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CHAPTER

1 Economy–environment interactions

1.1 Introduction

Economic choices shape nature just as nature can shape our choices. Economists and environmental scientists have long argued that better linkage and integration of the social and natural science disciplines would improve both science and policymaking. The inspiration behind integration is that explicitly accounting for economic and biological circumstances and the key feedback loops between the systems yields more precise information about the risks faced by humans and the environment. An integrated approach accounts for the ability of humans to respond to changes in their surroundings, and vice versa. When an ecosystem changes, humans adapt by altering their behaviour, which then affects the ecosystem. When human systems change, the ecosystem responds to this change, and humans respond in turn. Capturing the outcome of this economic system–environment interaction requires one to account for both adaptation and feedbacks within and between the systems.

The risk to biodiversity provides a good example. Biologists maintain that thresholds of species endangerments are functions of the present sizes, trends and distributions of species' populations and their likely interactions with habitats – strictly a biological question. But this perspective is too narrow. Economic circumstances affect the quality of habitat. The circumstances that matter include the relative returns to human users from alternative sites, the relative returns from alternative uses on a particular site and human welfare. Sites with low relative returns in their 'highest and best' use are more likely to be left undisturbed. Moreover the rich can better afford to set aside quality habitat to protect biodiversity. Species survival is thus determined by both economic and biological parameters.

This chapter gives a brief overview of the ways in which the economy and the natural environment are interlinked. To an extent, these interlinkages are all-embracing; every economic action can have some effect on the environment, and every environmental change can have an impact on the economy. By 'the economy' we refer to the population of economic agents, the institutions they form (which include firms and governments) and the interlinkages between agents and institutions, such as markets. By 'environment' we mean the biosphere, the '. . . thin skin on the earth's surface on which life exists' (Nisbet, 1991), the atmosphere, the geosphere (that part of the earth lying below the biosphere) and all flora and fauna. Our definition of the environment thus includes life forms, energy and material resources, the stratosphere (high atmosphere) and troposphere (low atmosphere). These constituent parts of the environment interact with each other: an example is the effect of changes in biosphere composition on the composition of the atmosphere. More important from our perspective are the effects of human activity on the environment, and the consequences of these effects on human well-being.

As an example, consider the generation of electricity. In extracting fossil fuels to use as an energy source, we deplete the stock of such fuels in the geosphere. In burning these fuels to release their energy, we also release carbon dioxide (CO_2), sulphur dioxide (SO_2) and particulates, all of which may produce undesirable environmental impacts that reduce human well-being. Higher carbon dioxide emissions mean greater global climate change, with consequent predicted costs for people in many parts of the developing world (Markandya and Halnaes, 2004). Climate change also threatens global biodiversity: for instance, endangering the winter habitat of the North American monarch butterfly in Mexico (Oberhauser and Peterson, 2003) and leading to the predicted loss of 24–65% of suitable habitats for Northern European butterflies over the next 100 years (Hill *et al.*, 2002). Higher sulphur dioxide emissions mean more acid rain, impacting on fisheries in sensitive locations (Flower and Batterbee, 1983; MacMillan and Ferrier, 1994). Increased particulate emissions can mean health problems for older and more vulnerable citizens in both developed (COMEAP, 1998) and developing countries (Pearce, 1996).

As another example, agricultural support policies may have environmentally damaging effects which in turn rebound on human welfare. Thus, subsidising cereal production in the European Community (EC) led to higher prices for such cereals, which are important inputs to the livestock sector. Two effects amongst many may be remarked on: higher output prices encouraged farming practices which contributed to soil erosion in Europe (Colombo *et al.*, 2003), while livestock farmers' demand for cheaper substitutes for feed resulted in the loss of rainforest in Thailand, as producers in Thailand sought to increase cassava production for export to EC livestock farmers.

