CHAPTER 2 The origins of the sustainability problem

The global challenge can be simply stated: To reach sustainability, humanity must increase the consumption levels of the world's poor, while at the same time reducing humanity's ecological footprint

Meadows *et al.* (2005), p. xv

Learning objectives

In this chapter you will

- learn how economic activity depends upon and affects the natural environment
- be introduced to some basic material from the environmental sciences
- learn about the proximate drivers of the economy's impact on the environment – population, affluence and technology
- review the current state of human economic development
- consider the argument that the environment sets limits to economic growth
- learn about the emergence of the idea of sustainable development

Introduction

We inhabit a world in which the human population has risen dramatically over the past century and may almost double during the next. The material demands being made by the average individual have been increasing rapidly, though many human beings now alive are desperately poor. Since the 1950s and 1960s economic growth has been generally seen as *the* solution to the problem of poverty. Without economic growth, poverty alleviation involves redistribution from the better-off to the poor, which encounters resistance from the better-off. In any case, there may be so many poor in relation to the size of the better-off group that the redistributive solution to the problem of poverty is simply impossible – the cake is not big enough to provide for all, however thinly the slices are cut. Economic growth increases the size of the cake. With enough of it, it may be possible to give everybody at least a decent slice, without having to reduce the size of the larger slices.

However, the world's resource base is limited, and contains a complex, and interrelated, set of ecosystems that are currently exhibiting signs of fragility. It is increasingly questioned whether the global economic system can continue to grow without undermining the natural systems which are its ultimate foundation.

This set of issues we call 'the sustainability problem' – how to alleviate poverty in ways that do not affect the natural environment such that future economic prospects suffer. In this chapter we set out the basis for the belief that such a problem exists.

This chapter is organised as follows. We first look at the interdependence of the economy and the environment, and give a brief overview of some environmental science basics that are relevant to this. In the second section the proximate drivers of

the economy's impact on the environment are considered. The third section of the chapter presents data on the current state of human development in relation to the problems of poverty and inequality. In this section we note the attachment of economists to economic growth as the solution to the poverty problem. In the next section we consider limits to growth. The chapter ends by looking at the emergence in the 1980s of the idea of sustainable development – growth that does not damage the environment – and progress towards its realisation.

2.1 Economy–environment interdependence

Economic activity takes place within, and is part of, the system which is the earth and its atmosphere. This system we call 'the natural environment', or more briefly 'the environment'. This system itself has an environment, which is the rest of the universe. Figure 2.1 is a schematic representation of the two-way relationships between, the interdependence of, the economy and the environment.[1]

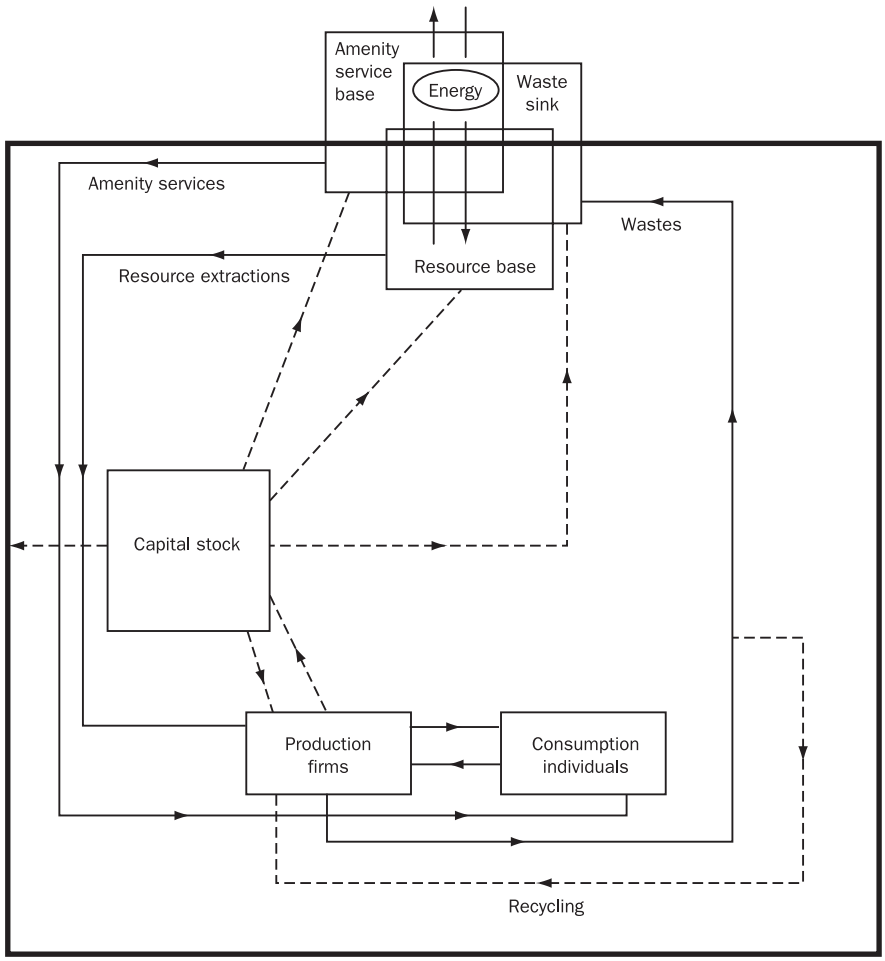


Figure 2.1 Economic activity in the natural environment

[1] Figure 2.1 is taken from Common (1995), where economy–environment interdependence is discussed at greater length than here. References to works which deal more fully, and rigorously, with the natural science matters briefly reviewed here are provided in the Further Reading section at the end of the chapter.

The outer heavy black lined box represents the environment, which is a thermodynamically closed system, in that it exchanges energy but not matter with its environment. The environment receives inputs of solar radiation. Some of that radiation is absorbed and drives environmental processes. Some is reflected back into space. This is represented by the arrows crossing the heavy black line at the top of the figure. Matter does not cross the heavy black line. The balance between energy absorption and reflection determines the way the global climate system functions. The energy in and out arrows are shown passing through three boxes, which represent three of the functions that the environment performs in relation to economic activity. The fourth function, represented by the heavy black lined box itself, is the provision of the life-support services and those services which hold the whole functioning system together. Note that the three boxes intersect one with another and that the heavy black line passes through them. This is to indicate that the four functions interact with one another, as discussed below.

Figure 2.1 shows economic activity located within the environment and involving production and consumption, both of which draw upon environmental services, as shown by the solid lines inside the heavy lined box. Not all of production is consumed. Some of the output from production is added to the human-made, reproducible, capital stock, the services of which are used, together with labour services, in production. Figure 2.1 shows production using a third type of input, resources extracted from the environment. Production gives rise to wastes inserted into the environment. So does consumption. Consumption also uses directly a flow of amenity services from the environment to individuals without the intermediation of productive activity.

We now discuss these four environmental functions, and the interactions between them, in more detail.

2.1.1 The services that the environment provides

As noted in the previous chapter, natural resources used in production are of several types. One distinguishing characteristic is whether the resource exists as a stock or a flow. The difference lies in whether the level of current use affects future availability. In the case of flow resources there is no link between current use and future availability. The prime example of a flow resource is solar radiation – if a roof has a solar water heater on it, the amount of water heating done today has no implications for the amount that can be done tomorrow. Wave and wind power are also flow resources. Stock resources are defined by the fact that the level of current use does affect future availability.

Within the class of stock resources, a second standard distinction concerns the nature of the link between current use and future availability. Renewable resources are biotic populations – flora and fauna. Non-renewable resources are minerals, including the fossil fuels. In the former case, the stock existing at a point in time has the potential to grow by means of natural reproduction. If in any period use of the resource is less than natural growth, stock size grows. If use, or harvest, is always the same as natural growth, the resource can be used indefinitely. Such a harvest rate is often referred to as a 'sustainable yield'. Harvest rates in excess of sustainable yield imply declining stock size. For non-renewable resources there is no natural reproduction, except on geological timescales. Consequently, more use now necessarily implies less future use.

Within the class of non-renewables the distinction between fossil fuels and the other minerals is important. First, the use of fossil fuels is pervasive in industrial economies, and could be said to be one of their essential distinguishing characteristics. Second, fossil fuel combustion is an irreversible process in that there is no way in which the input fuel can be even partially recovered after combustion. In so far as coal, oil and gas are used to produce heat, rather than as inputs to chemical processes, they cannot be recycled. Minerals used as inputs to production can be recycled. This means that whereas in the case of minerals there exists the possibility of delaying, for a given use rate, the date of exhaustion of a given initial stock, in the case of fossil fuels there does not. Third, fossil fuel combustion is a major source of a number of waste emissions, especially into the atmosphere. One such emission is carbon dioxide, CO_2, the most important of the greenhouse gases which are driving climate change.

Many of the activities involved in production and consumption give rise to waste products, or residuals, to be discharged into the natural environment. Indeed, as we shall see when we discuss the materials balance principle, such insertions into the environment are the necessary corollary of the extraction of material resources from it. In economics, questions relating to the consequences of waste discharge into the environment are generally discussed under the heading of 'pollution'. To the extent, and only to the extent, that waste discharge gives rise to problems perceived by humans, economists say that there is a pollution problem. Pollution problems can be conceptualised in two ways. One, which finds favour with economists, sees pollution as a stock of material resident in the natural environment. The other, which finds favour more with ecologists, sees pollution as a flow which affects the natural environment.

In the former case, pollution is treated in the same way as a stock resource, save that the stock has negative value. Residual flows into the environment add to the stock; natural decay processes subtract from it. We will look at pollution modelled this way in Chapter 16. The flow model treats the environment as having an 'assimilative capacity', defined in terms of a rate of residual flow. Pollution is then the result of a residual flow rate in excess of assimilative capacity. There is no pollution if the residual flow rate is equal to, or less than, assimilative capacity. If the residual flow rate is persistently in excess of assimilative capacity, the latter declines over time, and may eventually go to zero.

In Figure 2.1 amenity services flow directly from the environment to individuals. The biosphere provides humans with recreational facilities and other sources of pleasure and stimulation. Swimming from an ocean beach does not require productive activity to transform an environmental resource into a source of human satisfaction, for example. Wilderness recreation is defined by the absence of other human activity. Some people like simply lying out of doors in sunshine. The role of the natural environment in regard to amenity services can be appreciated by imagining its absence, as would be the case for the occupants of a space vehicle. In many cases the flow to individuals of amenity services does not directly involve any consumptive material flow. Wilderness recreation, for example, is not primarily about consuming resources in the wilderness area, though it may involve this in the use of wood for fires, the capture of game for food and so on. A day on the beach does not involve any consumption of the beach in the way that the use of oil involves its consumption. This is not to say that flows of amenity services never impact physically on the natural environment. Excessive use of a beach area can lead to changes in its character, as with the erosion of sand dunes following vegetation loss caused by human visitation.

The fourth environmental function, shown in Figure 2.1 as the heavy box, is difficult to represent in a simple and concise way. Over and above serving as resource base, waste sink and amenity base, the biosphere currently provides the basic life-support functions for humans. While the range of environmental conditions that humans are biologically equipped to cope with is greater than for most other species, there are limits to the tolerable. We have, for example, quite specific requirements in terms of breathable air. The range of temperatures that we can exist in is wide in relation to conditions on earth, but narrow in relation to the range on other planets in the solar system. Humans have minimum requirements for water input. And so on. The environment functions now in such a manner that humans can exist in it. An example will illustrate what is involved.

Consider solar radiation. It is one element of the resource base, and for some people sunbathing is an environmental amenity service. In fact, solar radiation as it arrives at the earth's atmosphere is harmful to humans. There it includes the ultraviolet wavelength UV-B, which causes skin cancer, adversely affects the immune system and can cause eye cataracts. UV-B radiation affects other living things as well. Very small organisms are likely to be particularly affected, as UV-B can penetrate only a few layers of cells. This could be a serious problem for marine systems, where the base of the food chain consists of very small organisms living in the surface layers of the ocean, which UV-B reaches. UV-B radiation also affects photosynthesis in green plants adversely.

Solar radiation arriving at the surface of the earth has much less UV-B than it does arriving at

the atmosphere. Ozone in the stratosphere absorbs UV-B, performing a life-support function by filtering solar radiation. In the absence of stratospheric ozone, it is questionable whether human life could exist. Currently, stratospheric ozone is being depleted by the release into the atmosphere of chlorofluorocarbons (CFCs), compounds which exist only by virtue of human economic activity. They have been in use since the 1940s. Their ozone-depleting properties were recognised in the 1980s, and, as discussed in Chapter 9, policy to reduce this form of pollution is now in place.

The interdependencies between economic activity and the environment are pervasive and complex. The complexity is increased by the existence of processes in the environment that mean that the four classes of environmental services each interact one with another. In Figure 2.1 this is indicated by having the three boxes intersect one with another, and jointly with the heavy black line representing the life-support function. What is involved can be illustrated with the following example.

Consider a river estuary. It serves as resource base for the local economy in that a commercial fishery operates in it. It serves as waste sink in that urban sewage is discharged into it. It serves as the source of amenity services, being used for recreational purposes such as swimming and boating. It contributes to life-support functions in so far as it is a breeding ground for marine species which are not commercially exploited, but which play a role in the operation of the marine ecosystem. At rates of sewage discharge equal to or below the assimilative capacity of the estuary, all four functions can coexist. If, however, the rate of sewage discharge exceeds assimilative capacity, not only does a pollution problem emerge, but the other estuarine functions are impaired. Pollution will interfere with the reproductive capacity of the commercially exploited fish stocks, and may lead to the closure of the fishery. This does not necessarily mean its biological extinction. The fishery may be closed on the grounds of danger to public health. Pollution will reduce the capacity of the estuary to support recreational activity, and in some respects, such as swimming, may drive it to zero. Pollution will also impact on the non-commercial marine species, and may lead to their extinction, with implications for marine ecosystem function.

An example at the global level of the interconnections between the environmental services arising from interacting environmental processes affected by economic activity is provided by the problem of global climate change, which is discussed below and, at greater length, in Chapter 9.

2.1.2 Substituting for environmental services

One feature of Figure 2.1 remains to be considered. We have so far discussed the solid lines. There are also some dashed lines. These represent possibilities of substitutions for environmental services.

Consider first recycling. This involves interception of the waste stream prior to its reaching the natural environment, and the return of some part of it to production. Recycling substitutes for environmental functions in two ways. First, it reduces the demands made upon the waste sink function. Second, it reduces the demands made upon the resource base function, in so far as recycled materials are substituted for extractions from the environment.

Also shown in Figure 2.1 are four dashed lines from the box for capital running to the three boxes and the heavy black line representing environmental functions. These lines are to represent possibilities for substituting the services of reproducible capital for environmental services. Some economists think of the environment in terms of assets that provide flows of services, and call the collectivity of environmental assets ‘natural capital’. In that terminology, the dashed lines refer to possibilities for substituting reproducible capital services for natural capital services.

In relation to the waste sink function consider again, as an example, the discharge of sewage into a river estuary. Various levels of treatment of the sewage prior to its discharge into the river are possible. According to the level of treatment, the demand made upon the assimilative capacity of the estuary is reduced for a given level of sewage. Capital in the form of a sewage treatment plant substitutes for the natural environmental function of waste sink to an extent dependent on the level of treatment that the plant provides.

An example from the field of energy conservation illustrates the substitution of capital for resource

base functions. For a given level of human comfort, the energy use of a house can be reduced by the installation of insulation and control systems. These add to that part of the total stock of capital equipment which is the house and all of its fittings, and thus to the total capital stock. Note, however, that the insulation and control systems are themselves material structures, the production of which involves extractions, including energy, from the environment. Similar fuel-saving substitution possibilities exist in productive activities.

Consider next some examples in the context of amenity services. An individual who likes swimming can do this in a river or lake, or from an ocean beach, or in a manufactured swimming pool. The experiences involved are not identical, but they are close substitutes in some dimensions. Similarly, it is not now necessary to actually go into a natural environment to derive pleasure from seeing it. The capital equipment in the entertainment industry means that it is possible to see wild flora and fauna without leaving an urban environment. Apparently it is envisaged that computer technology will, via virtual reality devices, make it possible to experience many of the sensations involved in being in a natural environment without actually being in it.

It appears that it is in the context of the life-support function that many scientists regard the substitution possibilities as most limited. However, from a purely technical point of view, it is not clear that this is the case. Artificial environments capable of supporting human life have already been created, and in the form of space vehicles and associated equipment have already enabled humans to live outside the biosphere, albeit in small numbers and for limited periods. It would apparently be possible, if expensive, to create conditions capable of sustaining human life on the moon, given some suitable energy source. However, the quantity of human life that could be sustained in the absence of natural life-support functions would appear to be quite small. It is not that those functions are absolutely irreplaceable, but that they are irreplaceable on the scale that they operate. A second point concerns the quality of life. One might reasonably take the view that while human life on an otherwise biologically dead earth is feasible, it would not be in the least desirable.

The possibilities for substituting for the services of natural capital have been discussed in terms of capital equipment. Capital is accumulated when output from current production is not used for current consumption. Current production is not solely of material structures, and reproducible capital does not only comprise equipment – machines, buildings, roads and so on. 'Human capital' is increased when current production is used to add to the stock of knowledge, and is what forms the basis for technical change. However, while the accumulation of human capital is clearly of great importance in regard to environmental problems, in order for technical change to impact on economic activity it generally requires embodiment in new equipment. Knowledge that could reduce the demands made upon environmental functions does not actually do so until it is incorporated into equipment that substitutes for environmental functions.

