PART I Foundations

CHAPTER 1 An introduction to natural resource and environmental economics

Contemplation of the world's disappearing supplies of minerals, forests, and other exhaustible assets has led to demands for regulation of their exploitation. The feeling that these products are now too cheap for the good of future generations, that they are being selfishly exploited at too rapid a rate, and that in consequence of their excessive cheapness they are being produced and consumed wastefully has given rise to the conservation movement.

Hotelling (1931)

Learning objectives

In this chapter you will

- be introduced to the concepts of efficiency, optimality and sustainability
- learn about the history of natural resource and environmental economics
- have the main issues of modern resource and environmental economics identified
- see an overview and outline of the structure of this text

Introduction

The three themes that run through this book are efficiency, optimality and sustainability. In this chapter we briefly explain these themes, and then look at the emergence of the field of study which is the economic analysis of natural resources and the environment. We then identify some of the key features of that field of study, and indicate where, later in the book, the matters raised here are discussed more fully.

1.1 Three themes

The concepts of efficiency and optimality are used in specific ways in economic analysis. We will be discussing this at some length in Chapter 4. However, a brief intuitive account here will be useful. One way of thinking about efficiency is in terms of missed opportunities. If resource use is wasteful in some way then opportunities are being squandered; eliminating that waste (or inefficiency) can bring net benefits to some group of people. An example is energy inefficiency. It is often argued that much energy is produced or used inefficiently, and that if different techniques were employed significant resource savings could be gained with no loss in terms of final output.

This kind of argument usually refers to some kind of technical or physical inefficiency. Economists usually assume away this kind of inefficiency, and focus on allocative inefficiencies. Even where resources are used in technically efficient ways, net benefits are sometimes squandered. For example, suppose that electricity can be, in technically efficient ways, generated by the burning of either some heavily polluting fossil fuel, such as coal, or a less polluting alternative fossil fuel, such as gas. Because of a lower price for the former fuel, it is chosen by profit-maximising electricity producers. However, the pollution results in damages which necessitate expenditure on health care and clean-up operations. These expenditures, not borne by the electricity supplier, may exceed the cost saving that electricity producers obtain from using coal.

If this happens there is an inefficiency that results from resource allocation choices even where there are no technical inefficiencies. Society as a whole would obtain positive net benefits if the less polluting alternative were used. We show throughout the book that such allocative inefficiencies will be pervasive in the use of natural and environmental resources in pure market economies. A substantial part of environmental economics is concerned with how economies might avoid inefficiencies in the allocation and use of natural and environmental resources.

The second concept – optimality – is related to efficiency, but is distinct from it. To understand the idea of optimality we need to have in mind:

1. a group of people taken to be the relevant 'society';
2. some overall objective that this society has, and in terms of which we can measure the extent to which some resource-use decision is desirable from that society's point of view.

Then a resource-use choice is socially optimal if it maximises that objective given any relevant constraints that may be operating.

As we shall see (particularly in Chapter 4), the reason efficiency and optimality are related is that it turns out to be the case that a resource allocation cannot be optimal unless it is efficient. That is, efficiency is a necessary condition for optimality. This should be intuitively obvious: if society squanders opportunities, then it cannot be maximising its objective (whatever that might be). However, efficiency is not a sufficient condition for optimality; in other words, even if a resource allocation is efficient, it may not be socially optimal. This arises because there will almost always be a multiplicity of different efficient resource allocations, but only one of those will be 'best' from a social point of view. Not surprisingly, the idea of optimality also plays a role in economic analysis.

The third theme is sustainability. For the moment we can say that sustainability involves taking care of posterity. Why this is something that we need to consider in the context of resource and environmental economics is something that we will discuss in the next chapter. Exactly what 'taking care of posterity' might mean is discussed in Chapter 3. On first thinking about this, you might suspect that, given optimality, a concept such as sustainability is redundant. If an allocation of resources is socially optimal, then surely it must also be sustainable? If sustainability matters, then presumably it would enter into the list of society's objectives and would get taken care of in achieving optimality. Things are not quite so straightforward. The pursuit of optimality as usually considered in economics will not necessarily take adequate care of posterity. If taking care of posterity is seen as a moral obligation, then the pursuit of optimality as economists usually specify it will need to be constrained by a sustainability requirement.

1.2 The emergence of resource and environmental economics

We now briefly examine the development of resource and environmental economics from the time of the industrial revolution in Europe.

1.2.1 Classical economics: the contributions of Smith, Malthus, Ricardo and Mill to the development of natural resource economics

While the emergence of natural resource and environmental economics as a distinct sub-discipline has been a relatively recent event, concern with the substance of natural resource and environmental issues has much earlier antecedents. It is evident, for example, in the writings of the classical economists, for whom it was a major concern. The label 'classical' identifies a number of economists writing in the eighteenth and nineteenth centuries, a period during which the industrial revolution was taking place (at least in much of Europe and North America) and agricultural productivity was growing rapidly. A recurring theme of political–economic debate concerned the appropriate institutional arrangements for the development of trade and growth.

