equals $MC$. But with markets being incomplete, there is no opportunity for the parties to trade for alternative levels of water quality even though both Riley and Ole could be better off with the trade.

The Coase theorem works as follows. First suppose that a neutral third party creates a legal bargaining framework by assigning the property rights to clean water to Ole. The marginal cost curve in Figure 2.1 represents Ole's supply of clean water, while the marginal benefit curve represents Riley's demand for clean water. Given 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 there will be a surplus of clean water as Riley will not demand as much as Ole wants to supply. If Ole asks for a lower level of compensation, $C < C^*$, there will be a shortage 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, $x^*$.

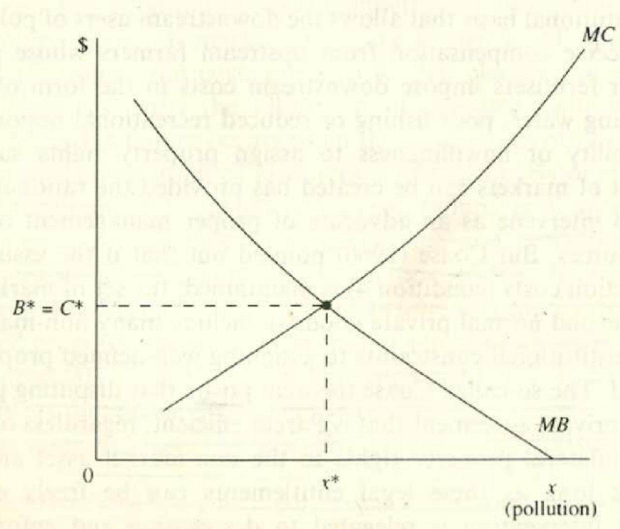


**Figure 2.1** ***Socially optimal level of pollution***



Now suppose that the neutral third party assigns the property rights to pollute to Riley. The marginal cost ($MC$) curve presented in Figure 2.1 now represents Ole's demand for pollution control, while the marginal benefit ($MB$) 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 $B^*$ for each unit of pollution control. If Riley demands a higher bribe, $B > B^*$, there will be a surplus of pollution control as Ole will not demand as much pollution control as Riley is willing to supply. If Riley asks for a lower bribe, $B < B^*$, there will be a shortage of pollution control as Ole will demand more than supplied. The bribe $B^*$ clears the market: the demand for pollution control equals the supply at the socially optimal level of pollution, $x^*$.

Theoretically, the Coase theorem works: regardless of the initial assignment of property rights, the optimal per unit bribe equals the optimal per unit compensation, $B^* = C^*$, at the socially optimal level of pollution, $x^*$.

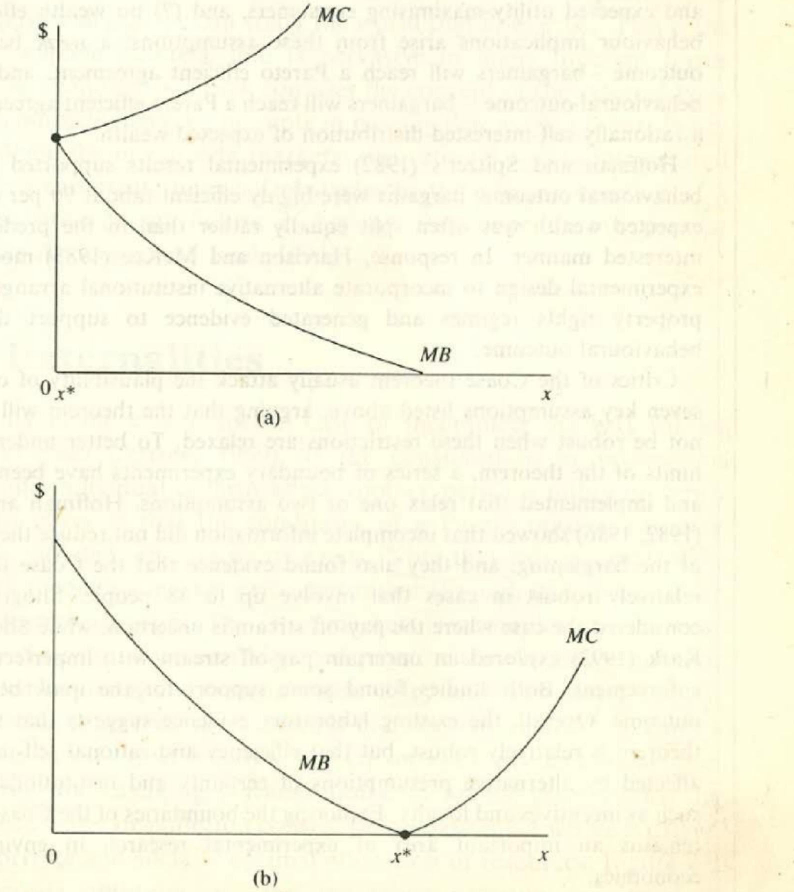


**Figure 2.2** ***Alternative socially optimal levels of pollution***

The market achieves the optimal level of pollution. Figure 2.2 further shows that, depending on the relative magnitude of the *MB* and *MC* curves, the optimal level of pollution may well be zero (high marginal costs) or equal to the private optimum where marginal benefits equal zero (low marginal costs).

**Box 2.1** ***Experimental evaluations of the Coase theorem***

Beginning with the seminal work of Hoffman and Spitzer (1982), the robustness of the Coase theorem has been tested in several laboratory experiments. Hoffman and Spitzer argued that the Coase theorem depended on a set of seven key assumptions: (1) zero transaction costs, (2) two agents to each bargain, (3) perfect knowledge of each other's well-defined profit or utility functions, (4) competitive markets for legal entitlements, (5) a costless court system to uphold all legal contracts, (6) profit-maximising producers and expected utility-maximising consumers, and (7) no wealth effects. Two behaviour implications arise from these assumptions: a *weak* behavioural outcome – bargainers will reach a Pareto efficient agreement, and a *strong* behavioural outcome – bargainers will reach a Pareto efficient agreement with a rationally self-interested distribution of expected wealth.

Hoffman and Spitzer's (1982) experimental results supported the *weak* behavioural outcome; bargains were highly efficient (about 90 per cent), but expected wealth was often split equally rather than in the predicted self-interested manner. In response, Harrison and McKee (1985) modified the experimental design to incorporate alternative institutional arrangements of property rights regimes and generated evidence to support the *strong* behavioural outcome.

Critics of the Coase theorem usually attack the plausibility of one of the seven key assumptions listed above, arguing that the theorem will probably not be robust when these restrictions are relaxed. To better understand the limits of the theorem, a series of boundary experiments have been designed and implemented that relax one or two assumptions. Hoffman and Spitzer (1982, 1986) showed that incomplete information did not reduce the efficiency of the bargaining, and they also found evidence that the Coase theorem is relatively robust in cases that involve up to 38 people. Shogren (1992) considered the case where the pay-off stream is uncertain, while Shogren and Kask (1992) explored an uncertain pay-off stream with imperfect contract enforcement. Both studies found some support for the *weak* behavioural outcome. Overall, the existing laboratory evidence suggests that the Coase theorem is relatively robust, but that efficiency and rational self-interest are affected by alternative presumptions of certainty and institutional features such as incentives and loyalty. Exploring the boundaries of the Coase theorem remains an important area of experimental research in environmental economics.



The basic complaint with the Coase theorem is that it is a tautology: the assumptions of two bargainers with zero transaction costs implies that an efficient agreement will be signed given the two agents have no incentive to quit bargaining until an efficient resource allocation is achieved. But if numerous parties are involved in the dispute, the large numbers should make bargaining too costly and complex (Baumol, 1972). Box 2.1 discusses laboratory experiments designed to test the robustness of the Coase theorem given alternative assumptions on the bargaining environment.

