Sustainability: An Interdisciplinary Guide

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ABSTRACT: A definition of sustainability as maintaining 'utility' (average human wellbeing) over the very long term future is used to build ideas from physics, ecology, evolutionary biology, anthropology, history, philosophy, economics and psychology, into a coherent, interdisciplinary analysis of the potential for sustaining industrial civilisation. This potential is highly uncertain, because it is hard to know how long the 'technology treadmill', of substituting accumulated tools and knowledge for declining natural resource inputs to production, can continue. Policies to make the treadmill work more efficiently, by controlling its pervasive environmental, social and psychological external costs, and policies to control population, will help to realise this potential. Unprecedented levels of global co-operation, among very unequal nations, will be essential for many of these policies to work effectively. Even then, tougher action may be required, motivated by an explicit moral concern for sustainability. An evolutionary analysis of history suggests that technology and morality can and will respond to a clearly perceived future threat to civilisation; but we cannot easily predict the threat, or whether our response will be fast enough.

KEYWORDS: Economics, environment, evolution, history, natural resources, policy, population, psychology, sustainability, technology

1 INTRODUCTION

The last five years have seen a widespread wave of concern about the ability of environmental resources to sustain human civilisation. Since the publication of *Our Common Future* (WCED 1987), 'sustainable development', 'sustainable growth' or just 'sustainability' have become widely used catchwords for this new concern, and literature on sustainability has burgeoned accordingly. However, the purpose of this article is not to review this literature as such (for this, see for example Lele 1991 and Klaassen and Opschoor 1991), but to summarise

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the key *issues* which are relevant to sustainability, and to cite at least one recent review on each. Those issues which have been thoroughly debated include a great deal of economic analysis, tempered by important lessons drawn from thermodynamics and ecology. The main issue which I feel has been neglected, and which forms a frequent theme below, is an *evolutionary perspective*[1] on the anthropology, history, psychology, morality and technology of sustainability. This shows how deep are some of the underlying forces driving human social and environmental behaviour, and forces us to be realistic about how much it can and should be changed.

Given the wide range of disciplines covered, I have had to rely on just a few sources in many sections, which may therefore strike specialists as simplistic. Few illustrative data are given, and little hard environmental science is included. There are also many shifts between review and speculation. I ask the reader's forbearance for all these shortcomings. The paper is intended to provide a coherent framework for linking a wider range of issues to sustainability than is normally done, and to suggest fresh insights and research ideas in specific areas. It is not intended to be definitive; nor is it a call to action, full of 'musts' and 'shoulds', although several broad policy conclusions are drawn.

Before proceeding further, it seems useful to clarify what will be meant below by capital and exhaustible resources. 'Capital' is now a very broad term, meaning any economically useful stock. 'Natural capital' includes any stock provided by nature such as forests, groundwater or crude oil. 'Physical capital' (the original meaning of capital, called *tools* here) is stocks of buildings, machines, etc., which have been accumulated by saving out of current consumption. 'Human capital' and 'intellectual capital' (called *knowledge* here) are respectively stocks of embodied or disembodied skills which have also been accumulated by saving. Physical, human and intellectual capital are together sometimes called 'human-made capital'. 'Exhaustible resources' includes both renewable and non-renewable natural resources here. Other writers (for example Dasgupta and Heal 1979, 113 & 153) define exhaustible resources as just non-renewable resources, which leaves no term for renewables and non-renewables together.

Another necessary clarification is to remind the non-economic reader that economic attitudes to sustainability are very diverse. *Mainstream* academic economics (especially macroeconomics, as noted by Daly 1991) typically ignores pollution, natural resources and intergenerational fairness. Various *specialist* branches of economics do analyse these factors, using either conventional 'neoclassical' techniques, or 'alternative' techniques, and their conclusions about sustainability are often different from those few that exist in the mainstream. Criticisms made by non-economists such as 'economics cares only about short-term values measured by the market, and not at all about long-term environmental values' should therefore be mainly directed at political speeches and newspaper editorials on economics, which crudely reflect the academic mainstream, rather than at every economist.

The paper relates most aspects of sustainability to the economic concepts of *production functions* and *utility functions*. Production functions describe alternative transformations of bundles of natural and manmade resource inputs into given outputs of useful goods and services and (often) harmful wastes. Utility functions are what economists use to describe how human wellbeing (called 'utility') is determined by the consumption of marketed goods and services, by pollution and the state of the natural environment, etc.. Wellbeing or utility could be replaced here by 'advantage', 'pleasure', 'happiness' or 'welfare', without affecting the definition, for *utility is effectively defined as whatever people maximise when they make rational choices* (which economics assumes they always do).

Unless otherwise stated, *sustainability* is defined throughout this paper as:

> *non-declining utility of a representative member of society for millennia into the future*.[2]

Sustainable *development*, then, will imply at least some periods when utility definitely increases. In Pezzey (1989a), I simply claimed that non-declining utility had "self-evident appeal as a criterion for intergenerational equity", but I would now add three qualifications. Firstly, grammatically speaking, the above is really a definition of *sustainedness*, since it demands not just that the economy-environment system has the potential for utility to be non-declining, but also that this potential is actually achieved. Where essential, this distinction is made below, but generally 'sustainability' covers both meanings (as it does in much of the literature). Secondly, I do not now insist that sustainability should be regarded as an intergenerational equity constraint which overrides all other social goals (see Section 3.4 for further details). Sustainability is simply treated as a highly desirable goal, and we consider what may be needed to achieve it. Thirdly, the word 'millennia' is an important addition. A few thousand years is vastly longer than any current political timescale, but does not allow significant natural genetic evolution in human beings.[3]

Well-known alternative ways of introducing sustainability are:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (WCED 1987, 43)

and

> The alternative approach [to sustainable development] is to focus on natural capital assets and suggest that they should not decline through time. (Pearce, Markandya and Barbier, 1989, 37)

The first of these is hard to use in economic analysis because of the difficulty of the concept of 'need'. The second approach suggests a *necessary condition* for sustaining utility, based on the assumption that there are limits beyond which human-made capital cannot substitute for natural capital in production processes. This is not inconsistent with a *goal* of non-declining utility, but the two approaches emphasise different things. The natural capital approach focuses more on the physical and ecological limits to sustainability (often dubbed 'environmental sustainability'). The utility approach focuses more on the roles of technical progress and psychological adaptation (the latter of which could perhaps be called 'social sustainability').

The paper is organised as follows. Section 2 summarises the importance of physics and ecology in setting ultimate limits to the *physical* growth of the economy. Section 3 reviews human biology, anthropology, history, and morality from a mainly evolutionary perspective, to explain how current sustainability problems have arisen. Section 4 gives a more detailed economic analysis of how to sustain utility insofar as it depends on *absolute* levels of per capita consumption and environmental quality. Section 5 considers the implications for sustainability of the effects of *relative* levels of consumption and environmental quality on utility. Section 6 concludes.