These issues are central to the work of Adam Smith (1723–1790). Smith was the first writer to systematise the argument for the importance of markets in allocating resources, although his emphasis was placed on what we would now call the dynamic effects of markets. His major work, *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776), contains the famous statement of the role of the 'invisible hand':

> But it is only for the sake of profit that any man employs a capital in the support of industry; and he will always, therefore, endeavour to employ it in the support of that industry of which the produce is likely to be of the greatest value, or to exchange for the greatest quantity, either of money or of other goods.
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> As every individual, therefore, endeavours as much as he can both to employ his capital in the support of domestic industry, and so to direct that industry that its produce may be of the greatest value; every individual necessarily labours to render the annual revenue of the society as great as he can. He generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it . . . he is, in this as in many other cases, led by an invisible hand to promote an end which was no part of his intention . . .
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> . . . By pursuing his own interest he frequently promotes that of society more effectively than when he really intends to promote it.
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> *Smith ([1776] 1961), Book IV, Ch. 2, p. 477*

This belief in the efficacy of the market mechanism is a fundamental organising principle of the policy prescriptions of modern economics, including resource and environmental economics, as will be seen in our account of it in the rest of the book.

A central interest of the classical economists was the question of what determined standards of living and economic growth. Natural resources were seen as important determinants of national wealth and its growth. Land (sometimes used to refer to natural resources in general) was viewed as limited in its availability. When to this were added the assumptions that land was a necessary input to production and that it exhibited diminishing returns, the early classical economists came to the conclusion that economic progress would be a transient feature of history. They saw the inevitability of an eventual stationary state, in which the prospects for the living standard of the majority of people were bleak.

This thesis is most strongly associated with Thomas Malthus (1766–1834), who argued it most forcefully in his *Essay on the Principle of Population* (1798), giving rise to the practice of describing those who now question the feasibility of continuing long-run economic growth as 'neo-Malthusian'. For Malthus, a fixed land quantity, an assumed tendency for continual positive population growth, and diminishing returns in agriculture implied a tendency for output per capita to fall over time. There was, according to Malthus, a long-run tendency for the living standards of the mass of people to be driven down to a subsistence level. At the subsistence wage level, living standards would be such that the population could just reproduce itself, and the economy would attain a steady state with a constant population size and constant, subsistence-level, living standards.

This notion of a steady state was formalised and extended by David Ricardo (1772–1823), particularly in his *Principles of Political Economy and Taxation* (1817). Malthus's assumption of a fixed stock of land was replaced by a conception in which land was available in parcels of varying quality. Agricultural output could be expanded by increasing the intensive margin (exploiting a given parcel of land more intensively) or by increasing the extensive margin (bringing previously uncultivated land into productive use). However, in either case, returns to the land input were taken to be diminishing. Economic development then proceeds in such a way that the 'economic surplus' is appropriated increasingly in the form of rent, the return to land, and development again converges toward a Malthusian stationary state.

In the writings of John Stuart Mill (1806–1873) (see in particular Mill (1857)) one finds a full statement of classical economics at its culmination. Mill's work utilises the idea of diminishing returns, but recognises the countervailing influence of the growth of knowledge and technical progress in agriculture and in production more generally. Writing in Britain when output per person was apparently rising, not falling, he placed less emphasis on diminishing returns, reflecting the relaxation of the constraints of the extensive margin as colonial exploitation opened up new tranches of land, as fossil fuels were increasingly exploited, and as innovation rapidly increased agricultural productivity. The concept of a stationary state was not abandoned, but it was thought to be one in which a relatively high level of material prosperity would be attained.

Foreshadowing later developments in environmental economics, and the thinking of conservationists, Mill adopted a broader view of the roles played by natural resources than his predecessors. In addition to agricultural and extractive uses of land, Mill saw it as a source of amenity values (such as the intrinsic beauty of countryside) that would become of increasing relative importance as material conditions improved. We discuss a modern version of this idea in Chapter 11.

Mill's views are clearly revealed in the following extract from his major work.

> Those who do not accept the present very early stage of human improvement as its ultimate type may be excused for being comparatively indifferent to the kind of economic progress which excites the congratulations of ordinary politicians: the mere increase of production . . . It is only in the backward countries of the world that increased production is still an important object; in those most advanced, what is needed is a better distribution . . . There is room in the world, no doubt, and even in old countries, for a great increase in population, supposing the arts of life to go on improving, and capital to increase. But even if innocuous, I confess I see very little reason for desiring it. The density of population necessary to enable mankind to obtain, in the greatest degree, all of the advantages both of cooperation and of social intercourse, has, in all the most populous countries, been attained. A population may be too crowded, though all be amply supplied with food and raiment. It is not good for man to be kept perforce at all times in the presence of his species . . . Nor is there much satisfaction in contemplating the world with nothing left to the spontaneous activity of nature: with every rood of land brought into cultivation, which is capable of growing food for human beings; every flowery waste or natural pasture ploughed up, all quadrupeds or birds which are not domesticated for man's use exterminated as his rivals for food, every hedgerow or superfluous tree rooted out, and scarcely a place left where a wild shrub or flower could grow without being eradicated as a weed in the name of improved agriculture. If the earth must lose that great portion of its pleasantness which it owes to things that the unlimited increase of wealth and population would extirpate from it, for the mere purpose of enabling it to support a larger, but not a happier or better population, I sincerely hope, for the sake of posterity, that they will be content to be stationary long before necessity compels them to it.
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> *Mill (1857), Book IV*

