Chapter 1
Nature as an Asset

Introduction

We are all asset managers. Whether as farmers or fishermen, hunters or gatherers, foresters or miners, households or companies, governments or communities, we manage the assets we have access to in line with our motivations, as best as we can. This Review pays close attention to a class of assets we call Nature and studies it in relation to the many other assets in our portfolios.

It is commonly accepted that growing urbanisation accompanying economic growth has created a distance between people and the natural world. There is evidence of that (Chapter 11). Rural communities in low income countries are a lot closer to Nature than are urban households in high income countries. Daily engagements in rural Africa require goods and services extracted from the local landscape, in contrast to the daily lives in urban Scandinavia, where people depend equally on and extract more from Nature, but do so at several steps removed, often drawing on natural resources from distant parts of the world. Households in villages in Niger, in contrast to households in towns in Germany, may not have water on tap to drink, wash and cook with, nor access to electricity. One measure of resource degradation facing rural communities in poorer regions is the increased time needed for daily household production (Box 1.1). But exit is not an option, for neighbouring villages also face increasing resource scarcity and out of necessity are not welcoming.

In contrast, degradation of nature in distant lands has little to no bite on the lives of people in high income countries, for there are alternative sources of supply from other parts of the world, at least for now. Pendrill et al. (2019) for example have estimated that about one-sixth of the carbon footprint of the average diet in the European Union can be linked directly to deforestation in tropical countries.

As this is a global Review, we will often speak of the demands humanity makes on Nature. But much of the time we will peer closely at smaller economic units. Differences in the way communities are able to live tell us that people do not experience increasing resource scarcity in the same way. Food, potable water, clothing, a roof over one's head, clean air, a sense of belonging, participating with others in one's community and a reason for hope are no doubt universal needs, but the emphasis people place on the goods and services natural assets supply differs widely. To farmers in South Asia and sub-Saharan Africa it would be declining sources of water and increasing variability in rainfall in the foreground of global climate change; to indigenous populations in Amazonia it would be eviction not just from their physical home, but also from their spiritual home; to inhabitants of shanty towns everywhere the worry would be the infections they are subjected to from open sewers; to hunter-gatherers in the African grasslands it would be their shrinking resource base; to the suburban household in the UK it may be the absence of bees and butterflies in their garden; to residents of mega-cities it would be the poisonous air they breathe; to the multi-national company it could be the worry about supply chains as disruptions to the biosphere makes old sources of primary products unreliable and investments generally more risky; and to governments everywhere it would be the call from citizens, including children, to stem global climate change. Degradation of Nature is not experienced in the same way by everyone.

1.0 Portfolio Management

Nevertheless, their varied experiences have a feature in common: each of the actors – or *agents*, as we may call them – is responding to an asset management problem. Which is why it has become customary among economists to refer to natural resources generically as *natural capital*. It is convenient

(even natural) to create a two-way classification of natural capital in terms of whether the assets are *renewable* such as fisheries (we will use the term 'self-regenerative') or *non-renewable* (fossil fuels, minerals). As this is a review of the economics of biodiversity, we pay attention almost entirely to living systems, which are self-regenerative unless they have been degraded beyond repair.[33]

Biodiversity means the diversity of life. In Chapter 2, it is shown that biodiversity resembles diversity in the portfolios held by manufacturers and financial companies, and that it does so in two ways. First, biodiversity is akin to the complementarities among inputs in factory production, meaning that all inputs are significant in production. Second, biodiversity plays the same role in natural capital as diversity does in financial portfolios: it reduces variability (uncertainty) in yield. For many people the diversity of life has value independent of human wants and needs, but we will find that it pays to build the study of biodiversity's value from an anthropocentric perspective and then add non-anthropocentric perspectives to give further urgency to repairing our relationship with Nature (see Chapter 12). We will confirm, however, that by biodiversity we should not mean a headcount of species – the concept is a lot richer.

By the 'agents' facing asset management problems we do not simply mean individuals. The agent could be a person, household, village, company, the state, a nation or even an international body whose management strategies are reached on the basis of their respective decision-making processes (personal welfare, respect for tradition, bargaining, majority vote, rank order rule, the sway of their Chair and so on). The coin with which the agent chooses her portfolio or commends a portfolio to others depends on her role in the decision-making process. In the local garden centre, she values goods in terms of her personal needs, the quoted prices and her budget; as member of the local council, she would be expected to value maintenance expenditure on the village common in terms of the welfare of the local community; as civil servant, she would be charged, when comparing a wetland reclamation scheme to a highway construction project, to evaluate the options on the basis of a conception of the common good, or more broadly social well-being (Chapters 10–13). It could be that the agent chooses (or recommends) portfolios in a well-functioning economy; it could be that she faces an asset management problem in a society in turmoil; or it could be that she operates in one of the many societies that lie in between. But no matter where and no matter what the context happens to be, she would wish to allocate assets so as to achieve a portfolio that is best under the circumstances. The account we offer below covers all agents – from the individual household, to the corporate fund manager, to the government decision-maker.

Box 1.1
Managing Assets as Daily Chores

Some 65–75% of people in the world's poorest regions are rural (World Bank, 2020a and c). In semi-arid regions of South Asia rural households have been found to spend four to five hours a day collecting water from water holes, gathering firewood, and picking fruit, berries and medicinal herbs from the local vegetation (Cain, 1977). The cooking area in the family hut among the rural poor is organised as what economists call a 'vertically integrated industry'. Daily work there requires women to work from raw materials. There are no pre- cooked meals on offer, nor even processed ingredients. Food preparation can take up to five to six hours a day. Rural women in Bangladesh, for example, have been found to spend 50–55% of their day cooking (Chowdhury et al. 2011).[34]

[33] Throughout, we will use Nature, the natural world, the biosphere, natural resources, and natural capital interchangeably. The context will, we hope, make clear which aspect of Nature we are emphasising.

[34] In an account of daily life of village people in a micro-watershed in the central Himalayas in India, the Centre for Science and Environment (1990) recorded that of the total number of hours worked in a day, 30% was devoted to cultivation, 20% to fodder collection and about 25% was spread evenly between fuel collection, animal care and grazing. Some 20% of time was spent on household chores, of which cooking took up the greatest portion, and the remaining 5% was involved in other activities, such as marketing.