But Coase (1988) argues he has been misunderstood. He did not champion a zero transactions costs world; rather he argued that the institutional constraints on defining property rights are immaterial to economics from an efficiency standpoint only when transaction costs are zero. Since this world does not exist, efficiency is affected by the assignment of property rights. Coase (1988, p. 15) states that 'What 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, and is pervasive in many different forms throughout the economy. We now consider the concept of the externality as a result of incomplete markets, but note in passing that market failure is not entirely to blame for incomplete markets: institutional constraints created by government can create financial obstacles to the effective creation of a market. Such government failure is beyond the scope of our present discussion (see Anderson and Leal, 1991).

## 2.3 Externalities

The externality is the classic special case of incomplete markets for an environmental asset (Arrow, 1969). If the consumption or production activities of one individual or firm affect another person's utility or firm's production function so that the conditions of a Pareto optimal resource allocation are violated, an externality exists. Note that this external effect does not work through a market price, but rather through its impact on the production of utility or profit. The set of markets is incomplete in that there is no exchange institution where the person pays for the external benefits or pays a price for imposing the external costs. Riley and Ole's dispute about pollution in the Cloquet river is an example of a negative externality. Riley's disposal action has a direct negative impact on Ole's production of safe, enjoyable rafting and kayaking. If transaction costs are too great, so that the market for clean water or pollution control is non-existent, a wedge is driven between the private and socially optimal allocation of resources. Figure 2.3 shows the private optimum, $x'$, and the social optimum, $x^*$, level of pollution for the Riley and Ole example, given markets are incomplete.

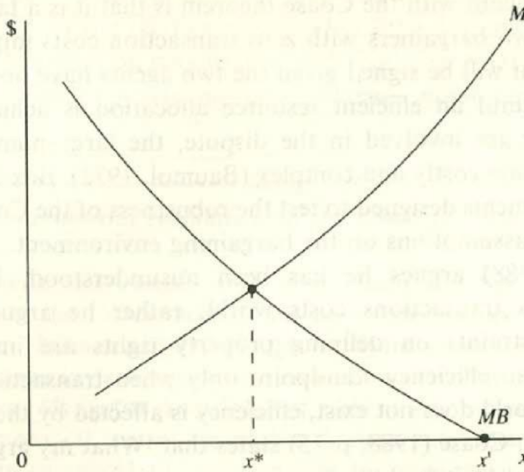


**Figure 2.3** ***Socially and privately optimal level of pollution***

Consider a simple representation of the externality in the Riley and Ole example. Given that Riley selects a privately optimal level of pollution, $x$, let his net profits, $\pi^R$, be written as

$$\boxed{\pi^R = \pi^r \quad c(x)}$$

amount

where $\pi^r$ is the profits before emission abatement, and $c(x) \geq 0$ is the cost of abatement such that costs decrease with increased pollution, $c'(x) \equiv dc/dx < 0$, where marginal abatement costs equal zero, $c'(x') = 0$, at a threshold level of pollution, $x'$. Therefore Riley's marginal benefit from increased pollution equals $-c'(x)$.

Let Ole's net profits, $\pi^O$, given he is damaged by Riley's pollution, be written as

$$\boxed{\pi^O = \pi^o - D(x)}$$

where $\pi^o$ is Ole's profits given no pollution, and $D(x)$ is the monetary equivalent of the damage suffered where damages increase with increased pollution, $D'(x) \equiv dD/dx > 0$. Ole's marginal cost of increased pollution is therefore equal to $D'(x)$.

The socially optimal level of pollution is determined by taking account of Riley's impact on Ole. The social optimum requires that Riley's marginal benefit be balanced against Ole's marginal costs, $-c'(x) = D'(x)$, represented by $x^*$ in Figure 2.3. If Riley ignores his negative impact on Ole, he will continue to pollute until his marginal benefits from pollution are zero, $-c'(x) = 0$; that is, Riley will pollute until he no longer receives any benefit. Riley's optimal level of pollution is represented by $x'$ in Figure 2.3. Since $x' > x^*$, the market has failed to allocate resources efficiently: too much



pollution is released into the Cloquet river. See Baumol and Oates (1988) for a general equilibrium representation of the efficiency impacts of an externality on a market system.

The cause and effect of the above externality was clear: Riley's emissions affected Ole's production of a service. However, cause and effect is often not as direct as economists assume. Rather the actions of one person can affect an ecosystem at one point which then reverberates through the ecosystem, ultimately affecting another person in a completely unexpected manner or at an unanticipated point. The pesticide DDT was banned not so much because it directly killed birds but rather because DDT thinned the shells of bird eggs to levels at which the embryo could not survive, a completely unpredicted cause and effect relationship. Citizens of Kern County, California around the turn of the century killed nearly all the natural predators in the area to protect domestic animals and children. Unfortunately, the ultimate effect was the largest rodent infestation experienced in the United States, with rodents invading the villages and farms, wiping out crops and causing untold mental stress.

Crocker and Tschirhart (1993) develop a general equilibrium model to show how these misunderstood ecosystem externalities reverberate through both economic and ecological systems. We present the basic version of their model for the Kern County example, and advise the interested reader to consult their detailed model for additional implications of ecosystem externalities.

Suppose there are three species that are linked: grain, which is consumed by rodents, which are consumed by predators such as owls, foxes and coyotes. Individual consumers are only affected by the grain for bread making and predator species; rodents do not directly affect their allocation of resources. How these rodents indirectly affect the allocation, however, will prove to be the missing link behind the ecosystem externality.

The Pareto optimal level of effort on making bread from the grain versus the elimination of the predators is determined as follows. Suppose a consumer's utility function is represented by

$$u = u(b, p, l) \tag{2.1}$$

where $b$ is the level of bread consumed, $p$ is the level of predators, and $l$ is the amount of leisure. Assume increased bread and leisure increase utility, $u_b \equiv \partial u/\partial b > 0$, and $u_l \equiv \partial u/\partial l > 0$, while more predators decrease utility, $u_p \equiv \partial u/\partial p < 0$.

The link between predator removal and bread production works in three steps. First, the consumer gives up $L_p$ units of leisure to eliminated the predator such that

$$p = p(L_p) \tag{2.2}$$

where $p' \equiv dp/dL_p < 0$. Second, grain is produced by

$$g = g(L_g, p) \tag{2.3}$$

where $L_g$ is the labour units to produce grain, $g_1 \equiv \partial g/\partial L_g > 0$. Note that grain production also depends on the predator such that $g_2 \equiv \partial g/\partial p \neq 0$. This is the ecosystem externality, and we do not assume a negative or positive effect at this point. Third, the production of bread is represented by

$$b = b(g, L_b) \tag{2.4}$$

where $L_b$ is the labour devoted to bread production, $b_1 \equiv \partial b/\partial g > 0$ and $b_2 \equiv \partial b/\partial L_b > 0$. Also note the total amount of available labour is

$$L = L_b + L_g + L_p + l$$

such that available leisure is given by

$$l = L - [L_b + L_g + L_p] \tag{2.5}$$

The Pareto optimal allocation of resources is determined by substituting equations (2.2) to (2.5) into the consumer's utility (2.1) so that

$$u(b(g(L_g, p(L_p)), L_b), p(L_p), L - [L_g + L_b + L_p]) \tag{2.6}$$

Solving for the optimal level of labour employed yields the first-order conditions for an interior solution

$$L_g\colon\ u_b b_1 g_1 - u_l = 0 \tag{2.7}$$

$$L_b\colon\ u_b b_2 - u_l = 0 \tag{2.8}$$

$$L_p\colon\ u_b b_1 g_2 p' + u_p p' - u_l = 0 \tag{2.9}$$

Rearranging and manipulating the conditions yields the following Pareto optimal allocation of labour:

$$\frac{u_p}{u_b} = \frac{b_2 - b_1 g_2 p'}{p'} \tag{2.10}$$

where the left-hand side of the equation represents the marginal rate of substitution between bread production and predator removal, and the right-hand side is the marginal rate of transformation between bread and predator removal.