It is worth noting explicitly that at the time that Mill wrote this the global population was less than one quarter of what it is now, and that average per capita income, as gross domestic product (GDP), in the then rich parts of the world was of the order of 10% of what it is now.[1] We briefly review some of the recent research on the determinants of self-assessed individual human happiness in Chapter 3.

1.2.2 Neoclassical economics: marginal theory and value

A series of major works published in the 1870s began the replacement of classical economics by what subsequently became known as 'neoclassical economics'. One outcome of this was a change in the manner in which value was explained. Classical economics saw value as arising from the labour power embodied (directly and indirectly) in output, a view which found its fullest embodiment in the work of Karl Marx. Neoclassical economists explained value as being determined in exchange, so reflecting preferences and costs of production. The concepts of price and value ceased to be distinct. Moreover, previous notions of absolute scarcity and value were replaced by a concept of relative scarcity, with relative values (prices) determined by the forces of supply and demand. This change in emphasis paved the way for the development of welfare economics, to be discussed shortly.

At the methodological level, the technique of marginal analysis was adopted, allowing earlier notions of diminishing returns to be given a formal basis in terms of diminishing marginal productivity in the context of an explicit production function. Jevons (1835–1882) and Menger (1840–1921) formalised the theory of consumer preferences in terms of utility and demand theory. The evolution of

[1] These statements are based on estimates in Table 2.1 in Maddison (2007). It gives world population as 1272 million in 1870 and 6279 million in 2003, and per capita GDP for Western Europe as 1960 1990$s in 1870 and 19 912 1990$s in 2003.

neoclassical economic analysis led to an emphasis on the structure of economic activity, and its allocative efficiency, rather than on the aggregate level of economic activity. Concern with the prospects for continuing economic growth receded, perhaps reflecting the apparent inevitability of growth in Western Europe at this time. Leon Walras (1834–1910) developed neoclassical General Equilibrium Theory, and in so doing provided a rigorous foundation for the concepts of efficiency and optimality that we employ extensively in this text. Alfred Marshall (1842–1924) (see *Principles of Economics*, 1890) was responsible for elaboration of the partial equilibrium supply-and-demand-based analysis of price determination so familiar to students of modern microeconomics. A substantial part of modern environmental economics continues to use these techniques as tools of exposition, as do we at many points throughout the book.

We remarked earlier that concern with the level (and the growth) of economic activity had been largely ignored in the period during which neoclassical economics was being developed. Economic depression in the industrialised economies in the inter-war years provided the backcloth against which John Maynard Keynes (1883–1946) developed his theory of income and output determination. The Keynesian agenda switched attention to aggregate supply and demand, and the reasons why market economies may fail to achieve aggregate levels of activity that involve the use of all of the available inputs to production. Keynes was concerned to explain, and provide remedies for, the problem of persistent high levels of unemployment, or recession.

This direction of development in mainstream economics had little direct impact on the emergence of resource and environmental economics. However, Keynesian 'macroeconomics', as opposed to the microeconomics of neoclassical economics, was of indirect importance in stimulating a resurgence of interest in growth theory in the middle of the twentieth century, and the development of a neoclassical theory of economic growth. What is noticeable in early neoclassical growth models is the absence of land, or any natural resources, from the production function used in such models. Classical limits-to-growth arguments, based on a fixed land input, did not have any place in early neoclassical growth modelling.

The introduction of natural resources into neoclassical models of economic growth occurred in the 1970s, when some neoclassical economists first systematically investigated the efficient and optimal depletion of resources. This body of work, and the developments that have followed from it, is natural resource economics. The models of efficient and optimal exploitation of natural resources that we present and discuss in Chapters 14, 15, 17 and 18 are based on the writings of those authors. We will also have call to look at such models in Chapter 19, where we discuss the theory of accounting for the environment as it relates to the question of sustainability.

1.2.3 Welfare economics

The final development in mainstream economic theory that needs to be briefly addressed here is the development of a rigorous theory of welfare economics. Welfare economics, as you will see in Chapter 4, attempts to provide a framework in which normative judgements can be made about alternative configurations of economic activity. In particular, it attempts to identify circumstances under which it can be claimed that one allocation of resources is better (in some sense) than another.

Not surprisingly, it turns out to be the case that such rankings are only possible if one is prepared to accept some ethical criterion. The most commonly used ethical criterion adopted by classical and neoclassical economists derives from the utilitarian moral philosophy, developed by David Hume, Jeremy Bentham and John Stuart Mill. We explore this ethical structure in Chapter 3. Suffice to say now that utilitarianism has social welfare consisting of some weighted average of the total utility levels enjoyed by all individuals in the society.