1.2 Interlinkages between the economy and the environment

Figure 1.1 summarises the interlinkages between the economy and the environment. We simplify the economy into two sectors: production and consumption. Exchanges of goods, services and factors of production take place between these two sectors. The environment is shown here as the three interlinked circles *E*1, *E*2 and *E*3, and the all-encompassing system boundary labelled *E*4. The production sector extracts energy

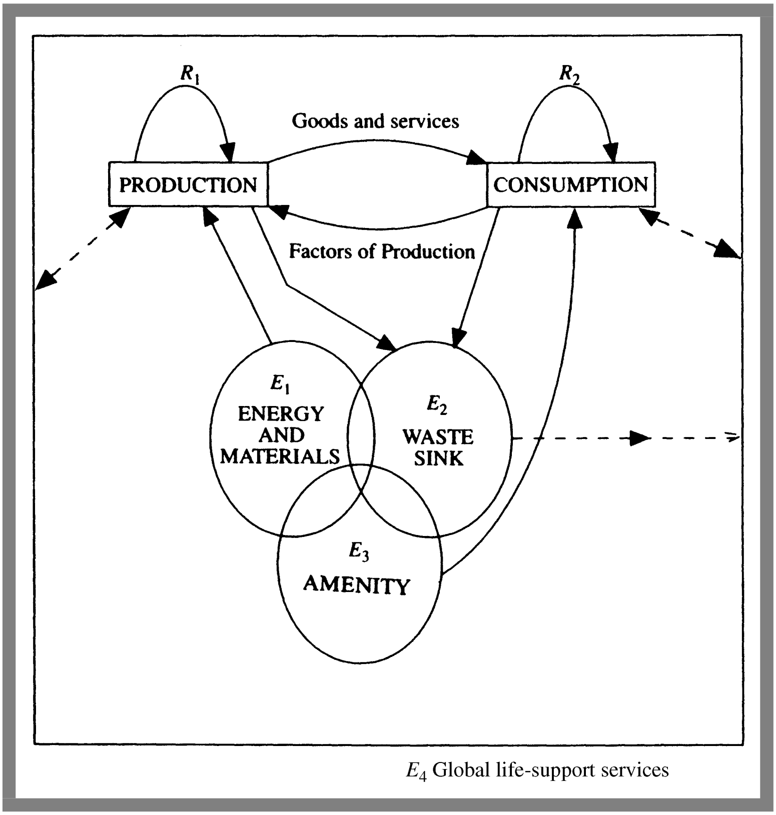

Figure 1.1 Economy–environment interactions

resources such as oil and material resources such as iron ore from the environment. These are transformed into outputs: some useful – goods and services supplied to consumers – and some which are waste products, such as effluent water and air pollutants. There is some recycling of resources within the production sector, shown by the loop *R*1, and within the consumption sector, as shown by the loop *R*2. The environment's first role, then, is as a *supplier of resources*.

The second role is as a *sink for waste products*. These wastes may result directly from production, as already mentioned, or from consumption: when an individual puts out their garbage, or when they drive to work, they are contributing to this form of waste. In some cases, wastes are biologically or chemically processed by the environment, or both. For example, organic emissions to an estuary from a distillery are broken down by natural processes – the action of micro-organisms – into their chemical component parts. Whether this will have a harmful effect on the estuary depends on a number of factors, including the volume of waste relative to the volume of the receiving water, the temperature of the water and its rate of replacement. That is to say the estuary has a limited 'assimilative capacity' for the waste. As the level of organic input increases, the process of breaking it down will use up more and more of the oxygen dissolved in water, reducing the ability of the estuary to support fish.

The notion of assimilative capacity has been criticised (see, for example, Nisbet, 1991), implying as it does that up to a fixed point emissions can occur with no deleterious impact. This is not strictly true in most cases, since what we have is a gradually increasing impact – although the rate of increase may exhibit abrupt changes due to 'threshold' effects. This is illustrated in Figure 1.2. However, the notion is useful in that it suggests that, up to a point, effects are not deemed important: only once the oxygen in the river drops below a critical level so that, for example, fish are no longer present, does