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Mention agricultural land, threshing grounds, grazing fields, village tanks and ponds, woodlands and forests, rivers and streams, coastal fisheries, mangroves, or coral reefs, and the importance of the *local* natural resource base becomes self-evident. Details differ across regions, but such tasks as collecting water, gathering fuel and minding domestic animals are often the responsibility of children. Children have been found to work from as young as six years old. Material needed for repairing homes is prepared using such resources as timber, straw, stone and mud, which are collected locally. Herbs from plants in the vicinity serve to contain illness. It is not that rural households in low income countries do not exchange goods in the market; it is more that, unlike households in high income countries, they produce much of their daily requirements in the home. In fact, the local ecosystem offers more to the household. Pattanayak and Sills (2001) have provided quantitative evidence of the importance of non-timber products as a buffer against agricultural shocks in the Brazilian rainforests. Preserving the local resource base has the features of purchasing insurance against hard times. Village life in the world's poorest countries continues to be experienced in what the historical demographer Tony Wrigley (2004) has called 'organic economies'. To exclude the local natural resource base when studying the lives of the world's rural poor is not to know how the poor live.[35] Chapters 8 and 14 provide more on this.

The term *asset* has an evaluative hint to it – we say, for example, that our children are our greatest assets. Assets are desired or are recognised to be desirable. The asset manager places a positive value to them. A recurring societal problem we point to in the chapters that follow is that no matter who she is and no matter where she resides, many types of natural capital and the services they provide come free to her. But a free good does not appear to a person as scarce any more than sunlight. She could of course extract or harvest those resources for immediate use, or even store them for later use, but they do not appear to her as limited in quantity. *The demands she makes are limited only by the extraction and harvesting costs that she has to bear; she is not required to pay for the resources*.[36] That, as we will see, has profound consequences. We will also confirm (Chapter 8 and Annex 8.1) that matters have been made even worse by governments subsidising the use of what were previously free goods. If we include government subsidies, the previously free goods have a negative price.

Such institutional imperfections create a gap between the prices we face for the goods and services we produce and consume, and the social worth of those same goods and services (Chapters 7–9). That creates a tension between our motivations in private life and our hopes and aspirations as citizens. We realise that market prices of Nature's goods and services often do not reflect their social worth, and we understand that the criteria we use to manage our personal assets differ from the criteria that we as citizens would want to use. The Review studies this tension and tries to uncover ways in which private incentives can be brought into alignment with public aspirations.

Assets are durable objects, producing streams of services. Durability does not mean everlasting. Durable goods depreciate (machines suffer from wear and tear, plants wither, skills are lost through neglect, indigenous knowledge disappears, people die), but unlike services they do not disappear instantly. Assets acquire their value from the services they provide over their remaining life. A refrigerator preserves food products by keeping them cold. It provides that service until it breaks down beyond

[35] For a book-length account of the place of the local natural resource base in rural life, see Dasgupta (1993). For pioneering studies on the embeddedness of life in the organic economy that is rural India, see Jodha (2001). Tallis et al. (2011) is a fine essay on rural poverty as seen through the reliance of the poor on the goods and services available to them from their immediate landscape.

[36] A formal demonstration of this feature of our use of natural resources is set out in Dasgupta, Mitra and Sorger (2019).

repair. The refrigerator's worth is a measure of the benefits it provides over its remaining life. An asset's future performance is built into it today.[37]

1.1 Classification of Capital Goods

It is tempting to call all assets *capital goods*. This term has proved to be so attractive that it now stretches to include public knowledge ('knowledge capital'); the law, the market system, and financial institutions ('institutional capital'); mutual trust and solidarity ('social capital'); culture and norms of behaviour ('cultural capital'); and even religion ('religious capital'). Economists have been a lot more reticent; they confine the use of the term to assets that are measurable. In the past, economists used to reserve the term 'capital goods' even more stringently than they do now, for they only included assets that are material (tangible) and alienable (i.e. whose ownership is transferable). Roads, buildings, machines and ports are ready examples. As patents held by a firm are part of the firm's asset base, they appear in its balance sheet. So intangible and alienable assets are included on the list of capital goods. Taken together, they are called *produced capital*.

The range of capital goods in the economist's lexicon has broadened over the years to include intangible and non-alienable assets such as health, education and skills, which, taken together form *human capital*. Economists include human capital as a category of capital goods because they have discovered ways to measure its value, not only to the individuals who acquire it, but also to society at large.

In the past decades, economists have developed methods for measuring the value individuals place on natural resources, so we now have a third category of capital goods: *natural capital*. The methods can be involved, for natural capital ranges over plants (tangible and alienable), pollinators (tangible and often non-alienable), the view from one's sea-front home (intangible and alienable) and the global climate (intangible and non-alienable). Interactions among produced, human and natural capital are depicted in Figure 1.1.

As this Review studies reasons for the growing disparity between private incentives and public aspirations, we pay particular attention to the wedge between market prices of capital goods, especially natural capital, and what we may call their social scarcity values, known as *accounting prices* or 'shadow prices' (Figure 1.2). By a capital good's *accounting price,* we mean the contribution an additional unit of it would make to the flow of social benefits (Chapter 10). Accounting prices reflect an accommodation between the socially desirable and the socio- ecologically possible. There are cases where market prices approximate accounting prices, but for reasons we explore in the Review (Chapter 7), many kinds of natural capital simply do not have markets. They are free to the user. So special methods have to be devised for estimating accounting prices (Box 1.2). Moreover, measurement problems are also rife in estimating the *stock* of many kinds of natural capital (even the number of species today is thought to lie in a wide range of between 8 and 20 million, possibly more), but it is far better to work with rough and ready figures than to ignore whole swathes of capital goods by pretending they do not exist. Unfortunately, the macroeconomic growth and development theories that have shaped our beliefs about economic possibilities and our understanding of the progress and regress of nations do not recognise humanity's dependence on Nature. One purpose of this Review is to correct that mistake.[38]

[37] Pollution can last as well, but as we confirm in Chapter 2, pollutants can be viewed as assets with a negative value.

[38] Prominent representations of modern growth and development economics are Aghion and Howitt (1998), Barro and Sala-i-Martin (2003), Helpman (2004), Acemoglu (2008), and Galor (2011). The absence of Nature is also prominent in the models that inform government finance ministries and central banks. Chapter 4* contains a contrasting model of global economic possibilities.