Economists have attempted to find a method of ranking different states of the world which does not require the use of a social welfare function, and makes little use of ethical principles, but is nevertheless useful in making prescriptions about resource allocation. The notion of economic efficiency, also known as allocative efficiency or Pareto optimality (because it was developed by Vilfredo Pareto (1897)), is what they have come up with. These ideas are examined at length in Chapter 4. It can be shown that, given certain rather stringent conditions, an economy organised as a competitive market economy will attain a state of economic efficiency. This is the modern, and rigorous, version of Adam Smith's story about the benign influence of the invisible hand.

Where the conditions do not hold, markets do not attain efficiency in allocation, and a state of 'market failure' is said to exist. One manifestation of market failure is the phenomenon of 'externalities'. These are situations where, because of the structure of property rights, relationships between economic agents are not all mediated through markets. Market failure and the means for its correction will be discussed in Chapter 4.

The problem of pollution is a major concern of environmental economics. It first attracted the attention of economists as a particular example of the general class of externalities. Important early work in the analysis of externalities and market failure is to be found in Marshall (1890). The first systematic analysis of pollution as an externality is to be found in Pigou (1920). However, environmental economics did not really 'take off' until the 1970s. The modern economic treatment of problems of environmental pollution is covered in Chapters 5, 6 and 7, and in Chapter 16.

Environmental economics is also concerned with the natural environment as a source of recreational and amenity services, which is what Mill was drawing attention to in the quotation above. This role for the environment can be analysed using concepts and methods similar to those used in looking at pollution problems. This branch of modern environmental economics is covered in Chapters 11, 12 and 13. Like pollution economics, it makes extensive use of the technique of cost–benefit analysis, which emerged in the 1950s and 1960s as a practical vehicle for applied welfare economics and policy advice. The basic structure and methodology of cost–benefit analysis is dealt with in Chapter 11, building on the discussion of market failure and public policy in Chapter 4.

The modern sub-disciplines of natural resource economics and environmental economics have largely distinct roots in the core of modern mainstream economics. The former emerged mainly out of neoclassical growth economics, the latter out of welfare economics and the study of market failure. Both can be said to date effectively from the early 1970s, though of course earlier contributions can be identified.

1.2.4 Ecological economics

Ecological economics is a relatively new, interdisciplinary, field. In the 1980s a number of economists and natural scientists came to the conclusion that if progress was to be made in understanding and addressing environmental problems it was necessary to study them in an interdisciplinary way. The International Society for Ecological Economics was set up in 1989. The precise choice of name for this society may have been influenced by the fact that a majority of the natural scientists involved were ecologists, but more important was the fact that economics and ecology were seen as the two disciplines most directly concerned with what was seen as the central problem – sustainability.

Ecology is the study of the distribution and abundance of animals and plants. A central focus is an ecosystem, which is an interacting set of plant and animal populations and their abiotic, non-living, environment. The Greek word 'oikos' is the common root for the 'eco' in both economics and ecology. Oikos means 'household', and it could be said that ecology is the study of nature's housekeeping, while economics is the study of human housekeeping. Ecological economics could then be said to be the study of how these two sets of housekeeping are related to one another. Earlier in this chapter we said that sustainability involves taking care of posterity. Most of those who would wish to be known as ecological economists are concerned that the scale of human housekeeping is now such that it threatens the viability of nature's housekeeping in ways which will adversely affect future generations of humans.

The distinguishing characteristic of ecological economics is that it takes as its starting point and its central organising principle the fact that the economic system is part of the larger system that is planet earth. It starts from the recognition that the economic and environmental systems are interdependent, and studies the joint economy–environment system in the light of principles from the natural sciences, particularly thermodynamics and ecology. We shall briefly discuss these matters in the next chapter, which has the title ‘The origins of the sustainability problem’, as it is the interdependence of economic and natural systems that gives rise to the sustainability problem.

Kenneth Boulding is widely regarded as one of the ‘founding fathers’ of ecological economics. Box 1.1 summarises a paper that he wrote in 1966 which uses vivid metaphors to indicate the change in ways of thinking that he saw as necessary, given the laws of nature and their implications for economic activity. As we have seen, the dependence of economic activity on its material base – the natural environment – was a central concern of classical economics, but not of neoclassical economics. Boulding was one of a few scholars, including some economists, who continued, during the ascendancy of neoclassical economics, to insist on the central importance of studying economics in a way which takes on board what is known about the laws of nature as they affect the material basis for economic activity. As is made clear in Box 1.1, Boulding did not, and ecological economics does not, take the view that everything that resource and environmental economics has to say, for example, about using price incentives to deal with environmental problems is wrong. Rather, the point is that what it has to say needs to be put in the proper context, one where the economic system is seen as a subsystem of a larger system.