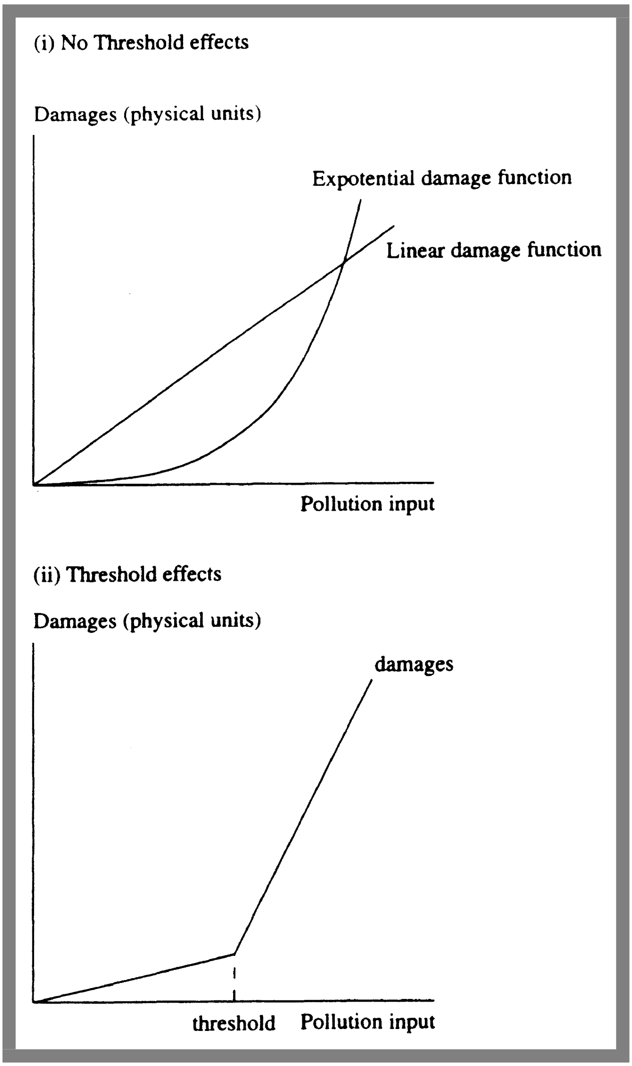

Figure 1.2 Possible damage functions

the effect become 'significant' on some criteria. In some types of waterbody, however, the nature of the ecosystem dynamics, as they respond to human impacts, may be so complex that they cause us to re-think how we construct our economic models. One example is pollution impacts on shallow lakes, and the hysteresis which describes this process (Scheffer *et al.*, 2001). Chaotic dynamics in ecology–economic relationships are also of interest, since they mean the system can 'flip' from one state to another rather than evolving in a linear fashion (Brock *et al.*, 2000).

For some inputs to the environment, there are no natural processes to transform them into harmless, or less harmful, substances. Such inputs, which are variously termed 'cumulative' and 'conservative' pollutants, include metals such as lead and cadmium, and man-made substances such as polychlorinated biphenyls (PCBs) and dichloro-diphenyl-trichloroethane (DDT). If, in our estuary example, PCBs are discharged into the water, then they will not be broken down either by chemical processes (oxidation) or through biological processes by micro-organisms (McLusky, 1989). Instead, they will build up either in the mud at the bottom of the estuary, or in fish or invertebrates. This latter process is known as bioaccumulation. For conservative pollutants a positive flow in a year F_t adds to the stock S_t. This is not true for degradable, assimilative wastes, where the stock in any time period S_t depends on current flows less that amount removed by biodegradation, or by chemical reactions in the case of gases such as methane. For degradable pollutants, such as organic effluents from brewing or paper production, and methane, the stock in any time period t is given by:

$$S_t^a = F_t - A_t \tag{1.1}$$

where A is the amount assimilated in any period. For cumulative pollutants, the stock in any period t^* is

$$S_{t*}^c = \sum_{t_0}^{t=t*} F_t \tag{1.2}$$

(where t_0 is the historical date when emissions began) since assimilation is zero. For a given location, Equation (1.2) may not accurately predict the stock of cumulative pollutants, since some transport of the pollutants to another location is possible, while sediments may build up over the stock pollutant and put it 'out of harm's reach'.