2 PHYSICAL AND ECOLOGICAL PERSPECTIVES ON SUSTAINABILITY

Environmentalists frequently insist that economics must be radically changed to respect physical (thermodynamic) and ecological laws. The first law of thermodynamics essentially states that total matter and energy both remain constant in any isolated system; the first part of it is also called the law of matter conservation. The second law essentially means that the total amount of *usefully concentrated* matter and energy in an isolated system must decline.

Georgescu-Roegen (1971) held that the second law condemns civilisation to decline once earthly stocks of concentrated matter and energy have been dissipated. However, the earth is not an isolated system, and some level of continual resource use can be sustained by solar-powered recycling (Young 1991). Many other authors (e.g. Daly 1987) still hold that this means sustained economic growth is impossible, because current rates of materials and energy use are already too high to be sustained by such recycling. However, economic growth is fundamentally a growth in the *value* of output, which does not *necessarily* require a growth in materials and energy use, since technical progress can reduce the materials and energy needed to produce a unit of value (see Section 4.3).

On their own, thermodynamic laws therefore tell us frustratingly little about sustainability in simple, absolute terms. The first law means that matter and energy both are essential inputs to the economy, and must eventually end up back in the natural environment, where they may do much damage. And there is clearly some minimum physical content of the goods that fulfill basic needs: to stay alive, each person needs a minimum calorific value of food input, and this requires some minimum input of nutrients such as phosphorus. But that does not tell us how long material stocks will last, how much solar energy can be usefully captured by humans, what stock of material goods can be maintained in circulation, or what value these goods will have. These are complex *empirical* questions, to which we return in Section 4.6.

The main lessons for sustainability that have so far been drawn from ecology are as follows.[4] Firstly, all life forms, including humans, depend on a highly complex web of food chains. All these chains start from plants, which use solar energy, water, carbon dioxide and nutrients to photosynthesise food. Secondly, unlike many purely physical processes of decline, the decline of any living system eventually crosses a *threshold* when some catastrophic decline suddenly happens or starts to happen irreversibly. The most obvious threshold is death, whether caused by predation, starvation, or failure to breed. (Threshold instability also exists for some biomass-atmosphere systems, such as forests that create their own rainfall.)

Thirdly, (and more controversially; see Krebs 1985, 581 and Lovelock 1989, 50) simple and novel ecosystems tend to be more unstable than complex ones. A chilling example of this was when 29 reindeer were introduced onto St Matthew Island in the Bering Sea, where there were no predators, in 1944. Their numbers rose to 6,000 in 1963, and then crashed to 41 females and a sterile male in 1964 when supplies of lichen became exhausted. Similar cases of *ecological suicide* tend to involve populations which suddenly became free of the usual controls on their numbers (Diamond 1991, 282). We know little about how large human populations which have become free of involuntary controls may grow, or how much matter and energy they can take from or dump in the natural environment, without causing ecological catastrophes.

3 THE NATURAL HISTORY OF SUSTAINABILITY

Here we survey the history of how various human populations have been sustainable or unsustainable over the last 40,000 years, starting from our biological origins. A recurrent theme is that evolution by genetic or cultural selection can explain many overall trends in history, such as the pervasiveness of *treadmill* effects. Once an advantageous innovation (whether a sharper tooth, a sharper sword, or a superior legal system) is made, it will eventually be spread by natural selection until it becomes a *need*, and life without it would be worse than before. But evolutionary change is a random, not continuous process, so there are long periods when behaviour which hinders or is irrelevant to a species' reproductive success can survive.

3.1 *Human biology*

Like any other animal, we need to breathe and eat, and therefore need air, energy, water and nutrients from the environment. We are not very strong or fast, and we cannot survive cold climates without clothes or shelter. But we have many extraordinary features, the most phenomenal being our intelligence and dexterity (Diamond 1991, 193), which together I call 'cleverness'. Many other features have co-evolved with cleverness, including speech (which greatly aids *group co-operation*); the ability to accumulate useful *knowledge* and *tools*; and our relatively long childhood which is needed to acquire knowledge from our parents (Diamond 1991, 57-8).

All these features are part of our genetic inheritance, which has changed very little since our cultural evolution first surged forward about 40,000 years ago (Diamond 1991, Ch. 2). Sociobiologists such as Wilson (1975, Ch. 27) and Trivers (1985) argue that this genetic inheritance has a pervasive influence on our current behaviour. This is an intensely controversial subject (see for example Rose et al. 1984), but nevertheless I suggest that the following psychological motivations do have some genetic basis (for the reasons outlined in brackets).[5] They are therefore also significant and durable influences on utility, which must be taken into account in forming sustainability policies.

M1 *To acquire food and artefacts*, up to some level of satiation. (Essential for individual survival)

M2 *To seek out natural environments*. (As a means of getting food)

M3 *To belong to a group*. (Important for individual survival, once human co-operation is essential for obtaining food)

M4 *To compete with other groups*. (Important for group survival, once human groups are formed and can use weapons)

M5 *To seek status in one's group*. (Having high status relative to others is important in securing a mate.)

M6 *To be affected more by changes than by constancy*, generally known as 'adaptation effects'. (Vital for hunting, mating and avoiding death)

M7 *To be affected more by loss than by gain of a given benefit*. (A fairly small loss could cause a death, whereas a small gain could not create a life)

M8 *To have a strong but diminishing concern for the future*. (One's genetic interest in ensuring that one's offspring live long enough to reproduce is halved with each successive generation)

Irrespective of their possible genetic origins, all these motivations are well-known to psychologists and have a significant effect on utility,[6] and therefore reappear at appropriate points below.

3.2 *History*

There are three main phases through which groups of genetically modern humans have evolved in the last 40,000 years: about 30,000 years with only hunting-gathering, 10,000 years with agriculture (the extensive use of tame animals and/or plants) as well, and 250 years with industrialism (the extensive use of non-renewable resources from beneath the soil) as well.

Viewed from a modern perspective, *hunter-gatherers* present some puzzles for sustainability analysts.[7] To judge from both the dead and living relics of their populations, their way of life used negligible non-renewable resources. In the absence of external threats like climatic change, it was therefore sustainable (and, indeed, often sustained) for millennia without innovation, i.e. *statically sustainable* (what Wilkinson 1973 calls 'ecological equilibrium'). Life was not necessarily 'brutish and short'. Many hunter-gatherers enjoyed remarkable leisure: the !Kung bushmen of southwestern Africa typically worked only 2.5 days per week (Sahlins 1973, 21). Thanks to a varied diet, many hunter-gatherers were quite healthy (Wilkinson 1973, 42; Ponting 1991, 20, Diamond 1991, 169). Population stability was achieved not just by high involuntary death rates, but also by widespread practices of primitive population control (e.g. sexual abstinence and infanticide – see Section 4.5 below).