Box 1.1 Economics of ‘Spaceship Earth’

In a classic paper written in 1966, ‘The economics of the coming Spaceship Earth’, Kenneth Boulding discusses a change in orientation that is required if mankind is to achieve a perpetually sustainable economy. He begins by describing the prevailing image which man has of himself and his environment. The ‘cowboy economy’ describes a state of affairs in which the typical perception of the natural environment is that of a virtually limitless plain, on which a frontier exists that can be pushed back indefinitely. This economy is an open system, involved in interchanges with the world outside. It can draw upon inputs from the outside environment, and send outputs (in the form of waste residuals and so on) to the outside. In the cowboy economy perception, no limits exist on the capacity of the outside to supply or receive energy and material flows.

Boulding points out that, in such an economy, the measures of economic success are defined in terms of flows of materials being processed or transformed. Roughly speaking, income measures such as GDP or GNP reflect the magnitudes of these flows – the cowboy perception regards it as desirable that these flows should be as large as possible.

However, Boulding argues, this economy is built around a flawed understanding of what is physically possible in the long run. A change in our perception is therefore required to one in which the earth is recognised as being a closed system or, more precisely, a system closed in all but one respect – energy inputs are received from the outside (such as solar energy flows) and energy can be lost to the outside (through radiative flows, for example). In material terms, though, planet earth is a closed system: matter cannot be created or destroyed, and the residuals from extraction, production and consumption activities will always remain with us, in one form or another.

Boulding refers to this revised perception as that of the ‘spaceman economy’. Here, the earth is viewed as a single spaceship, without unlimited reserves of anything. Beyond the frontier of the spaceship itself, there exist no reserves from which the spaceship’s inhabitants can draw resources nor sinks into which they can dispose of unwanted residuals. On the contrary, the spaceship is a closed material system, and energy inputs from the outside are limited to those perpetual but limited flows that can be harnessed from the outside, such as solar radiation.

Within this spaceship, if mankind is to survive indefinitely, man must find his place in a perpetually reproduced ecological cycle. Materials usage is limited to that which can be recycled in each time period; that, in turn, is limited by the quantity of solar and other external energy flows received by the spaceship.

Box 1.1 ***continued***

What is an appropriate measure of economic performance in spaceship earth? It is not the magnitude of material flows, as measured by GNP or the like. On the contrary, it is desirable that the spaceship maintain such flows of material and energy throughput at low levels. Instead, the well-being of the spaceship is best measured by the state – in terms of quality and quantity – of its capital stock, including the state of human minds and bodies.

So, for Boulding, a 'good' state to be in is one in which certain stocks are at high levels – the stock of knowledge, the state of human health, and the stock of capital capable of yielding human satisfaction. Ideally we should aim to make material and energy flows as small as possible to achieve any chosen level of the spaceship's capital stock, maintained over indefinite time.

Boulding is, of course, arguing for a change in our perceptions of the nature of economy–environment interactions, and of what it is that constitutes economic success. He states that

> The shadow of the future spaceship, indeed, is already falling over our spendthrift merriment. Oddly enough, it seems to be in pollution rather than exhaustion, that the problem is first becoming salient. Los Angeles has run out of air, Lake Erie has become a cesspool, the oceans are getting full of lead and DDT, and the atmosphere may become man's major problem in another generation, at the rate at which we are filling it up with junk.

Boulding concludes his paper by considering the extent to which the price mechanism, used in a way to put prices on external diseconomies, can deal with the transition to spaceship earth. He accepts the need for market-based incentive schemes to correct such diseconomies, but argues that these instruments can only deal with a small proportion of the matters which he raises. Boulding concludes:

> The problems which I have been raising in this paper are of larger scale and perhaps much harder to solve . . . One can hope, therefore, that as a succession of mounting crises, especially in pollution, arouse public opinion and mobilize support for the solution of the immediate problems, a learning process will be set in motion which will eventually lead to an appreciation of and perhaps solutions for the larger ones.

Source: Boulding (1966)

To date, the impact of ecological economics on the approach to the natural environment that emerged from mainstream economics has been somewhat limited, and this book will largely reflect that. We will be dealing mainly with mainstream resource and environmental economics, though the next two chapters do address the problem of sustainability. While the theme of sustainability runs through the book, it is not obviously at the forefront in Chapters 4 to 18 which are, mainly, about the mainstream approach. We do, however, at some points in those chapters briefly consider how adopting an ecological economics perspective would affect analysis and policy. In the final chapter of the book, Chapter 19, sustainability returns to the forefront in the context of a discussion of the prospects for promoting it by better economic accounting.

1.3 Fundamental issues in the economic approach to resource and environmental issues

Here we provide a brief anticipatory sketch of four features of the economic approach to resource and environmental issues that will be covered in this book.

1.3.1 Property rights, efficiency and government intervention

We have already stated that a central question in resource and environmental economics concerns allocative efficiency. The role of markets and prices is central to the analysis of this question. As we have noted, a central idea in modern economics is that, given the necessary conditions, markets will bring about efficiency in allocation. Well-defined and enforceable private property rights are one of the necessary conditions. Because property rights do not exist, or are not clearly defined, for many environmental resources, markets fail to allocate those resources efficiently. In such circumstances, price signals fail to reflect true social costs and benefits, and a prima facie case exists for government policy intervention to seek efficiency gains.