With regard to Equation (1.1), we should note that the amount assimilated in any period (A_t) may depend on the level of emissions in previous periods: emissions of either the pollutant whose stock is being modelled or another pollutant. As an example of the latter case, the hydroxyl radical in the atmosphere is responsible for breaking down methane, an important greenhouse gas. Methane (CH_4) is broken down in the atmosphere by the hydroxyl radical (OH) in the presence of nitrous oxides (NO) into water vapour, hydrogen and carbon monoxide. However, the amount of OH in the upper atmosphere is a function of the level of other pollutants, such as carbon monoxide (CO), and of hydroxyl production (which in turn depends partly on ozone levels in the lower atmosphere). The higher the CO levels are, the lower, *ceteris paribus*, will be OH levels, and thus the less CH_4 will be broken down.

So far we have seen that the environment acts as a waste sink and as a source of energy and material resources. The next role to be considered is that marked *E*3 in Figure 1.1. The environment acts as a *supplier of amenity, and educational and spiritual values* to society. For example, people living in Europe may derive pleasure from the existence of wilderness areas in Northern Canada or in tropical rainforests, while native peoples living in these areas attach spiritual and cultural values to them, and the flora and fauna therein. We need to make precise the sense in which such values count for economists. The theory of environmental valuation is set out in detail in Chapter 11. For present purposes, however, the question can be addressed by asking what constitutes economic value within the currently dominant economic paradigm of neoclassical economics. Neoclassical economics judges economic value as being dependent on social well-being, measured in a particular way. Social well-being is seen as depending on the (possibly weighted) sum of individuals' levels of well-being. Individual well-being is measured by utility, and social welfare is the sum of individual utilities. There is thus no separate collective good. The weighting of individual utilities is implicit in the social welfare function, see Johansson (1991) for a discussion.

Individuals derive utility from consuming goods and services (meals, holidays) and from the state of the natural environment. This is because individuals use the natural environment for recreation, as an input to the production of goods/services, and because they are made happier by the mere existence of environmental assets such as wilderness areas and blue whales. A representative individual j may have preferences which could be represented in the following generalised way:

$$U_j = U\,(X_1, X_2, \ldots, X_n; Q_1, Q_2, \ldots, Q_m) \qquad (1.3)$$

where U_j is utility for person j, $X_1, \ldots, X_n$ are goods and services produced in the production sector and consumed by person j and $Q_1, \ldots, Q_m$ are environmental assets. For instance, Q_1 could be local air quality, Q_2 local water quality and Q_m the stock of blue whales. The environment thus supplies utility directly to individual j via the vector of environmental assets $\boldsymbol{Q}$, and indirectly via its roles in the production of the vector of goods and services $\boldsymbol{X}$. Clearly one result of an increase in the output of any element of the $\boldsymbol{X}$ vector could be a decrease in the quantity or quality of an element in the $\boldsymbol{Q}$ vector. For example, suppose X_1 is consumption of services provided by owning a car, but driving a car causes decreases in air quality, Q_1. An increase in the consumption of 'car services' increases utility ($\partial U_j/\partial X_1$ is positive), but this increase in car use decreases air quality. This fall in air quality reduces utility in an amount ($\partial U_j/\partial Q_1 \cdot \partial Q_1/\partial X_1$). The net effect is thus ambiguous, depending on the relative strengths of these positive and negative changes. Note also that the level of Q_1 will actually depend on the choices and therefore actions of many individuals, not just person j: for instance, it may depend on the travel-to-work choices of everyone in the city where j lives. We can also think of pollution impacting on people's health, and thus on the productivity of the economy (sick workers being less productive than healthy workers).