Figure 1.1 Interaction Between the Capitals

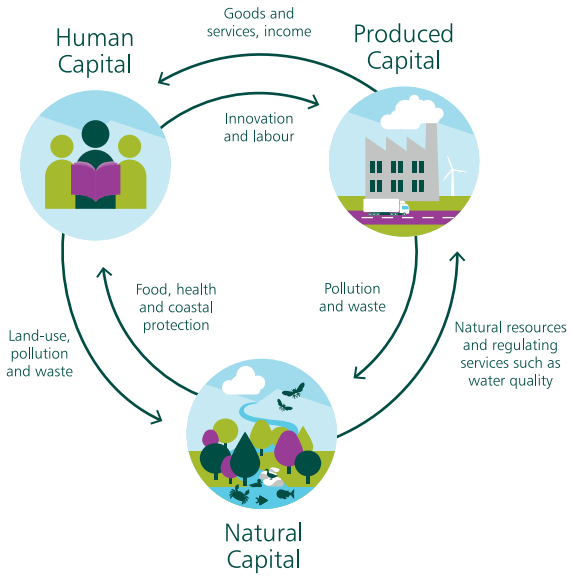
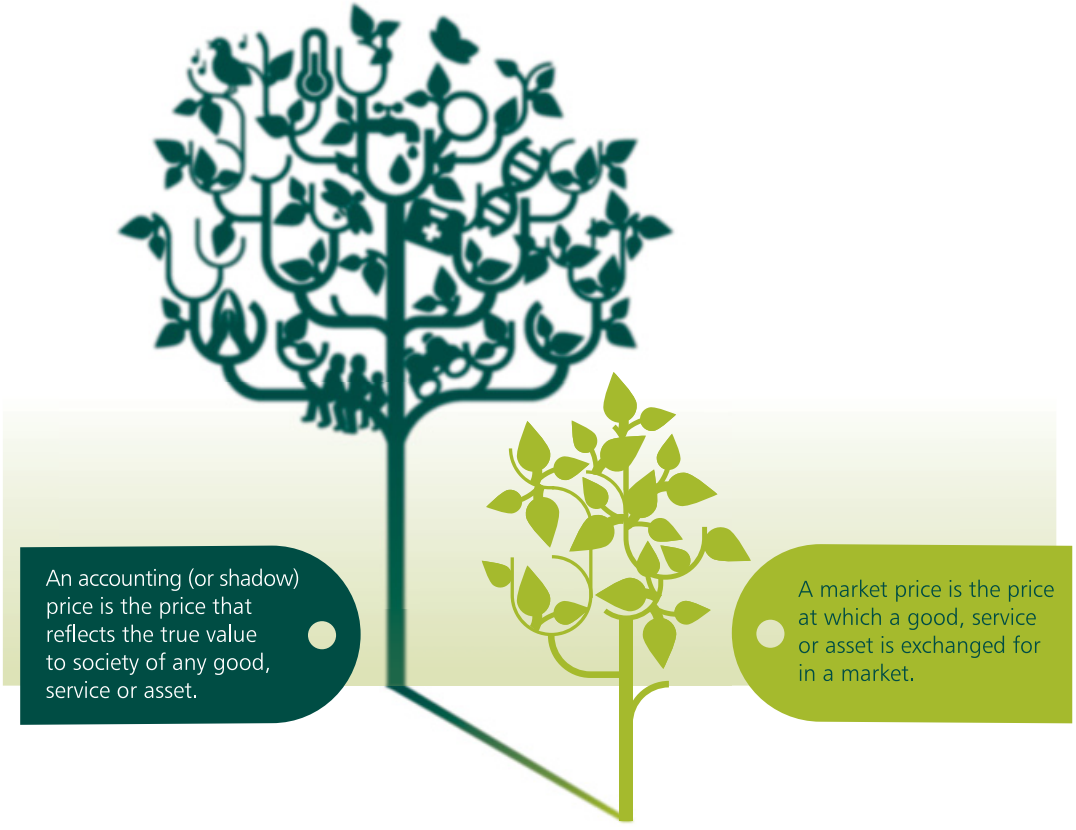


Figure 1.2 Market Prices and Accounting (or Shadow) Prices



Box 1.2

Valuing Nature's Stocks

Estimating natural resource stocks is difficult (Annexes 2.2 and 2.3 and Chapters 12–13). Aerial surveys provide information about forest cover and soil quality, and sonar technologies further enable fishing companies to estimate fish stocks in the oceans. But as they generate aggregate figures, important details are missed.[39] Economists have worked less on ways to measure stocks of natural capital (it has been the object of interest among environmental scientists) and more on ways to measure the benefits we derive from them (Chapter 12). The latter also poses problems, because many forms of natural capital are free, meaning there are no market prices that could be used as proxy. The benefits we derive from natural resources can be direct (e.g. the pleasure of a walk in the park) or they can be indirect, often several steps removed from experience (e.g. filtration of water by wetlands, or the natural regeneration of soil). Valuation exercises on natural resources that are of direct benefit now form a rich, informative literature.[40] The exercises frequently involve asking people in subtly devised questionnaires to disclose the value they place on those benefits (Chapter 12). Valuation exercises on natural resources that are of indirect benefit (i.e. they are factors in the production of goods and services that are of direct benefit) require an understanding not only of the processes that regenerate them but also their role as factors of production (Chapters 12–13*).

1.2 Rates of Return and Arbitrage Conditions

Of central importance to asset management is the concept of *yield* on investment (also known as an *own rate of return)*. Formally, the yield on investment in a capital good is the increase in its size that can be expected tomorrow if a unit more of it were added to a portfolio today. The additional unit today is the investment in question. An example would be the additional biomass of a fishery less a unit that would be expected tomorrow if the biomass in the fishery were increased by a unit today. A further example would be the increase in a tree's biomass per unit of biomass if we waited a while. Waiting suggests that an asset's yield is the *growth* one obtains from investing in it.

The yield on investment in produced capital is its marginal product. But these contrasting examples suggest that investment has a wider meaning than electric drills and workers in hard hats applying tarmac to a road. Investment can be passive. If restoration of a wetland is investment, then so is conservation: *investment can mean simply waiting*.[41]

Yield is a pure number of per unit of time. Its dimension is therefore the inverse of time (i.e. $time^{-1}$). An example is the return the UK government offers, which has historically averaged approximately 4% (or 0.04) a year, for its long-term bonds (Thomas and Dimsdale, 2017).[42] So 4% a year is the yield.