Deciding where a case for intervention exists, and what form it should take, is central in all of resource and environmental economics, as we shall see throughout the rest of this book. The foundations for the economic approach to policy analysis are set out in Chapter 4, and the approach is applied in the subsequent chapters. Some environmental problems cross the boundaries of nation states and are properly treated as global problems. In such cases there is no global government with the authority to act on the problem in the same way as the government of a nation state might be expected to deal with a problem within its borders. The special features of international environmental problems are considered in Chapter 9.

1.3.2 The role, and the limits, of valuation, in achieving efficiency

As just observed, many environmental resources – or the services yielded by those resources – do not have well-defined property rights. Clean air is one example of such a resource. Such resources are used, but without being traded through markets, and so will not have market prices. A special case of this general situation is external effects, or externalities. As discussed in Chapter 4, an externality exists where a consumption or production activity has unintended effects on others for which no compensation is paid. Here, the external effect is an untraded – and unpriced – product arising because the victim has no property rights that can be exploited to obtain compensation for the external effect. Sulphur emissions from a coal-burning power station might be an example of this kind of effect.

However, the absence of a price for a resource or an external effect does not mean that it has no value. Clearly, if well-being is affected, there is a value that is either positive or negative depending on whether well-being is increased or decreased. In order to make allocatively efficient decisions, these values need to be estimated in some way. Returning to the power station example, government might wish to impose a tax on sulphur emissions so that the polluters pay for their environmental damage and, hence, reduce the amount of it to the level that goes with allocative efficiency. But this cannot be done unless the proper value can be put on the otherwise unpriced emissions.

There are various ways of doing this – collectively called valuation techniques – which will be explored at some length in Chapter 12. Such techniques are somewhat controversial. There is disagreement between economists over the extent to which the techniques can be expected to produce accurate valuations for unpriced environmental services. These are discussed in Chapter 12. Many non-economists with an interest in how social decisions that affect the environment are made raise rather more fundamental problems about the techniques and their use. Their objection is not, or at least not just, that the techniques may provide the wrong valuations. Rather, they claim that making decisions about environmental services on the basis of monetary valuations of those services is simply the wrong way for society to make such decisions. These objections, and some alternative ways proposed for society to make decisions about the environment, are considered in Chapter 11.

1.3.3 The time dimension of economic decisions

Natural resource stocks can be classified in various ways. A useful first cut is to distinguish between 'stock' and 'flow' resources. Whereas stock resources, plant and animal populations and mineral deposits, have the characteristic that today's use has implications for tomorrow's availability, this is not the case with flow resources. Examples of flow resource are solar radiation, and the power of the wind, of tides and of flowing water. Using more solar radiation today does not itself have any implications for the availability of solar radiation tomorrow. In the case of stock resources, the level of use today does have implications for availability tomorrow.

Within the stock resources category there is an important distinction between ‘renewable’ and ‘non-renewable’ resources. Renewable resources are biotic, plant and animal populations, and have the capacity to grow in size over time, through biological reproduction. Non-renewable resources are abiotic, stocks of minerals, and do not have that capacity to grow over time. What are here called non-renewable resources are sometimes referred to as ‘exhaustible’, or ‘depletable’, resources. This is because there is no positive constant rate of use that can be sustained indefinitely – eventually the resource stock must be exhausted. This is not actually a useful terminology. Renewable resources are exhaustible if harvested for too long at a rate exceeding their regeneration capacities.

From an economic perspective, stock resources are assets yielding flows of environmental services over time. In considering the efficiency and optimality of their use, we must take account not only of use at a point in time but also of the pattern of use over time. Efficiency and optimality have, that is, an intertemporal, or dynamic, dimension, as well as an intratemporal, or static, dimension. Chapter 11 sets out the basics of intertemporal welfare economics. In thinking about the intertemporal dimension of the use of environmental resources, attention must be given to the productiveness of the capital that is accumulated as a result of saving and investment. If, by means of saving and investment, consumption is deferred to a later period, the increment to future consumption that follows from such investment will generally exceed the initial consumption quantity foregone. The size of the pay-off to deferred consumption is reflected in the rate of return to investment.

Environmental resource stocks similarly have rates of return associated with their deferred use. The relations between rates of return to capital as normally understood in economics and the rates of return on environmental assets must be taken into account in trying to identify efficient and optimal paths of environmental resource use over time. The arising theory of the efficient and optimal use of natural and environmental resources over time is examined in Chapters 14, 15, 17 and 18, and is drawn on in Chapter 19. As discussed in Chapter 16, many pollution problems also have an intertemporal dimension, and it turns out that the analysis developed for thinking about the intertemporal problems of resource use can be used to analyse those problems.

1.3.4 Substitutability and irreversibility

Substitutability and irreversibility are important, and related, issues in thinking about policy in relation to the natural environment. If the depletion of a resource stock is irreversible, and there is no close substitute for the services that it provides, then clearly the rate at which the resource is depleted has major implications for sustainability. To the extent that depletion is not irreversible and close substitutes exist, there is less cause for concern about the rate at which the resource is used.