What this example shows is that using the environment for one purpose (as a supplier of material resources) can reduce its ability to supply us with other services, such as the ability to breathe clean air. This is why in Figure 1.1, the three circles *E*1, *E*2 and *E*3 are shown as overlapping: potential conflicts in resource use arise. Some examples of these conflicts are the following:

- using a mountain region as a source of minerals means its amenity value as a recreation destination is reduced;
- using a river as a waste-disposal unit means its amenity value to fishermen and riverside walkers is reduced and that we can no longer extract so many material resources (fish to eat) from it;
- felling a forest for its timber reduces the electricity-generating capacity of a dam, owing to soil erosion, and reduces amenity values since the forest's inhabitants (animal and human) are displaced or destroyed;
- preserving a wetland for its aesthetic qualities forgoes the use of drained land for agriculture.

The environment is thus a *scarce resource*, with many conflicting demands placed on it. The scarcity problem resulting from these conflicting demands, *relative scarcity*, could in principle be resolved by a correct set of (shadow) prices. This we distinguish from *absolute scarcity*, whereby all demands on environmental services are simultaneously increasing (Daly, 1991). The major cause of absolute scarcity is economic growth: this implies an increasing demand for materials and energy, and an increase in waste outputs (by the first law of thermodynamics (Daly, 1987). Yet if the amounts of environmental resources are fixed (limited assimilative capacity, limited supplies of minerals and so on) then absolute scarcity will increase as world economic growth occurs (see Box 1.1).

BOX 1.1

Does rising output mean rising energy use?

As economic growth occurs, energy and material demands per real dollar of output have tended to fall. For example, energy required per unit of real GDP in Denmark fell by 27% between 1979 and 1989 (World Resources Institute, 1992). In the UK, the ratio of primary energy use to GDP fell dramatically over the period 1950–90 (DTI, 1992), whilst the ratio of the value of manufacturing output to total energy use fell over the period 1990–2001 (DEFRA, 2003). This type of trend is now known as *decoupling.* However, rising world population and an increased scale of economic activity would seem likely to produce a net increase in absolute scarcity over time. Moreover, work on energy saving and GDP growth by Robert Kaufman (1992) suggests that previous estimates of energy saving may be too high.

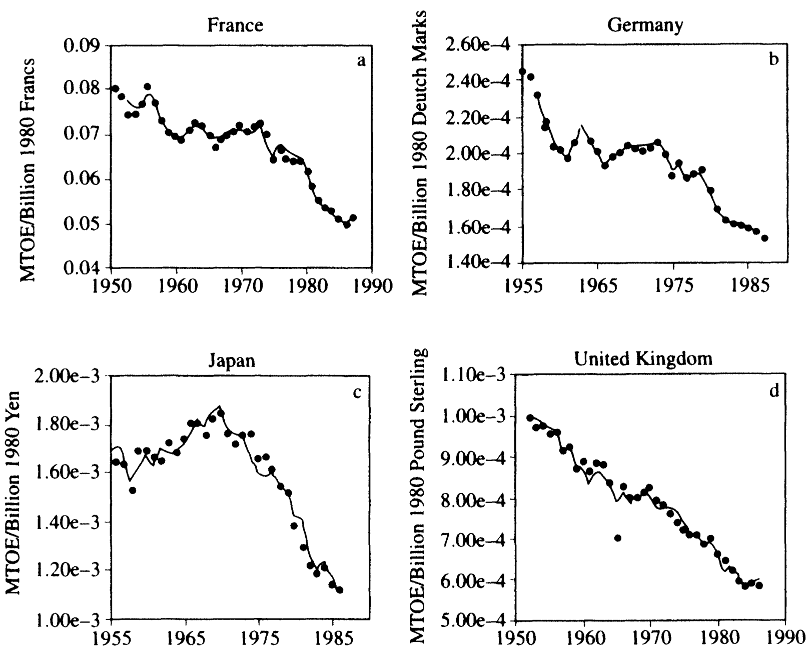

Figure B1.1 Energy use to GDP ratios in four countries

Note: Actual value for the energy real/GDP ratio (circles) and the value predicted by Kaufman's regression model (solid line).

Source: R.K. Kaufman (1992). 'A biophysical analysis of energy/real GDP ratios', *Ecological Economics*, 6(1), 35–56.