Capital for environmental service substitution is not the only form of substitution that is relevant to economy–environment interconnections. In Figure 2.1 flows between the economy and the environment are shown as single lines. Of course, each single line represents what is in fact a whole range of different flows. With respect to each of the aggregate flows shown in Figure 2.1, substitutions as between components of the flow are possible and affect the demands made upon environmental services. The implications of any given substitution may extend beyond the environmental function directly affected. For example, a switch from fossil fuel use to hydroelectric power reduces fossil fuel depletion and waste generation in fossil fuel combustion, and also impacts on the amenity service flow in so far as a natural recreation area is flooded.

2.1.3 Some environmental science

We now briefly review some elements of the environmental sciences which are important to an understanding of the implications of economy–environment interdependence. The review is necessarily very selective; references to useful supplementary reading are provided at the end of the chapter.

2.1.3.1 Thermodynamics

Thermodynamics is the science of energy. Energy is the potential to do work or supply heat. It is a characteristic of things, rather than a thing itself. Work is

involved when matter is changed in structure, in physical or chemical nature, or in location. In thermodynamics it is necessary to be clear about the nature of the system under consideration. An 'open' system is one which exchanges energy and matter with its environment. An individual organism – a human being for example – is an open system. A 'closed' system exchanges energy, but not matter, with its environment. Planet earth and its atmosphere are a closed system. An 'isolated' system exchanges neither energy nor matter with its environment. Apart from the entire universe, an isolated system is an ideal, an abstraction.

The first law of thermodynamics says that energy can neither be created nor destroyed – it can only be converted from one form to another. Many of those who are concerned about the environment want to encourage people to go in for 'energy conservation'. But, the first law says that there is always 100% energy conservation whatever people do. There is no real contradiction here, just an imprecise use of language on the part of those seeking to promote 'energy conservation'. What they actually want to encourage is people doing the things that they do now but in ways that require less heat and/or less work, and therefore less energy conversion.

The second law of thermodynamics is also known as 'the entropy law'. It says that heat flows spontaneously from a hotter to a colder body, and that heat cannot be transformed into work with 100% efficiency. It follows that all conversions of energy from one form to another are less than 100% efficient. This appears to contradict the first law, but does not. The point is that not all of the energy of some store, such as a fossil fuel, is available for conversion. Energy stores vary in the proportion of their energy that is available for conversion. 'Entropy' is a measure of unavailable energy. All energy conversions increase the entropy of an isolated system. All energy conversions are irreversible, since the fact that the conversion is less than 100% efficient means that the work required to restore the original state is not available in the new state. Fossil fuel combustion is irreversible, and of itself implies an increase in the entropy of the system which is the environment in which economic activity takes place. However, that environment is a closed, not an isolated, system, and is continually receiving energy inputs from its environment, in the form of solar radiation. This is what makes life possible.

Thermodynamics is difficult for non-specialists to understand. Even within physics it has a history involving controversy, and disagreements persist, as will be noted below. There exist some popular myths about thermodynamics and its implications. It is, for example, often said that entropy always increases. This is true only for an isolated system. Classical thermodynamics involved the study of equilibrium systems, but the systems directly relevant to economic activity are open and closed systems which are far from equilibrium. Such systems receive energy from their environment. As noted above, a living organism is an open system, which is far from equilibrium. Some energy input is necessary for it to maintain its structure and not become disordered – in other words, dead.

The relevance of thermodynamics to the origins of the problem of sustainability is clear. The economist who did most to try to make his colleagues aware of the laws of thermodynamics and their implications, Nicholas Georgescu-Roegen (who started academic life as a physicist), described the second law as the 'taproot of economic scarcity' (Georgescu-Roegen, 1979). His point was, to put it graphically, that if energy conversion processes were 100% efficient, one lump of coal would last for ever.

Material transformations involve work, and thus require energy. Given a fixed rate of receipt of solar energy, there is an upper limit to the amount of work that can be done on the basis of it. For most of human history, human numbers and material consumption levels were subject to this constraint. The exploitation of fossil fuels removes this constraint. The fossil fuels are accumulated past solar energy receipts, initially transformed into living tissue, and stored by geological processes. Given this origin, there is necessarily a finite amount of the fossil fuels in existence. It follows that in the absence of an abundant substitute energy source with similar qualities to the fossil fuels, such as nuclear fusion, there would eventually be a reversion to the energetic situation of the pre-industrial phase of human history, which involved total reliance on solar radiation and other flow sources of energy. Of course, the technology deployed in such a situation would be different

from that available in the pre-industrial phase. It is now possible, for example, to use solar energy to generate electricity.

2.1.3.1.1 Recycling

The laws of thermodynamics are generally taken to mean that, given enough available energy, all transformations of matter are possible, at least in principle. On the basis of that understanding it has generally been further understood that, at least in principle, complete material recycling is possible. On this basis, given the energy, there is no necessity that shortage of minerals constrain economic activity. Past extractions could be recovered by recycling. It is in this sense that the second law of thermodynamics is the ultimate source of scarcity. Given available energy, there need be no scarcity of minerals. This is what drives the interest in nuclear power, and especially nuclear fusion, which might offer the prospect of a clean and effectively infinite energy resource.

Nicholas Georgescu-Roegen, noted above as the economist who introduced the idea of the second law as the ultimate basis for economic scarcity, subsequently attacked the view just sketched as 'the energetic dogma', and insisted that 'matter matters' as well (Georgescu-Roegen, 1979). He argued that even given enough energy, the complete recycling of matter is, in principle, impossible. This has been dubbed 'the fourth law of thermodynamics' and its validity has been denied: e.g. 'complete recycling is physically possible if a sufficient amount of energy is available' (Biancardi *et al*., 1993). The basis for this denial is that the fourth law would be inconsistent with the second. This disagreement over what is a very basic scientific issue is interesting for two reasons. First, if qualified scientists can disagree over so fundamental a point, then it is clear that many issues relevant to sustainability involve uncertainty. Secondly, both sides to this dispute would agree that, as a practical matter, complete recycling is impossible however much energy is available. Thus, the statement above rebutting the fourth law is immediately followed by: 'The problem is that such expenditure of energy would involve a tremendous increase in the entropy of the environment, which would not be sustainable for the biosphere' (Biancardi *et al*., 1993). Neither party to the dispute is suggesting that policy should be determined on the basis of an understanding that matter can actually be completely recycled.

2.1.3.2 The materials balance principle

'The materials balance principle' is the term that economists tend to use to refer to the law of conservation of mass, which states that matter can neither be created nor destroyed. An early exposition of the principle as it applies to economic activity is found in Kneese *et al*. (1970). As far as economics goes, the most fundamental implication of the materials balance principle is that economic activity essentially involves transforming matter extracted from the environment. Economic activity cannot, in a material sense, create anything. It does, of course, involve transforming material extracted from the environment so that it is more valuable to humans. But, another implication is that all of the material extracted from the environment must, eventually, be returned to it, albeit in a transformed state. The 'eventually' is necessary because some of the extracted material stays in the economy for a long time – in buildings, roads, machinery and so on.

Figure 2.2 shows the physical relationships implied by the materials balance principle. It abstracts from the lags in the circular flow of matter due to capital accumulation in the economy. It amplifies the picture of material extractions from and insertions into the environment provided in Figure 2.1. Primary inputs (ores, liquids and gases) are taken from the environment and converted into useful products (basic fuel, food and raw materials) by 'environmental' firms. These outputs become inputs into subsequent production processes (shown as a product flow to non-environmental firms) or to households directly. Households also receive final products from the non-environmental firms sector.

The materials balance principle states an identity between the mass of materials flow from the environment (flow A) and the mass of residual material discharge flows to the environment (flows $B + C + D$). So, in terms of mass, we have $A \equiv B + C + D$. In fact several identities are implied by Figure 2.2. Each of the four sectors shown by rectangular boxes receives an equal mass of inputs to the mass of its outputs. So we have the following four identities:

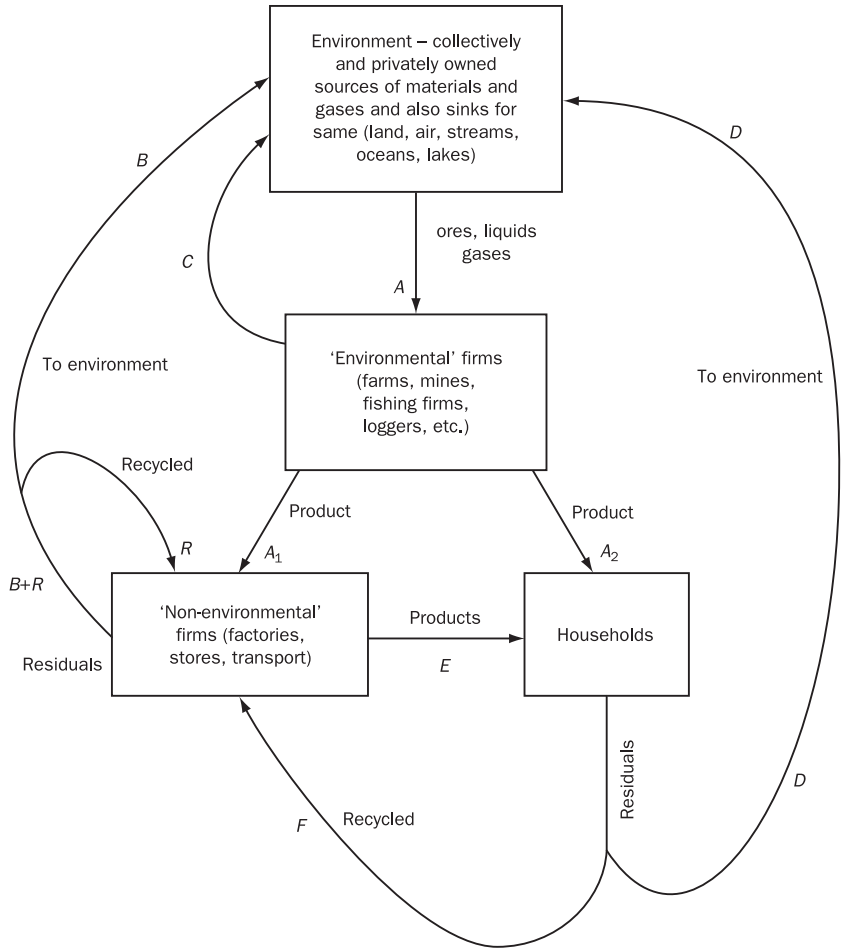


Figure 2.2 A materials balance model of economy–environment interactions
Source: Adapted from Herfindahl & Kneese (1974)

The environment:	$A \equiv B + C + D$ as above
Environmental firms:	$A \equiv A_1 + A_2 + C$
Non-environmental firms:	$B + R + E \equiv R + A_1 + F$
Households:	$A_2 + E \equiv D + F$

Several insights can be derived from this model. First, in a materially closed economy in which no net stock accumulation takes place (that is, physical assets do not change in magnitude) the mass of residuals into the environment ($B + C + D$) must be equal to the mass of fuels, foods and raw materials extracted from the environment and oxygen taken from the atmosphere (flow A). Secondly, the treatment of residuals from economic activity does not reduce their mass, although it alters their form. Nevertheless, while waste treatment does not 'get rid of' residuals, waste management can be useful by transforming residuals to a more benign form (or by changing their location).

Thirdly, the extent of recycling is important. To see how, look again at the identity $B + R + E \equiv R + A_1 + F$. For any fixed magnitude of final output, E, if the amount of recycling of household residuals, F, can be increased, then the quantity of inputs into final production, A_1, can be decreased. This in turn implies that less primary extraction of environmental

resources, A, need take place. So the total amount of material throughput in the system (the magnitude A) can be decreased for any given level of production and consumption if the efficiency of materials utilisation is increased through recycling processes.

2.1.3.2.1 Production function specification

In most of microeconomics, production is taken to involve inputs of capital and labour. For the ith firm, the production function is written as

$$Q_i = f_i(L_i, K_i) \tag{2.1}$$

where Q represents output, L labour input and K capital input. According to the materials balance principle, this cannot be an adequate general representation of what production involves. If Q_i has some material embodiment, then there must be some material input to production – matter cannot be created.

If we let R represent some natural resource extracted from the environment, then the production function could be written as:

$$Q_i = f_i(L_i, K_i, R_i) \tag{2.2}$$

Production functions with these arguments are widely used in the resource economics literature. In contrast, the environmental economics literature tends to stress insertions into the environment – wastes arising in production and consumption wastes – and often uses a production function of the form

$$Q_i = f_i(L_i, K_i, M_i) \tag{2.3}$$

where M_i is the flow of waste arising from the ith firm's activity. Equation 2.3 may appear strange at first sight as it treats waste flows as an input into production. However, this is a reasonable way of proceeding given that reductions in wastes will mean reductions in output for given levels of the other inputs, as other inputs have to be diverted to the task of reducing wastes.

A more general version of equation 2.3 is given by

$$Q_i = f_i\left(L_i, K_i, M_i, A\left[\sum_i M_i\right]\right) \tag{2.4}$$

in which A denotes the ambient concentration level of some pollutant, which depends on the total of waste emissions across all firms. Thus, equation 2.4 recognises that ambient pollution can affect production possibilities.

However, as it stands, equation 2.4 conflicts with the materials balance principle. Now, matter in the form of waste is being created by economic activity alone, which is not possible. A synthesis of resource and environmental economics production functions is desirable, which recognises that material inputs (in the form of environmental resources) enter the production function and material outputs (in the form of waste as well as output) emanate from production. This yields a production function such as

$$Q_i = f_i\left(L_i, K_i, R_i, M_i[R_i], A\left[\sum_i M_i\right]\right) \tag{2.5}$$

Where some modelling procedure requires the use of a production function, the use of a form such as equation 2.5 has the attractive property of recognising that, in general, production must have a material base, and that waste emissions necessarily arise from that base. It is consistent, that is, with one of the fundamental laws of nature. This production function also includes possible feedback effects of wastes on production, arising through the ambient levels of pollutants. It is, however, relatively uncommon for such a fully specified production function to be used in either theoretical or empirical work in economics. In particular cases, this could be justified by argument that for the purpose at hand – examining the implications of resource depletion, say – nothing essential is lost by an incomplete specification, and the analysis is simplified and clarified. We shall implicitly use this argument ourselves at various points in the remainder of the book, and work with specialised versions of equation 2.5. However, it is important to keep in mind that it is equation 2.5 itself that is the correct specification of a production process that has a material output.

2.1.3.3 Ecology

Ecology is the study of the distribution and abundance of plants and animals. A fundamental concept in ecology is the ecosystem, which is an interacting set of plant and animal populations, together with their abiotic, i.e. non-living, environment. An

ecosystem can be defined at various scales from the small and local – a pond or field – through to the large and global – the biosphere as a whole.

2.1.3.3.1 Stability and resilience

Two concepts of fundamental importance in ecology are stability and resilience. The ecologist Holling (1973, 1986) distinguishes between stability as a property attaching to the populations comprising an ecosystem, and resilience as a property of the ecosystem. Stability is the propensity of a population to return to some kind of equilibrium following a disturbance. Resilience is the propensity of an ecosystem to retain its functional and organisational structure following a disturbance. The fact that an ecosystem is resilient does not necessarily imply that all of its component populations are stable. It is possible for a disturbance to result in a population disappearing from an ecosystem, while the ecosystem as a whole continues to function in broadly the same way, so exhibiting resilience.

Common and Perrings (1992) put these matters in a slightly different way. Stability is a property that relates to the levels of the variables in the system. Cod populations in North Atlantic waters would be stable, for example, if their numbers returned to prior levels after a brief period of heavy fishing was brought to an end. Resilience relates to the sizes of the parameters of the relationships determining ecosystem structure and function in terms, say, of energy flows through the system. An ecosystem is resilient if those parameters tend to remain unchanged following shocks to the system, which will mean that it maintains its organisation in the face of shocks to it, without undergoing catastrophic, discontinuous, change.

Some economic activities appear to reduce resilience, so that the level of disturbance to which the ecosystem can be subjected without parametric change taking place is reduced. Expressed another way, the threshold levels of some system variable, beyond which major changes in a wider system take place, can be reduced as a consequence of economic behaviour. Safety margins become tightened, and the integrity and stability of the ecosystem is put into greater jeopardy. This aligns with the understanding, noted above, of pollution as that which occurs when a waste flow exceeds the assimilative capacity of the receiving system, and that which if it occurs itself reduces the system's assimilative capacity.