When comparing assets in a portfolio, however, own rates of return are not enough. Unless the economy is in a stationary state, assets' relative prices can be expected to change over time. To illustrate, suppose a household values assets in pounds sterling. The *rate of return* on an asset (as opposed to the asset's *own* rate of return) is its yield plus the capital gains it enjoys over a unit of time. Portfolio

[39] See the lively interchange between Zhang et al. (2020) and Feng et al. (2020) on estimates of the size of water bodies in China.

[40] Freeman (2003) and Haque, Murty, and Shyamsundar (2011) are prominent publications.

[41] Solow (1963) reinstated the place of own rates of return in the economics of growth and distribution. His analysis, which is what we follow here, covered investment in both its active and passive senses.

[42] More recently, this has been closer to 1% (Bank of England, 2020).

management requires that the household chooses a portfolio with the maximum value among all the portfolios that are available to it. Of course, yields would typically be uncertain, as would future prices. Value maximisation would reflect the uncertainty and the household's attitude toward risk and uncertainty (Chapter 5).

The portfolio decisions individual households make do not influence rates of return in the economy: they are negligible in size. So, the prices and risks the individual household faces are exogenous to it. At the other extreme are agents serving government, whose choices over macroeconomic policies influence yields and the future accounting prices of goods and services. As elsewhere in macroeconomics, there is circularity here: government policies influence yields and accounting prices, even while, as portfolio managers, governments are required to choose policy on the basis of yields and (accounting) prices. These mutual influences come together when the choices made are optimal. Good governance exploits the circularity (Chapters 7, 13).

An asset that has a lower rate of return than another will not be chosen. A portfolio is the best for the agent *only* if the assets in it have the same rate of return. Rules governing portfolio selection are summarised in *arbitrage conditions* (Box 1.3). But people differ in the way they read the world; they differ in their attitudes to risk and uncertainty; and they differ by way of the opportunities open to them. That is why not everyone chooses to hold the same portfolio. The value of an agent's portfolio to her is her *wealth*.

However, even the arbitrage conditions are not sufficient for the task facing an asset manager. The conditions tell her how to choose the right mix of assets to hold in her portfolio, but they do not say what she should do with the returns. They do not say what proportion of returns she could justifiably put aside for consumption and how the remainder should be allocated so as to add to her portfolio. The study of optimal mixes of consumption and investments leads us to discuss ideas underlying well-being across time and the generations (Chapters 10–13). We confirm that optimum programmes of consumption and investment necessarily satisfy the arbitrage conditions, and that they also necessarily satisfy a further set of arbitrage conditions involving the agent's valuation of the present in comparison to the future. Those considerations are summarised in ethical objects such as 'social discount rates' (Chapter 10). The Review studies reasons behind humanity's failure to manage our portfolios well and explores ways in which we could shift direction. The concept of inclusive wealth is crucial for the exercise (Chapter 13).

Box 1.3
Arbitrage Conditions

An individual in a deterministic world is considering whether to place £500,000 in an investment bank that offers an annual 5% yield or whether to purchase an apartment at that price and rent it at the going market rate of £15,000 a year. Under the first option the person's wealth in a year's time would be £525,000, which would seemingly trump the second option but for the capital gains she may enjoy in a year's time from owning the apartment. Imagine that the capital gains were £10,000. Then the return she would enjoy from the apartment would be £25,000 (£15,000 rental income + £10,000 capital gains). Because 25,000/500,000 = 5%, the person would be indifferent between the two options. That is a requirement of an efficient capital market. If capital gains on her apartment were to be either less or more, the two markets would be in imbalance. If it were less, she and others in her situation would place their funds in the bank; if it were more, they would purchase apartments and avoid the bank. For both markets in the example to exist, rates of return on the two assets must be equal. That equality is the *arbitrage condition* in the example. The condition identifies a process in which investors arbitrage their portfolios in such a way that at the margin they are indifferent as to the mix of the assets they hold in their portfolio. If asset markets were functioning well, their prices would adjust so as to equalise the rates of return.

To add to the example, suppose the same £500,000 could buy an agent a tract of timberland and that sales of timber would generate £20,000 in net profit to him over a year. The agent would be indifferent between purchasing the tract and investing in the government bond if the market value of the tract were to increase by £5,000 over the year, because the rate of return from the forest would then be 5%. That is another example of arbitrage conditions.

To study arbitrage conditions in a formal way, we continue for simplicity to consider a market economy in a deterministic world. Let us choose an asset that is to serve as the unit of account. That is the *numeraire*. The price of a unit of our numeraire is therefore 1.

We imagine that time is continuous. It is denoted by t. Let the yield on the numeraire be $r(t)$. Let p_i(t) be the price of asset i at t. If $r_i(t)$ is the yield on i at t, then for the two assets to be equally attractive to the agent, the arbitrage condition reads

$$r(t) = r_i(t) + [\mathrm{d}p_i(t)/\mathrm{d}t]/p_i(t) \qquad \text{(B1.1)}$$

The second term on the right-hand side of equation (B1.1) is the percentage rate of change in $p_i(t)$. That is capital gains in asset i (it could of course be losses, in which case the sign of the term is negative). Repeated use of equation (B1.1) tells us that for any pair of assets i and j in the agent's portfolio, it must be that

$$r_j(t) + [dp_i(t)/\mathrm{d}t]/p_i(t) = r_j(t) + [\mathrm{d}p_j(t)/\mathrm{d}t]/p_j(t) \qquad \text{(B1.2)}$$

Define the price of asset j relative to the price of asset i as p_{ij}. Then equation (B1.2) can be expressed as

$$r_j(t) + [\mathrm{d}p_{ij}(t)/\mathrm{d}t]/p_{ij}(t) = r_i(t) \qquad \text{(B1.3)}$$

Equation (B1.3) is a formalisation of the numerical examples with which we started.

Because economies suffer from distortions, asset holders do not all face the same prices. That means even if each agent were to allocate the assets at her command efficiently, the economy in the aggregate would be inefficient. Environmental externalities are a prime cause behind economy-wide inefficiencies (Chapters 7–8). Cases of particular interest are assets that are open to all to use as each sees fit, free of charge. They are known as 'open access' resources. The atmosphere as a sink for our carbon emissions is the most well-known example. Marine fisheries are another. The classic 'tragedy of the commons' speaks to them (Hardin, 1968). In those cases, equation (B1.1) does not hold, because being free ($p_i = 0$), open access assets appear to each individual as unlimited in size. The only thing that prevents people from drawing on them at an infinite rate are harvesting and extraction costs.