In Figure B1.1, energy use per unit of real GDP can be seen to have fallen for France, Germany, Japan and the UK over the last 40 years. This fall has traditionally been attributed to two factors: technological progress, which reduces the amounts of all inputs, energy inclusive, needed to produce one unit of output and a real price effect, whereby rising real energy prices cause producers and consumers to substitute capital or labour for energy.

Kaufman notes, however, that there are other reasons why the energy/real GNP ratio may fall. First is a change in the composition of energy use. Different forms of energy (oil, coal, nuclear) are aggregated by converting them into heat units (kilocalories). However, the amount of work per unit of heat equivalent is not constant across energy sources, with some energy sources (higher quality) being able to do more work per kilocalorie than others (lower quality). Thus if, over time, there is a transition from lower to higher quality energy sources – say from coal to natural gas – then the energy/GDP ratio will fall. Second, a change in the mix of final demand can also change energy use per unit of GDP if energy-intensive commodities are replaced by less energy-intensive ones (where energy intensity is measured as kilocalories per dollar of output). Kaufman also argues that traditional measures of energy substitution due to real price effects overestimate energy savings, since they ignore the energy component of the capital and labour used instead of energy. Evidence on this point has been gathered by other authors: for example, Pimental *et al.* (1973) calculated that, while the amount of direct energy used to produce a bushel of corn in the US fell by 15% between 1959 and 1970, total energy use per bushel actually rose by 3% once the energy content of other inputs (tractors, pesticides) was accounted for.

Using econometric analysis, Kaufman shows that most of the reduction in the energy/real GDP ratios in France, Japan, Germany and the UK over the study period is accounted for by changes in the composition of energy use (away from coal and towards petroleum and nuclear sources) and changes in the composition of output. Future substitution possibilities towards high quality energy sources are limited owing to an indication of diminishing returns. Real prices still have a significant effect, although the price elasticity of energy demand is much lower than previous studies at −0.045 to −0.389, since Kaufman allows for the indirect energy costs of labour and capital, which are considerable.

It is apparent, therefore, that economics has a role to play in understanding how best to manage our global environment, since economics is a discipline concerned with allocating scarce resources to conflicting demands. But it will also become clear that a free market system can fail to allocate environmental resources efficiently. The reasons for this failure are largely addressed in Chapter 3, but we can preview the more important ones by saying that an imperfect specification of property rights results in a set of prices which send the wrong signals to producers, consumers and governments and that individual benefits of preserving our environment understate the collective benefits of preservation.

Returning to Figure 1.1, the boundary marked *E*4 represents the global life-support services provided by the environment. These include

- maintenance of an atmospheric composition suitable for life. The earth's atmosphere is made up largely of nitrogen (78%), oxygen (21%), argon (0.93%), water vapour (variable) and carbon dioxide (0.035%), with numerous trace gases. The limits of variability in this mixture, from the point of view of continued existence, are small.
- maintenance of temperature and climate. The naturally occurring greenhouse effect warms the earth from its 'effective' mean temperature of −18 °C to the current global average of 16 °C. Changes in the composition of the upper atmosphere can change this warming, and produce a wide range of impacts on the economy both directly

(e.g. by changing agricultural productivity) and indirectly (e.g. through effects on biodiversity).

- recycling of water and nutrients. Examples are the hydrological and carbon cycles.

Economic activity operates within this environment, and thus is shown as being encapsulated by it. The dashed line between *E*2 and *E*4 indicates that emissions can affect these global support services; whilst the dashed lines between *E*4 and production and consumption shows the direct and indirect feedback effects from changes in these global services on the economy.

1.3 The rest of this book

This book is intended for graduate-level courses in Environmental Economics, although parts of it will certainly be suitable for honours undergraduate teaching. We have tried to achieve a balance of formal theoretical explanation, intuition and empirical examples – the last of these often contained in 'box sections' in the text. A reasonable background in undergraduate-level mathematics for economists is assumed.