Such evidence suggests that hunter-gatherers consciously aimed for sustainability, and achieved it; but other evidence shows that over the millennia, hunting-gathering was also associated with profound instability, which cannot be explained solely by external causes such as climatic change. Humans spread across the world in a way which no other large animal has done (Diamond 1991, 41-2, 198-9). The innovations of fire, tools, clothes, art and music were developed, and the first three of these (and probably language as well – see Diamond 1991, 47-8) then became *necessary* for survival in newly occupied, harsher ecological niches. Above all, massive extinctions of large animals in Australasia, the Americas and Polynesia were coincident with the arrival of humans (Smith, 1992, 4-5), and sometimes led to the local extinction of humans as well (Diamond 1991, 282, 291).

Agriculture can be statically sustained by solar energy, provided that soil quantity and quality are conserved. Because agriculture directs more of the solar energy, water and nutrients in a given land area towards human use, it can support much higher population densities than hunting-gathering. As with hunter-gatherers, there are many examples of apparently statically sustainable agricultural societies (Sahlins 1973, Ch. 2; Wilkinson 1973, Ch. 3) which again exhibit leisure as well as primitive population control.

But the higher population densities of agriculture can put a strain on environmental resources and make static sustainability impossible. There is persuasive evidence that many agricultural civilisations of history, such as the Sumerians, Greeks, Romans, Mayans, Easter Islanders, Anasazis and Petrans, declined to a shadow of their former selves because of deforestation, soil erosion, nutrient exhaustion and/or salination (Ponting 1991, Chs. 1, 5; Diamond 1991, 296-301). Also, the need to clear and tend land and make implements, vessels and dwellings means that settled agriculture can be harder work than hunting-gathering (Ponting 1991, 41; Boserup 1981, Ch. 4). And it also often caused poorer health, because it limited the diet to just a few staples, and involved living close to disease-ridden animals (Ponting 1991, 225; Diamond 1991, 167-9).

Why then was hunting-gathering replaced over much of the world (but only very slowly, Diamond 1991, 166) by the often tougher lifestyle of agriculture? And why was each type of society sometimes sustained and sometimes unsustained? Evolution offers a plausible explanation (but not *justification*) as follows. By chance, some societies meet environmental constraints by stabilising their population rather than innovating. By chance, other societies discover (from either internal or external sources) an innovation, like horses, guns, or an empty continent, and then expand their population as far as the innovation will allow. In so doing they may go beyond what their environment can sustain, often because of ignorance. One of four things can then happen. The environment may collapse completely, taking the society with it. Or, the innovators may be forced painfully back into ecological equilibrium. Or, they may find another innovation, to keep them going for a few more centuries, or decades. (These last two alternatives are the ‘poverty’ and the ‘progress’ of Wilkinson 1973; see for example pp.70-2.) Or finally, since innovating societies generally have higher population densities and superior weapons, they may drive out statically sustainable societies, whether by war, genocide, disease or habitat destruction, and thus acquire new resources which will keep them going for a few more centuries, or decades (Diamond 1991, 171-2).

In contrast with hunting-gathering and agriculture, *industrialism* cannot be statically sustainable, since it constantly depletes available reserves of environmental resources, especially non-renewable ones. Only the dynamic sustainability of a successful treadmill is possible: new reserves *must* be discovered, and new tools[8] (machinery, buildings, vehicles, etc.) and knowledge *must* be accumulated, to avoid decline. As with the transition from hunting-gathering to agriculture, technical ‘progress’ often means switching to more arduous techniques: for example, coal was used for power in England only when the cleaner, more convenient resource of wood was exhausted (Wilkinson 1973, 114-8). As such cycles of exhaustion and innovation continue, production processes become more roundabout, and measures of total economic activity can increasingly overstate the production of directly useful goods (Common 1988).

Nevertheless, industrial progress has taken a rather different turn over the last 150 years or so, as emphasised by Baumol, Blackman and Wolff (1989). Technical innovation has been encouraged for its own sake, as well as to relieve resource constraints. In *rich* countries it has *so far* generally outstripped resource exhaustion, and has produced spectacular rises in material living standards, in opportunities for education, travel and leisure, and in health and life expectancy (what could be called 'decadal security'). But innovation may not have improved millennial security, i.e. sustainability, as we discuss in the rest of this paper.

First, however, let us finish our evolutionary perspective. From the 15th century onwards, Europe exploited its technical superiority (which was probably a biogeographical accident – see Diamond 1991, Ch. 14), to set up colonies around the world. With the coming of industrialism in the 18th century, colonial expansion proceeded further and faster, using the same evolutionary forces of war, genocide, disease or habitat destruction much more than mutual agreement (Ponting 1991, Chs. 7, 10; Diamond 1991, Ch. 16).

However, industrialism has altered evolutionary pressures in two profound ways. Firstly, the vast expansion of intercontinental trade, started by European imports of natural resources from and exports of manufactures to its colonies, has created a truly global economy, albeit one with great inequalities (see Section 4.7.3). Intimate trading links now make it much harder to say whether any single country's development is sustainable or not. Secondly, the pace of change is now dramatically faster, and still accelerating. Changes in lifestyle which typically took millennia to happen in undisturbed hunting-gathering societies, and centuries in undisturbed agricultural societies, now happen in mere decades in industrial societies. Together, these changes in scale and pace leave the human species very little time to discover whether its current development is sustainable, and no space to repeat the experiment if it is not.

3.3 *Challenges to environmental sustainability*

Excellent surveys of where history has left us in terms of cumulative and current human impacts on environmental resources are contained in Moore (1985), Simmons (1989) or *World Resources* (biennially); here we merely list a few salient issues.

Humans now dominate the earth. Vitousek et al. (1986) estimate that nearly 40% of the potential net primary productivity (NPP, mostly from plant photosynthesis) of the earth's land surface is currently appropriated by humans. This figure cannot rise anywhere near 100% without causing a total breakdown of the earth's biological systems, but it may be rising rapidly. World population, having taken 10,000 years to grow from about 5 million to 1 billion in 1825, doubled in just the next 100 years, and is currently doubling in less than 50 years (see Figure 1), an explosive growth which has been likened to a planetary cancer (Hern 1990). Since plausible increases in the efficiency with which the world's food systems use NPP are ultimately limited by inputs of nutrients like phosphorus, population growth on its own shows why the automatic assumption (made for example by Beckerman 1992) that the growth in living standards in rich countries over just the last 200 years will continue indefinitely – an assumption that begs most of the sustainability debate – is fiercely challenged by many.