Public bodies, whose remit would not be the same as that of private investors, would also want to choose their portfolios efficiently. They too would seek to choose their portfolios so as to satisfy the arbitrage conditions. But unlike the agents in the examples we have just studied, the prices they would use would be *accounting prices*. The enormous literature on valuation of environmental resources alluded to in the text is about ways to estimate accounting prices (Chapter 12). Equations (B1.1)–(B1.2) have been derived for a deterministic world. Investors typically add discounts on assets to correct for risk and uncertainty in their returns. These issues are discussed in Chapter 5.

1.3 Public Asset Management and the Wealth/Well-Being Equivalence Theorem

We have identified three categories of assets that can be called *capital goods*: produced capital, human capital and natural capital. The sum of the accounting values of a society's capital goods is known as

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inclusive wealth, the qualifier signalling that by wealth we mean not only the accounting price of produced capital and human capital, but also of natural capital. The Review explains why inclusive wealth should be the coin with which *citizens* would wish to evaluate economic change – but it will take us all of 12 chapters to get there. In Chapter 13 we show by way of what may be called the *wealth/well-being equivalence theorem*, that social well-being is maximised *if and only if* inclusive wealth is maximised. Accounting prices provide the link between wealth and well-being, which is why the theorem is valid no matter which conception of well-being is adopted by the portfolio manager. The theorem will bring us back full circle to where we began, that the task of asset managers is to maximise the value of their portfolios, and that inclusive wealth is the social value of an economy's portfolio of capital goods. In ideal circumstances the market value of a portfolio would equal its accounting value, but for reasons the Review unravels, that ideal cannot be reached. Private incentives and social imperatives inevitably differ, so a government's task is to put into practice policies that bring the two into alignment as close as possible.

The equivalence theorem is fundamental for economic evaluation. To see why, consider the demand citizens could make of their government that it should only select policies that advance the quality of their lives. The problem is that the demand does not offer guidance on what should be selected. Even if restoring a degraded woodland advances the quality of life, there would be contending projects, each with its own characteristics. Moreover, the same resource may be an input in alternative projects. There would also be projects that may not appear to be life-affirming but would contribute to their quality of life indirectly. As always, there are alternative ways to allocate goods and services, each with its own set of likely consequences. And goods and services do not come marked with 'quality of life' stamps. Accounting prices are the necessary stamps. The equivalence theorem says using inclusive wealth to evaluate society's options is in line with the requirement that its portfolio reflects societal ends, no matter what the ends happen to be. And because it is an equivalence theorem, we know there can be no measure other than inclusive wealth that can serve the purpose.

What about all those assets that are not on our list of capital goods? Quantifying such assets as public knowledge, institutions and mutual trust raises insuperable difficulties. Try, for example, to estimate the accounting price of differential calculus, or good governance, or the extent of trust among citizens, and the stumbling block becomes apparent. So we create a separate category named *enabling assets*, for they help societies to allocate capital goods. We will find (Chapter 12) that the value of enabling assets is reflected in the accounting prices of capital goods. A classroom in a society at peace can function in ways it cannot in a country at civil war. That alone means its accounting price is not the same in the two contexts. A society could raise its inclusive wealth and thereby social well-being simply by improving its institutions and practices.[43]

Biodiversity is a characteristic of natural capital, as diversity of aspirations, talents and drives are features of human capital. In Chapter 2, we review a literature that has found biodiversity to be a factor influencing the productivity of natural capital, or more concretely, ecosystems. Biodiversity is an enabling asset. Which is why environmental and resource economists estimate the accounting prices of items of natural capital – for example ecosystems – not biodiversity. The value of biodiversity is embedded in the accounting prices of natural capital.

[43] The partitioning of a society's durable entities into capital goods and enabling assets was proposed in Dasgupta and Mäler (2000), who also stated and proved the equivalence between societal well-being and inclusive wealth in a general setting. The equivalence result was extended by Arrow, Dasgupta and Mäler (2003a,b). Chapter 13 contains a detailed account. The term 'inclusive wealth' was introduced in UNU-IHDP and UNEP (2012, 2014). Arrow et al. (2012) used the term 'comprehensive wealth'.

1.4 Two Types of Comparison

Portfolio management involves making two types of comparisons. We illustrate them by considering public decision-makers.

One type of evaluation involves evaluating the change to a portfolio brought about by a decision at a point in time, the hallmark of *policy analysis*. An example would be to evaluate a proposal to change the government's tax schedule (Meade (Report), 1978; Mirrlees (Review), 2011). Evaluation is necessary because the government would not otherwise know whether the proposed change is desirable. A particular type of policy evaluation is *cost-benefit analysis*, or *project evaluation*, which offers a methodology for evaluating investment projects. The exercise involves evaluating alternative uses to which capital goods and their yields can be put – for example, judging how much of the yield should be consumed and how much should be reinvested, and in what form. The word 'social' is added to the term 'cost-benefit analysis', as in *social cost-benefit analysis*, when the agent chooses on behalf of a public body.[44]

Another type of comparison involves valuing the change a portfolio displays over time. This is the hallmark of *sustainability assessment*, which responds to such questions as, is our country more prosperous today than it was a year ago? There is no presumption that by prosperity the person asking the question is looking for GDP figures (there are in fact very good reasons why he should not do so); it is more likely that prosperity is taken by him to mean the quality of life, possibly even *well-being* (Chapters 10–11). However, during the year in question there could have been an accumulation of produced capital and human capital and a decumulation of natural capital. That is the experience of most countries in recent years (Managi and Kumar, 2018). The problem then is to weigh the changes in the asset structure so as to judge whether well-being today and projected well-being in the future is greater now than it was previously. The exercise involves inferring the extent to which one's 'ends' have been met from changes in the 'means' to those ends.

There is a third type of comparison, which is related to the above two but differs from them in important ways. It involves comparisons of the state of affairs in different economies. For 'economy' we could, for example, read 'country'. We may then ask whether country A is more prosperous than country B. At the formal level, the question falls under the domain of sustainability assessment. The difference is that it involves cross-country comparisons at a moment in time rather than comparisons of the state of affairs in one country across time. Neither involves policy choice. But problems arise in making such comparisons because political cultures differ across countries. The use of a common metric is questionable. The current practice among international agencies such as the World Bank is to make comparisons in terms of features that are commonly thought to speak to human dignity, independent of differences in political cultures. Life expectancy at birth, the maternal mortality rate, literacy and the standard of living as measured by market prices are commonly used measures. There have been attempts to aggregate them into a single index – for example, the United Nations' Human Development Index (HDI) – but those moves can be questioned because they apply weights to the various components of the index that are independent of political cultures. Cross-country experiences can nevertheless be of enormous use to individual countries as they search for policies that bring about or maintain prosperity. So, although the economics of biodiversity is concerned with all three types of comparisons, the Review for the main part develops the first two: policy analysis and sustainability assessment.