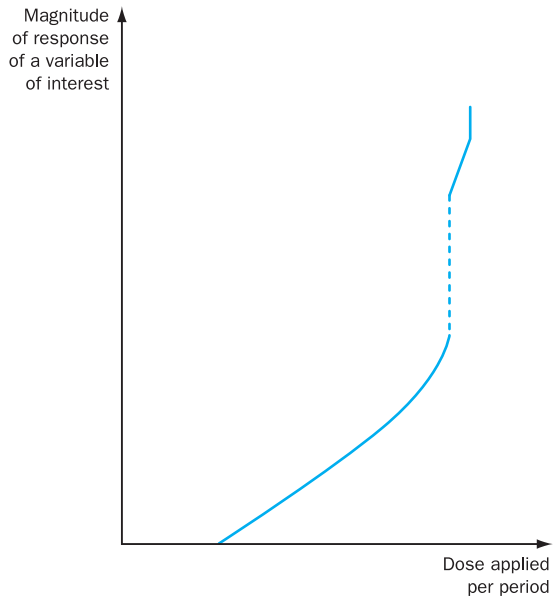


Figure 2.3 Non-linearities and discontinuities in dose–response relationships

When such changes takes place, dose–response relationships may exhibit very significant non-linearities and discontinuities. Another way of putting this is to say that dose–response relationships may involve thresholds. Pollution of a water system, for example, may have relatively small and proportional effects at low pollution levels, but at higher pollutant levels, responses may increase sharply and possibly jump discontinuously to much greater magnitudes. Such a dose–response relationship is illustrated in Figure 2.3.

2.1.3.3.2 The ecological impact of humanity

From an ecological perspective, humanity is one animal species among many. Animals feed on plants, and, in some cases, other animals. Box 2.1 reports estimates of humanity's global impact in terms of that species' appropriation of the plant food available to all animals.

Box 2.1 Human appropriation of the products of photosynthesis

The basis for life on earth is the capture by plants of radiant solar energy, and its conversion to organic material by the process of photosynthesis. The rate at which plants produce plant tissue is primary productivity, measured in terms of energy per unit area per unit time – calories per square metre per year, say. Gross primary productivity is the total amount of solar energy that is fixed by photosynthesis, whereas net primary productivity is that less the amount of energy lost to the environment as respiration, and so the amount that is actually stored in the plant tissue. Net primary productivity is the measure of the energy that is potentially available to the animals that eat the plants.

Table 2.1 shows estimates of the proportion of net primary productivity that is appropriated by humanity. About 70% of the earth's surface is covered by water. The aquatic zone produces about 40% of total global net primary productivity. The terrestrial zone, although accounting for only 30% of the surface area, accounts for about 60% of total primary productivity.

For each zone, and for both zones together, Table 2.1 shows estimates of human appropriation on three different bases:

- Low – for this estimate what is counted is what humans and their domesticated animals directly use as food, fuel and fibre.
- Intermediate – this counts the current net primary productivity of land modified by humans. Thus, for example, whereas the low estimate relates to food eaten, the intermediate estimate is of the net primary productivity of the agricultural land on which the food is produced.
- High – this also counts potential net primary productivity that is lost as a result of human activity. Thus, with regard to agriculture, this estimate includes what is lost as a result, for example, of transforming forested land into grassland pasture for domesticated animals. It also includes losses due to desertification and urbanisation.

Table 2.1 Human appropriation of net primary productivity

	Percentages		
	Low	Intermediate	High
Terrestrial	4	31	39
Aquatic	2	2	2
Total	3	19	25

Source: Vitousek *et al.* (1986)

For the aquatic zone, it makes no difference which basis for estimation is used. This reflects the fact that human exploitation of the oceans is much less than it is of land-based ecosystems, and that the former is still essentially in the nature of hunter–gatherer activity rather than agricultural activity. It also reflects that what are reported are rounded numbers, to reflect the fact that we are looking at – for both zones – approximations rather than precise estimates.

For the terrestrial zone, the basis on which the human appropriation of net primary productivity is measured makes a lot of difference. If we look at what humans and their domesticates actually consume – the low basis – it is 4%. If we look at the net primary productivity of land managed in human interests – the intermediate basis – it is 31%. Commenting on the high terrestrial figure, the scientists responsible for these estimates remark:

> An equivalent concentration of resources into one species and its satellites has probably not occurred since land plants first diversified.
> (Vitousek *et al.*, 1986, p. 372)

Rojstaczer *et al.* (2001) report the results of a similar study using a wider range of more recent data, confining their attention to terrestrial net primary production and looking only at the intermediate basis for estimation. As well as reporting the mean estimate for human appropriation, Rojstaczer *et al.* used Monte Carlo methods to assess the range of uncertainty implied by the available data. Their mean estimate of the proportion of terrestrial net primary production appropriated by humans is 32%, which is almost exactly the same as that of Vitousek *et al.*, 31% in Table 2.1 here, for intermediate terrestrial appropriation. The 95% confidence limits reported by Rojstaczer *et al.* are 32% ± 22%, i.e. a lower bound of 10% and an upper bound of 54%. They comment:

> Although there is a large degree of uncertainty, it is clear that human impact on TNPP [terrestrial net primary production] is significant. The lower bound on our estimate . . . indicates that humans have had more impact on biological resources than any single species of megafauna known over the history of the earth.

2.1.3.3.3 Ecological footprints

The quotation which introduces this chapter refers to 'humanity's ecological footprint'. This is another way of expressing the ecological impact of the human species. An ideal definition (Wackernagel and Rees, 1997) of a particular human economy's ecological footprint is:

> the aggregate area of land and water in various ecological categories that is claimed by participants in the economy to produce all the resources they consume, and to absorb all the wastes they generate on a continuing basis, using prevailing technology.

We describe this as an 'ideal' definition because to date estimates of the size of ecological footprints have been based on just subsets of consumed resources and generated wastes, and are in that sense conservative estimates. It should also be noted that the footprint size will vary with technology as well as with levels and patterns of production and consumption. Wackernagel *et al*. (2002) report estimates of the size of the footprint for each of the years from 1961 to 1999, for the whole global economy. Considering the demands for land and water on account of

- growing crops
- grazing domesticated animals
- harvesting timber
- fishing
- space for locating human artefacts such as houses, factories, roads, etc.
- sequestering the CO_2 released in fossil-fuel combustion

in relation to the available amounts in the biosphere, they find that for all of humanity the ratio of the former demand to the latter supply increased from approximately 0.7 in 1961 to approximately 1.2 in 1999, and conclude that as presently constituted the global economy is not sustainable in that it would 'require 1.2 earths, or one earth for 1.2 years, to regenerate what humanity used in 1999'. For 2003 the global human ecological footprint was 1.25 (from http://www.footprintnetwork.org/, May 2008). On a per capita basis the global average demand for biologically productive space in 2003 was 2.3 hectares, whereas other studies have estimated per capita footprints of 9.7 hectares for the USA, 5.4 for the UK and 4.7 for Germany. The implication is that if the developing world were to attain the consumption levels of the developed world, using current technology, the total footprint for the world would be the size of several earths.

2.1.3.3.4 Biodiversity

A definition of biodiversity is:

> the number, variety and variability of all living organisms in terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are parts.[2]

It is evident from this definition that biodiversity is intended to capture two dimensions: first, the number of biological organisms and, second, their variability. There are three levels at which biodiversity can be considered:

1. Population: genetic diversity within the populations that constitute a species is important as it affects evolutionary and adaptive potential of the species, and so we might measure biodiversity in terms of the number of populations.
2. Species: we might wish to measure biodiversity in terms of the numbers of distinct species in particular locations, the extent to which a species is endemic (unique to a specific location), or in terms of the diversity (rather than the number) of species.
3. Ecosystems: in many ways, the diversity of ecosystems is the most important measure of biodiversity; unfortunately, there is no universally agreed criterion for either defining or measuring biodiversity at this level.

For the purposes of this classification of levels, a species can be taken to be a set of individual organisms which have the capacity to reproduce, while a population is a set that actually do reproduce. A population is, that is, a reproductively isolated subset of a species.

[2] This definition is taken from the Convention on Biological Diversity adopted at the UNCED conference in Rio de Janeiro in 1992: see 2.5.2 below.

Biodiversity is usually considered in terms of species, and the number of distinct species is often used as the indicator of biodiversity. There are problems with this measure. For example, within one population of any species there will be considerable genetic variation. Suppose a harvesting programme targets individuals within that population with a particular characteristic (such as large size). The target individuals are likely to possess genetic material favouring that characteristic, and so the harvesting programme reduces the diversity of the gene pool in the remaining population. Managed harvesting programmes, therefore, may result in loss of biodiversity even though the number of extant species shows no change.

Biodiversity is important in the provision of environmental services to economic activity in a number of ways. In regard to life-support services, diverse ecological systems facilitate environmental functions, such as carbon cycling, soil fertility maintenance, climate and surface temperature regulation, and watershed flows. The diversity of flora and fauna in ecosystems contributes to the amenity services that we derive from the environment. In relation to inputs to production, those flora and fauna are the source of many useful products, particularly pharmaceuticals, foods and fibres; the genes that they contain also constitute the materials on which future developments in biotechnology will depend. In terms of agriculture, biodiversity is the basis for crop and livestock variability and the development of new varieties.

Ecologists see the greatest long-term importance of biodiversity in terms of ecosystem resilience and evolutionary potential. Diverse gene pools represent a form of insurance against ecological collapse: the greater is the extent of diversity, the greater is the capacity for adaptation to stresses and the maintenance of the ecosystem's organisational and functional structure.

We have very poor information about the current extent of biodiversity. The number of species that currently exist is not known even to within an order of magnitude. Estimates that can be found in the literature range from 3–10 million (May, 1988) to 50–100 million (Wilson, 1992). A current best guess of the actual number of species is 12.5 million (Groombridge, 1992). Even the currently known number of species is subject to some dispute, with a representative figure being 1.7 million species described to date (Groombridge, 1992). About 13 000 new species are described each year. Table 2.2 reports current knowledge about species numbers for a variety of important taxonomic classes.

Table 2.2 Numbers of described species and estimates of actual numbers for selected taxa (thousands)

Taxa	Species described	Estimated number of species: high	Estimated number of species: low	Working figure
Viruses	4	1 000	50	400
Bacteria	4	3 000	50	1000
Fungi	72	2 700	200	1500
Protozoa and algae	80	1 200	210	600
Plants	270	500	300	320
Nematodes (worms)	25	1 000	100	400
Insects	950	100 000	2000	8000
Molluscs	70	200	100	200
Chordates	45[a]	55	50	50

Source: Jeffries (1997, p. 88), based in turn on Groombridge (1992) and Heywood (1995)

[a] Of the 45 000 chordates (vertebrate animals), there are about 4500 mammals, 9700 birds, 4000 amphibians and 6550 reptiles

2.1.3.3.5 The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment, MEA, was called for by the UN Secretary-General in 2000. It was conducted over 2001 to 2005, being coordinated by the United Nations Environment Programme. The MEA was intended to assess the implications for human well-being of ecosystem change, and to establish the scientific basis for actions to enhance the conservation and sustainable use of ecosystems and their contribution to human well-being. It proceeded on the basis of synthesising existing information, rather than seeking to generate new data. It involved some 2000 scientists. The results of this huge undertaking are reported in several volumes, which are available as books and for downloading from the MEA website, the address for which is http://www.millenniumassessment.org/en/index.aspx.

The four main findings of the MEA are reported in the Summary for Decision-Makers section of the overall synthesis volume (Millennium Ecosystem Assessment, 2005a) as follows:

Box 2.2 Biodiversity loss and human impact

For ecologists, the appropriation of the products of photosynthesis described in Box 2.1 is the most fundamental human impact on the natural environment, and is the major driver of the current high rate of biodiversity loss. In a speech at the Natural History Museum on 28 November 2001, the ecologist Lord Robert May, President of the Royal Society and formerly the UK government's chief scientist, stated that:

> There is little doubt that we are standing on the breaking tip of the sixth great wave of extinction in the history of life on earth. It is different from the others in that it is caused not by external events, but by us – by the fact that we consume somewhere between a quarter and a half of all the plants grown last year.
> (Quoted in *The Guardian*, 29 November 2001)

Just how fast is the stock of genetic resources being depleted? Given that the number of species existing is not known, statements about rates of extinction are necessarily imprecise, and there are disagreements about estimates. Table 2.3 shows data for *known* extinctions since 1600. The actual number of extinctions would certainly be equal to or exceed this. The recorded number of extinctions of mammal species since 1900 is 20. It is estimated from the fossil record that the normal, long-run average, rate of extinction for mammals is one every two centuries. In that case, for mammals the known current rate of extinction is 40 times the background rate.

To quote Lord Robert May again:

> If mammals and birds are typical, then the documented extinction rate over the past century has been running 100 to more like 1000 times above the average background rate in the fossil record. And if we look into the coming century it's going to increase. An extinction rate 1000 times above the background rate puts us in the ballpark of the acceleration of extinction rates that characterised the five big mass extinctions in the fossil records, such as the thing that killed the dinosaurs.
> (*The Guardian*, 29 November 2001)

According to Wilson (1992) there could be a loss of half of all extant birds and mammals within 200–500 years. For all biological species, various predictions suggest an overall loss of between 1% and 10% of all species over the next 25 years, and between 2% and 25% of tropical forest species (UNEP, 1995). In the longer term it is thought that 50% of all species will be lost over the next 70 to 700 years (Smith *et al.*, 1995; May, 1988).

Lomborg (2001) takes issue with most of the estimates of current rates of species loss made by biologists. His preferred estimate for the loss of animal species is 0.7% per 50 years, which is smaller than many of those produced by biologists. It is, however, in Lomborg's own words: 'a rate about 1500 times higher than the natural background extinction' (p. 255). There really is no disagreement about the proposition that we are experiencing a wave of mass extinctions, and that it is due to the human impact on the environment.

Table 2.3 Species extinctions since 1600

Kingdom	Extinct species
Vertebrates	**337**
Mammals	87
Birds	131
Reptiles	22
Amphibians	5
Fishes	92
Invertebrates	**389**
Insects	73
Molluscs	303
Crustaceans	9
Others	4
Plants	**90**
Mosses	3
Conifers, Cycads, etc.	1
Flowering plants	86

Source: Table 1.4 Convention on Biological Diversity 2001 (access at http://www.cbd.int/gbo1/chap-01-02.shtml)

Over the past 50 years, humans have changed ecosystems more rapidly and more extensively than in any comparable period of human history, largely to meet rapidly growing demands for food, fresh water, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on earth.

The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing cost in the form of the degradation of many ecosystem services, increased risk of nonlinear changes, and the exacerbation of poverty for some groups of people. These problems, unless addressed, will substantially diminish the benefits that future generations obtain from ecosystems.

The degradation of ecosystem services could grow significantly worse during the first half of this century and is a barrier to achieving the

Millennium Development Goals. (See section 2.5.4 at the end of this chapter for discussion of these goals.)

The challenge of reversing the degradation of ecosystems while meeting increasing demands for their services can be partially met under some scenarios that the MA has considered, but these involve significant changes in policies, institutions and practices that are not currently under way. Many options exist to conserve or enhance specific ecosystem services in ways that reduce negative trade-offs or that provide positive synergies with other ecosystem services.

In regard to biodiversity loss, the MEA estimates that the rate of known extinctions in the past century was 50–500 times greater than the 'normal' extinction rate calculated from the fossil record, which is 0.1–1 extinctions per 1000 species per 1000 years. If species that have possibly gone extinct in the past 100 years are included, the extinction rate for the past century is 'up to 1000 times higher than the background extinction rates' as calculated from the fossil record. For more information on the MEA of the situation in regard to biodiversity loss see the biodiversity synthesis volume (Millennium Ecosystem Assessment, 2005b).

The major cause of the acceleration in the extinction rate is, according to the MEA, the appropriation of the products of photosynthesis by the human species. Figure 3 in the overall synthesis volume (Millennium Ecosystem Assessment, 2005a) reports estimates of the proportions of 13 (out of a total of 14) of the world's terrestrial biomes that our species has converted to use for the human species. A biome is the largest unit of ecological classification, and comprises many inter-connected ecosystems. For 4 biomes – mediterranean forests, woodlands and scrub; temperate forest steppe and woodland; temperate broadleaf and mixed forests; tropical and sub-tropical dry broadleaf forests – the percentage already converted exceeds 50% (and for the first two is around 70%). It is estimated that for three more – flooded grasslands and savannas; tropical and sub-tropical grasslands, savannas and shrublands; tropical and sub-tropical coniferous forests – the proportion converted will exceed 50%, and approach 70%, by 2050. These seven biomes are the most productive, in terms of photosynthetic conversion.

2.2 The drivers of environmental impact

The environmental impact of economic activity can be looked at in terms of extractions from or insertions into the environment. In either case, for any particular instance the immediate determinants of the total level of impact are the size of the human population and the per capita impact. The per capita impact depends on how much each individual consumes, and on the technology of production. This is a very simple but useful way to start thinking about what drives the sizes of the economy's impacts on the environment. It can be formalised as the IPAT identity.

2.2.1 The IPAT identity

The IPAT identity is

$$I \equiv P \times A \times T \tag{2.6}$$

where

I is impact, measured as mass or volume
P is population size
A is per capita affluence, measured in currency units
T is technology, as the amount of the resource used or waste generated per unit production

Let us look at impact in terms of mass, and use GDP for national income. Then T is resource or waste per unit GDP. Then for the resource extraction case, the right-hand side of (2.6) is

$$\text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{Resource use}}{\text{GDP}}$$

where cancelling the two population terms and the two GDP terms leaves Resource use, so that (2.6) is an identity. If mass in measured in tonnes, GDP in \$, and population is n, we have

$$\text{tonnes} \equiv n \times \frac{\$}{n} \times \frac{\text{tonnes}}{\$}$$

where on the right-hand side the ns and the \$s cancel to leave tonnes.