The private or competitive equilibrium is determined as follows. Let $k$ and $w$ represent the price of bread and labour where all production of bread occurs in one firm (for simplicity). The firm's profits is given by

$$\pi = kb(\cdot) - w(L_g + L_b) \tag{2.11}$$

The firm selects the level of labour on bread and grain production to maximise (2.11) and the consumer selects the level of labour on grain production and predator removal and leisure to maximise (2.1) subject to the budget constraint $kb(\cdot) - w(L - l - L_p)$ yielding the condition



$$\frac{u_p}{u_b} = \frac{b_2}{p'} \tag{2.12}$$

Comparing condition (2.12) with condition (2.10) reveals that the private optimum does not accord with the Pareto optimal allocation of resources. The ecosystem externality term is missing from the private solution. Now in general the sign of the ecosystem externality term will depend on the precise linkages within the ecosystem. The empirical evidence in Kern County suggests that there was a negative impact of removing the predators, implying that the private optimum results in too few resources devoted to bread production and too many resources devoted to predator removal. The consumer ignores the negative impact that predator removal has on grain production. The ecosystem externality stresses that the economist must strive beyond his or her normal bounds to try to understand the biological and physical cause–effect relationships that are not always obvious and anticipated in standard cost–benefit analysis.

Another interesting aspect of the externality is the idea that environmental risks can be transferred through time and space by choice of pollution abatement strategy. The concept of the *transferable externality* implies that the individual protects himself from the external damages by simply transferring an environmental risk through space to another location or through time to another generation. The consequences of self-protection from pollution are not limited to the self-protected, but rather are passed on to others. The transferable externality differs from the traditional view of the pollution externality in that transferability is motivated by intentional behaviours, not by the simple, unintentional residuals of production. Agents select an abatement technology that transfers a risk, thereby creating conflict that induces strategic behaviour between people, firms or countries.

From a materials balance perspective, most environmental programmes 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 programmes simply transfer these masses through time and across space. Future generations and other jurisdictions then suffer the damages. For example, in the United States, the midwestern industrial states have reduced regional air pollution problems by building tall stacks at emitter sites. Prevailing weather patterns then transport increased proportions of regional emissions to the northeastern states and to eastern Canada. The midwestern states have reduced their damages by adopting abatement technologies which increase air pollution damages elsewhere. Other examples include agriculture where pollution from other sources encourages land, fertiliser and pesticide substitutions, which produce pollution that affects others. Intensive use of pesticides accelerates the development of immune insect strains with which future human generations must contend. In addition, some governments forbid the storage of toxins within their jurisdictions, thereby causing the toxins to be stored or dumped elsewhere.

The Des Moines, Iowa water works provides a good example of a transferable externality. The water works built the world's largest nitrates removal facility to clean nitrates from the city's Des Moines river drinking water supply. In 1991, nitrates at the water works intake exceeded 10 ppm for 29 days, prompting a legally imposed nitrate alert. Nitrate pollution, it is feared, promotes stomach cancer and methaemoglobinaemin (the blue baby syndrome). The removal facility simply transfers this risk, however, in that once removed, the nitrates are to be dumped back in the Des Moines river to pose threats downstream. L.D. McMullen, manager of the water works, notes that 'Unfortunately, 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 individuals purposely try to make others worse off to make themselves better off. The non-co-operative, unilateral use of self-protecting technologies creates environmental conflicts that add another layer of inefficiency to the market system – over investment in pollution abatement. Consider a simple model to illustrate the impact of the transferable externality.

Suppose Riley and Ole now have the ability to select an abatement technology that transfers the risk from a hazard from themselves to the other player. Riley and Ole select a level of self-protection, $s^R$ and $s^O$, to minimise the sum of the damages from the hazard and the cost of the protection. Riley's cost minimisation problem is written as

$$C^R(s^R, s^O) = D^R(s^R, s^O) + \varphi^R(s^R) \tag{2.13}$$

while Ole's problem is

$$C^O(s^R, s^O) = D^O(s^R, s^O) + \varphi^O(s^O) \tag{2.14}$$

where Riley's damages decrease with an increase in his own self-protection, $D^R_R \equiv \partial D^R/\partial s^R < 0$, but increase with an increase in Ole's protection, $D^R_O \equiv \partial D^R/\partial s^O > 0$. Ole's damages are similar: they decrease with own protection, $D^O_O \equiv \partial D^O/\partial s^O < 0$, and increase with Riley's effort, $D^O_R \equiv \partial D^O/\partial s^R > 0$. Costs of protection increase with increased effort, $\varphi^O_O \equiv \partial \varphi^O/\partial s^O > 0$ and $\varphi^R_R \equiv \partial \varphi^R/\partial s^R > 0$.

If the players do not co-ordinate their self-protection efforts, Riley and Ole independently and simultaneously select their optimal level of self-protection to minimise their private costs, $C^R(s^R, s^O)$ and $C^O(s^R, s^O)$,



ignoring the impact on the other player. Assuming a minimum exists, these actions yield the non-co-operative first-order conditions

$$-D^R_R = \varphi^R_R \tag{2.15}$$

and

$$-D^O_O = \varphi^O_O \tag{2.16}$$

These non-co-operative conditions imply that each player selects the level of self-protection that equates his marginal benefits, $-D^i_i$ $(i = R, O)$, with his marginal cost, $\varphi^i_i$ $(i = R, O)$.

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

$$-D^R_R = \varphi^R_R + D^O_R \tag{2.17}$$

and

$$-D^O_O = \varphi^O_O + D^R_O \tag{2.18}$$

Now these co-operative conditions imply that both players select the level of self-protection that equates their marginal benefits, $-D^i_i$ $(i = R, O)$, with two marginal costs: their private costs, $\varphi^i_i$ $(i = R, O)$ and the external cost they impose on the other player, $D^j_i$ $(i = R, O; j = R, O; j \neq i)$. Figure 2.4 shows

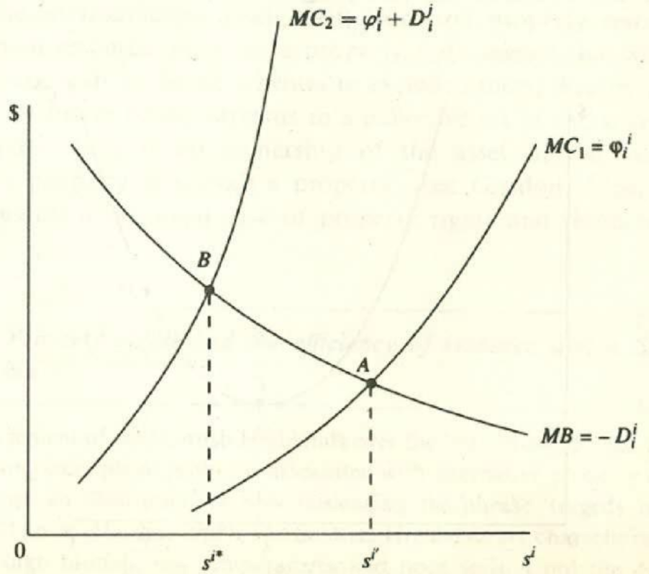


**Figure 2.4** ***Co-operative and non-co-operative self-protection***

that, if one accounts for the external cost, each player should cut back on their level of self-protection as the non-co-operative level exceeds the co-operative level, point *A* versus point *B*. Figure 2.5 shows that the co-operative solution $(s^* = s^{R^*} + s^{O^*})$ minimises the joint cost while the non-co-operative solution $(s' = s^{R'} + s^{O'})$ implies that costs are excessive – too much abatement with transferable externalities, point *C* versus point *D*. One can show this by substituting the non-co-operative solution (equations (2.15) and (2.16)) for self-protection into the co-operative equations (2.15) and (2.16), thereby yielding the positively sloped external marginal cost. This implies that the non-co-operative solution is on the right-hand-side of the minimum point on the total cost curve, point *D* (see Shogren and Crocker, 1991).

Environmental polices that allow unilateral transfers of pollution rather than encouraging co-operative resolutions will result in excessive expenditures on self-protection. Without public limits to individuals' non-co-operative self-protection activities, environmental abatement efforts are too expensive. Policy strategies that encourage self-protection need to be reconsidered since such strategies intensify the inefficiencies.