[44] Little and Mirrlees (1968, 1974), Arrow and Kurz (1970), and Dasgupta, Marglin, and Sen (1972) developed the theory of social cost-benefit analysis in imperfect economies.

But these are *two* lines of enquiry. The wealth/well-being equivalence theorem shows that, fortunately, policy analysis and sustainability assessment involve the same considerations: *both require estimating the value of changes to the stocks in our portfolio of capital goods*. Because the value of a portfolio represents *inclusive wealth*, both policy analysis and sustainability assessment involve wealth *comparisons* (Chapter 13).

To illustrate the use of inclusive wealth, imagine someone asks whether the United Nations' Sustainable Development Goals (SDGs) would be sustainable if attained. Suppose also that a national government produces a plan for attaining the SDGs, which requires accumulating produced capital and human capital in sufficient amounts while distributing them appropriately. Meanwhile, however, biodiversity loss and rising mean global temperature are found to be depreciating natural capital. The government recognises that growth in produced capital and human capital needs to be balanced against the depreciation of natural capital. The study of inclusive wealth enables the government to do that. Assessing the progress or regress of national economies requires one to study movements over time of the inclusive wealth of nations, not the GDP of nations, nor the HDI of nations. The wealth/well-being equivalence theorem assures that.[45]

Inclusive wealth accounts for a country correspond to the balance sheets of firms. But we should not expect countries to move from their current systems of national accounts to a comprehensive system of wealth accounts. Measuring the value of natural capital stocks, not to mention the quantity and quality of stocks, is notoriously difficult (Annexes 2.2 and 2.3, and Chapters 12–13). The moves currently being made in individual countries such as the UK and New Zealand involve the preparation of satellite accounts of sectors such as forests, fisheries and ground water. They involve estimating accounting prices of their stock. There are countries that are at a more advanced stage and have satellite accounts in which the value of natural capital is presented in an aggregate form.[46]

1.5 The Earth System and Economic Growth

Natural capital is essential for our existence (the air we breathe, the water we drink are immediate examples); of direct use as consumption goods (fisheries); of indirect use as inputs in production (timber, fibres); and essential for our emotional well-being (green landscape, sacred sites). Many have multiple uses (forests, rivers, the oceans). We are embedded in Nature; we are not external to it. But until relatively recently, influential writers on economic development saw natural capital only as luxuries. An unnecessary debate took place between those who expressed environmental concerns in low income countries and those who saw the need for economic growth there above all else. Well-meaning writers tried to reconcile the two viewpoints. An editorial in the UK's *Independent* (4 December 1999), for example, observed that "[economic] growth is good for the environment because countries need to put poverty behind them in order to care," and a column in *The Economist* (4 December, 1999: 17) insisted "trade improves the environment, because it raises incomes, and the richer people are, the more willing they are to devote resources to cleaning up their living space."[47]

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[45] Arrow et al. (2004, 2012), UNU-IHDP and UNEP (2012, 2014) and Managi and Kumar (2018) contain quantitative studies of movements of the inclusive wealth of nations. The publications covered periods between 1995 and 2010. See Chapter 13 and Annex 13.1.

[46] See Bright, Connors, and Grice (2019) and a literature, published by scholars involved in several 'natural capital projects', that presents estimates of the monetary value of various forms of natural capital, mostly at the national level. They include Kareiva et al. (2011), Fenichel et al. (2016), Kumar (2010), Natural Capital Committee (2019) and the ongoing work of the UN Statistical Division as represented by their most recent, 2017, publication. We report on these works in Chapters 12–13.

[47] Visions of a prosperous world in which Nature plays no part continues to thrive. Criticising the young climate activist Greta Thunberg for her speech at the United Nations in September 2019, the economics editor of Sky News wrote in *The Times* (27 September, 2019: p. 30): "Eternal economic growth is not a phrase one spits out in derision; it is precisely what we should be aiming for."

The origins of this limited view of the place of nature in economic life can be traced to the World Bank (1992), which reported that in cross-country studies the emission of sulphur oxides had been found to be related to GDP per head capita in the form of an inverse-U. Emissions were found to increase with GDP per capita when countries are poor, but to decline with GDP per capita when countries are rich. Inevitably, the relationship was named the 'environmental Kuznets curve' in honour of the economist Simon Kuznets, who had observed an inverse-U relationship between GDP per capita and income inequality (Kuznets, Epstein and Jenks, 1941).[48]

Emissions of sulphur oxides are unrepresentative of environmental harm. The oxides are emitted by industry and automobiles and blow away to become someone else's problem when emissions cease. But if a company destroys a mangrove forest to make way for shrimp farms, the protection it had afforded neighbouring villages against storms is lost irretrievably (Chapter 2). At an extreme is loss of species, which is irreversible.[49]

In fact, a piece of natural capital can be a luxury for some even while it is a necessity for others. Many goods and services that are provided by watersheds are necessities for local inhabitants (forest dwellers, downstream farmers, fishermen), some are sources of revenue for commercial firms (timber companies), while others are luxuries for outsiders (eco-tourists). Some benefits accrue to nationals (agricultural crops), while others spill over across national boundaries (carbon sequestration). Watersheds offer joint products (protection of biodiversity, flood control, household goods; Chapters 2, 9–10), but they also offer services that compete against one another (commercial timber, agricultural land, biodiversity).

Competition among rival services has been a prime force behind the way the biosphere has been transformed. Moreover, commercial demand frequently trumps local needs, especially under non-democratic regimes (Chapters 8–9). International public opinion and pressure from the country's elite are often tepid. These complex interrelationships have generally been ignored by growth and development economists (the newspaper quotes above are after all, only two decades old, the last only some months old). In the event, the economics of biodiversity was left to be studied by a few groups of economists and ecologists working together.[50]

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[48] See also Cropper and Griffiths (1994) and Grossman and Krueger (1995).