In what follows, we set out the main aspects of economic theory concerning how these links between the economy and the environment operate, how markets allocate environmental resources and how this allocation can differ from what society views as optimal. In Chapter 2, the economics of sustainable development are set out, in terms of what sustainability means, how it might be achieved and how it can be measured. Chapter 3 explains under what circumstances markets allocate resources efficiently and when they fail to do so. Market failure seems endemic where many environmental resources are concerned. Chapter 4 thus asks how the power of the market can be made to work to correct environmental market failures, whilst Chapter 5 goes into some of the instruments which arise in more practical detail. Chapter 6 moves on to consider what economics has to say about the difficulties of managing global environmental problems (such as climate change) where international co-operation is required for effective and socially efficient responses.

Chapters 7–10 are concerned with the issue of how natural resource stocks should best be managed, for both non-renewable (Chapters 7 and 8) and renewable (Chapters 9 and 10) resources. Issues of property rights and market structure turn out to be crucial. In Chapter 11, focus turns to the valuation of non-market environmental resources, such as clean air and biodiversity. Both the theory underlying these values and the empirical methods for estimating them are explained. Environmental risk is investigated in Chapter 12, with the focus being on people's decision-making under risk and on the value of reducing environmental risks. Finally, Chapter 13 considers some of the issues underlying the impacts of trade on the environment.

Whether you are using this book to help you teach a course, or whether you are a student, the authors encourage your comments – contact details can be found on the back cover.

BOX 1.2

Uncertainty and the precautionary principle

In many, if not all, cases of environmental management, there is some uncertainty over the effects of actions on the environment and of the impact on humans of subsequent environmental changes. In some cases, the extent of this uncertainty is considerable. For example, while we know that carbon dioxide causes global warming, there is uncertainty as to the extent of warming caused by, say, a doubling of current CO_2 levels, and even more uncertainty about the physical effects this warming will have. Environmentalists will often argue that society should take action before such uncertainty is resolved, since the costs of not taking action may well be greater than the costs of preventative or anticipatory action taken now, especially when the absence of action today leads to irreversible undesirable environmental consequences (Taylor, 1991).

The policy stance of taking action before uncertainty about possible environmental damages is resolved has been referred to as the *precautionary principle*. This was defined in the Declaration of the Third Ministerial Conference on the North Sea as, '. . . action to avoid potentially damaging impacts of substances that are persistent, toxic and liable to bioaccumulate even where there is no scientific evidence to prove a causal link between effects and emissions' (quoted in Haigh, 1993). Many international environmental agreements might be seen as taking action before we are sure about the precise nature and effects of environmental damages, including the Montreal Protocol on substances likely to damage the ozone layer and the Kyoto Protocol on greenhouse gas emission reductions. Indeed, the 1874 Alkali Act, often cited as one of the first pieces of environmental legislation in the UK, did not insist on proof that gases discharged from factories actually caused deleterious health effects before they could be subject to control. The Precautionary Principle (PP), which can be extended to other areas of environmental management such as the conservation of fish stocks, would thus seem to be a widely accepted principle for wise environmental management.

However, two qualifications have emerged. First, the 1992 UN environment summit adopted the PP to be applied by all countries, but only 'according to their capabilities', implying that the costs of actions under the PP should be considered, and might be deemed too great for some (poorer) countries. Second, the UK government, in its 1990 White Paper on the environment stated that the PP should be applied only 'if the balance of likely costs and benefits justifies it'. This second restriction is rather more severe, since to apply it would involve some estimates of the probabilities of different possible outcomes being known, that these outcomes could be physically described and that they could be valued in monetary terms. But if this were so, then a more formal application of cost-benefit analysis could guide policy analysis: the PP would be incorporated in the treatment of risk (e.g. by giving greater weight to the worst possible outcomes). However, it should be noted that some have taken acceptance of the PP to mean that society should have as a firm objective the total elimination of activities where uncertain environmental damages are involved. Examples of such bans do exist: for example, the banning of the disposal of radioactive wastes in the deep ocean and the incineration of toxic wastes at sea. Alternatively, the PP could be taken to mean the minimisation of inputs of any effluents to any ecosystem. However, the economist might worry that the costs of either banning the disposal or minimising the input of effluents would be disproportionately large, and incur unnecessarily high opportunity costs for society.

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