There are two main dimensions to substitutability issues. First, there is the question of the extent to which one natural resource can be replaced by another. Can, for example, solar power substitute for the fossil fuels on a large scale? This is, as we shall see, an especially important question given that the combustion of fossil fuels not only involves the depletion of non-renewable resources, but also is a source of some major environmental pollution problems, such as the so-called greenhouse effect which entails the prospect of global climate change, as discussed in Chapter 9.

Second, there is the question of the degree to which an environmental resource can be replaced by other inputs, especially the human-made capital resulting from saving and investment. As we shall see, in Chapters 3, 14 and 19, this question is of particular significance when we address questions concerning long-run economy–environment interactions, and the problem of sustainability.

Human-made capital is sometimes referred to as reproducible capital, identifying an important difference between stocks of it and stocks of non-renewable resources. The latter are not reproducible, and their exploitation is irreversible in a way that the use of human-made capital is not. We shall discuss this further in the next chapter, and some arising implications in later chapters, especially 14 and 19. With renewable resource stocks, depletion is reversible to the extent that harvesting is at rates that allow regeneration. Some of the implications are discussed in Chapter 17. Some pollution problems may involve irreversible effects, and the extinction of a species of plant or animal is certainly irreversible.

Some assemblages of environmental resources are of interest for the amenity services, recreation and aesthetic enjoyment that they provide, as well as for their potential use as inputs to production. A wilderness area, for example, could be conserved as a national park or developed for mining. Some would also argue that there are no close substitutes for the services of wilderness. A decision to develop such an area would be effectively irreversible, whereas a decision to conserve would be reversible. We show in Chapter 13 that under plausible conditions this asymmetry implies a stronger preference for non-development than would be the case where all decisions are reversible, and that this is strengthened when it is recognised that the future is not known with certainty. Imperfect knowledge of the future is, of course, the general condition, but it is especially relevant to decision making about many environmental problems, and has implications for how we think about making such decisions.

1.4 Reader's guide

We have already noted in which chapters various topics are covered. Now we will briefly set out the structure of this text, and explain the motivation for that structure.

In Part I we deal with 'Foundations' of two kinds. First, in Chapter 2, we explain why many people think that there is a sustainability problem. We consider the interdependence of the economy and the environment, look at the current state of human development, and at some views on future prospects. Second, in the next two chapters, we work through the conceptual basis and the analytical tools with which economists approach environmental problems. Chapter 3 looks at the ethical basis for policy analysis in economics. Chapter 4 is about welfare economics and markets – what they achieve when they work properly, why they do not always work properly, and what can be done about it when they do not work properly.

Throughout the book we have put as much of the mathematics as is possible in appendices, of which extensive use is made. These appendices will be found on the companion website for this book: www.pearsoned.co.uk/perman. Readers who have learned the essentials of the calculus of constrained optimisation will have no problems with the mathematics used in the appendices in Part I. Appendix 3.1 provides a brief account of the mathematics of constrained optimisation. The arguments of Part I can be followed without using the mathematics in the appendices, but readers who work through them will obtain a deeper understanding of the arguments and their foundations.

Part II is about 'Environmental pollution'. It turns out that much, but not all, of what economists have to say about pollution problems relates to the question of intratemporal allocative efficiency and does not essentially involve a time dimension. The static analysis of pollution problems is the focus of Part II. Static, as opposed to dynamic, analysis follows naturally from the material covered most intensively in Chapter 4, and, subject to an exception to be noted shortly, the mathematics used in the appendices in Part II is of the same kind as used in the appendices in Part I.

Chapter 5 considers the setting of targets for pollution control, and Chapter 6 looks at the analysis of the policy instruments that could be used to meet those targets. In these chapters it is assumed that the government agency responsible for pollution control has complete information about all aspects of the pollution problem to be addressed. This is a patently unrealistic assumption, and Chapter 7 examines the consequences of its relaxation. The analysis in these three chapters is partial, analysing the control of a particular pollutant as if it were the only such problem, and as if what were done about it had no implications for the rest of the economy. Chapter 8, in contrast, takes an approach which looks at the economy as a whole, using input–output analysis and introducing applied general equilibrium modelling. This chapter includes an appendix that provides a brief review of the matrix algebra which facilitates the understanding and application of these methods. Part II finishes with Chapters 9 and 10, which deal, respectively, with environmental problems that cross national frontiers, and with how thinking about international trade is affected by the existence of environmental problems.