The framework presented above can be extend in numerous ways to show that transferability will prompt too much self-protection from recipients who have an elastic damage function. Limited empirical evidence supports the existence of an elastic damage function for environmental aesthetics when pollution levels are low and an inelastic damage function when pollution levels are high. Therefore non-co-operative environmental improvements could be self-defeating when pollution levels are already

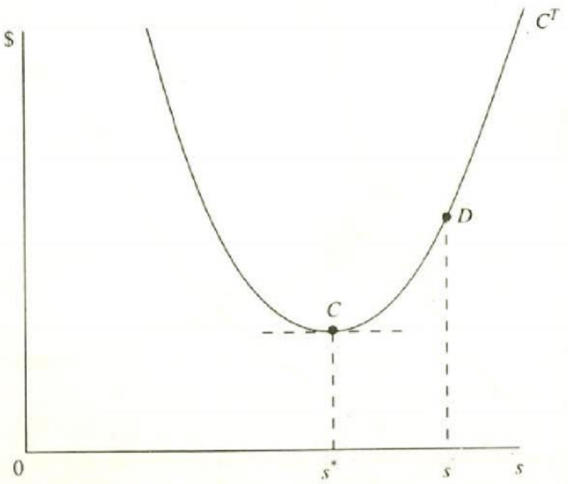


**Figure 2.5** ***Total cost of co-operative and non-co-operative self-protection***



low. Aggregate expenditures on protection may then outweigh the environmental benefits. In contrast, some pollutants, such as ambient carbon monoxide, exhibit inelastic damages at low levels and elastic damages at high levels. It follows that accurate assessments of the benefits of policies to reduce environmental hazards require precise and accurate knowledge of the responsiveness of damages to non-co-operative forms of self-protection. Damage function elasticities are likely to be hazard-specific and activity-specific, as well as concentration- or level-specific.

## 2.4 Non-exclusion and the commons

Another case where the market may fail to allocate resources efficiently is when it is impossible or at least very costly to deny access to an environmental asset. If your consumption of an asset rivals my consumption but we both have legal access to the asset, we both have an incentive to capture as many of the benefits that the asset provides as soon as possible before the other person captures them. In such cases we may overuse the asset relative to what is best for society. When overuse occurs as the result of non-exclusion the market has failed to signal the true scarcity of the asset. While the potential problems associated with non-exclusion implied by such open access property rights have long been recognised, the issue was popularised by Hardin's (1968) article entitled 'The Tragedy of the Commons'. Before we continue, a few definitions are in order: '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 to a collective set of users; and 'open access' implies there is no ownership of the asset in the sense that 'everybody's property is nobody's property' (see Gordon, 1954, p. 124). Box 2.2 presents a historical case of property rights and resource use in Scotland.

**Box 2.2** ***Property rights and the efficiency of resource use: a Scottish history lesson***

The management of the Scottish Highlands over the last thousand years offers an interesting example of problems associated with alternative property rights regimes, and an illustration of how misleading the phrase 'tragedy of the commons' can be (Hardin, 1968). The Scottish Highlands are characterised by relatively high rainfall, low temperatures and poor soils. Until the Act of Union with England at the end of the sixteenth century, however, the majority of the Scottish population was resident there, settling in the glens (valleys) and surviving on hunting, the growing of oats and bere (a type of barley) and fishing. 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-eighteenth 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 each individual was 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 are that output was sufficient, however, to keep the population above starvation levels (Grant, 1965).

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 minimise the likelihood of a similar uprising recurring, 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 privatising the clan lands, taking them into their ownership. Increasingly, a cash economy developed out of the former barter system, with tenants having to pay money rents for their holdings, which became concentrated on poor land as the landowners sought to increase their incomes. To do this, they turned to a number of ventures, including sheep (which led to the wholesale clearance of people from the glens, and their partly subsidised 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 desperate. 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 children. Any improvements made in the value of the croft can be realised 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 thus 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 may 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 individuals who, for example, own the deer stalking rights too), with strict limits on the number of animals each individual can put on the hill. While this might and indeed has 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 simplistic overuse portrayed by Hardin.

Fishing grounds are the best know example of a potential open access resource. Given that more fish caught by one party implies less fish for all others, all fishermen or women have an incentive to increase their fishing effort beyond the point where the market price for the fish equals the marginal cost of harvesting. Effort is expended to the level where market price equals the average cost of production. The scarcity value of the resource is ignored. The potential result is overfishing and a depletion of the stock to a level that cannot sustain itself. A recent example is the 1992 declaration of a moratorium on fishing endangered species such as cod and flounder off Canada's Grand Banks in the North Atlantic, once one of the richest fishing grounds. The moratorium has put nearly 30 000 Newfoundlanders out of work, and has stirred up a conflict between Canada and Spain, whose fleets continue to fish just off Canada's 200-mile limit.

The Black Sea is another example of a commons that has been severely affected by the unco-ordinated economic activity of numerous countries. The Black Sea coast is a common resource of six countries – Bulgaria, Georgia, Romania, the Russian Republic, Turkey and Ukraine – and also serves as a common receptacle for a drainage basin five times the area of the sea itself encompassing 16 countries (the six cited above, plus Austria, Bielorussia, Croatia, the Czech Republic, Germany, Moldova, Poland, Serbia, Slovakia and Slovenia) and 165 million people.

The inability to exclude agents from using or dumping waste into the commons has had a detrimental impact on the structure and functioning of the coastal marine ecosystem of the Black Sea (see Gomoiu, 1992; Mee, 1994). The main culprit is the increasing quantity of nutrients (inorganic and organic) flowing into the sea, causing marine eutrophication – overfertilisation of the sea. For example, the Danube currently introduces approximately 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 overfertilisation of the sea, leading directly to increased global quantities of phytoplankton and the occasional algae bloom. The effects of marine eutrophication include (1) a gradual shallowing of the euphotic zone – the surface layer where light is sufficient for net biological production; (2) disturbances in the oxygen content of the sea water, creating the appearance of hypoxic and anoxic conditions, leading to massive fish kill – a single occurrence of anoxia in 1991 eliminated an estimated 50 per cent of the remaining benthic fish; (3) increased quantities of dissolved and particulate organic matter in sea water and sediment two to three times greater than in the 1960s; (4) mass mortality of benthic organisms such as fish, molluscs and crustaceans, reducing filter-feeding populations and actually increasing the nutrient content of the sea; (5) a modification of the base of the marine food chain encouraging the development of nanoplankton; and (6) major structural modifications of fish and mammal populations in the Black Sea – drastic reductions, for example, in the stocks of sturgeon, turbot, mackerel and the dolphin. Only six of 26 species of commercial fish of the 1960s remain in significant quantities to harvest.

Chemical and microbiological pollution has also contributed to the decline in the fisheries. While data are sketchy, monitoring data from the 1989 Bucharest Declaration suggests that the Danube itself discharges 1000 tons of chromium, 900 tons of copper, nearly 60 tons of mercury, 4500 tons of lead, 6000 tons of zinc and 50 000 tons of oil. There are also inflows of synthetic organic contaminants such as DDT and other pesticides, heavy metals, radionuclides from Chernobyl, microbial pathogens such as cholera, dumping and toxic waste from the 16 official dump sites in the western Black Sea, and oil pollution from shipping and offshore exploration.