The IPAT identity decomposes total impact into three multiplicative components – population,

Table 2.4 Global carbon dioxide scenarios

	P (billions)	*A* (PPP US$)	*T* (tonnes per $)	*I* (billions of tonnes)
Current	6.5148	9 543	0.0004662	28.9827
$P \times 1.5$	9.7722	9 543	0.0004662	32.3226
$P \times 1.5$ and $A \times 2$	9.7722	19 086	0.0004662	86.9520
$P \times 1.5$ and $A \times 2$ with *I* at current	9.7722	19 086	0.0001554	28.9827

Source: UNDP (2007) Tables 1, 5 and 24

affluence and technology. To illustrate the way in which IPAT can be used, consider global carbon dioxide emissions. The first row of Table 2.4 shows the current situation. The first-row figures for *P*, *A* as 2005 world GDP per capita in 2005 PPP US$, and *I* as 2004 global carbon dioxide emissions are taken from the indicated source: the figure for *T* is calculated by dividing *I* by *P* times *A* to give tonnes of carbon dioxide per $ of GDP.[3] The second row uses the *T* figure from the first to show the implications for *I* of a 50% increase in world population, for constant affluence and technology. The third row also uses the *T* figure from the first to show the implications of that increase in population together with a doubling of per capita GDP. A 50% increase in world population is considered because that is a conservative round number for the likely increase to 2100 (see below), and a doubling of per capita GDP is used as a round-number conservative estimate of what would be necessary to eliminate poverty (see below). As will be discussed in Chapter 9, many climate experts take the view that the current level of carbon dioxide emissions is dangerously high. The fourth row in Table 2.4 solves IPAT for *T* when *I* is set equal to its level in the first row, and *P* and *A* are as in the third row – compared with the first-row figure for *T*, it shows that carbon dioxide emissions per unit GDP would have to be reduced to one-third of their current level in order to keep total emissions at their current level given a 50% population increase and a doubling of affluence.

We now look briefly at the current situation, a little history, and future prospects in regard to each of *P*, *A* and *T*.

2.2.2 Population

At the time that this chapter was being written, April 2008, the most recent year for which data on global population size was available was 2005. In that year the estimated human population was 6.5148 billion. The estimated growth rate for 1975–2005 was 1.6% per year. The staggering increase in human population in the second half of the twentieth century can be gauged by the fact that in 1950 world population was 2.5 billion – it more than doubled over 50 years to 6 billion in 2000. At the beginning of the nineteenth century the world's population is estimated to have been about 0.9 billion.

The projections for the global human population shown in Figure 2.4 are taken from the Executive Summary of a publication of the Population Division of the UN's Department of Economic and Social Affairs (UN Population Division, 2000). They differ according to the assumptions made about fertility. The medium projection assumes that fertility in all major areas of the world stabilises at the replacement level around 2050. The low projection assumes that fertility is half a child lower than for medium, and the high projection half a child higher. As Figure 2.4 shows, the long-run prospects for the size of the human population are very sensitive to what is assumed about future fertility – the vertical axis units are millions. All the projections make the same assumption about longevity.

[3] PPP stands for purchasing power parity. In making international GDP comparisons, and aggregating GDP across countries, using market exchange rates overlooks the fact that average price levels differ across countries, and are generally lower in poor countries. Using market exchange rates exaggerates differences in real income levels. Purchasing power parity exchange rates, relative to the US$, are calculated by the International Comparison Programme in order to overcome this problem, and PPP US$ GDP data convert local-currency GDP at these exchange rates: see UN Statistical Division (1992). The difference between the market exchange-rate GDP figure and the PPP exchange-rate figure can be large – for China in 1999, for example, the latter was more than four times the former. Whereas on the former basis the US economy was nine times as big as the Chinese economy, on the latter basis it was twice as big. In terms of carbon dioxide emissions per unit GDP, on the market exchange-rate measure of GDP the Chinese figure for *T* is more than five times that for the US; on the PPP exchange-rate basis of GDP measurement it was just 25% bigger.

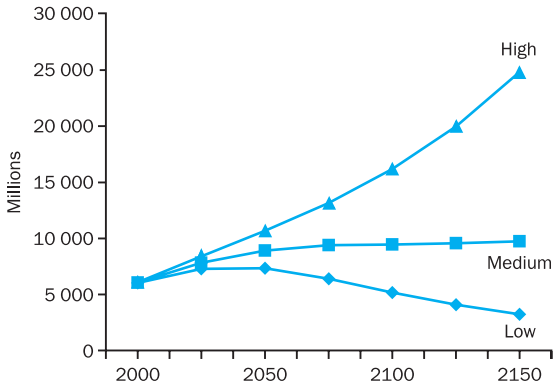


Figure 2.4 World population projections
Source: Data from UN Population Division (2000)

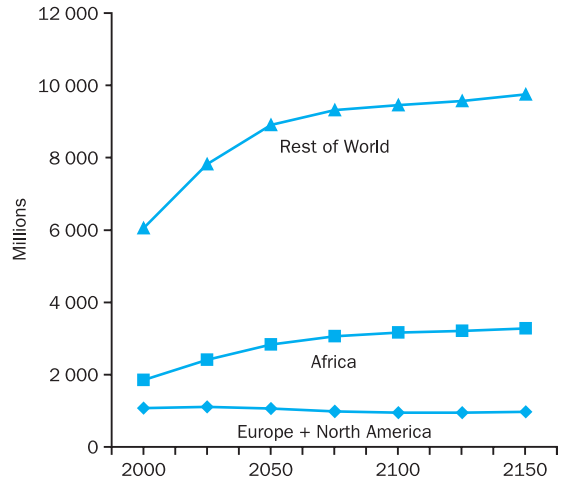


Figure 2.5 Contributions to world population growth to 2150
Source: Data from UN Population Division (2000)

The percentage rate of increase of global population is already well below its historical peak, having decreased in recent years in all regions of the world. Growth rates currently average less than 1% per year in developed countries (0.8% over 1975–2005 for the OECD) and less than 2% in developing countries (1.9% over 1975–2005 for developing as defined by the UNDP).[4] In many countries (including most OECD countries and China), fertility rates are below the replacement rates that are required for a population size to be stationary in the long run. For these countries, population is destined to fall at some point in the future even though the momentum of population dynamics implies that population will continue to rise for some time to come. For example, although the Chinese birth-rate fell below the replacement rate in 1992, population is projected to rise from 1.3 billion in 2005 to 1.5 billion by 2050, on the medium UN scenario discussed above.

Differences in fertility, and longevity, rates as between different parts of the world mean that the distribution of the world population as between different regions will change. Figure 2.5, based on data from the same source as used for Figure 2.4, illustrates. It relates to the medium scenario. The lower line shows the combined population of Europe and North America more or less constant in absolute terms, and so falling as a proportion of the total (from about 18% now to about 10% in 2150). The gap between the lower and middle lines shows what is happening to the population of Africa – it grows absolutely and as a proportion of the world total (from about 13% now to about 24% in 2150).

2.2.3 Affluence

As shown in Table 2.4, the 1999 world average for GDP per capita, in round numbers of 2005 PPP US$, was 9500. To get some sense of what this means, note the following figures (also from UNDP, 2007) for 2005 GDP per capita in 2005 PPP US$ for a few selected individual nations:

USA	41 890
UK	33 238
Germany	29 461
Czech Republic	20 538
Portugal	20 410
Hungary	17 887
China	6 757
India	3 452
Kenya	1 240
Sierra Leone	806

The world average is more than twice that for India, and about 20% of that for the USA.

[4] The figures here are taken from UNDP (2007), Table 5.

Over the period 1975 to 2005, world average GDP per capita grew at 1.4% per annum. At that rate of growth, over 50 years the level of world average GDP would just about double, taking it to about the current level for the Czech Republic. A longer-term perspective is provided in Maddison (1995), where per capita GDP, in 1990 PPP $s, is estimated for 57 countries from 1820 through to 1992. For this sample of countries, which currently account for over 90% of world population, mean estimated per capita GDP grew from about $1000 in 1820 to about $8500 in 1992. Notwithstanding the necessary imprecision in estimates of this kind, it is clear that over the past two centuries, average global affluence has increased hugely. It is also clear that it is currently distributed very unevenly – a matter to which we return below.

2.2.4 Technology

Given the range of things that we extract from and insert into the environment, even a summary documentation of values for T as mass extracted, or inserted, per $ of economic activity would be very long, and well beyond the scope of this book. One way of giving some summary sense of the role of technology in environmental impact is to look at energy use. There are three reasons for this. First, energy is the potential to do work and energy use increases with work done. Moving and transforming matter requires work, and the amount of energy used directly reflects the amount of movement and transformation. It is the levels of extractions and insertions by the economy that determine its environmental impact, and those levels, which are linked by the law of conservation of mass, are measured by the level of energy use. While it is true that some extractions and insertions are more damaging than others, the level of its energy use is a good first approximation to the level of an economy's environmental impact.

The second and third reasons both follow from the fact that in the modern industrial economies that now dominate the global economy, about 90% of energy use is based on the combustion of the fossil fuels – coal, oil, gas. These are non-renewable resources where recycling is impossible. Hence the second reason for looking at energy – the more we use now, the less fossil fuel resources are available to future generations. The third reason is that fossil fuel combustion is directly a major source of insertions into the environment, and especially the atmosphere. Particularly, about 80% of carbon dioxide emissions originate in fossil fuel combustion, and carbon dioxide is the most important of the greenhouse gases involved in the enhanced greenhouse effect.

The energy that an animal acquires in its food, and which is converted into work, growth and heat, is called somatic energy. When the human animal learned how to control fire, about 500 000 years ago, it began the exploitation of extrasomatic energy. It began, that is, to be able to exert more power than was available from its own muscles. The human energy equivalent, HEE, is a unit of measure which is the amount of somatic energy required by a human individual. This amount varies across individuals and with circumstances. A convenient amount to use for the HEE is 10 megajoules per day, which is a round-number version of what is required by an adult leading a moderately active life in favourable climatic conditions.

Human history can be divided into three main phases, the distinguishing characteristics of which are technological. The first two phases are distinguished according to the technology for food production. The first is the hunter–gatherer phase, which lasted from the beginning of human history until about 12 000 years ago – it accounts for most of human history. During this phase food production involved gathering wild plants and hunting wild animals. It is estimated that the use of fire by an individual in hunter–gatherer societies was, on average and approximately, equivalent to the use of 1 HEE – per capita the use of fire was about equivalent to the amount of energy flowing through a human body. The total per capita use of energy was, that is, about 2 HEE.[5]

The agricultural phase of human history lasted about 12 000 years, and ended about 200 years ago.

[5] The estimates for HEE for hunter–gatherers and agriculturalists here are taken from Boyden (1987), as is the global average figure for 1900 given below. The HEE estimates for 1997 are based on data from WRI (2000).

Agriculture involves producing food by domesticating some plant and animal species, and managing the environment so as to favour those species as against wild species. The technology of energy use was evolving throughout the agricultural phase of history. By its end the average human being was deploying some 3–4 HEE, so that in addition to her own muscle power she was using extrasomatic energy at the rate of 2–3 HEE. In addition to fire, almost entirely based on biomass (mainly wood) combustion, the sources of extrasomatic energy were animal muscles, the wind, and water. Animals – horses, oxen, donkeys – were used mainly for motive power in transport and agriculture. The wind was used to propel boats, to drive pumps for lifting water, and to drive mills for grinding corn. Water mills were also used for grinding corn, as well as powering early machinery for producing textiles and the like.

Comparing the situation at the end of the agricultural phase of human history with that of the hunter–gatherer phase, the per capita use of energy had approximately doubled, and the population size had increased by a factor of about 200, so that total energy use by humans had increased by a factor of about 400.

The industrial phase of human history began about 200 years ago, around 1800. Its distinguishing characteristic has been the systematic and pervasive use of the fossil fuels. In the first instance this was mainly about the use of coal in manufacturing, and then in transport. In the twentieth century oil use became much more important, as did the use of it, as well as coal, to produce electricity. In the twentieth century, the use of fossil fuels and electricity became standard, in the more advanced economies, in the domestic household sector, and in agricultural production. In a modern economy, nothing is produced that does not involve the use of extrasomatic energy, and most of what is used is based on fossil fuel combustion.

By 1900 the average human used about 14 extrasomatic HEE. By the end of the twentieth century the average human used about 19 extrasomatic HEE – the equivalent of 19 human slaves. This global average for 1997 comes from a wide range for individual nations. In 1997, per capita extrasomatic energy use in the USA was 93 HEE, while in Bangladesh it was 4 (mainly from biomass). Comparing the situation at the end of the twentieth century with that at the end of the eighteenth, the human population had increased in size by a factor of approximately 6, while extrasomatic energy use per capita had also increased by a factor of approximately 6. In 200 years total global extrasomatic energy use had increased by a factor of about 35. As noted above, this implies that the work done in moving and transforming matter – the scale of economic activity and its impact on the environment – had increased by a factor of 35.

2.2.5 Behavioural relationships

IPAT is an accounting identity. Given the way that *P*, *A* and *T* are defined and measured, it must always be the case that *I* is equal to *PAT*. As we saw, IPAT can be useful for figuring the implications of certain assumptions, for producing scenarios. In Table 2.4 we used it, for example, to calculate *I* on the assumption that *P* increased by 50%, *A* increased by 100%, and *T* remained the same. *P*, *A* and *T* are the proximate drivers of *I*. But we could ask, what drives *P*, *A* and *T*? Apart from being an interesting question, this is important if we want to consider policies to drive some *I*, such as carbon dioxide emissions for example, in a particular direction. We could, that is, look to build a model which incorporates the behavioural relationships that we think determine what happens to *P*, *A* and *T*, and other variables, over time. In such a model we would very likely have relationships between *P*, *A* and *T*, as well as between them and other variables.

There are many behavioural relationships that affect, and are affected by, movements in *P*, *A* and *T*. Economists are particularly interested, for example, in supply and demand functions for inputs to production. These determine the relative prices of those inputs, and hence affect *T* – a high price for fossil fuels will reduce their use, and hence reduce carbon dioxide emissions. Much of the rest of the book will be concerned with the role of the price mechanism in relation to the determination of the level of extractions from and insertions into the natural environment. Here we will look at two examples of behavioural relationships where affluence is the driver.

2.2.5.1 Affluence and population growth: the demographic transition

A statistical relationship that is often remarked upon is the negative correlation between income level and population growth rate. Several attempts have been made to explain this observed relationship, the most well known of which is the theory of demographic transition (Todaro, 1989). The theory postulates four stages through which population dynamics progress, shown in Figure 2.6. In the first stage, populations are characterised by high birth-rates and high death-rates. In some cases, the death-rates reflect intentions to keep populations stable, and so include infanticide, infant neglect and senilicide (see Harris and Ross, 1987). In the second stage, rising real incomes result in improved nutrition and developments in public health which lead to declines in death-rates and rapidly rising population levels. In the third stage of the demographic transition, economic forces lead to reduced fertility rates. These forces include increasing costs of childbearing and family care, reduced benefits of large family size, higher opportunity costs of employment in the home, and changes in the economic roles and status of women. In the final stage, economies with relatively high income per person will be characterised by low, and approximately equal, birth- and death-rates, and so stable population sizes.

The theory of demographic transition succeeds in describing the observed population dynamics of many developed countries quite well. If the theory were of general applicability, it would lead to the conclusions that rising population is a transient episode, and that programmes which increase rates of income growth in developing countries would lower the time profile of world population levels. But it remains unclear whether the theory does have general applicability. For many developing countries the second stage was reached not as a consequence of rising real income but rather as a consequence of knowledge and technological transfer. In particular, public health measures and disease control techniques were introduced from overseas at a very rapid rate. The adoption of such measures was compressed into a far shorter period of time than had occurred in the early industrialising countries, and mortality rates fell at unprecedented speed. During the nineteenth century, the higher-income countries typically experienced falls in birth-rates relatively soon after falls in mortality rates. However, while birth-rates are falling in most developing countries, these falls are lagging behind drops in the mortality levels, challenging the relevance of the theory of demographic transition. Dasgupta (1992) argues that the accompanying population explosions created the potential for a vicious cycle of poverty, in which the resources required for economic development (and so for a movement to the third stage of the demographic transition) were crowded out by rapid population expansion.