Part III has the title ‘Project appraisal’. Its focus is on the rationale for, and application of, the methods and techniques that economists have developed for evaluating whether going ahead with some discrete investment project, or policy innovation, is in the public interest. Of particular concern here, of course, are projects and policies with environmental impacts. Also, the focus is on projects and policies which have consequences stretching out over time. Chapter 11 deals with the principles of intertemporal welfare economics and their application in cost–benefit analysis. Chapter 11 also looks at some alternative methods for project appraisal that have been advocated, especially by those who have ethical objections to the use of cost–benefit analysis where the natural environment is involved. A necessary input to a cost–benefit analysis of a project with effects on the natural environment is a monetary evaluation of those effects. The methods that economists have devised for monetary evaluation of non-marketed environmental services are explained in Chapter 12. Chapter 13 looks at the implications for project appraisal of recognition of the facts that when looking at projects with environmental impacts, we are often dealing with impacts that are irreversible, and always considering future effects about which our knowledge is incomplete.

In Part III the arguments and analysis are developed mainly in the context of the recreation and amenity services that the natural environment provides, though they are, of course, also relevant to the problem of environmental pollution, the focus of Part II. In Part IV we turn to a focus on the issues associated with the extraction of natural resources from the environment for use as inputs to production. The problems that have most interested economists here are essentially dynamic in nature, that is, are problems in intertemporal allocation. In addressing these problems, economists typically use the mathematics of ‘optimal control’. We have minimised the explicit use of this mathematics in the body of the text, but we do make extensive use of it in the appendices in Part IV. For readers not familiar with this sort of mathematics, Appendix 14.1 provides a brief account of it, treating it as an extension of the ideas involved in ordinary constrained optimisation developed in Appendix 3.1.

Chapter 14 introduces the application of the basic ideas about intertemporal optimality and efficiency, developed in Chapter 11, to the question of natural resource extraction. Chapter 15 looks specifically at the extraction of non-renewable resources, that is, stocks of minerals and fossil fuels. The case of renewable resources – populations of plants and animals harvested for use in production and consumption – is dealt with in Chapter 17. Trees are plants with some special characteristics, and Chapter 18 reviews the major elements of forestry economics. Many important pollution problems have the characteristic that the pollutant involved accumulates in the environment as a stock, which may decay naturally over time. Analysis of such pollution problems has much in common with the analysis of natural resource extraction, and is dealt with in Chapter 16. Finally in Part IV we return to the sustainability issue. Chapter 19 is about modifying standard accounting procedures so as to have economic performance indicators reflect environmental impacts, and particularly so as to measure sustainable national income.

Summary

There is not a single methodology used by all economists working on matters related to natural resources and the environment. Ecological economists have argued the need to work towards a more holistic discipline that would integrate natural-scientific and economic paradigms. Some ecological economists argue further that the sustainability problem requires nothing less than a fundamental change in social values, as well as a scientific reorientation. While some movement has been made in the direction of interdisciplinary cooperation, most analysis is still some way from having achieved integration. At the other end of a spectrum of methodologies are economists who see no need to go beyond the application of neoclassical techniques to environmental problems, and stress the importance of constructing a more complete set of quasi-market incentives to induce efficient behaviour. Such economists would reject the idea that existing social values need to be questioned, and many have great faith in the ability of continuing technical progress to ameliorate problems of resource scarcity and promote sustainability. Ecological economists tend to be more sceptical about the extent to which technical progress can overcome the problems that follow from the interdependence of economic and environmental systems.

However, there is a lot of common ground between economists working in the area, and it is this that we mainly focus upon in this text. Nobody who has seriously studied the issues believes that the economy's relationship to the natural environment can be left entirely to market forces. Hardly anybody now argues that market-like incentives have no role to play in that relationship. In terms of policy, the arguments are about how much governments need to do, and the relative effectiveness of different kinds of policy instruments. Our aim in this book is to work through the economic analysis relevant to these kinds of questions, and to provide information on the resource and environmental problems that they arise from. We begin, in the next chapter, by discussing the general interdependence of the economic and environmental systems, and the concerns about sustainability that this has given rise to.

Further reading

As all save one of the topics and issues discussed in this chapter will be dealt with more comprehensively in subsequent chapters, we shall not make any suggestions for further reading here other than for that one topic – the history of economics. Blaug (1985), *Economic Theory in Retrospect*, is essential reading for anybody who wants to study the history of economic ideas in detail. For those who do not require a comprehensive treatment, useful alternatives are Barber (1967) and Heilbronner (1991). Crocker (1999) is a short overview of the history of environmental and resource economics, providing references to seminal contributions.

The leading specialist journals, in order of date of first issue, are: *Land Economics*, *Journal of Environmental Economics and Management*, *Ecological Economics*, *Environmental and Resource Economics*, *Environment and Development Economics*. The first issue of *Ecological Economics*, February 1989, contains several articles on the nature of ecological economics. The May 2000 issue, Vol. 39, number 3, of the *Journal of Environmental Economics and Management* marks the journal's 25th anniversary and contains articles reviewing the major developments in environmental and resource economics over its lifetime.

The *Journal of Environmental Economics and Management* is run by the Association of Environmental and Resource Economists, whose website at www.aere.org has useful information and links. The equivalent European association is the European Association of Environmental and Resource Economists – www.vwl.unimannheim.de/conrad/eaere/ – which runs the journal *Environmental and Resource Economics*. The address for the website of the International Society for Ecological Economics is www.ecoeco.org/.