Figure 2.6 illustrates the incentives to overharvest an open access fishery. Suppose Riley and Ole both fish on Big Lake. Riley and Ole have a choice: they can either co-operate with each other by limiting their fishing fleet to one ship per day, or they can act non-co-operatively by sending out three ships every day. If they co-operate and send out only one ship they can each earn net profits of 30 (box A in Figure 2.6). But if Riley sends out three ships while Ole only sends out one, Riley can increase his net profits to 40 by capturing a disproportionate share of the rents. Ole would only earn net profits of 10 (box B). Since net profits of 40 exceeds 30, Riley has an



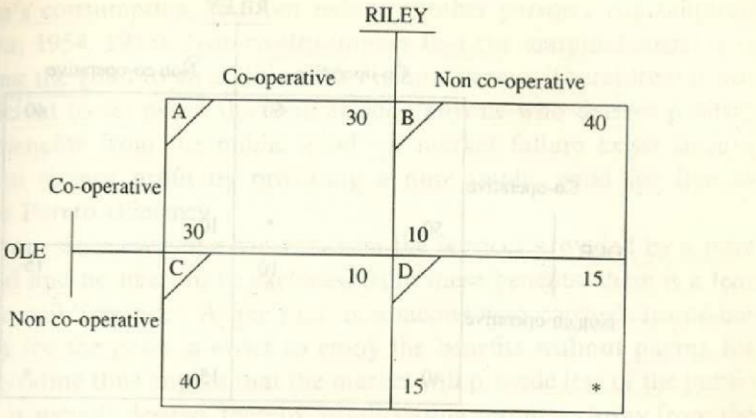


**Figure 2.6** ***Open access and the prisoners' dilemma***

incentive to cheat and send out three ships. Ole has the same incentive: if Riley co-operates and Ole does not, Ole can earn net profits of 40 while Riley only earns 10 (box C). If both fall for this incentive to act non-co-operatively by sending out three ships, they overfish Big Lake and their net profits fall to 15 each (box D). The end result is that both fisherman only earn total net profits of 30 (15 + 15), while the social optimum is total net profits of 60 (30 + 30) when both co-operate.

Technically, the choice of non-co-operation is the dominant strategy for each player. A dominant strategy gives a player a greater pay-off regardless of the other player's actions. In our example, the non-co-operative strategy dominates the co-operative one since $40 > 30$ and $15 > 10$. This outcome is called a Nash equilibrium. A Nash equilibrium exists if neither player will unilaterally change his strategy since a unilateral action would leave a player worse off without a reciprocal move by the other player. Our example of both players falling into the non-co-operative solution is the classic 'prisoners' dilemma' game: each prisoner has an incentive to betray his fellow partner in crime to secure a milder punishment for himself even though all are better off if they just keep their mouths shut (also see Ostrom, 1990).

Not all non-excludable resources are defined by the prisoners' dilemma game where the players are doomed to exist in a downward spiral of misallocated resources. Commons can also be represented by the game presented in Figure 2.7 – a co-ordination game. In this co-ordination game, there are two Nash equilibria, one where both players act non-co-operatively as before and the other where both co-operate. Each outcome is a Nash equilibrium since neither has a unilateral incentive to deviate from

| | | RILEY | |
|---|---|---|---|
| | | Co-operative | Non co-operative |
| OLE | Co-operative | 50 / 50 * | 40 / 10 |
| | Non co-operative | 10 / 40 | 15 / 15 * |

**Figure 2.7** ***Co-ordination game***

the strategy. Co-operation is a Nash equilibrium since a player receives 50 if both co-operate and only 40 if he unilaterally cheats. Non-co-operation is still a Nash equilibrium because a player receives 15 if he cheats and only 10 if he co-operates while the other player does not. Obviously, both players would prefer the co-operative Nash equilibrium since the pay-offs are the greatest, 50 each; society also prefers the co-operative outcome since the joint profits are the greatest: $100 = 50 + 50$.

Though there is no guarantee that the players will co-ordinate their strategies in such a way that they achieve the preferred co-operative solution, Ostrom (1990) documents several examples of actual common property resources where a group of players achieve a co-operative outcome. These groups establish self-governing common property regimes without strict private property rules or government intervention. Successful self-co-ordination 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 always occur with commons, but usually some boundary rule to exclude others is required.

## 2.5 Non-rivalry and public goods

An environmental asset is considered a pure public good if its consumption is non-rival and non-excludable. A pure public good is available to all and



one person's consumption does not reduce another person's consumption (Samuelson, 1954, 1955). Non-rivalry implies that the marginal social cost of supplying the good to an additional individual is zero. Therefore it is not Pareto efficient to set prices that will 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 for free 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, these is a fear that people will 'free ride'. A free rider is someone who conceals his or her preferences for the good in order to enjoy the benefits without paying for them. Free-riding thus implies that the market will provide less of the public good than is socially desired, thereby misallocating resources away from the environmental asset to private goods where the conditions of rivalry and exclusive use hold (see Olson, 1965).

to hid

An example of a public good is a tropical forest that provides public goods to the local economy, given its capacity to manage water flow, soil erosion and nutrient recycling. The forest also provides public goods to the global economy, given the non-rival benefits of biodiversity, ecosystem linkages and carbon sequestration (see Myers, 1992, pp. 261–6). Wetlands also 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 run-off, by providing water purification and habitat services. An ecosystem, in general, provides public services, given its ability to underpin and buffer the market economy against the external shocks of production and consumption activities. Note that 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, for example, does not reduce the loss suffered by another. These public 'bads' will be oversupplied by the market.

To illustrate the market failure associated with a pure public good, now suppose that Riley and Ole voluntarily contribute to the provision of a public good. This public good could be abatement effort to reduce emissions that are feared to reduce the ozone layer or increase global warming. The aggregate level of the public good is represented by $Q = q^R + q^O$, 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, $Q$. This is the 'summation' representation of a public good. See Cornes and Sandler (1986) for a discussion of alternative representations of how public goods can be supplied to the collective.

Let the utility function of each contributor be written as

$$u^i(z^i, Q) \qquad i = R, O$$

rival - complete

where $z^i$ represents a private good. A person's utility increases as the consumption of the private good and the public good increases

$$u^i_z \equiv \partial u^i/\partial z^i > 0$$

and

$$u^i_Q \equiv \partial u^i/\partial Q > 0 \qquad i = R, O$$

Both Riley and Ole select their privately optimal levels of the private good and public good given a budget constraint

$$M = z^i + cq^i \qquad i = R, O$$

where $M$ is a person's monetary income and $c$ is the per unit cost of providing the public good. Assume for simplicity that the price of the private good, $z^i$, equals unity.

Riley will select a level of the private and public goods to maximise his utility subject to his budget constraint

$$\max_{z^R, q^R} [u^R(z^R, Q) | M = z^R + cq^R; Q = q^R + q^O]$$

We can simplify the presentation of Riley's problem by substituting the budget constraint into his utility function given $z^R = M - cq^R$,

$$\max_{q^R} [u^R(M - cq^R, q^R + q^O)]$$

Riley now selects his optimal contribution to the public good yielding

$$c = \frac{u^R_Q}{u^R_z}$$

or

$$c = MRS^R_{Qz}$$

These equations say that the per unit cost of the public good, $c$, equals the marginal benefits from the public good, in terms of the private good, that is, the marginal cost equals the marginal rate of substitution between the public and private good, $u^R_Q/u^R_z = MRS^R_{Qz}$.

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

$$\max_{q^O} [u^O(M - cq^O, q^R + q^O)]$$

such that Ole's optimal level is determined by

$$c = \frac{u^O_Q}{u^O_z}$$



or

$$c = MRS^O_{Qz}$$

Ole balances the marginal cost of his contribution with the marginal benefit from the public good, in terms of the private good.