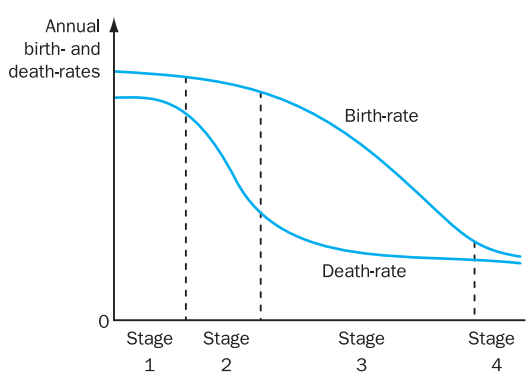
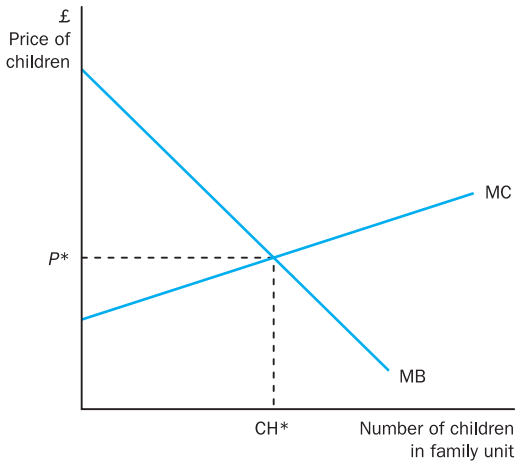


Figure 2.6 The theory of demographic transition

Two important determinants of the rate at which a population changes over time are the number of children born to each female of reproductive age, and the life expectancy of each child. There have been dramatic increases in life expectancy throughout the world, attributed to improved medical and public health services. The number of children born into each household is primarily the outcome of a choice made by (potential) parents. Family size is the choice-variable; contraceptive and other family planning practices are the means by which that choice is effected. Microeconomic theory suggests that the marginal costs and the marginal benefits of children within the family (see Figure 2.7) determine family size. The marginal costs of children depend on the costs of childbearing, child rearing and education, including the opportunity costs of parental time in these activities. Marginal benefits of children to the family include the psychic benefits of children, the contribution of children to family income, and



MC = The marginal cost to the family of a child
MB = The marginal benefit to the family of a child
= (the demand curve for children)

Figure 2.7 The microeconomics of fertility

the extent to which security in old age is enhanced by larger family size.

An important advantage of this line of analysis is that it offers the prospect of deriving guidelines for population policy: attempts to alter desired family size should operate by shifting the marginal cost of bearing and raising children, or the marginal benefits derived from children within the family. What measures might governments take, or what intermediate goals might they pursue, to reduce the desired family size? Several suggest themselves:

- Increased levels of education, particularly education of women. This could affect fertility through three related routes. First, education enhances the effectiveness of family planning programmes: families become more proficient at having the number of children that they choose. Secondly, greater participation in education increases the status of women: it is now widely agreed that where females have low-status roles in the culture of a society, fertility rates are likely to be high. Thirdly, greater education decreases labour-market sex discrimination, allows females to earn market incomes, and raises real wage rates in the labour market. These changes increase the opportunity cost of children, and may well also reduce the marginal benefits of children (for example, by salaried workers being able to provide for old age through pension schemes).
- Financial incentives can be used to influence desired family size. Financial penalties may be imposed upon families with large numbers of children. Alternatively, where the existing fiscal and welfare state provisions create financial compensation for families with children, those compensations could be reduced or restructured. There are many avenues through which such incentives can operate, including systems of tax allowances and child benefits, subsidised food, and the costs of access to health and educational facilities. There may well be serious conflicts with equity if financial incentives to small family size are pushed very far, but the experiences of China suggest that if government is determined, and can obtain sufficient political support, financial arrangements that increase the marginal cost of children or reduce the marginal benefits of children can be very powerful instruments.
- Provision of care for and financial support of the elderly, financed by taxation on younger groups in the population. If the perceived marginal benefits of children to parents in old age were to be reduced (by being substituted for in this case), the desired number of children per family would fall. As the tax instrument merely redistributes income, its effect on welfare can be neutral. But by reducing the private marginal benefits of children it can succeed (at little or no social cost) in reducing desired family size.
- The most powerful means of reducing desired family size is almost certainly economic development, including the replacement of subsistence agriculture by modern farming practices, giving farm workers the chance of earning labour market incomes. There may, of course, be significant cultural losses involved in such transition processes, and these should be weighed against any benefits that agricultural and economic development brings. Nevertheless, to the extent that subsistence and non-market farming dominates an economy's agricultural sector, there will be powerful incentives for large family size. Additional children are valuable assets to the family, ensuring that the perceived

marginal benefits of children are relatively high. Furthermore, market incomes are not being lost, so the marginal cost of child-rearing labour time is low. Important steps in the direction of creating markets for labour (and reducing desired family size) can be taken by defining property rights more clearly, giving communities greater control over the use of local resources, and creating financial incentives to manage and market resources in a sustainable way.

2.2.5.2 Affluence and technology: the EKC

The *World Development Report 1992* (World Bank, 1992) was subtitled 'Development and the environment'. It noted that 'The view that greater economic activity inevitably hurts the environment is based on static assumptions about technology, tastes and environmental investments'. If we consider, for example, the per capita emissions, e, of some pollutant into the environment, and per capita income, y, then the view that is being referred to can be represented as

$$e = \alpha y \tag{2.7}$$

so that e increases linearly with y, as shown in Figure 2.8(a). Suppose, alternatively, that the coefficient α is itself a linear function of y:

$$\alpha = \beta_0 - \beta_1 y \tag{2.8}$$

Then, substituting equation 2.8 into equation 2.7 gives the relationship between e and y as:

$$e = \beta_0 y - \beta_1 y^2 \tag{2.9}$$

For β_1 sufficiently small in relation to β_0, the e/y relationship takes the form of an inverted U, as shown in Figure 2.8(b). With this form of relationship, economic growth means higher emissions per capita until per capita income reaches the turning point, and thereafter actually reduces emissions per capita.

It has been hypothesised that a relationship like that shown in Figure 2.8(b) holds for many forms of environmental degradation. Such a relationship is called an 'environmental Kuznets curve' (EKC) after Kuznets (1955), who hypothesised an inverted U for the relationship between a measure of inequality in the distribution of income and the level of income. If the EKC hypothesis held generally, it would imply that instead of being a threat to the environment as is often argued (see the discussion of *The Limits to Growth* below), economic growth is the means to environmental improvement. That is, as countries develop economically, moving from lower to higher levels of per capita income, overall levels of environmental degradation will eventually fall.

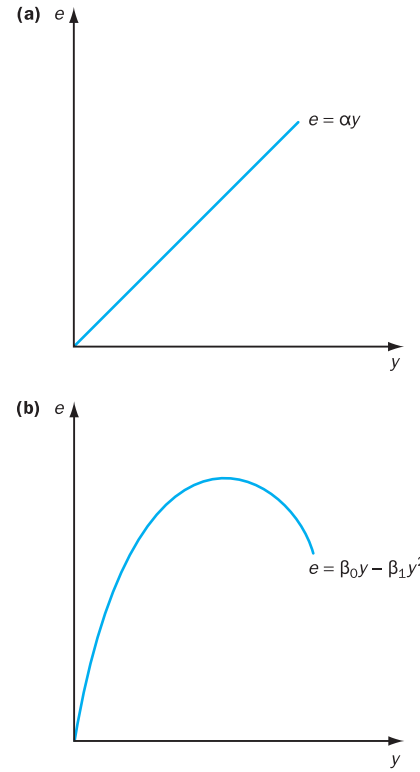


Figure 2.8 Environmental impact and income
Source: Adapted from Common (1996)

The argument for an EKC hypothesis has been succinctly put as follows:

> At low levels of development both the quantity and intensity of environmental degradation is limited to the impacts of subsistence economic activity on the resource base and to limited quantities of biodegradable wastes. As economic development accelerates with the intensification of agriculture and other resource extraction and the takeoff of industrialisation, the rates of resource depletion begin to exceed the rates of resource regeneration, and waste generation increases in quantity and toxicity. At higher

> levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result in levelling off and gradual decline of environmental degradation.
>
> *Panayotou (1993)*

Clearly, the empirical status of the EKC hypothesis is a matter of great importance. If economic growth is actually and generally good for the environment, then it would seem that there is no need to curtail growth in the world economy in order to protect the global environment. In recent years there have been a number of studies using econometric techniques to test the EKC hypothesis against the data. Some of the results arising are discussed below. According to one economist, the results support the conclusion that

> there is clear evidence that, although economic growth usually leads to environmental degradation in the early stages of the process, in the end the best – and probably the only – way to attain a decent environment in most countries is to become rich.
>
> *Beckerman (1992)*

Assessing the validity of this conclusion involves two questions. First, are the data generally consistent with the EKC hypothesis? Second, if the EKC hypothesis holds, does the implication that growth is good for the global environment follow? We now consider each of these questions.

2.2.5.2.1 Evidence on the EKC hypothesis

In one of the earliest empirical studies, Shafik and Bandyopadhyay (1992) estimated the coefficients of relationships between environmental degradation and per capita income for ten different environmental indicators as part of a background study for the *World Development Report 1992* (World Bank, 1992). The indicators are lack of clean water, lack of urban sanitation, ambient levels of suspended particulate matter in urban areas, urban concentrations of sulphur dioxide, change in forest area between 1961 and 1986, the annual rate of deforestation between 1961 and 1986, dissolved oxygen in rivers, faecal coliforms in rivers, municipal waste per capita, and carbon dioxide emissions per capita. Some of their results, in terms of the relationship fitted to the raw data, are shown in Figure 2.9. Lack of clean water

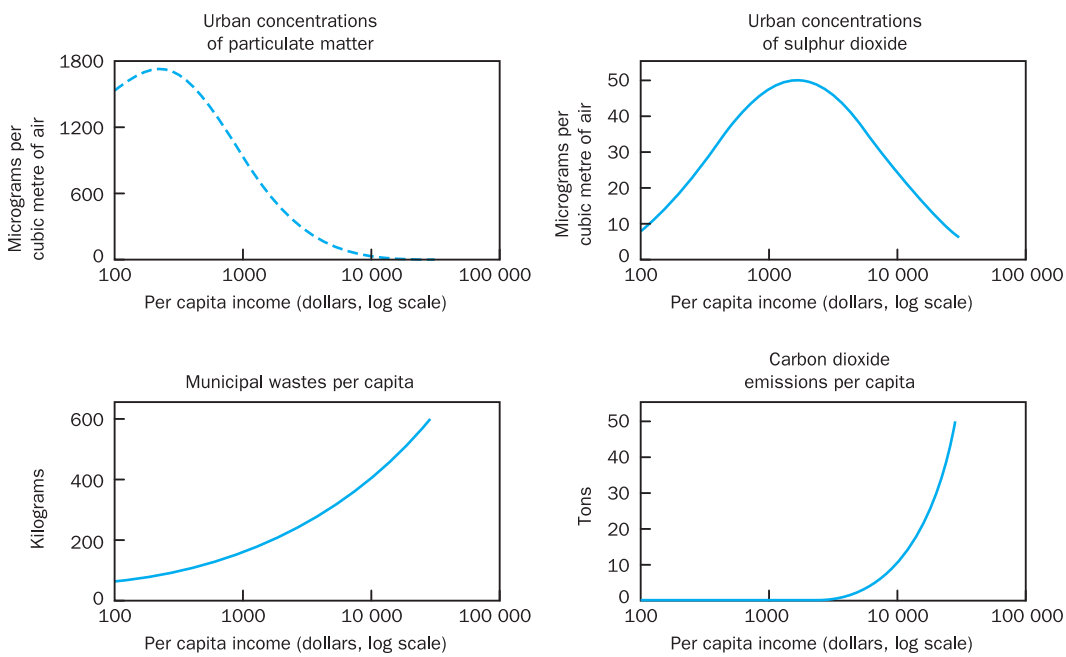


Figure 2.9 Some evidence from the EKC. Estimates are based on cross-country regression analysis of data from the 1980s
Source: Adapted from World Bank (1992)

and lack of urban sanitation were found to decline uniformly with increasing income. The two measures of deforestation were found not to depend on income. River quality tends to worsen with increasing income. As shown in Figure 2.9, two of the air pollutants were found to conform to the EKC hypothesis. Note, however, that CO_2 emissions, a major contributor to the 'greenhouse gases' to be discussed in relation to global climate change in Chapter 9, do not fit the EKC hypothesis, rising continuously with income, as do municipal wastes. Shafik and Bandyopadhyay summarise the implications of their results by stating:

> It is possible to 'grow out of' some environmental problems, but there is nothing automatic about doing so. Action tends to be taken where there are generalised local costs and substantial private and social benefits.

Panayotou (1993) investigated the EKC hypothesis for: sulphur dioxide (SO_2), nitrogen oxide (NO_x) suspended particulate matter (SPM) and deforestation. The three pollutants are measured in terms of emissions per capita on a national basis. Deforestation is measured as the mean annual rate of deforestation in the mid-1980s. All the fitted relationships are inverted Us, consistent with the EKC hypothesis. The result for SO_2 is shown in Figure 2.10, where the turning point is around $3000 per capita.

There is now an extensive literature investigating the empirical status of the EKC hypothesis. The Further Reading section at the end of the chapter provides points of entry to this literature, and the key references. Some economists take the results in the literature as supporting the EKC for local and regional impacts, such as sulphur for example, but not for global impacts, such as carbon dioxide for example. However, Stern and Common (2001) present results that are not consistent with the existence of an EKC for sulphur. The EKC hypothesis may hold for some environmental impacts, but it does not hold for all.

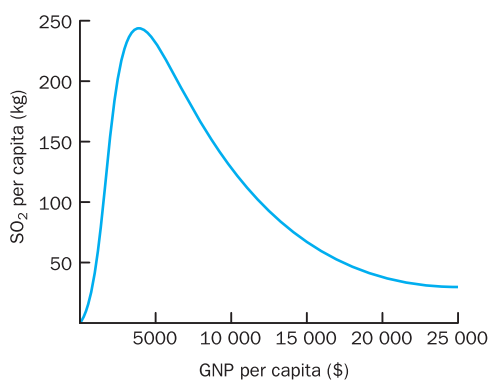


Figure 2.10 An EKC for SO_2
Source: Adapted from Panayotou (1993)

2.2.5.2.2 Implications of the EKC

If the EKC hypothesis were confirmed, what would it mean? Relationships such as that shown in Figure 2.10 might lead one to believe that, given likely future levels of income per capita, the global environmental impact concerned would decline in the medium-term future. In Figure 2.10 the turning point is near world mean income. In fact, because of the highly skewed distribution for per capita incomes, with many more countries – including some with very large populations – below rather than above the mean, this may not be what such a relationship implies.

This is explored by Stern *et al*. (1996), who also critically review the literature on the existence of meaningful EKC relationships. Stern *et al*. use the projections of world economic growth and world population growth published in the *World Development Report 1992* (World Bank, 1992), together with Panayotou's EKC estimates for deforestation and SO_2 emissions, to produce global projections of these variables for the period 1990–2025. These are important cases from a sustainable development perspective. SO_2 emissions are a factor in the acid rain problem: deforestation, especially in the tropics, is considered a major source of biodiversity loss. Stern *et al*. projected population and economic growth for every country in the world with a population greater than 1 million in 1990. The aggregated projections give world population growing from 5265 million in 1990 to 8322 million in 2025, and mean world per capita income rising from $3957 in 1990 to $7127 in 2025. They then forecast deforestation and SO_2 emissions for each country individually using the coefficients estimated by Panayotou. These forecasts were aggregated to give global projections for forest cover and SO_2 emissions.

Notwithstanding the EKC relationship shown in Figure 2.10, total global SO_2 emissions rise from 383 million tonnes in 1990 to 1181 million tonnes in 2025; emissions of SO_2 per capita rise from 73 kg to 142 kg from 1990 to 2025. Forest cover declines from 40.4 million km^2 in 1990 to a minimum of 37.2 million km^2 in 2016, and then increases to 37.6 million km^2 in 2025. Biodiversity loss on account of deforestation is an irreversible environmental impact, except on evolutionary time-scales, so that even in this case the implications of the fitted EKC are not reassuring.

Generally, the work of Stern *et al*. shows that the answer to the second question is that even if the data appear to confirm that the EKC fits the experience of individual countries, it does not follow that further growth is good for the global environment. Arrow *et al*. (1995) reach a similar position on the relevance of the EKC hypothesis for policy in relation to sustainability. They note that:

> The general proposition that economic growth is good for the environment has been justified by the claim that there exists an empirical relation between per capita income and some measures of environmental quality.

They then note that the EKC relationship has been 'shown to apply to a selected set of pollutants only', but that some economists 'have conjectured that the curve applies to environmental quality generally'. Arrow *et al*. conclude that

> Economic growth is not a panacea for environmental quality; indeed it is not even the main issue

and that

> policies that promote gross national product growth are not substitutes for environmental policy.

In Box 2.3 we report some simulation results that indicate that even if an EKC relationship between income and environmental impact is generally applicable, given continuing exponential income growth, it is only in very special circumstances that there will not, in the long run, be a positive relationship between income and environmental impact.

Box 2.3 The environmental Kuznets curve and environmental impacts in the very long run

The environmental Kuznets curve (EKC) implies that the magnitude of environmental impacts of economic activity will fall as income rises above some threshold level, when both these variables are measured in per capita terms. Here we assume for the sake of argument that the EKC hypothesis is correct. Common (1995) examines the implications of the EKC hypothesis for the long-run relationship between environmental impact and income. To do this he examines two special cases of the EKC, shown in Figure 2.11.

In case **a** environmental impacts per unit of income eventually fall to zero as the level of income rises. Case **b** is characterised by environmental impacts per unit income falling to some minimum level, *k*, at a high level of income, and thereafter remaining constant at that level as income continues to increase. Both of these cases embody the basic principle of the EKC, the only difference being whether environmental impacts per unit income fall to zero or just to some (low) minimum level.