[49] See the comments in Arrow et al. (1995) on the environmental Kuznets curve and the responses it elicited in symposia built round the article, in Ecological Economics, 1995, 15(1); Ecological Applications, 1996, 6(1); and Environment and Development Economics, 1996,1(1). See also the special issue on the subject in Environment and Development Economics, 1997, 2(4).

[50] Prominent among institutions that have laid the groundwork for the economics of biodiversity (although that was not the term in use) are Resources for the Future (RFF), Washington, DC; the World Resources Institute (WRI), Washington, DC; the Beijer Institute of Ecological Economics, Stockholm; the South Asian Network of Development and Environmental Economists (SANDEE), Kathmandu; Resource Accounting Network for Eastern and Southern Africa (RANESA) and the Centre for Environmental Economics and Policy in Africa (CEEPA), Pretoria; and Latin American and Caribbean Environmental Economics (LACEEP) and the Tropical Agricultural Research and Higher Education Center (CATIE), Costa Rica. RFF in the 1960s-70s studied the economics of irreversible investment, persistent pollutants, material balances (Chapters 4* and 13*) and valuation methods for environmental amenities; while WRI in the 1970s produced among the first economic estimates of the degradation of tropical rainforests. At an institutional level, however, the economics of biodiversity has found its greatest expression since the early 1990s in research and teaching networks elsewhere. The Beijer Institute, reinstated in 1991, has brought ecologists and economists together in a manner unthinkable previously. As will become apparent, Chapters 2–4 have been greatly influenced by their work. SANDEE, RANESA/CEEPA, and LACEEP/CATIE, established later in the 1990s, have organised regular teaching and research workshops and funded work by young economists in South Asia, Eastern and Southern Africa, and Central and South America, respectively, so as to help develop the interface of poverty and the local natural capital base there. Members of all four groups shaped the pioneering Millennium Ecosystem Assessment (MA 2005 a-d).
The journal Environment and Development Economics, which was established in 2000 with support from the Beijer Institute, has actively sought and published papers from South Asia, sub-Saharan Africa and Latin America. As will become apparent, Chapters 7–8 and 12–13 have leant greatly on their work. On the closely related subject of reproductive behaviour in regions that are still far from experiencing a demographic transition, the Population Council, New York, the London School of Hygiene and Tropical Medicine, the Guttmacher Institute and the United Nations Population Division, New York, have consistently produced work of great relevance for the population-environment nexus, Population and Development Review being a prominent quarterly publication. Chapter 9 has leant greatly on their work.

There is a deeper, more general point that lies behind the thought that because there is no obvious bound on human ingenuity, technological progress and institutional improvements can enable the global output of final goods and services to grow indefinitely. This is to imagine the human enterprise as being *external* to Nature; it is to see humanity dipping into the biosphere for its goods and services, transforming what is taken for production and consumption, and depositing the residue back into it as waste. We show that this view allows us to claim that in due course human ingenuity can enable us to increase global output indefinitely without making anything but vanishingly small further demands on the biosphere. Never mind that indefinite growth will require continuing investment in research and development and equipment, the hope is that those further investments will require vanishingly small inputs from Nature.

To entertain that hope today is more than ironic. Over the past 70 years, global GDP has increased in real terms by a factor of nearly 15, even while our global demand for the biosphere's goods and services – our ecological footprint – now far exceeds the biosphere's ability to supply its goods and services on a sustainable basis (Chapter 4). Which is why a group of Earth scientists have identified mid-20th century as the point at which we entered the Anthropocene.[51]

The economics of biodiversity takes its cue from the environmental sciences to build on the fact that we are *embedded* in Nature (Chapter 4*). We will not be able to extricate ourselves from the Earth System even if we try to invest continually for indefinite economic growth. This somewhat metaphysical distinction between being 'external' to the biosphere and being 'embedded' within it has potent force. The viewpoint adopted in the Review says that the finiteness of Nature places bounds on the extent to which GDP can be imagined to grow. It also places bounds on the extent to which inclusive wealth can grow.

1.6 Total vs. Marginal Values

Asset management involves *comparisons* of portfolios – of portfolios across time or of portfolios at a point in time (Section 1.2). In contrast, the absolute value of a portfolio carries no information. The value of a marginal change to the biosphere is meaningful because it is presumed that humanity will survive the change to experience it, but the matter is different when it comes to valuing the biosphere as a whole. It may be that because growth and development economists ignored our place in Nature that environmentalists some years ago were tempted to value the entire biosphere, presumably to show that it is of great economic worth. In a widely cited publication in *Science*, the authors estimated that the global flow of the biosphere's services was, toward the end of the 20th century, worth US$16-54 trillion annually, with an average figure of US$33 trillion (Costanza et al. 1997). As that figure was larger than global Gross National Product (GNP) in the mid-1990s (estimated by the authors at the time to be approximately US$18 trillion annually) we were meant to appreciate the economic significance of the biosphere.

The estimate is a case of misplaced quantification. If the biosphere was to be destroyed, life would cease to exist. Who would then be here to receive US$33 trillion of annual benefits if humanity were to exchange its very existence for them? Economics, when used with care, is meant to serve our ethical values. The language it provides helps us to choose in accordance with those values. But the authors of the paper sought to persuade us that the biosphere is valuable *because* it can be imputed a large monetary value. That is to get things backward.[52]

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[51] The term 'Anthropocene' was popularised by Crutzen and Stoermer (2000) to mark a new epoch in which humans dominate the biosphere. Ehrlich and Ehrlich (2008) study the evolutionary consequences of our growing dominance. Dasgupta and Ehrlich (2012) read the human overreach of the biosphere in terms of adverse externalities associated with consumption and reproductive externalities.

[52] Formally, we have a case where the value of an entire something has no meaning, and is therefore of no use, even though the value of marginal changes to that same thing – expressed as differences – not only has meaning, but also has use. Examples abound in economics (cardinal utility) and physics (potential field).

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At smaller levels of aggregation, total values of Nature's services can be meaningful and yet not be useful for policy. It is tempting, for example, to cite the estimate that pollination contributes an annual £510–690 million to the UK's agricultural production as providing a reason for restoring the population of pollinators (Breeze, Roberts, and Potts, 2012). But should we regard it to be a large or small figure? Based on 2019 data from the UK Office of National Statistics, as a proportion of the UK's annual agricultural output, it is approximately 5%. As a proportion of the UK's GDP, it is 0.03%, a negligible figure. So why care whether any pollinators are left?