As we can see, both Riley and Ole make their contribution decisions without concern for the way their contribution affects the other person. Turning to the question of the socially optimal allocation of resources for the public good, we have to consider how Riley's contribution affects Ole and vice versa. We determine the efficient level of the aggregate public good by selecting the levels of $q^R$ and $q^O$ to maximise one person's utility, say Riley, subject to the constraint that Ole achieves a utility level of $v$,

$$\max_{q^R, q^O} [u^R(M - cq^R, q^R + q^O) | v = u^O(M - cq^O, q^R + q^O)]$$

yielding

$$q^R: -u^R_z c + u^R_Q - \lambda u^O_Q = 0 \tag{2.19}$$

and

$$q^O: u^R_Q - \lambda[-u^O_z c + u^O_Q] = 0 \tag{2.20}$$

where $\lambda$ represents the Lagrangian multiplier that represents the shadow price of the constraint. Solving for $\lambda$ in equation (2.19) and substituting it into equation (2.20) yields the condition for optimal provision of the public good

$$c = \frac{u^R_Q}{u^R_z} + \frac{u^O_Q}{u^O_z}$$

or

$$c = MRS^R_{Qz} + MRS^O_{Qz}$$

The efficient level of the public good says that the aggregate marginal benefit for the public good, in terms of the private good, should equal its marginal cost. The intuition behind the aggregate marginal benefits rests in the assumptions of non-rival and non-excludable consumption – the benefits of the public good are all inclusive. The source of the inefficiency with the private provision of the public good derives from Riley ignoring his impact on Ole and vice versa. Therefore 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 2.8 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

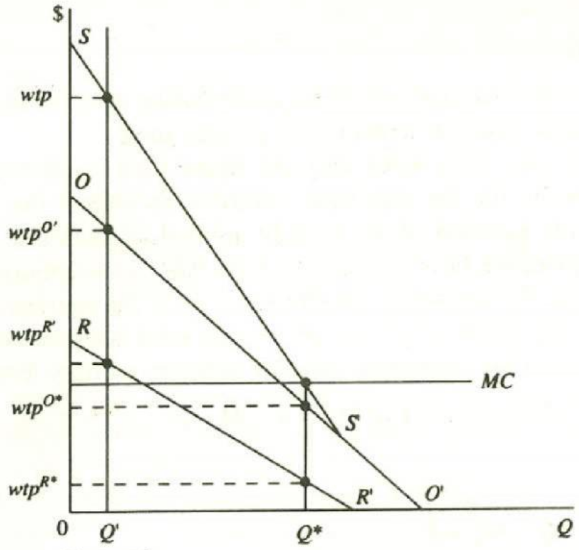


**Figure 2.8** ***Pure public goods***

marginal willingness to pay is $wtp^R$, and Ole's marginal willingness to pay is $wtp^O$ for a total demand of $wtp' = wtp^R + wtp^O$. Because there are no rivalries with the public good, marginal social value is the vertical summation of the two persons' marginal values, such that 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 marginal cost. At this optimal level, each person would pay a personalised price: Riley would pay $wtp^{R^*}$ and Ole would pay $wtp^{O^*}$. Actually revealing these personalised prices for pure public goods, however, is difficult in practice, as we will see in the chapters on non-market valuation (Chapters 12 and 13).

## 2.6 Non-convexities

Up to this point we have assumed that the marginal benefit and cost functions associated with increased pollution have been well-behaved: marginal benefits are decreasing, while marginal costs are increasing (recall Figure 2.1). These well-behaved curves guarantee that, if an equilibrium level of pollution exists, it is unique. Therefore, if a set of complete markets exist for clean water or pollution control, the market will send the correct signal about the socially optimal level of pollution. Figure 2.9 shows that the net benefit curve is 'single-peaked', implying that there is one efficient level of pollution.



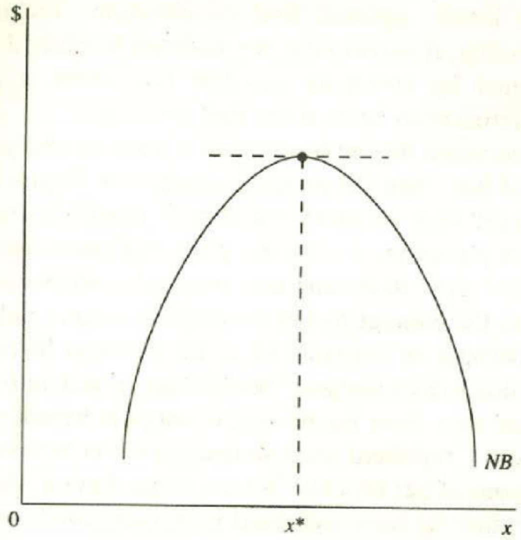


**Figure 2.9** ***Single-peaked net benefit curve***

But for many physical systems the marginal benefit or cost curve need not be so well-behaved. For example, marginal costs may at first increase with increased pollution but then may actually decrease or go to zero as the physical system is so badly damaged that there are simply no more costs as pollution increases. This is a non-convexity and it implies that there may be

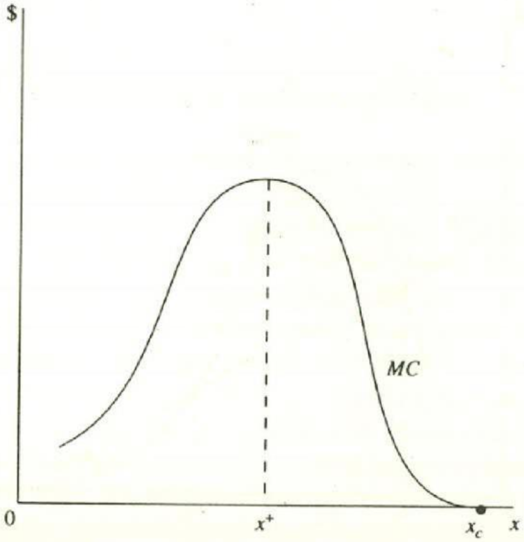


**Figure 2.10** ***Non-convex marginal costs***

more than one locally optimal level of pollution. Technically, a non-convexity means that, if we consider two different levels of a good or bad, a third level defined by averaging the first two levels is inferior in the individual's preferences to both of the first two levels.

To better understand the implications of a non-convexity, let us go back to the example of Riley and Ole on the Cloquet river. Figure 2.10 shows that Ole's marginal cost with increased pollution is 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 that the damage to Ole is complete – more pollution does not raise his costs because he has suffered all the damages he can.

Figure 2.11 adds Riley's marginal benefits curve back into the picture. We see that there are now three points where 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 overall or 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 hatched areas marked $D$ and $E$. Area $D$ represents the net marginal costs of increasing pollution to point $C$, 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 where

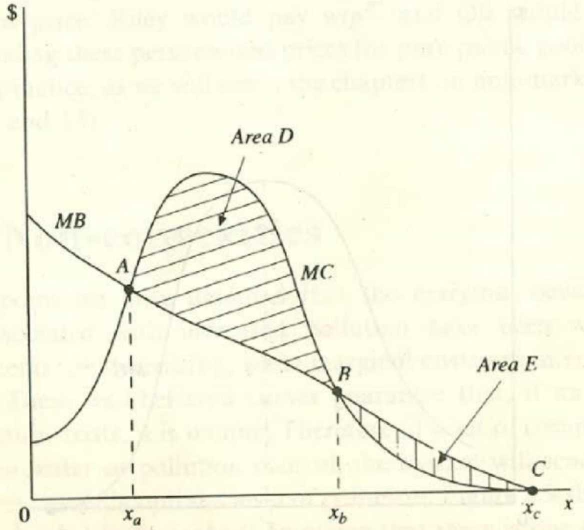


**Figure 2.11** ***Non-convexity and the optimal level of pollution***



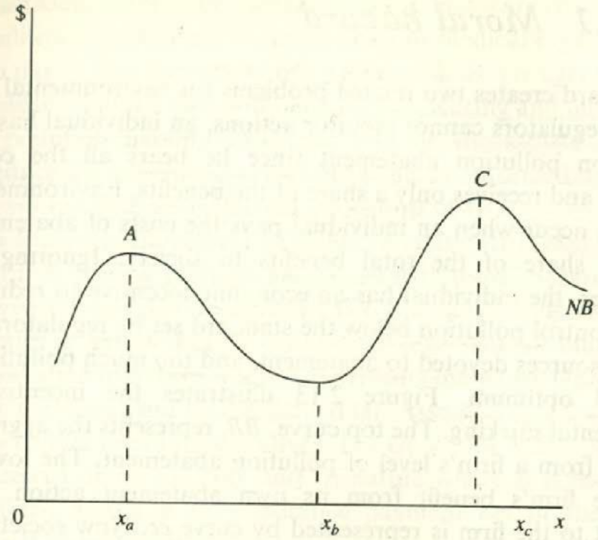


**Figure 2.12** ***Multi-peaked net benefit curve***

$MB$ equals zero. Figure 2.12 shows the multi-peaked net benefit curve where the higher level of pollution is the global optimum. With a non-convexity, even if a set of complete markets exists, the market price might not send a correct signal as the local maximum point $A$ may be selected rather than the global maximum of point $C$. Alternatively, if the net marginal benefits exceed the net marginal costs (area $E$ > area $D$), the global optimum is the higher level of pollution, point $C$.