Suppose that the world consists of two countries that we call 'developed' and 'developing' which are growing at the same constant rate of growth, *g*. However, the growth process began at an earlier date in the developed country and so at any point in time its per capita income level is higher than in the developing country. Common investigates what would

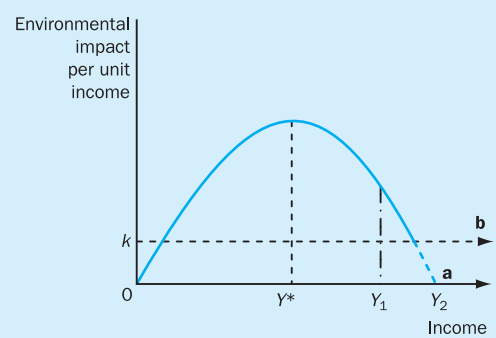


Figure 2.11 Two possible shapes of the environmental Kuznets curve in the very long run
Source: Adapted from Common (1995)

Box 2.3 ***continued***

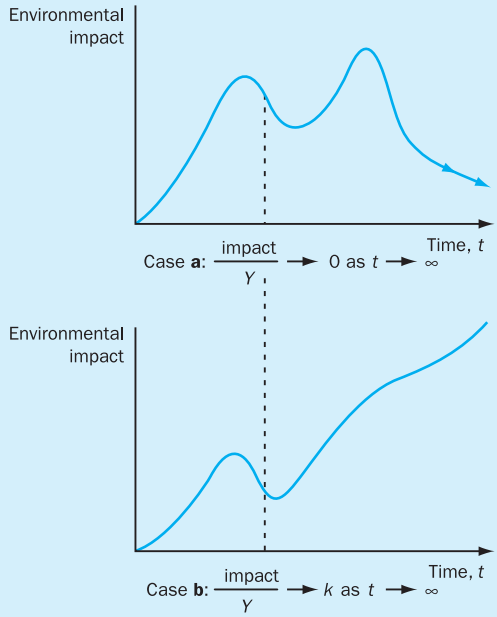


Figure 2.12 Two scenarios for the time profile of environmental impacts
Source: Adapted from Common (1995)

happen in the long run if case **a**, the highly optimistic version of the EKC, is true. He demonstrates that the time path of environmental impacts one would observe would be similar to that shown in the upper part of Figure 2.12. Why should there be a dip in the central part of the curve? For some period of time, income levels in the two countries will be such that the developed country is on the downward-sloping portion of its EKC while the developing country is still on the upward-sloping part of its EKC. However, as time passes and growth continues, both countries will be at income levels where the EKC curves have a negative slope; together with the assumption in case **a** that impacts per unit income fall to zero, this implies that the total level of impacts will itself converge to zero as time becomes increasingly large.

But now consider case **b**. No matter how large income becomes the ratio of environmental impacts to income can never fall below some fixed level, k. Of course, k may be large or small, but this is not critical to the argument at this point; what matters is that k is some constant positive number. As time passes, and both countries reach high income levels, the average of the impacts-to-income ratio for the two countries must converge on that constant value, k. However, since we are assuming that each country is growing at a fixed rate, g, the total level of impacts (as opposed to impacts per unit income) must itself eventually be increasing over time at the rate g. This is shown in the lower part of Figure 2.12.

What is interesting about this story is that we obtain two paths over time of environmental impacts which are entirely different from one another in qualitative terms for very small differences in initial assumptions. In case a, k is in effect zero, whereas in case **b**, k is greater than zero. Even if environmental impacts per unit of income eventually fell to a tiny level, the total level of impacts would eventually grow in line with income.

Which of these two possibilities – case **a** or case **b** – is the more plausible? Common argues that the laws of thermodynamics imply that k must be greater than zero. If so, the very-long-run relationship between total environmental impacts and the level of world income would be of the linear form shown (for per capita income) in panel (a) of Figure 2.8. The inference from the inverted U shape of the EKC that growth will reduce environmental damage in the very long run would be incorrect.

2.3 Poverty and inequality

Each year the United Nations Development Programme (UNDP) produces a *Human Development Report*, which draws on reports and data collections from a wide range of United Nations and other international agencies, and is the most useful single source of data and analysis on the current global state of humanity. This section draws heavily on these reports.

In the *Human Development Report 2001* (UNDP, 2001) it is stated that:

> Human development challenges remain large in the new millennium . . . Across the world we see

> unacceptable levels of deprivation in people's lives. Of the 4.6 billion people in developing countries, more than 850 million are illiterate, nearly a billion lack access to improved water sources, and 2.4 billion lack access to basic sanitation. Nearly 325 million boys and girls are out of school. And 11 million children under age five die each year from preventable causes – equivalent to more than 30 000 a day. Around 1.2 billion people live on less than $1 a day (1993 PPP US$), and 2.8 billion live on less than $2 a day.

In its report for 1998 (UNDP, 1998), the UNDP had additionally noted that of the population of the developing nations: 1.1 billion lacked adequate housing; 0.9 billion were undernourished; 0.9 billion had no access to modern health services.

Against this background, the report for 2001 comments that:

> The magnitude of these challenges appears daunting. Yet too few people recognize that the impressive gains in the developing world in the last 30 years demonstrate the possibility of eradicating poverty. A child born today can expect to live eight years longer than one born 30 years ago. Many more people can read and write, with the adult literacy rate having increased from an estimated 47% in 1970 to 73% in 1999. The share of rural families with access to safe water has grown more than fivefold. Many more people can enjoy a decent standard of living, with average incomes in developing countries having almost doubled in real terms between 1975 and 1998, from $1300 to $2500 (1985 PPP US$).

We now examine the current situation and recent trends in a little more detail. For a fuller version of what is a complex story, the reader should consult recent editions of the *Human Development Report*, and other references provided in the Further Reading section at the end of the chapter.

2.3.1 The current state of human development

Table 2.5 gives data on a number of indicators taken from the *Human Development Report 2007/2008*. The data cover 177 nations. There are 17 members of the UN that are not included in these data on the grounds that reliable information for them is not available. The excluded nations have an aggregate population of about 100 million out of a total world population of about 6.5 billion. The largest excluded nations are: Afghanistan, Democratic Republic of Korea, Iraq, Serbia and Somalia.

The nations of the world are grouped in different ways in different contexts. The three groupings in Table 2.5 are one of the classifications used in the *Human Development Report*. OECD stands for 'Organisation for Economic Co-operation and Development'. This organisation has 30 members, and corresponds roughly to the set of advanced industrial nations sometimes referred to as the 'developed world' or 'the North'. As indicated, Turkey is a member, as is Mexico. 'CE, EE and CIS'

Table 2.5 International comparisons at the start of the twenty-first century

	Life expectancy[a]	Infant mortality[b]	% of population undernourished[c]	GDP per capita[d]	Electricity per capita[e]
World	68.1	52	17	9 543	2 701
OECD	78.3	9	..	29 197	8 795
USA	77.9	6	<2.5	41 890	14 240
Turkey	71.4	26	3	8 407	2 122
CE, EE and CIS	68.6	22	..	9 527	4 539
Hungary	72.9	7	<2.5	17 887	4 070
Uzbekistan	66.8	57	25	2 063	1 944
Developing	66.1	57	17	5 282	1 221
Least developed	54.5	97	35	1 499	119
Sub-Saharan	49.6	102	32	1 998	478

[a] Years at birth, 2005, Table 1, UNDP (2007)
[b] Per 1000 live births, 2005, Table 10, UNDP (2007)
[c] 2002/4, Table 7, UNDP (2007) (.. means not available)
[d] 2005, PPP US$, Table 1, UNDP (2007)
[e] Kilowatt hours, 2004, Table 22, UNDP (2007)

is short for 'Central and Eastern Europe and the Commonwealth of Independent States', which is the former Soviet Union and its satellites. This grouping includes countries at very different levels of development, as illustrated by Hungary and Uzbekistan. All of the nations that are covered by the data but in neither the OECD nor CE, EE and CIS are classified as 'developing'. For most indicators the *Human Development Report* provides data for several subsets of this classification, two of which are included in Table 2.5. Many of the 'least developed' nations are located in Sub-Saharan Africa; non-African members of the least developed nations set include Bangladesh, Cambodia, Haiti, Lao People's Democratic Republic, Myanmar and Nepal.

The 2005 population sizes for the three groups of nations are: OECD 1173 million; CE, EE and CIS 405 million; developing 5215 million. The population of the set of least developed is 766 million, and for Sub-Saharan Africa it is 723 million.

On average, people in the OECD can expect to live almost 12 years longer than people in the developing world. OECD infant mortality is less than one-fifth the rate in the developing world. Undernourishment is rare in most of the countries of the OECD and CE, EE and CIS: <2.5 means less than 2.5%. Almost one-fifth of the world's total population are undernourished, and almost one-third of those in the worse-off parts of the developing world are. In round-number terms, the *Human Development Report* follows the World Bank and defines poverty as an annual income of less than PPP US$600 in terms of current PPP $s – this corresponds to $1 per day in terms of 1993 PPP US$. On that basis, according to Table 2.5, even for the least developed nations average income is above the poverty line. However, as quoted above, looking behind the average, it is estimated that 1.2 billion people are below the poverty line. In terms of averages, GDP per capita in the OECD is more than five times that in the developing world, and more than 19 times that in the least developed nations. For electricity consumption per capita, the relativities are broadly the same as for income per capita.

The data in Table 2.5 are for just a small sample of the possible indicators of human development. The picture that they show is broadly the same across all indicators – many human beings currently experience poverty and deprivation, and there are massive inequalities. In regard to income inequality, the *Human Development Report 2001* (UNDP, 2001) cites some results from a study that is based on household survey data rather than national income data. The study relates to the period 1988–1993 and covers 91 countries with 84% of world population. According to this study:

- The income of the poorest 10% was 1.6% of that of the richest 10%.
- The richest 1% of the world population received as much income in total as the poorest 57%.
- Around 25% of the population received 75% of total income.

2.3.2 Recent trends

An important question is whether things have been getting better in recent history. Table 2.6 shows the ratio of the values taken by the Table 2.5 indicators to their values as near to a quarter of a century ago as the data allow.

Life expectancy increased proportionately more in the developing world than in the OECD. It actually decreased for the CE, EE and CIS as a whole, though in some of its constituent nations it did increase a little. In the Russian Federation, life expectancy decreased from 69 for 1970–1975 to 64.8 for 2000–2005. This is associated with economic collapse and a major breakdown in preventive health care. Also culpable may be the cumulative effects of serious environmental contamination over many years in the Soviet Union, especially toxic wastes from chemical plants, pesticides from agriculture and nuclear radiation from various sources. For infant mortality a ratio of less than one indicates improvement over the period. Considering the three groupings, the improvement was least in CE, EE and CIS. Looking at undernourishment, there are no data for the OECD and CE, EE and CIS. It is known that for some countries in the latter it increased, as shown for Uzbekistan in Table 2.6. For the developing world as a whole and for the sub-groups shown in Table 2.6, the proportion of the population undernourished fell. Given the increase in population in developing countries, the absolute numbers undernourished fell by less than is shown in Table 2.6.

Table 2.6 Ratios for recent change

	Life expectancy[a]	Infant mortality[b]	% of population undernourished[c]	GDP per capita[d]	Electricity per capita[e]
OECD	1.11	0.22	..	1.81	1.42
USA	1.08	0.30	..	1.81	1.33
Turkey	1.24	0.17	..	1.71	3.08
CE, EE and CIS	0.99	0.56	..	1.52	..
Hungary	1.04	0.19	..	1.47	1.21
Uzbekistan	1.05	0.69	3.13	0.89	..
Developing	1.17	0.52	0.81	2.10	2.40
Least Developed	1.18	0.64	0.92	1.31	1.29
Sub-Saharan	1.07	0.71	0.89	0.86	1.04

[a] For 2000–05 divided by 1970–75, Table 10, UNDP (2007)
[b] 2005 divided by 1970, Table 8, UNDP (2007)
[c] 2002/4 divided by 1990/2, Table 7, UNDP (2007) (.. means not available)
[d] 2005 divided by 1975, calculated from annual growth rates, Table 14, UNDP (2007)
[e] 2004, from Table 22, UNDP (2007), divided by 1980 from Table 19 UNDP (2002)

In the developing world as a whole GDP per capita grew by more than it did in the OECD, more than doubling. However, here again, there is much variation within the developing world. For the least developed nations, per capita income increased by just 31% over 30 years, and for Sub-Saharan Africa it actually fell by 14%. There was also a lot of variation within the CE, EE and CIS group, where, as shown for Uzbekistan, GDP per capita fell in some countries. Over the 1990s the total number of people living below the poverty line as defined above was more or less constant at 1.2 billion. Given that the world population grew over this period, the proportion of the world's population living in poverty so defined fell slightly.

What about inequality? The *Human Development Report 2001* (Box 2.3) reports calculations based on GDP per capita data which show that from 1970 to 1997 the ratio of the income of the richest 10% to the poorest 10% increased from 19.4 to 26.9, indicating increasing inequality. On the other hand, if the ratio is calculated for the top and bottom 20% it falls from 14.9 to 13.1, indicating decreasing inequality.

Table 2.7 is based on the GDP per capita data used for Tables 2.5 and 2.6. It shows the ratio of GDP per capita for a group or nation to that of the USA for the same year. Thus, for the OECD as a whole GDP per capita was 70% of that of the USA in 1975 and 2005 – the OECD and the USA grew at the same rate, so that relative to the latter the former became neither better off nor worse off – the inequality remained constant. Turkey grew faster than the USA and the degree of inequality was reduced. For CE, EE and CIS as a whole, and for Uzbekistan and Hungary the ratio fell so that inequality increased. For the developing world as a whole, inequality in relation to the USA decreased a little, in that the ratio increases from 0.11 to 0.13. However, for the least developed nations and Sub-Saharan Africa, in relation to the USA and – given the above observations on the USA and the OECD – the OECD as a whole, income inequality increased. In the case of Sub-Saharan Africa, per capita GDP fell by 14% while USA per capita GDP increased by about 80% (Table 2.6), and the ratio of the former to the latter fell by 50%.

Table 2.7 GDP per capita relativities to the USA

	1975	2005
OECD	0.70	0.70
USA	1.00	1.00
Turkey	0.12	0.20
CE, EE and CIS	0.27	0.23
Hungary	0.53	0.43
Uzbekistan	0.10	0.05
Developing	0.11	0.13
Least developed	0.05	0.04
Sub-Saharan	0.10	0.05

Calculated from Tables 2.5 and 2.6

2.3.3 Growth as the solution

Economists have a very strong attachment to economic growth as a major policy objective. A major

reason for this is that they see it as the only feasible way to solve the problem of poverty. The argument is that with economic growth, the lot of the poor can be improved without taking anything away from the better-off. Generally the better-off will resist attempts to redistribute from them to the poor, so that this route to poverty alleviation will involve social tension and possibly violent conflict. Further, over and above such considerations, poverty alleviation via redistribution may not work even if it is politically and socially feasible. The problem is that typically the poor are much more numerous than the rich, so that there is simply not enough to take from the rich to raise the poor above the poverty line. When, in the years following the Second World War, economists thought that they understood how to bring about economic growth they came to think that they could solve an age-old problem of the human condition – they came to think that the poor need not always be with us.

Indeed, perhaps the most famous economist of the twentieth century, J.M. Keynes, saw in economic growth the prospect that the very problem that was taken to be the essential economic problem – scarcity – would be abolished, so that economists would become largely redundant. In an essay (Keynes, 1931), written in the early 1930s, on the economic prospects for the grandchildren of adults then alive, Keynes was concerned to put in perspective the waste entailed in the then-prevalent under-use of available resources, especially labour. If the means to avoid such waste could be found and adopted, Keynes argued, economic growth, i.e. increasing per capita GDP, at 2% per year would easily be attained and sustained. This, he pointed out, would mean that in one hundred years output would increase sevenfold. Scarcity would be abolished, and a situation arise in which economics and economists were no longer important. In the years after the Second World War, most economists thought that Keynesian macroeconomics was the means to achieving full employment and sustained growth throughout the world.

The arithmetic of compound growth – growth at a constant proportional rate – is indeed striking. And, there is no doubt that historically economic growth has raised the consumption levels of the mass of the population in the rich industrial world to levels that could scarcely have been conceived of at the start of the industrial revolution, 200 years ago. There is also no doubt that for the developing world as a whole, economic growth in the latter part of the twentieth century reduced the extent of poverty. The arithmetic of economic growth does not, however, necessarily imply any reduction in economic inequality. If the incomes of the rich and the poor grow at the same rates, the proportionate difference between them stays the same, and the absolute difference – in dollars per year – actually increases. The original Kuznets curve hypothesis was that, with growth, income inequality first increased then decreased. The evidence on this hypothesis is mixed. As noted above, global income inequalities have not generally decreased in recent years. Within some advanced economies inequality has increased.

2.4 Limits to growth?

An important event in the emergence in the last three decades of the perception that there is a sustainability problem was the publication in 1972 of a book, *The Limits to Growth* (Meadows *et al.*, 1972), which was widely understood to claim that environmental limits would cause the collapse of the world economic system in the middle of the twenty-first century.

The book was roundly condemned by most economists, but influenced many other people. It is arguable that it was a stimulus to the re-emergence of interest in natural resources on the part of economists in the early 1970s noted in Chapter 1. One economist argued, at around the same time, that the limits to growth were social rather than environmental.