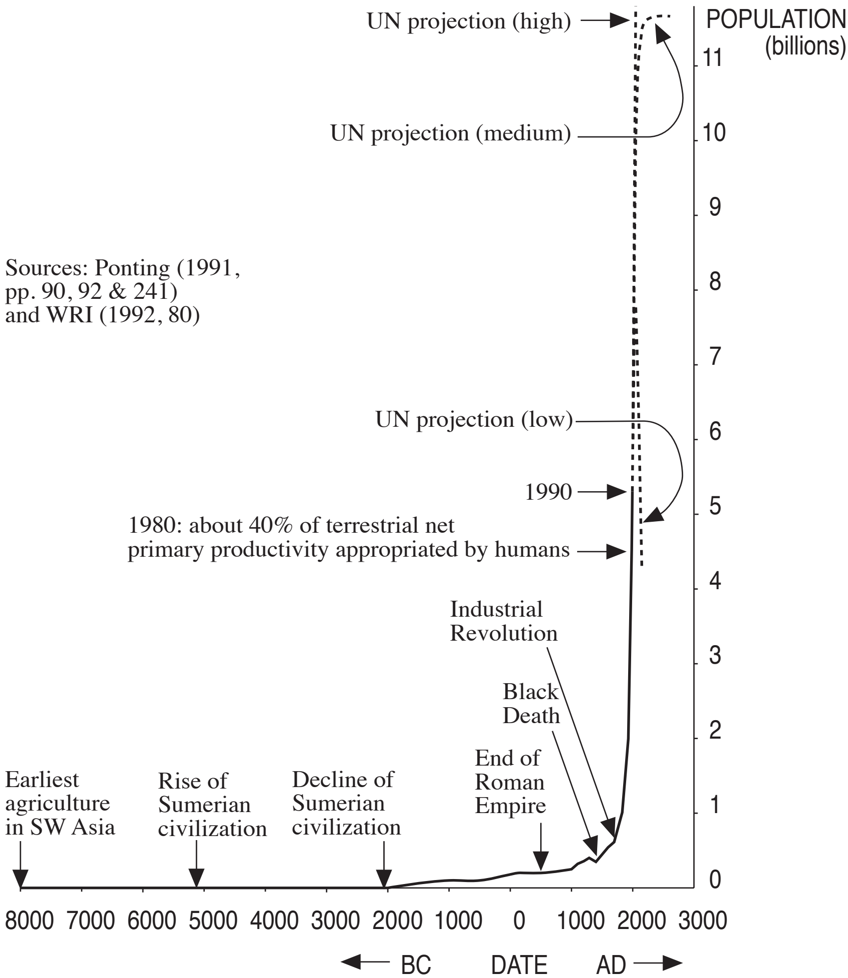


FIGURE 1.
World Population over 11,000 years

Some of the worrying effects of having reached a state where nearly half the world's land ecosystems are devoted to humans are:

(a) rapid depletion of renewable natural resources (e.g. forests, fish, land and sea mammals);

(b) rapid depletion of known reserves of non-renewable energy and minerals, although new discoveries and new extraction techniques have *so far* avoided any decline in availability;

(c) rapid depletion of non-renewable stocks of genetic diversity (see Wilson 1988) and soil;

(d) severe problems of local, transient pollution in industrialising countries;

(e) steadily growing problems of cumulative pollution, both regional and global, principally acid rain, ozone depletion, and the accumulation of greenhouse gases such as CO_2 which are likely to cause global warming (Cline 1991);

(f) wide, and recently growing, inequalities between rich and poor nations (UNDP 1992); and

(g) greatly increased rates of change in most areas of life, as noted above. Many graphs of pollution, energy use, metal use, patents filed, university graduates, species made extinct, etc., would show the same extreme 'time compression' as Figure 1 (see for example Ponting 1991, 384).

Merely listing such effects does not settle any arguments about how much local or global sustainability is really threatened. Indeed, the vast *complexity* of these effects, and their generally *gradual* nature, explain why many people feel that the human species now faces a serious threat from itself; and yet others do not believe there is a threat, or at least do not respond to its gradualness. These features also perhaps explain the hesitant and controversial rise of sustainability as a moral imperative, to which we now turn.

3.4 *Justifying sustainability as a moral goal*

The definition of sustainability as non-declining utility of a representative member of society provokes two main questions. Why choose this particular sustainability criterion? And should any sustainability criterion override all other policy criteria?

Regarding the first question, two criteria other than non-declining utility are often used to judge the fairness of a future development path of society. The first is physical *survival*. This was a central theme in Sections 3.1-2, and is of course a pre-requisite for non-declining utility; but most of the modern sustainability debate is about more than just staying alive. The second is *constant utility*, which is used by most formal literature on intergenerational equity (see for example Solow 1986). This seems too strict a criterion, as it would prevent the current generation from choosing a future with growing welfare in preference to one with constant welfare. It ignores the *asymmetry of time*, which means that the current generation can be consulted in decisions about losses in its welfare, whereas the future generation cannot. Other criteria, such as *stability* or *resilience* (being able to resist small shocks or survive large shocks over time), are not directly discussed here (see Common and Perrings 1992 for further detail).

We explore the second question, of how one can justify any strict criterion of sustainability or 'fairness to the future', by means of questions and tentative answers (see Pezzey 1989b, 10-14, Laslett and Fishkin 1992 and Broome 1992, Ch. 2, for further discussion).

Q1. Why should it be unacceptable to impose a very small decline in future generations' utility in return for a huge increase in utility for the current generation?

A1. An answer might be that it is unacceptable to seek to gain at the expense of another who is powerless because of the asymmetry of time. A way out might be to claim that the question is irrelevant, because huge benefits now in return for small costs later are not currently feasible.

Q2. Why should a sustainability requirement forbid any temporary decline in utility caused by investment, even when this investment could result in huge future increases in utility?

A1. This objection could perhaps be met by applying a sustainability constraint to a moving average of utility over say 5-10 years (any longer could condemn old people to a long decline with no compensation before their death).

Q3. What does one do if the current level of utility is already unsustainable?

A3. To reach a sustainable utility path, there must first be some transitional period when utility falls from its current level. One must then either exclude this transitional period from the sustainability constraint, or weigh the transitional cost with the benefit of achieving sustainability. Either modification departs from the simplicity of the original definition.

Q4. How is a 'representative member of society' defined?

A4. With great difficulty (Kirman 1992). The 'representative member' fiction hides the great intragenerational inequalities which motivate much concern for sustainability (WCED 1987). It also prejudges whether or not any weight in calculations of future welfare should be given to population size *per se* (Koopmans 1977, 270).

Q5. Why should we care about the sustainability of other countries?

A5. Either because it is morally right that we do so, and/or because we have an interest in preventing transboundary pollution, environmental refugees, loss of trade, etc. (see Section 4.7.3, but this argument is weak when applied to very poor, remote countries).

Q6. Why should we care so much about the welfare of amorphous people in future centuries, whose very being is determined by our actions, and whose *preferences we cannot predict?*

A6. These are two aspects of the 'identity problem'. It is hard to give a reason for caring other than by appealing to basic intuitive notions of fairness (see Toman and Crosson 1991); but the genetically-influenced motivations in Section 3.1 do give some outline of what future preferences might be.

Q7. Is infanticide a morally justifiable way to achieve sustainability?

A7. Clearly not for the readership of this journal; but are the Inuit or the Yanomamo Indians wrong to have been doing just this for centuries?

Sustainability thus raises very awkward moral questions, when seen from a conventional philosophical perspective, which are not resolved here.