## ■ 2.7 Asymmetric information

Market failure can 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 an insuree knows more about his level of precautionary behaviour than the insurer, or a seller knows more about the quality of a product than a buyer. Without complete information, markets will be 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 a second person. The *adverse selection* problem exists when one person cannot identify the type or character of the second person. We consider each in turn.

## 2.7.1 Moral hazard

Moral hazard creates two related problems for environmental assets. First, when the regulators cannot monitor actions, an individual has an 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 an individual pays the costs of abatement but only receives a share of the total benefits to society. Ignoring transferable externalities, the individual 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 2.13 illustrates the incentive effects of environmental shirking. The top curve, *BB*, represents the aggregate benefits to society from a firm's level of pollution abatement. The lower curve, *bb*, shows the firm's benefit from its own abatement action. The cost of abatement to the firm is represented by curve *cc*. Now society prefers that the firm invest in abatement level, $s^*$, since that is where marginal social benefits equal marginal costs. But, since the firm only receives a fraction of the total benefits generated but must suffer all the cost, it will set its abatement level at $s'$. Since $s^* > s'$ the market has not allocated enough resources to abatement.

Second, when the private market cannot monitor actions, an insurer will withdraw from the pollution liability market because the provision of insurance will also affect the individual's incentives to take precautions.

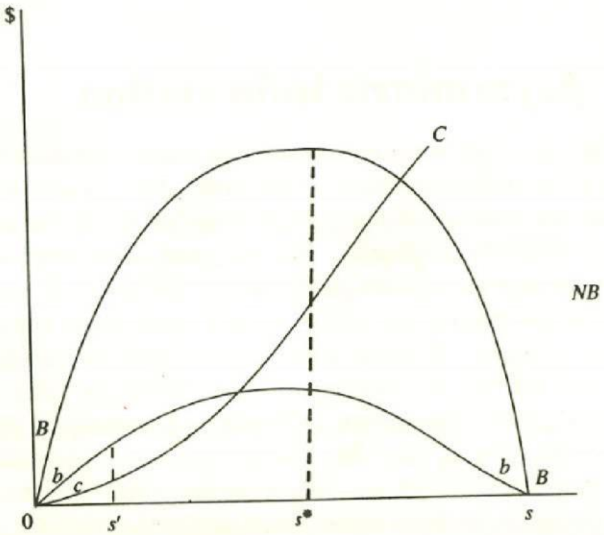


**Figure 2.13** ***Environmental shirking***



Given that accidental spills or storage of pollution can create potential financial liabilities (for example, clean-up costs or medical expenses), a firm would like to 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 will be incomplete as insurers attempt to reduce the information rents of the better-informed individual. The market will produce 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 individual who confronts two mutually exclusive and jointly exhaustive states of nature. Let $U_0 \equiv U(w-\beta)$ represent the utility received under the good state of nature where $w$ represents monetary wealth and $\beta$ is the insurance premium paid by the individual. Assume $U_0' > 0$ and $U_0'' < 0$, where primes denote relevant derivatives. Let $U_1 \equiv U(w - D + \alpha)$ represent the utility received under the bad state of nature where $D$ is the monetary damages suffered and $\alpha$ is the insurance payment net of the premium. Assume $U_1' > 0$ and $U_1'' < 0$.

Let $p^i$ be the probability that the bad state occurs, and $(1 - p^i)$ be the probability that the good state is realised. Assume the individual can influence these likelihoods by his self-protection, $s^i$, where $i = H, L$ represent high ($H$) and low ($L$) levels of self-protection, such that $s^H > s^L$ and $p^H > p^L$. Examples of self-protection include voluntary restraint on the development of a forest or the reduction in draining and tiling wetlands. For this simple model we assume the two levels of self-protection are fixed, and are separable from and measurable in utility terms.

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

$$V^H \equiv (1-p^H)U(w-\beta) + p^H U(w - D + \alpha) - s^H \tag{2.21}$$

and

$$V^L \equiv (1-p^L)U(w-\beta) + p^L U(w - D + \alpha) - s^L \tag{2.22}$$

Figure 2.14 shows the individual's indifference curves in premium-net pay-off space for the high effort self-protection. The slope or marginal rate of substitution between $\alpha$ and $\beta$ is given by

$$\left.\frac{d\beta}{d\alpha}\right|_{V^i} = \frac{p^i}{(1-p^i)}\frac{U_1'}{U_0'} > 0 \qquad i = H, L$$

The curvature of the indifference curves, reflecting the individual's aversion to risk, is

$$\left.\frac{d^2\beta}{d\alpha^2}\right|_{V^i} = \frac{p^i}{(1-p^i)}\frac{U_1'}{U_0'}\left[\frac{U_1''}{U_1'} + \frac{p^i}{(1-p^i)}\frac{U_0''}{U_0'}\right] < 0 \qquad i = H, L$$

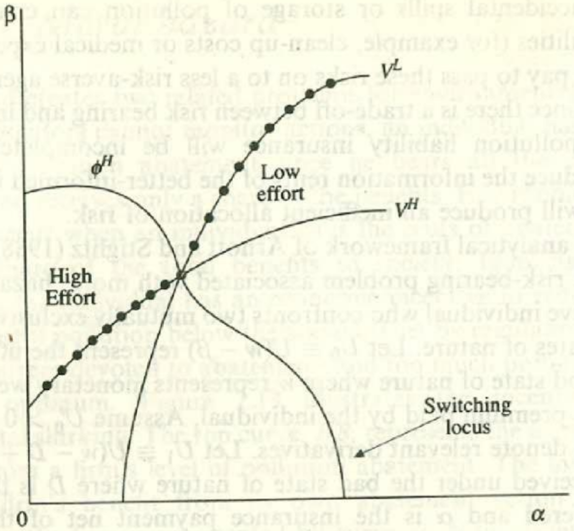


**Figure 2.14** ***Moral hazard (Arnott and Stiglitz, 1988)***

Note that 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

$$\left.\frac{d\beta}{d\alpha}\right|_{V^H} = \frac{p^H}{(1-p^H)}\frac{U_1'}{U_0'} < \frac{p^L}{(1-p^L)}\frac{U_1'}{U_0'} = \left.\frac{d\beta}{d\alpha}\right|_{V^L} \tag{2.23}$$

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 equations (2.21) and (2.22), we see that the comparative levels of expected utility depend on the relative magnitudes of the benefits $(U_0 - U_1)$ and costs $[(s^H - s^L)/(p^L - p^H)]$ of self-protection

$$V^H \gtreqless V^L \quad \text{as} \quad U_0 - U_1 \gtreqless \frac{(s^H - s^L)}{(p^L - p^H)} \tag{2.24}$$

The expected utility of high effort equals the expected utility of low effort if the difference in utility between the good and bad states, $(U_0 - U_1)$, equals the difference in effort, $(s^H - s^L)$, divided by the difference in the likelihood of realising the bad state $(p^L - p^H)$. For a given level of wealth, if the person believes that his or her self-protection causes a trivial reduction in the likelihood of damages, it is likely that $V^L > V^H$. Alternatively, if the individual perceives that his or her self-protection has a significant impact on the likelihood of a bad state, the opposite holds: $V^H > V^L$.