The reason we should not be dismissive of pollinators is that proportional figures do not signal worth. National asset management requires that pollinators enter projects with their accounting prices. Chapters 2 to 4 demonstrate that pollinators may be of great value even if their measurable services to GDP are of negligible worth.

1.7 Institutions and the Character of Natural Capital

Processes driving a wedge between our demand for the biosphere's goods and services and its ability to supply them without undergoing decline harbour *externalities*. These are the unaccounted-for consequences for others, including future people, of actions taken by one or more persons. The qualifier 'unaccounted for' means that the consequences in question follow without prior engagement with, or adequate consideration towards, those who are affected.

Human activities give rise to externalities because *property rights* to large segments of the biosphere are either weakly defined or inadequately enforced. And a common reason for the latter is that Nature is *mobile*: the wind blows, rivers flow, fish swim, the oceans circulate, and insects and birds fly. One consequence of this is that no one can contain the atmosphere they befoul, the soil they contaminate, the rivers they pollute. Moreover, the harm they cause is *non-excludable*, meaning that it is not possible for the person or agency to whose action the harm is traceable to pick and choose those who are affected.

That Nature is mobile is a familiar fact and easy to appreciate. What is a lot harder to appreciate is that both Nature and its processes are in large part *silent* and *invisible*, and so they are not easily detectable. One way to detect them is to infer their presence from their detectable effects. That is no easy matter, and requires hard science, and it provides the reason the rudiments of that science are studied in the following three chapters.

These features of Nature make it hard for anyone to trace the adverse effects of many of our actions back to us. Unlike point sources of pollution, such as the factory chimney, pollution such as nitrogen and phosphorus that discharge into an estuary are an aggregate of leakages from innumerable agricultural fields, factories and households long distances away. Polluters do not pay for using the estuary as a sink for their pollution.

By property rights we do not simply mean private property rights, we include group rights, for example, community rights and national rights. There are no property rights to the oceans beyond national jurisdiction – they are open to all, free of charge – which is why no one has an incentive to protect them from contamination or overfishing.

Externalities can be beneficial of course. An extreme form of beneficial externalities is provided by *public goods*, which are goods that are *non-rivalrous* (use by one person does not diminish the amount available to others) and non-excludable (use cannot be confined to any particular person or group). Public goods are thus a mirror image of open access resources. If the formula for manufacturing a vaccine were to be made freely available to all, the discovery would be a public good (the formula is by its very nature non-rivalrous, but if it were to be made free to all to use it as they wish, it would be non-excludable as well, making it an enabling asset). A reasoning identical to the one that was deployed

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above for explaining why open access resources are overused can be used to explain why public goods are underproduced.

Patents are a social contrivance for providing incentives to people to make discoveries. A patent for a new vaccine would make the formula for manufacturing it excludable: no one other than the patent owner would have the right to use the formula while the patent was in force. But the issue of a patent on the discovery, however, would award the owner a monopoly over vaccine production. Monopoly pricing would create a distortion in the market. A combination of the need to create incentives for scientific and technological establishments to make discoveries and to avoid creating distortions in the product market poses a social dilemma. The compromise that is practised everywhere is to limit the duration of patents (currently 20 years in the UK as defined in Section 25 of the Patents Act (1977)).[53]

Not all common property resources are 'global commons'. Geography plays a large role. The open oceans are extensive, in contrast to the village commons in England. Which is why the institutions that have evolved for managing what we may call *local commons* differ widely across the globe (Chapters 7–8). The village commons in England are under the jurisdiction of local authorities – they are subject to the laws of the land. The law's authority resides with the State. Village tanks (artificial ponds) in India and grazing fields in sub-Saharan Africa are also local commons, but their use is usually subject to social norms, whose force comes from mutual enforcement by the villagers themselves. The locus of mutual trust differs in the two cases (Chapter 6). However, there are many reasons community practices have been known to break down where they were once thriving. In some places, government rules replaced community norms; in other places, outsiders encroached on the inhabitants' land (worse, evicted the inhabitants); in still others, local knowledge was displaced by modern technology, and so on. For global commons like the atmosphere and the oceans as sinks for our waste, institutions never got a foothold to limit their use. The economics of biodiversity enquires why societies fail to manage their assets well, and it seeks to identify institutional changes that would improve management practice.

1.8 Anthropocentric Value of Biodiversity

In the chapters that follow, we mostly adopt an anthropocentric viewpoint – the value of biodiversity is studied in terms of its contributions to humanity, that is human well-being. This is an altogether limited point of view, and to many even a repugnant point of view (see Chapter 12 for other perspectives). Surely, it will be insisted, biodiversity has an *intrinsic value*, beyond what we humans impute to it. They would ask, for example, whether the biosphere had value before modern humans appeared on the scene some 200,000 years ago. The anthropocentric perspective could affirm its value even in that distant past on grounds that it furnished the environment in which we humans were able to emerge, but that alone shows the perspective's limitations.

There are nevertheless good reasons for concentrating on what one may call the *instrumental value* of biodiversity. One reason is that there are innumerable systems of thought that go beyond an anthropocentric perspective. Many people argue that life itself has intrinsic value, never mind that only a few among the 8 to 20 million species (of eukaryotes) on Earth are known to feel, never mind to have self-awareness.[54] There are also many systems of belief – alas, all too readily overridden by cosmopolitan society – in which objects that to the cosmopolitan are inanimate, are sacred. They may house life, but they are not life; nevertheless, they are sacred. Uluru in Australia is a famous example. It is sacred to the

[53] For a formal account of the tension that societies face between the need to create incentives for people to make discoveries and inventions and to create an environment in which discoveries and inventions are widely used, see Dasgupta and Stiglitz (1980).

[54] In a widely noted work, Singer (1975) presented a Utilitarian argument for awarding rights to animals. That animals can feel pain plays a justifiably crucial role in the viewpoint he developed in his book.

Pitjantjatjara, the Aboriginal people of the area surrounding it. And there is the river Ganges, sacred to Hindus (Box 2.8). But the narratives underlying their sacredness differ.

There is a second reason. If we are able to show, as we intend to in the Review, that biodiversity is of the utmost value to humanity, and that because we are embedded in Nature, gradual biological extinction will hasten our own extinction, then for purely anthropocentric reasons we would wish to preserve and promote it. But if biodiversity is worth preserving and promoting for purely anthropocentric reasons, it would be even more deserving of protection and promotion if it had sacred status. Therein lies the advantage of a limited point of view.