The following, tentative evolutionary perspective, which I derive from Alexander (1987), casts many of these questions in a very different light. Throughout our genetic and cultural evolution, our intelligence, dexterity and communication skills have meant that we humans have survived best by co-operating in groups, and that the main threat to a group's survival has been competition from other groups (hence motivations M3 and M4 above). Morality has evolved as a result:

> A tribe including many members who... were always ready to aid one another, and to sacrifice themselves for the common good, would be victorious over most other tribes; and this would be natural selection. (Darwin 1871, 500)

Our understanding of just why humans co-operate in *large, unrelated* groups is still poor (Axelrod and Dion 1988, Boyd and Richerson 1992), and this theory of moral evolution could help to explain such co-operation, and could be relevant to sustainability as follows. Some people now view human groups as facing a greater threat to their survival from the everyday actions of the whole species than from aggression by competing groups. In promoting sustainability as a moral imperative, such people have perhaps transferred morality from promoting the survival of the group, to promoting the sustainability of the species, even if they do not realise this (and morality can involve self-deception: see Alexander 1987, 117). Other people do not accept or perceive that the species is threatened, and therefore do not regard sustainability as morally necessary.

Two conclusions would follow from this. Firstly, the evolution of a sustainability ethic will ultimately depend more on how new information affects people's perceptions of the threat to their local or global environment, than on abstract philosophical arguments. Secondly, and more gloomily, ethical evolution may not be fast enough to achieve sustainability, to the extent that it requires a clear threat to actual *survival*, a threat which is likely to arrive only when dramatic declines in *utility* have already become inevitable. Both conclusions show why obtaining *and communicating* good information and predictions about environmental resource degradation is of the utmost importance.

4 ECONOMIC ANALYSIS OF SUSTAINABILITY

4.1 *The structure of the economy, and questions to be asked*

Many of the economic issues raised by sustainability are highlighted by the simplified economic model of a closed (non-trading) society shown in Figure 2.

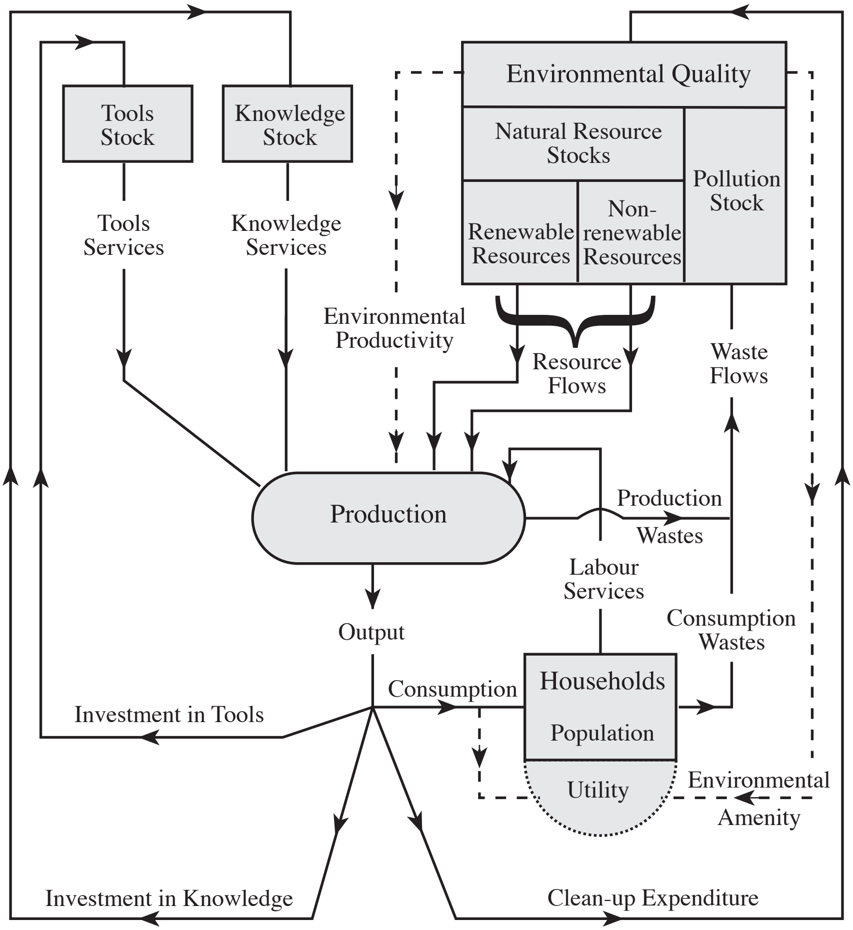


FIGURE 2.
Economic and environmental stocks and flows – a simple model

Various stocks determine the productive potential of the economy: 'tools' (equipment such as machinery and buildings), knowledge, and households are three human-made productive stocks; renewable resources and non-renewable resources are two natural productive stocks; and pollution is a human-made stock of bads in the natural environment. Obviously all these categories are aggregations of very diverse constituents, so there are many overlaps between categories.

Flows of services are derived from the three human-made stocks, leaving the stocks intact; flows of materials are extracted from the two natural resource stocks, leaving these stocks depleted (although natural growth will augment the renewable resources); and a non-extractive flow of productive services ('environmental productivity') is derived from the environment as a whole. All these flows feed into a 'production function' which determines how much real[9] value of output flow and what quantity of wastes are produced from given input flows.

Output is then divided into investment in tools, investment in knowledge, clean-up expenditure, and consumption. Materials that go into consumption eventually end up as waste flows which add to the pollution stock, although some pollutants can be quite rapidly assimilated by the environment. The absolute *and relative* levels of per capita consumption and another non-extractive flow of environmental services ('environmental amenity', which falls as the pollution stock rises) together determine the level of utility of a representative member of society.[10]

The *material standard of living* (or just 'living standard') here means the absolute level of per capita consumption; while the *quality of life* means the combined impact on utility of absolute (but not relative) levels of environmental amenity (which is assumed to be common to all) and per capita consumption.

We can now distinguish a number of different economic questions about the *feasibility* of sustainability:

1 Can the material standard of living continue to grow for millennia in existing industrialised countries?

2 Could the biosphere sustain a world where all countries enjoyed the current living standards of the richest countries?

3 Has the quality of life grown in recent decades in existing industrialised countries? Can it and will it continue to grow for millennia?

4 Can one country achieve a sustainable quality of life while its trading partner does not?

Attempts to answer these questions runs into massive complexity and uncertainty, and economic analysis cannot provide any simple quantitative answers. Qualitatively, the most obvious long-term threats to sustainability in an industrial society are that the ultimate stocks (if not the immediately available reserves) of non-renewable natural resources must decline, and that the pollution stock will increase because waste is dumped faster than the environment can assimilate it. Two crucial ways to sustain the quality of life are therefore to substitute more tools and knowledge for both flows of resources into and flows of waste out of the production process, and to control total population. Sections 4.3-6 explore these possibilities; but even if they are feasible, society may not *choose* them if it does not value its own future enough, and we turn to this next.