In Figure 2.14, the point where expected utilities are equal, $V^H = V^L$, represents a switching point between low and high self-protection. At low levels of insurance, individuals choose high effort, while at high levels the



individual picks low effort. The individual switches effort levels to increase his or her expected utility. The downward-sloping line, $\phi^{HL}$, 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 individual's complete indifference curve is determined by the individual selecting the highest level of utility given the level of insurance offered, $\max\{V^H, V^L\}$: the scallop-shaped utility curve marked with dots in Figure 2.14 represents the individual's indifference curve in premium and net pay-offs space; that is, the indifference curve is non-convex.

Figure 2.15 shows that the set of feasible contracts between the insurer and insuree is also non-convex. 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

$$\beta(1 - p^H) - \alpha p^H = 0$$

This locus is a ray from the origin with slope $p^H/(1 - p^H)$. The insurer earns zero profits when the price of insurance – the ratio of the premium to the net pay-offs – equals the ratio of the probability of an accident to the probability of no accident $\beta/\alpha = p^H/(1 - p^H)$. 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 2.15. The hatched lines represents the set of feasible contracts for the low and high self-protection; this set is also non-convex.

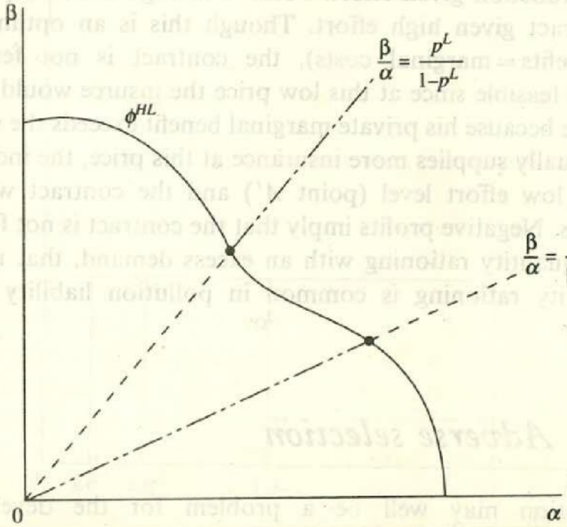


**Figure 2.15** ***Feasible insurance contracts given moral hazard***

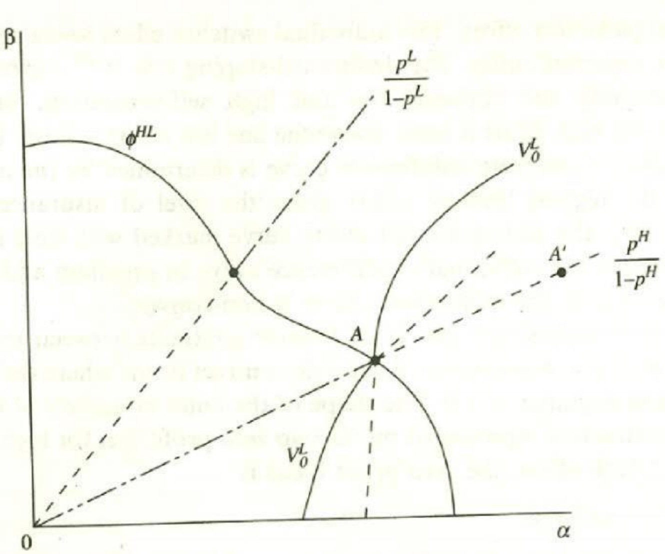


**Figure 2.16** ***Quantity rationing of insurance***

Finally, Figure 2.16 shows that the competitive equilibrium with moral hazard implies the quantity rationing of insurance. Assuming the case where the insurer can observe all insurance purchases by the individual and can therefore restrict the quantity of insurance sold, the equilibrium is characterised by an exclusive contract where the insuree buys all his insurance from one insurer. Let $V_0^H$ and $V_0^L$ represent the individual's non-convex utility function given effort. Point $A$ in Figure 2.16 represents one exclusive contract given high effort. Though this is an optimal contract (marginal benefits = marginal costs), the contract is not feasible. The contract is not feasible since at this low price the insuree would like to buy more insurance because his private marginal benefit exceeds the costs. But if the insurer actually supplies more insurance at this price, the individual will switch to the low effort level (point $A'$) and the contract would imply negative profits. Negative profits imply that the contract is not feasible, and there will be quantity rationing with an excess demand, that is, a market failure. Quantity rationing is common in pollution liability – insurance markets.

## ☐ 2.7.2 *Adverse selection*

Adverse selection may well be a problem for the development of ecoproducts that are produced with practices that are less harmful to the environment. Sustainable production of products from tropical forests, for



example, is a commonly promoted alternative to clear cutting activities. The problem with ecoproducts is that, while they may be of perceived higher quality to some consumers given the production process, these products may also be more expensive as the result of the lack of scale economies and the fact that the environment is not subsidising its production. Now if the buyer cannot distinguish the ecoproduct from the same product produced form standard practices, he will have no incentive to pay the extra premium. If the high quality, high price producers do not think that consumers will pay the premium then they will withdraw from the market. This process will continue until the market for the ecoproduct collapses.

Figure 2.17 shows a uniform distribution of quality, $\theta_i$, for products with different quality as defined by perceived 'eco-friendly' practices. Higher quality products are assumed to generate higher prices. Now if a consumer cannot identify the quality, he or she has no incentive to pay any more than the average price, $E\theta$. Why should he or she pay more than average when he or she cannot distinguish high quality from low quality products? If all consumers behave this way, the producers with a quality above the average, $\theta_i > E\theta$, have no incentive to sell their product because they will earn a profit lower than their opportunity cost. When the above average producers leave the market, the distribution of goods is truncated at the mean, $E\theta$.

But this is not the end of the story. Now, if consumers realise that the above average producers have left the market, the new average quality is at $E\theta'$. Again consumers should not pay more than this new average quality

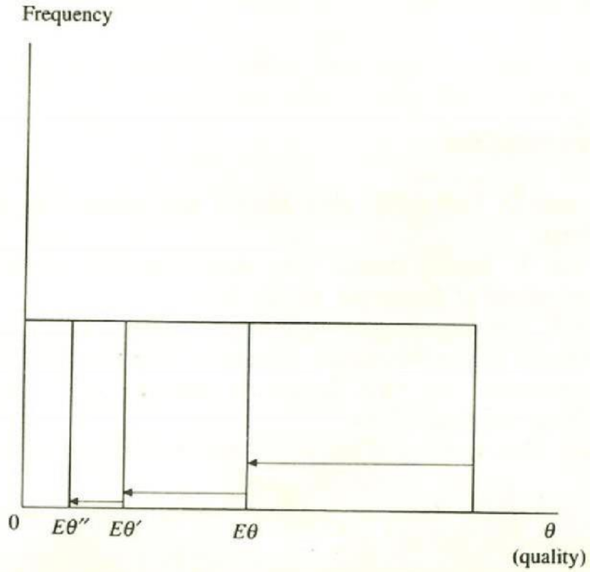


**Figure 2.17** ***Adverse selection***

level. However, those producers left in the market whose quality exceeds $E\theta'$ will now leave the market since they cannot receive enough revenue to cover their opportunity cost, and the market will be truncated again at the lower quality $E\theta'$. This behaviour will continue until either only the lowest quality producers are left in the market or the market collapses altogether. Unless there can be some acceptable warranty to verify production practices, the market for ecoproducts will be inefficient owing to the problem of adverse selection.

## 2.8 Concluding comments

Markets serve society by efficiently organising economic activity. But there are constraints to the effectiveness of market allocation of many environmental assets and risks. Prices do not exist or they understate the value of an asset. Market failure implies that decentralised decisions based on these prices, or lack of them, do not generate an efficient allocation of resources. This chapter has explored the six most prominent cases of market failure for environmental assets – incomplete markets, externalities, non-exclusion, non-rival consumption, non-convexities and asymmetric information. How society will reduce these forms of failure through privatisation, collective action or government intervention is the fundamental debate in public economics. Chapters 3, 4 and 5 explore how economic incentives can be and have been employed to reduce the inefficiencies associated with market failure.

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