2.4.1 Environmental limits

The Limits to Growth reported the results of a study in which a computer model of the world system, World3, was used to simulate its future. World3 represented the world economy as a single economy, and included interconnections between that economy and its environment. According to its creators, World3

> was built to investigate five major trends of global concern – accelerating industrialization, rapid population growth, widespread malnutrition, depletion of non-renewable resources, and a deteriorating environment. These trends are all interconnected in many ways, and their development is measured in decades or centuries, rather than in months or years. With the model we are seeking to understand the causes of these trends, their interrelationships, and their implications as much as one hundred years in the future.
>
> *Meadows et al. (1972), p. 21*

It incorporated:

(a) a limit to the amount of land available for agriculture;
(b) a limit to the amount of agricultural output producible per unit of land in use;
(c) a limit to the amounts of non-renewable resources available for extraction;
(d) a limit to the ability of the environment to assimilate wastes arising in production and consumption, which limit falls as the level of pollution increases.

The behaviour of the economic system was represented as a continuation of past trends in key variables, subject to those trends being influenced by the relationships between the variables represented in the model. These relationships were represented in terms of positive and negative feedback effects. Thus, for example, population growth is determined by birth- and death-rates, which are determined by fertility and mortality, which are in turn influenced by such variables as industrial output per capita, the extent of family planning and education – for fertility – and food availability per capita, industrial output per capita, pollution, and the availability of health care – for mortality. The behaviour over time, in the model of each of these variables, depends in turn on that of others, and affects that of others.

On the basis of a number of simulations using World3, the conclusions reached by the modelling team were as follows:

> 1. If the present growth trends in world population, industrialization, pollution, food production and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next 100 years. The most probable result will be a sudden and uncontrollable decline in both population and industrial capacity.
> 2. It is possible to alter these trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his or her individual human potential.
> 3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success.
>
> *Meadows et al. (1992), p. xiii*

What *The Limits to Growth* actually said was widely misrepresented. It was widely reported that it was an unconditional forecast of disaster sometime in the next century, consequent upon the world running out of non-renewable resources. In fact, as the quotation above indicates, what was involved was conditional upon the continuation of some existing trends. Further, this conditional prediction was not based upon running out of resources.

The first model reported run did show collapse as the consequence of resource depletion. Figure 2.13 is a reproduction of the figure in *The Limits to Growth* that reports the results for 'World Model Standard Run'. This run assumes no major changes in social, economic or physical relationships. Variables follow actual historical values until the year 1970. Thereafter, food, industrial output and population grow exponentially until the rapidly diminishing resource base causes a slowdown in industrial growth. System lags result in pollution and population continuing to grow for some time after industrial output has peaked. Population growth is finally halted by a rise in the mortality rate, as a result of reduced flows of food and medical services.

However, the next reported run involved the model modified by an increase in the resource availability limit such that depletion did not give rise to problems for the economic system. In this run, the proximate source of disaster was the level of pollution consequent upon the exploitation of the increased amount of resources available, following from the materials balance principle. A number of variant model runs were reported, each relaxing some constraint. The conclusions reached were

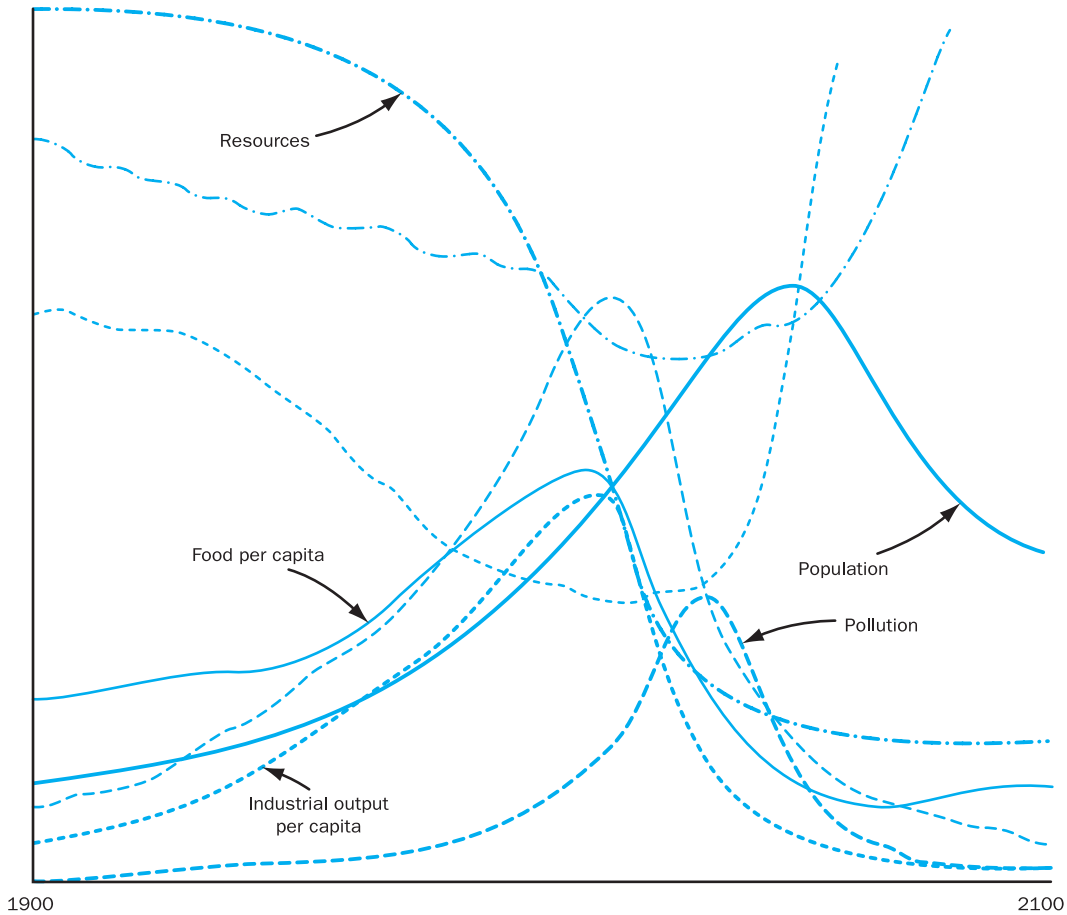


Figure 2.13 Base run projections of the 'limits to growth' model
Source: Meadows *et al.* (1972), page 124

based on consideration of all of the variant model runs. Successive runs of the model were used to ascertain those changes to the standard configuration that were necessary to get the model to a sustainable state, rather than to collapse mode.

It was widely reported that the World3 results said that there were limits to 'economic growth'. In fact, what they said, as the conclusions quoted above indicate, is that there were limits to the growth of material throughput for the world economic system. As economic growth is measured it includes the consumption of the output of the service sector, as well as the agricultural and industrial sectors.

A sequel (Meadows *et al.*, 1992) to *The Limits to Growth*, written by the same team and entitled *Beyond the Limits*, was published in 1992 to coincide with the UNCED conference held in Rio de Janeiro. The publication of the sequel generated much less controversy than the original did. This might suggest some major change in analysis and conclusions as between original and sequel. In fact there is very little substantive difference in the conclusions, and apart from updating of numerical values used, the model is stated to be modified in only minor ways from the original World3. The position on this as stated in the sequel is:

> As far as we can tell from the global data, from the World3 model, and from all we have learned in the past twenty years, the three conclusions we drew in *The Limits to Growth* are still valid, but they need to be strengthened.
>
> *Meadows et al. (1992), p. xv*

The quotation at the beginning of this chapter is from a second sequel to *The Limits to Growth*, with the title *Limits to Growth: The 30-Year Update* and published in 2005 (Meadows *et al*., 2005). As compared to the first sequel, this book uses a slightly modified World3, presents similar model-generated scenarios, and reaches similar conclusions. The authors state that 'they are much more pessimistic about the global future' than they were in 1972, and that:

> It is a sad fact that humanity has largely squandered the past 30 years in futile debates and well-intentioned, but halfhearted, responses to the global ecological challenge. We do not have another 30 years to dither. Much will have to change if the ongoing overshoot is not to be followed by collapse during the twenty-first century.
>
> *Meadows et al. (2005), p. xvi*

2.4.2 Economists on environmental limits

The response by economists to *The Limits to Growth* was almost entirely hostile. Given their commitment to economic growth as the solution to the problem of poverty and the widespread existence of the problem, noted in the previous section, this was hardly surprising. Prominent among the critical responses from economists were those by Page (1973), Nordhaus (1972), Beckerman (1972, 1974), Cole *et al*. (1973) and Lecomber (1975). According to one eminent economist it was 'a brazen, impudent piece of nonsense that nobody could possibly take seriously' (Beckerman, 1972). As noted above, economists have had much less to say, and much less critical things to say, about the sequel, *Beyond the Limits*. In a foreword to it, a Nobel laureate in economics, Jan Tinbergen, says of it: 'We can all learn something from this book, especially we economists.'

The main line of the criticism of the original by economists was that the feedback loops in World3 were poorly specified in that they failed to take account of behavioural adjustments operating through the price mechanism. In particular, it was argued that changing patterns of relative scarcity would alter the structure of prices, inducing behavioural changes in resource-use patterns. Given a well-functioning market mechanism, it was argued, limits to growth would not operate in the way reported by the modelling team. It was conceded by some of the economist critics that the force of this argument was weakened by the fact that for many environmental resources and services, markets did not exist, or functioned badly where they did. However, it was also argued that such 'market failure' could be corrected by the proper policy responses to emerging problems. This presumes that the sorts of substitutions for environmental services that we discussed above can be made, given properly functioning markets or policy-created surrogates for such, to the extent that will overcome limits that would otherwise exist. A major, and largely unresolved, question in the debates about the existence of a sustainability problem is the existence and effectiveness of substitutes for environmental services.

2.4.3 Social limits to growth

The argument for 'social limits to growth' was first advanced in a book with that title (Hirsch, 1977), published five years after *The Limits to Growth*. Hirsch argued that the process of economic growth becomes increasingly unable to yield the satisfaction which individuals expect from it, once the general level of material affluence has satisfied the main biological needs for life-sustaining food, shelter and clothing. As the average level of consumption rises, an increasing portion of consumption takes on a social as well as an individual aspect, so that

> the satisfaction that individuals derive from goods and services depends in increasing measure not only on their own consumption but on consumption by others as well.
>
> *Hirsch (1977), p. 2*

The satisfaction a person gets from the use of a car, for example, depends on how many other people do the same. The greater the number of others who use cars, the greater is the amount of air pollution and the extent of congestion, and so the lower is the satisfaction one individual's car use will yield. However, Hirsch's main focus was on what he calls 'positional goods', the satisfaction from which

depends upon the individual's consumption relative to that of others, rather than the absolute level of consumption. Consider, as an example, expenditure on education in an attempt to raise one's chances of securing sought-after jobs. The utility to a person of a given level of educational expenditure will decline as an increasing number of others also attain that level of education. Each person purchasing education seeks to gain individual advantage, but the simultaneous actions of others frustrate these objectives for each individual. As the average level of education rises, individuals will not receive the gains they expect from higher qualifications.

Once basic material needs are satisfied, further economic growth is associated with an increasing proportion of income being spent on such positional goods. As a consequence, Hirsch argued, growth in developed economies (such as members of the OECD) is a much less socially desirable objective than economists have usually thought. It does not deliver the increased personal satisfactions that it is supposed to. Traditional utilitarian conceptions of social welfare (see Chapters 3 and 4) may be misleading in such circumstances, as utilities are interdependent. Using terminology to be introduced and explained in Chapter 4, we can say that given the external effects arising due to the consumption of others affecting the utility that an individual derives from his or her own consumption, the simple summation of individual consumption levels overstates collective welfare.

Since the 1950s social scientists have been conducting surveys in which they ask individuals about how satisfied with their lives, or happy, they are. There is now a substantial body of data that can, among other things, be used to study the relationship between economic growth and happiness. As will be explained in Section 3.3.4 of the next chapter, the evidence from these data are consistent with Hirsch's argument. If, for example, we look at a plot of happiness against per capita national income across countries at a point in time, as in Figure 3.4, we find that happiness increases with income, but at a decreasing rate. Across rich countries, in terms of the national average, additional per capita national income delivers little in terms of self-assessed happiness.

2.5 The pursuit of sustainable development

Social limits to growth are not currently a problem in developing countries. Many people now live in conditions such that basic material needs are not satisfied. This is particularly true for people living in the poor nations of the world, but is by no means restricted to them. Even in the richest countries, income and wealth inequalities are such that many people live in conditions of material and social deprivation. For many years, it was thought that the eradication of poverty required well-designed development programmes that were largely independent of considerations relating to the natural environment. The goal of economic and political debate was to identify growth processes that could allow continually rising living standards. Economic development and 'nature conservation' were seen as quite distinct and separate problems. By some commentators, concern for the natural environment was seen as a rather selfish form of self-indulgence on the part of the better-off.

Perspectives have changed significantly since the 1970s. While the pursuit of economic growth and development continues, it is recognised that the maintenance of growth has an important environmental dimension. During the 1970s, a concern for sustainability began to appear on the international political agenda, most visibly in the proceedings of a series of international conferences. The common theme of these debates was the interrelationship between poverty, economic development and the state of the natural environment.

Perhaps the best-known statement of the sustainability problem derives from the 1987 report of the World Commission on Environment and Development, which set the agenda for much of the subsequent discussion of sustainability.

2.5.1 The World Commission on Environment and Development

The World Commission on Environment and Development, WCED, was established in 1983 by the United Nations. Its mandate was:

1. to re-examine the critical environment and development issues and to formulate realistic proposals for dealing with them;
2. to propose new forms of international cooperation on these issues that will influence policies and events in the direction of needed changes;
3. to raise the levels of understanding and commitment to action of individuals, voluntary organisations, businesses, institutes and governments.

WCED comprised 23 commissioners from 21 different countries. The chairperson was Gro Harlem Brundtland, who had previously been both Minister for the Environment and Prime Minister of Norway. Over a period of two years, the commissioners held public meetings in eight countries, at which people could submit their views on WCED's work. In regard to analysis and awareness-raising, WCED focused on population growth, food security, biodiversity loss, energy, resource depletion and pollution, and urbanisation.

2.5.1.1 The Brundtland Report

The report that WCED produced in 1987 – *Our Common Future* (WCED, 1987) – is often referred to as 'the Brundtland report' after the name of the WCED chairperson. It advanced, with great effect, the concept of 'sustainable development', which is now on political agendas, at least at the level of rhetoric, around the world. The Brundtland report was, in political terms, an outstanding and influential piece of work.

It provides much information about what we have called here the sustainability problem, setting out the nature of economy–environment interdependence, identifying a number of potential environmental constraints on future economic growth, and arguing that current trends cannot be continued far into the future. Thus, according to the Brundtland report,

> Environment and development are not separate challenges: they are inexorably linked. Development cannot subsist on a deteriorating environmental base; the environment cannot be protected when growth leaves out of account the costs of environmental protection.
>
> *p. 37*

while

> The next few decades are crucial. The time has come to break out of past patterns. Attempts to maintain social and ecological stability through old approaches to development and environmental protection will increase instability.
>
> *p. 22*

The Brundtland report does not conclude that future economic growth is either infeasible or undesirable. Having defined sustainable development as development that

> seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future
>
> *p. 43*

it states that:

> Far from requiring the cessation of economic growth, it [sustainable development] recognizes that the problems of poverty and underdevelopment cannot be solved unless we have a new era of growth in which developing countries play a large role and reap large benefits.
>
> *p. 40*

Nor does it require that those nations already developed cease to pursue economic growth:

> Growth must be revived in developing countries because that is where the links between economic growth, the alleviation of poverty, and environmental conditions operate most directly. Yet developing countries are part of an interdependent world economy; their prospects also depend on the levels and patterns of growth in industrialized nations. The medium term prospects for industrial countries are for growth of 3–4 per cent, the minimum that international financial institutions consider necessary if these countries are going to play a part in expanding the world economy. Such growth rates could be environmentally sustainable if industrialized nations can continue the recent shifts in the content of their growth towards less material- and energy-intensive activities and the improvement of their efficiency in using materials and energy.
>
> *p. 51*

In the light of an appreciation of the economy–environment interdependence and the current level of global economic activity, some environmentalists

have expressed the view that 'sustainable development' is an oxymoron. It is their assessment that the current situation is such that we already are at the limits of what the environment can tolerate, so that growth will inevitably damage the environment, and cannot, therefore, be sustainable. It is the assessment of the Brundtland report that environmental limits to growth can be avoided, given the adoption, worldwide, of policies to affect the form that economic growth takes. To make growth sustainable, those policies would have to involve reducing, at the global level, the material content of economic activity, economising in the use of resources as the value of output increases, and substituting the services of reproducible capital for the services of natural capital. Much of resource and environmental economics is about the policy instruments for doing that, as we shall see in later chapters.

Given the nature of the WCED, it is not surprising that the Brundtland report is not strong on detailed and specific policy proposals that would facilitate the move from 'past patterns' to sustainable development. It urges, for example, that national governments merge environmental and economic considerations in their decision making. It did make a specific recommendation regarding item 2 from its mandate. This was that the UN General Assembly convene an international conference

> to review progress made and promote follow-up arrangements that will be needed over time to set benchmarks and to maintain human progress within the guidelines of human needs and natural laws.
>
> *p. 343*

This recommendation was acted upon, and the result was the United Nations Conference on Environment and Development, UNCED, which took place in Rio de Janeiro in June 1992.