4.2 *Discounting*[11]

Discounting devalues the future; for example, using a market discount rate of 5% (i.e. a discount factor of 1.05) per year treats a £1 million cost or benefit occurring in 200 years' time as having the same *present value* as a cost or benefit now of just £58 (= £1,000,000/$(1.05)^{200}$). The market (or *consumption*) discount rate used to discount future monetary costs and benefits combines two distinct effects: the rate at which future consumption growth would make an extra unit of consumption less desirable as time passes, and the rate of impatience (also known as 'pure time preference' or the *utility* discount rate) of the current generation (motivation M8 in Section 3.1). If consumption growth is genuinely sustainable, the first effect justifies a positive consumption discount rate, even when the utility discount rate is zero.

Under ideal conditions and with infinitely lived people(!), it can be shown that market forces will choose the future for society that maximises the sum, over millennia, of the discounted present values of a representative person's utility. Economists generally refer to this as the *optimal* future for society, but there is no guarantee that this future will be sustainable: optimality confers no rights on the future.

It is often suggested that one important way of protecting these rights, and of helping to make the optimal future sustainable, is to *lower effective utility discount rates* throughout society. In a number of theoretical models of optimal economic growth with exhaustible resources (Dasgupta and Heal 1979, 299, Pezzey 1989a, 72-8, and Barbier and Markandya 1990, 667) lowering the utility discount rate helps sustainability. In other models, however, lowering discount rates increases investment demands on environmental resources, and thus speeds rather than slows their decline (Farzin 1984, Krautkraemer 1986); and it can also encourage investments with high capital costs now and high clean-up costs in the long-term (Price 1993, Ch. 21). But these latter results say nothing directly about utility as such, which is our ultimate concern. If environmental resources are correctly valued (including bans on their use beyond any threshold of catastrophe), their price could perhaps rise sufficiently in response to increased investment demands to ensure that a lower utility discount rate would not cause declining utility on the optimal path. Further theoretical and empirical research is needed in this important area.

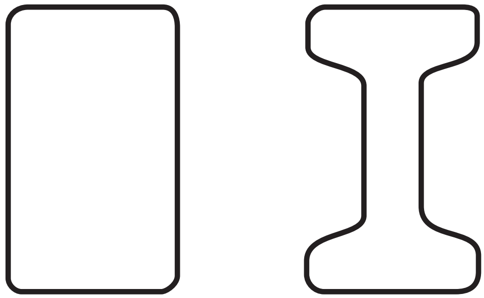
In situations where lowering utility discount rates generally helps sustainability, correcting *market failures* can often produce a similar effect. The lack of adequate futures markets, or of mechanisms to reflect the general social benefit of saving, means that the market discount rate is almost certainly too high. Policies to correct these failures (e.g. subsidising saving, correcting over-optimistic expectations of future growth) will therefore reduce it. But this may not be enough to achieve sustainability, in which case stronger policies (but probably not very different ones) will be needed, and an appeal to the moral imperative of sustainability will be necessary to justify them. And whatever the motive or mechanism for policy, to work properly it should influence both the *public* and *private* sectors of the economy, since both of these can undermine sustainability (Pezzey 1989a, 35-7, 48-54, 59).

It could also be important to know what utility discount rates would maximise reproductive success in primitive societies, since this level (motivation M8) provides a genetic background to current discount rates, and may constrain how easily they can be changed by cultural choice. Hansson and Stuart (1990) show how natural selection can bring the utility discount rate, the real interest rate, the population growth rate and the natural rate of productivity growth all into equality with each other. Rogers (1992) shows how the consumption discount rate favoured by selection varies with a person's age, and can be calculated from age-specific rates of birth and death. Further research on the evolution of discounting seems well worthwhile.

4.3 *Depletion of natural resources versus accumulation of tools and knowledge*

Does the finiteness of natural resource inputs used by the economy impose a limit on sustainability? Early studies of natural resource depletion certainly thought so, and were alarmed at how few years' worth of supply remained in the world's known reserves of non-renewable energy and raw materials (Meadows et al. 1972). *So far*, time has more or less proved them wrong, and earlier optimists like Barnett and Morse (1963) correct. The latter argued that the decline of existing reserves would continually be alleviated by new resource discoveries, innovations in resource extraction, transport and processing, and substitutions of one resource for another. This perpetual substitution of tools and knowledge to replace natural resource is essential to sustain consumption: that is, the industrial economy is a *technology treadmill*. We consider here what the theory of optimal economic growth with non-renewable resources can say about keeping the treadmill going. Smith and Krutilla (1979) give a good general introduction to the issues, and Pezzey (1989a, 22-3) and Krautkraemer (1990) give more recent reviews of the technical economic literature.

An important preliminary is to recall from Section 2 that *value*, which is what we use to measure production and consumption here, has no simple relationship to the amount of materials used. For example, a steel girder with the rectangular cross section below on the left is less useful than one of the same length with the I-shaped cross section on the right, which uses 40% less steel, but needs a more expensive machine for its manufacture. Making I-girders is thus substituting 'tools' for resources.



Mainstream optimal growth models like Dasgupta and Heal (1979, 205) show that even if non-renewable resources are essential for production, consumption can be sustained forever, if using more *tools* produces a big enough substitution response of increased output and/or reduced resource inputs. However, such models use types of production function which preclude any analysis of what happens if tools and natural resources are complementary (i.e. where cheaper tools would increase resource use, rather than decrease it, which is likely to make sustainability more difficult). This is a serious shortcoming, and alternative approaches such as Austrian capital theory (see for example Faber and Proops 1990) may yield very different insights.

Knowledge (in the form of technical progress) may be more important than tools. Sustaining some positive level of consumption forever from finite resource inputs is theoretically feasible given perpetual technical progress (Dasgupta and Heal 1979, 207), although this result implausibly requires that there is no minimum physical resource content per unit of output value. However, if there is a positive utility discount rate, then the growth paths actually chosen by the market will not be sustainable unless technical progress is sufficiently fast, or unless there is an active policy of resource conservation subsidies to induce slower depletion rates.

A closer look at the theory of knowledge is therefore important. Knowledge is actually more complex than shown on Figure 2, and comes in three conceptually distinct forms: pure or *disembodied* knowledge (referred to in Section 1 as intellectual capital; for example, blueprints for the I-girder's cross-sectional design); knowledge embodied into better tools (for example, the new machine needed to make the girder); and knowledge embodied into human skills (referred to in Section 1 as human capital; for example, people who know how to use the machine). The first two of these can be regarded as forms of *technology*. Disembodied knowledge does not decay over time or when someone uses it, and it can be accumulated without limit (Dasgupta 1987). But can it substitute directly for declining natural resource inputs in order to achieve sustainability?

There seems to be no simple answer to this crucial question. So far, theoretical models of the effect of knowledge on growth and sustainability have essentially made the assumptions needed to produce the desired results. The 1970s theory of growth with non-renewable resources (e.g. Dasgupta and Heal 1979) simply assumed exogenous rates of disembodied knowledge growth. The more recent theory of endogenous growth builds in market forces which determine both embodied and disembodied technical progress, but so far it has ignored resource inputs (Van De Klundert and Smulders 1992). In either case, perpetual growth in output is possible because disembodied knowledge is assumed to be directly substitutable for other inputs. In contrast, Ayres and Miller (1980) assume that knowledge must be embodied in tools before it is productive, so there is a limit to how much it can substitute for natural resource inputs, and perpetual output growth is impossible. Only empirical research will establish which theoretical assumption is more justified.

Knowledge is embodied in people through *education*, and casual observation reveals two opposing trends in the role of education in modern industrial societies. Many existing jobs are becoming easier through automation; but they are also disappearing, and the new jobs that replace them typically require more education. This is because, as the original reserves of natural resources are exhausted, production technologies become ever more complex (e.g. using sophisticated mining and processing technology instead of axes to provide fuel, and using nuclear reactors instead of open fires to burn it with). The understanding (e.g. of global climate and stratospheric chemistry) needed to protect the environment adequately is also becoming vastly more complex. Unless it turns out that only the most recent additions to knowledge are relevant, an ever longer education (which has been the trend observed over the last century, as noted by Norgaard 1986) may be *essential* just to maintain a constant living standard. If so, given the finite life that genetic evolution gives us (Alexander 1987, 62), the finite knowledge that the average person can absorb may ultimately limit growth more than the finite global stock of oil or capacity to absorb CO_2. An ever more highly educated workforce, although good for national competitiveness (the conventional economic view of education – see Baumol, Blackman and Wolff 1989, Ch. 9), may thus be a warning of impending global unsustainability.

The implications of all this for policies on education, research and development are complex. To the extent that new knowledge is freely available to all, it warrants subsidies or public provision; but to the extent that it gives a competitive advantage only to the first person or firm to discover it, it actually needs to be discouraged (Beath, Katsoulacos and Ulph 1989). It is also perhaps a matter for policy that the relentless growth of knowledge threatens social cohesion, by requiring people to become ever more specialised. Moreover, it becomes increasingly difficult for any one person to acquire a reasonable understanding of all the key issues that affect sustainability (a difficulty that has dogged the writing of this paper!).

4.4 *Environmental degradation*

4.4.1 *Externalities and ownership*

Figure 2 shows how declining environmental quality can lead to declining utility either directly, by reducing amenity, or indirectly, by reducing productivity. The environmental threat to sustainability is different from the threat posed by declining non-renewable resource inputs in two general ways. Firstly, while non-renewable resources are mostly not susceptible to catastrophic *threshold* effects, such as death or disruption of delicate natural flows, environments in and above the soil certainly are, though in very uncertain ways.

Secondly, most types of environmental productivity and amenity flows shown on Figure 2 are not controlled by the people they affect, and are called *externalities*, because they are external to and therefore ignored by market forces. Even when natural habitats such as forests are owned, many of their benefits, such as preventing soil erosion or maintaining biodiversity, are unowned and thus ignored by markets. Externalities threaten sustainability mainly when they give rise to *cumulative* degradation of the environment.

Among most animal species, externalities such as having food stolen or being eaten are the harsh realities of daily life. By contrast, among humans, the legal evolution of property rights which define *ownership* has allowed people much more control over externalities. However, laws almost always lag behind technical evolution. There are now such huge physical flows of resource inputs, which sooner or later end up as wastes (many of them novel, with highly durable and/or unpredicable effects) in the environment, that conventional property rights can no longer protect all the people and places that are affected.

4.4.2 *Internalising externalities*[12]

How then can the environmental threat to sustainability be contained? We distinguish two main approaches, though these overlap to some extent. The conventional (neoclassical) school of environmental economics assumes that environmental productivity and/or amenity can be substituted by other economic variables. Within this school there has been some work on the dynamic effects of cumulative pollution (see for example Forster 1980, and other models reviewed by Krautkraemer 1990, 11), but formal analysis of environmental effects on sustainability as such has only recently started. Pezzey (1989a) and

Howarth and Norgaard (1992) both model the dynamic effect of environmental externalities on changes in utility, i.e. on sustainability. The policy conclusions of the former are that using *economic incentives* (such as pollution taxes or tradeable pollution permits) to internalise cumulative environmental externalities will achieve the socially optimal future for society, and will probably also improve sustainability by effectively lowering discount rates. But to guarantee sustainability may require even stronger policies, which can be justified only by an appeal to intergenerational equity rather than to 'optimality', i.e. the collective interest of just the current generation (compare similar conclusions in Section 4.2). Howarth and Norgaard use a rather different model with overlapping generations and intergenerational resource transfers, but many of their conclusions are similar.

Even if the assumption that one can generally substitute tools and knowledge for environmental functions were not disputed (and we see below that it is), there are a number of practical and psychological problems with internalising externalities, especially when they are global. Firstly, internalisation requires that the environment is *valued* in monetary terms. Comprehensive environmental valuation would also enable the gross national product (GNP) that is measured by national accounting systems to become a better measure of the quality of life, and this could greatly change people's perceptions of what is progress (see WRI 1990, Ch. 14 for a survey of recent progress in this area, and Maler 1991 for theoretical analysis). But environmental valuation is never easy, even for local outdoor recreation in rich, well-documented countries (see Johansson 1990 for a survey of the techniques used). The much greater difficulty of valuing global environmental effects like climate change, ozone depletion or loss of biodiversity is clear from the soaring costs of the scientific and economic research programmes on these issues. However, this need not prevent action to control these effects, for one could argue that the *status quo* is current environmental stocks rather than current economic flows, so that the environment should be protected until the demands of the economy are proven to be sustainable.

Secondly, to be fully efficient, internalisation using incentive-based policies also logically requires that the environment be in effect *owned* (Pezzey 1992a). Ultimately, this is also true for the whole global environment, since unilateral action on problems like global warming even by major industrial blocks is likely to be ineffective (Pezzey 1992b, Hoel 1991); and even if the obvious political disputes over who should own which aspects of the environment are overcome, the informational and transactional costs of administering any global environmental policy will be very high. This is true even if the extreme free market solution of creating explicit property rights in global resources (Jeffreys 1991) is adopted, since the necessary labelling and exclusion technologies like stratospheric branding (e.g. the radioactive marking of CO_2 emissions!) or oceanic 'fencing' will hardly be cheap; though it is true that until wider property rights are allowed, there will be little incentive for improving such technologies.

Finally, something may be irretrievably lost to the human soul when there is no longer any true wilderness, no unprotected and yet untapped and untainted environments (McKibben 1989). Because conventional environmental policies entail ownership and control, they cannot protect such wilderness. Only a reduction in the overall scale of human activity of the planet, so that parts of the environment are no longer scarce and do not need to be owned, will help.

4.4.3 *Maintaining natural capital*

Solow (1986) (also Maler 1991) showed that if utility functions are stable, maintaining utility is equivalent to maintaining the value of all capital (tools plus natural capital, to which we would also add knowledge).[13] If tools and knowledge are not substitutable for natural capital in production processes – and given the huge uncertainties about environmental resources and the chance of ecological catastrophes, many writers hold that they must not be treated as such[14] – maintaining natural capital (i.e. environmental sustainability) is therefore essential. But this does not really avoid the need for valuation procedures to enable sensible trade-offs to be made within natural capital, since not every single species and habitat can be preserved (although some might argue that they should be, given that no adequate valuations yet exist).