2.5.2 UNCED: Rio de Janeiro 1992

The conference itself was preceded by over two years of preparatory international negotiations. Delegations were sent from 178 nations and the meeting was attended by 107 heads of government (or state). During UNCED several parallel and related conferences took place in Rio de Janeiro; the meeting for 'non-governmental organisations', mainly pro-environment pressure groups, involved more participants than UNCED itself. It has been estimated that, in total, over 30 000 people went to Rio de Janeiro in June 1992.

The preparatory negotiations dealt with four main areas: draft conventions on biodiversity conservation, global climate change, forest management, and the preparation of two documents for adoption at UNCED. The main UNCED outcomes were as follows. There was complete agreement on the non-binding adoption of the *Rio Declaration* and *Agenda 21*. The first of these comprises 27 statements of principle in regard to global sustainable development. The second is an 800-page document covering over 100 specific programmes for the attainment of global sustainable development: many of these programmes involve resource transfers from the industrial to the developing nations. UNCED also agreed on the creation of a new UN agency, a Commission for Sustainable Development, to oversee the implementation of *Agenda 21*. Agreement was also reached on the, non-binding, adoption of a set of principles for forest management. The industrial nations reaffirmed their previous non-binding commitments to a target for development aid of 0.7% of their GNP. It should be noted that it is still true that only a few of the industrial nations actually attain this target.

Two conventions were adopted, by some 150 nations in each case, which would be binding on signatories when ratified by them. These covered global climate change and biodiversity conservation: the latter was not signed by the USA at the Rio meeting, but the USA did sign in 1993 after a change of administration. Although binding, these conventions did not commit individual nations to much in the way of specific actions. The *Convention on Biological Diversity* deals with two main issues – the exploitation of genetic material and biodiversity conservation. In regard to the latter, signatories agree to create systems of protected areas, for example, but undertake no commitments regarding their extent. The *Framework Convention on Climate Change* was mainly about the principles according to which future negotiations – known as Conferences of the Parties, COPS – were to try to establish commitments and rules. A major principle was that commitments would be limited to the developed nations.

Many environmental activists, as well as many concerned to promote economic development in poor nations, regarded the actual achievements at UNCED as disappointing, but it did confirm that sustainable development was, and would remain, firmly on the world political agenda. While specific commitments were not a major feature of the outcomes, there were agreements with the potential to lead to further developments. The creation of the Commission for Sustainable Development is clearly an important institutional innovation at the international level.

The convening of, and the outcomes at, UNCED suggest that the need to address the economic and environmental problems arising from economy–environment linkages is widely accepted. Equally, UNCED and subsequent events suggest that even when the existence of a problem is widely agreed by national governments, agreement on the nature of appropriate policy responses is limited. Further, there is clearly reluctance on the part of national governments to incur costs associated with policy responses, and agreed action is even more difficult to realise than agreement about what should be done. The difficulties involved in achieving international action on environmental problems, such as climate change, are discussed in Chapter 9, along with progress that has been made since 1987.

2.5.3 The UN and Sustainable Development after Rio de Janeiro

As noted, the 1992 Conference brought into being the UN Commission on Sustainable Development to oversee the UN's work on the pursuit of sustainable development. Information on the activities of the Commission can be accessed at its website, http://www.un.org/esa/sustdev/csd/review.htm. Within the UN's administration, the parallel body to the Commission is the Division for Sustainable Development, http://www.un.org/esa/sustdev/index.html, which is part of the Department of Economic and Social Affairs.

The Commission has organised a number of meetings to build on the 1992 Conference. The most notable of these was the World Summit on Sustainable Development, WSSD, held in September 2002 in Johannesburg, also often referred to as 'Rio + 10' for obvious reasons. WSSD was attended by 9000 government delegates, including 104 heads of government or state, 8000 NGO representatives, 4000 members of the press, and many representatives of business organisations. A full account of what happened, and what was agreed, at WSSD can be found via the website addresses given above. All nations signed up for the Johannesburg Plan of Implementation, which included limited (and mainly un-quantified) targets on such environmental issues as biodiversity loss, and a set of targets for economic development very similar to the Millennium Development Goals.

Most commentators were disappointed with the progress at WSSD beyond what had been achieved, or set in motion, at the 1992 conference. According to one:

> Compared to the 1992 Earth Summit in Rio, this summer's World Summit on Sustainable Development (WSSD) in Johnnesburg was bound to be somewhat disappointing. The negotiations leading up to Johannesburg had not provided any reason to expect dramatic break-throughs, and there were none. After the meeting, many non-governmental organisations denounced the WSSD as a failure. Even seasoned UN officials, while relieved that the Summit had not broken down completely, were rather muted in their responses.
>
> *Hilary French, Worldwatch Institute Policy Brief No 12, October 2002, downloaded April 2008 from http://www.worldwatch.org/node/1744.*

2.5.4 The Millennium Development Goals

Many would argue that while economic growth is necessary for dealing with poverty, it is not sufficient. As we have seen in this chapter, in the second half of the twentieth century growth in the world economy co-existed with the persistence of poverty. This led many to the view that dealing with poverty required a commitment to economic growth and policies directly aimed at poverty and other impediments to realising a good quality of life.

In September 2000 the UN convened the Millennium Summit at its headquarters in New York, which was attended by representatives of 189 UN members, most of whom were heads of

government. The Summit adopted the Millennium Declaration, and its eight chapters were subsequently developed into an action plan with eight goals, which were called the Millennium Development Goals, MDGs. The plan calls for the MDGs to be achieved by 2015. Those goals are:

1. Eradicate extreme poverty and hunger.
2. Achieve universal primary education.
3. Promote gender equality and empower women.
4. Reduce child mortality.
5. Improve maternal health.
6. Combat HIV/AIDS, malaria, and other diseases.
7. Ensure environmental sustainability.
8. Develop a global partnership for development.

Each of these goals is related to more specific targets, of which there are 21 in all. In regard to the first goal, for example, the targets are to:

> halve, as compared with 1990, the proportion of people whose income is less than one dollar per day
>
> achieve full and productive employment and decent work for all, including women and young people
>
> halve, as compared with 1990, the proportion of people who suffer from hunger.

For more information on the MDGs and the targets visit the United Nations Development Programme (UNDP) website at http://www.undp.org/mdg/basics.shtml. Progress toward goals and targets is mixed. Looking, for example, at the income target noted above, for five of the 10 regions distinguished, the target is either 'not expected to be met by 2015' or there is 'no progress, or a deterioration or reversal', while for two 'target is already met or very close to being met' and for another two the target is expected to be met by 2015. For one region there is insufficient data. For the hunger target, the verdict is unfavourable for five regions, and favourable for five. The balance of favourable and unfavourable judgements of the prospects of success are similar across the other targets.[6]

Summary

Interdependence

The economy and the environment are linked through many complex relationships. Economic activity affects the environment, which affects the economy. The economy and the environment are interdependent systems.

Impact scale

The scale of humanity's current impact on the natural environment is without precedent, and raises the question of whether the natural environment can tolerate it without serious change, likely to be detrimental to human interests.

Impact drivers – IPAT

Humanity's impacts on the natural environment are driven by the size of the human population, the level of human affluence, and the technologies that humans use.

Behaviour

P, *A* and *T* all depend on human behaviour, which changes over time as the incentives facing people change. Policy affects the incentives that people face.

[6] These figures are taken from a chart prepared by the Statistics Division of the UN's Department of Economic and Social Affairs, and relate to 2008. The chart was downloaded from http://mdgs.un.org/unsd/mdg/default.aspx in January 2009. The corresponding figures for the same chart for 2007 were the same, as is true for most of the targets.

Poverty and inequality

The current human condition involves massive inequalities in many aspects of well-being and gross poverty for many millions of people.

Sustainable development

Sustainable development seeks to improve the lot of the world's poor without reducing the capacity of the natural environment to deliver a diverse set of services to the global economy.

Further reading

Data on the topics dealt with in this chapter can be found in the publications of agencies such as the United Nations (UN), the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), the World Bank, the Organisation for Economic Co-operation and Development (OECD), the International Energy Agency (IEA), and the World Conservation Union (WCN, formerly the International Union for the Conservation of Nature, IUCN). Each year the World Resources Institute (WRI) collates data from these and other sources in a series of tables in its publication *World Resources*. This is jointly produced by WRI, UNEP, the World Bank and UNDP. Each year this publication also focuses on some particular aspect of economy–environment interdependence – for example, at the time of writing the latest available report was *World Resources 2000–2001: People and Ecosystems*. Some data are available from the websites of these organisations:

UN – www.un.org
FAO – www.fao.org/default.htm
UNEP – www.unep.org
UNDP – www.undp.org
World Bank – www.worldbank.org
OECD – www.oecd.org
IEA – www.iea.org
WRI – www.wri.org
WCN – www.iucn.org

Lomborg (2001) is a useful point of entry to the vast array of statistical materials on the current state of the environment and human development. The appearance of Lomborg's book in English generated a great deal of interest and controversy, as he argues that what the statistics show is that those 'environmentalists' who claim that the human condition is deteriorating and that the ability of the environment to support economic activity is decreasing are, overall, quite wrong. Many of those environmentalists have, in turn, claimed that Lomborg is both wrong and irresponsible. Lomborg treats each potential environmental problem in isolation, rather than as the set of linked phenomena that they are. Lomborg has a website, www.lomborg.com, which provides links to various contributions to the controversy.

There are a number of well-documented examples of unsustainable societies in human history, where collapse followed resource exhaustion. Ponting (1992) is an environmental history of humanity and provides brief accounts of some examples, and references to more detailed works; see also Diamond (1993) and Diamond (2006).

Jackson and Jackson (2000) and Park (2001) are two standard texts that deal at greater length with the environmental science topics covered in this chapter. Both are at an introductory level: Jackson and Jackson assumes some prior knowledge of chemistry. Krebs (2001) is a successful ecology text that is comprehensive but assumes no prior knowledge of the subject. Folke (1999) is a brief overview of ecological principles as they relate to ecological economics, and provides useful references to the literature. As it is set out here, the idea of resilience as a property of an ecosystem is developed in Holling (1986). The paper by Ludwig *et al*. (1997)

is a clear, but technical, exposition of the basic mathematics of Holling resilience and how it relates to another concept of resilience that appears in the ecology literature.

There is no uniquely correct way to classify the services that the environment provides to the economy. Barbier *et al*. (1994), in Table 3.1, provide a four-way classification of what they call the 'life support functions of ecosystems' into regulation, production, carrier and information functions. Costanza *et al*. (1997) distinguish 17 classes of 'ecosystem service'. Common (1995), Dasgupta (1982) and Perrings (1987) consider economy–environment interdependence and some of its implications from an economics perspective. D'Arge and Kogiku (1972) is an early contribution to the resource and environmental economics literature that contains a growth model which obeys the law of conservation of matter. As noted in the body of the chapter, the economist who did most to draw the attention of economists to the laws of thermodynamics and their implications for economics was Nicholas Georgescu-Roegen; various assessments of his contribution are presented in a special issue of the journal *Ecological Economics*, Vol. 22, no 3, September 1997.

Barbier *et al*. (1994) is a good introduction to biodiversity issues. Wilson's classic work (Wilson, 1988) on biodiversity has been updated as *Biodiversity II* (Reaka-Kudla *et al*., 1996). UNEP (1995) is a definitive reference work in this field, dealing primarily with definition and measurement of biodiversity loss, but also containing good chapters on economics and policy. See also Groombridge (1992) and Jeffries (1997) for excellent accounts of biodiversity from an ecological perspective. Measurement and estimation of biodiversity are examined in depth in Hawksworth (1995), and regular updated accounts are provided in the annual publication *World Resources*. The state of the worlds' ecosystems and biodiversity was extensively reviewed in the Millennium Ecosystem Assessment, information about which and publications arising from which can be accessed at http://www.millenniumassessment.org/. The extent of human domination of global ecosystems is considered in Vitousek *et al*. (1997); for the range of uncertainty attending such estimates see Field (2001). The Global Footprint Network, see http://www.footprintnetwork.org/, produces and reports annual update estimates of national and global ecological footprints. Wackernagel and Rees (1996) is a simple introduction to ecological footprints which describes methods of calculation and reports a variety of results. The organisation Redefining Progress is active in promoting the idea of ecological footprinting, and further information is available at www.redefiningprogress.org, where there can also be found work on Genuine Progress Indicators. In March 2000, *Ecological Economics*, Vol. 32, no 3, included a forum comprising 12 short papers on the ecological footprint. Several of these papers set out the limitations of the concept as a guide to policy.

The IPAT identity was introduced in Ehrlich and Holdren (1971); see also Ehrlich and Ehrlich (1990). It was originally set out as $I \equiv PCT$ where C stands for consumption, but IPAT is a better acronym than IPCT, and it is income per capita rather than consumption that matters and is most easily measured. The identity indicates the scale of technological change that is necessary to hold impact constant for any given change in population and/or affluence. The feasible prospects for technological change are discussed in von Weizşker *et al*. (1997) – it is claimed that T could be reduced by a factor of four, so that affluence could double and impact be cut by 50%, for constant population. Lovins *et al*. (2000) is even more optimistic about technological possibilities.

Becker (1960) is the classic original source of the literature on the economics of population. Easterlin (1978) provides a comprehensive and non-mathematical survey of the economic theory of fertility, and his 1980 volume provides an excellent collection of readings.

The EKC hypothesis was the subject of a special issue of the journal *Environment and Development Economics* in October 1997 (Vol. 2, part 4), and also of the journal *Ecological Economics* in May 1998 (Vol. 25, no 2). See also de Bruyn and Heintz (1999). Useful recent surveys and assessments are Dinda (2004), Stern (2004) and Müller-Fürstenberger and Wagner (2007).

The UNDP's annual *Human Development Report* is the best single source of data and commentary on the global situation in regard to affluence, poverty

and inequality. As well as basic data, each year it reports country performance against a series of indices intended to capture several dimensions of human development. Arndt (1978) is a very interesting account of the rise to the top of the policy agenda of the growth objective in the 1950s and 1960s, and of reaction to claims that continuing economic growth was infeasible due to environmental limits. Useful accounts of debates over limits to growth are to be found in Simon (1981), Simon and Kahn (1984) and Repetto (1985). The October 1998 issue (Vol. 3, part 4) of the journal *Environment and Development Economics* included several papers which revisited the debate over *The Limits to Growth* in response to an article in *The Economist* with the title 'Environmental scares: plenty of gloom'.

McCormick (1989) provides a useful account of the modern history of environmental concerns and their impact on politics, and traces the evolution of the development versus environment debate through the various international conferences which preceded the publication of the Brundtland report. That report (WCED, 1987) is essential reading on sustainable development.

One very important dimension of the sustainability problem, where many particular issues come together and interact, is the matter of feeding the human population. We have not been able to cover this here because of space limitations. The Companion Website discusses some of the issues, and provides pointers to further reading.

Discussion questions

1. Many economists accept that a 'Spaceship Earth' characterisation of the global economy (see Box 1.1) is valid in the final analysis, but would dispute a claim that we are currently close to a point at which it is necessary to manage the economy according to strict principles of physical sustainability. On the contrary, they would argue that urgent problems of malnutrition and poverty dominate our current agenda, and the solution to these is more worthy of being our immediate objective. The objective of physically sustainable management must be attained eventually, but is not an immediate objective that should be pursued to the exclusion of all else.

   To what extent do you regard this as being a valid argument?

2. How effective are measures designed to increase the use of contraception in reducing the rate of population growth?

3. How may the role and status of women affect the rate of population growth? What measures might be taken to change that role and status in directions that reduce the rate of population growth?

4. Does economic growth inevitably lead to environmental degradation?

Problems

1. Use the microeconomic theory of fertility to explain how increasing affluence may be associated with a reduction in the fertility rate.

2. Suppose that families paid substantial dowry at marriage. What effect would this have on desired family size?

3. What effect would one predict for desired family size if family members were to cease undertaking unpaid household labour and undertake instead marketed labour?

4. Take the following data as referring to 2000 (they come from UNDP (2001), P and A are for 1999 and T uses CO_2 data for 1997), and the world as being the sum of these three groups of nations.

	P (millions)	*A* (PPP US$)	*T* (tonnes)
Rich OECD	848	26 050	0.0004837
EE and CIS	398	6 290	0.0011924
Developing	4 610	3 530	0.0005382

a. Calculate total world CO_2 emissions in 2000.
b. Work out the 2000 group shares of total population and CO_2 emissions.
c. Assume population growth at 0.5% per year in Rich OECD and EE and CIS and at 1.5% per year in Developing, out to 2050. Assume per capita income growth at 1.5% per year in Rich OECD, at 2.5% per year in EE and CIS, and at 3.0% in Developing, out to 2050. Work out total world emissions and group shares of the total for 2050, and also group shares of world population.

   By what factor does total world emissions increase over the 50-year period?
d. For the same population growth and per capita income growth assumptions, by how much would *T* have to fall in Rich OECD for that group's 2050 emissions to be the same as in 2000? With Rich OECD emissions at their 2000 level in 2050, assume that *T* for EE and CIS in 2050 is the same as *T* for Rich OECD in 2000 (which would be 2050 *T* for EE and CIS, being about half of its 2000 level) and work out what total world CO_2 emissions would then be.