Renewable resources are a special case here, even when they do not have external costs and benefits, because they can be made extinct through overharvesting if their stock is not maintained (Clark 1990). Barbier and Markandya (1990) model interactions between poverty, discount rates, and the need to keep natural capital above a 'catastrophe threshold', and conclude that an initial transfer of wealth could stop a poor country declining in a spiral of environmental destruction caused by poverty.

Another idea from the natural capital school is to use 'environmentally compensating projects' (Pearce, Markandya and Barbier 1989, 127-9) to make up for damage caused by public sector investment programmes, but this would not control the millions of daily private decisions (shall I use the bus or the car to get to work today? etc.) that have a huge environmental effect. As for the use of economic incentives as policy instruments, the natural capital approach would favour quantity-based instruments such as tradeable pollution permits, or even the regulatory standards that most real-world environmental policies use, because price-based instruments like charges offer less absolute protection against environmental catastrophes in an uncertain world (Baumol and Oates 1988, Ch. 5).

4.5 Population growth

Section 3.3 highlighted rapid world population growth as a prime threat to environmental sustainability, although there is considerable debate on this

(Todaro 1989, Ch. 6). It is therefore important to ask why population has grown, and how growth could be controlled. The following personal view of this complex question is consistent with the historical perspective of Section 3.2.

The modern world can be usefully stylised as comprising three types of societies: *statically sustainable societies*, *developed societies* and *developing societies*. (I ignore rapidly industrialising countries, as they raise few distinct issues here.) Death rates can be divided into *intended death rates* and *unintended death rates*, for reasons that will shortly become clear.

Statically sustainable societies (the undisturbed relics of the hunter-gatherer or primitive farming societies) by definition have stable populations; if not, they would have expanded beyond the limits of their environment and technology, and would have had to innovate. Population stability can be achieved not just by high unintended death rates (by infant mortality, disease, starvation, etc.), but also by a wide range of voluntary population controls which reduce birth rates (late marriage, celibacy, sexual abstinence while breast-feeding, coitus interruptus, abortion) or cause intended deaths (infanticide, infant neglect, senilicide); see Wilkinson (1973, 30-40) and Harris and Ross (1987, Ch. 1). Parallels to many of these practices occur in animal species living in stable environments. Given the often leisurely and fairly secure lifestyle in stable societies (already noted in Section 3.2), intended death here is not so much the result of miserable poverty, as Smith (1776/1937, lviii) thought, as an active way to avoid it.

Developed societies (typified by Western European countries) have been through three stages of *demographic transition* during the industrial era (Todaro 1989, 215). The first stage is not dissimilar to a statically sustainable society, with high rates of birth and of both unintended and intended death (Harris and Ross 1987, 90-2, note that infanticide was still widespread in pre-industrial Europe). In the second stage, rising industrial output leads to improved nutrition and public health measures, and hence to lower unintended death rates and perhaps also to lower intended death rates, as parents become more confident about raising their children. Population grows rapidly as a result, and the technological treadmill turns ever faster. In the third stage, rising output leads to reductions in fertility, thanks to economic influences, such as increased work opportunities for women and the rising net cost of children (Todaro 1989, 221-7), and to technical influences such as the arrival of reliable and affordable contraception. Eventually the fourth stage is reached, with low birth and death rates and a nearly stable population.

In the early to mid twentieth century, *developing* societies entered the second stage of the demographic transition. However, the main cause of this was not the internal influence of economic development, but outside technical and moral influences. Imported modern health technologies caused unintended death rates to fall much more rapidly in developing societies than in 19th-century Europe (Todaro 1989, 216). Imported legal and moral codes increased birth rates, and reduced intended death rates, by variously (if sometimes unintentionally) creating fertility incentives and discouraging abortion and infanticide (Wilkinson 1973, 60-68). The potential for economic development was thus often swamped by rapid population growth, before it could take off and usher in the third stage of transition. In extreme cases, downward spirals of population growth, poverty and environmental destruction occur (Dasgupta 1992).

Whether or not there should be an active policy of population control depends on one's interpretation of the above sequence of events. Pessimists like Ehrlich and Ehrlich (1990, 215, 59) argue that the demographic transition in developing countries will never get out of the second stage unless there is far-reaching policy intervention, intervention which is needed urgently because of the momentum for further growth that is already built into rapidly growing populations. Optimists like Simon (1981) argue that the demographic transition will be completed if left to run its natural course. Even if agreement is reached that some control is necessary, it is not clear whether it is needed more in developed countries with nearly stable populations and high per capita resource use (where control means population *reduction*), or in developing countries which have high population growth and low per capita resource use.

There is slightly more consensus about how to control population in a typical developing country (Todaro 1989, Ch. 7; Dasgupta 1992, 22-4). Increased educational and economic opportunities for women, better availability of contraception, and a more *equitable* distribution of income (so that economic development reaches the poorest, most numerous and most fertile members of society) are all widely seen as desirable and complementary methods of reducing birth rates without coercion. However, there will still be political resistance to the income redistribution needed to finance such programmes, and cultural and religious resistance to the emphasis on contraception. Also, some parts of the economic theory of fertility, on which these prescriptions are based, seem puzzling from a historical perspective. If material poverty makes people have large families to provide insurance for their old age, why does (or did) this not happen in statically sustainable societies, which are materially just as poor? And if poverty causes people to destroy their own environment, why again does this not happen in statically sustainable societies? More research on these questions would perhaps highlight changes in institutions for communal old age care and natural resource management which are also vital for effective population control.

4.6 *Empirical illustration: ingenuity versus growth*

The previous three sections have given some conceptual idea of how resource depletion, environmental degradation and population growth all threaten sustainability, and what policies are available to diminish these threats. All these threats are of course interrelated, since, as Ehrlich and Ehrlich (1990, 58) stress,

$$\text{Resource use} \equiv (\text{Resource use/GNP}) \times (\text{GNP/population}) \times \text{Population} \quad (1)$$

and the law of matter conservation means that increases in resource use probably cause increased environmental damage. How much can technical progress decrease *resource intensity* (resource use/GNP) and thus alleviate the pressures that rising living standards (increased real GNP/population) and population growth exert on finite environmental resources? Is the threat to the world's resource base greater from the developed or developing world? All we can do here is to give a few numbers and ideas to illustrate the issues raised by these hugely complex empirical questions about sustainability; for a more detailed appraisal see Todaro (1989, Ch. 6) or WRI (1992).

Theoretically, if resource intensities fall fast enough in both rich and poor countries, total resource use can fall while economic growth continues, at least for a time. But illustrative data in Table 1, on the change in three resource intensities in Brazil and USA between 1970 and 1986, show how this may not happen in practice.[15]

		Brazil		USA	
Date		1970	1986	1970	1986
Population (M)		96	138	205	242
Real GNP per capita (1987 $)		1260	1870	13800	18100
Real GNP (billions of 1987 $)		121	258	2834	4573
Resource intensities per $ of real GNP (in 1987 $)	Energy (MJ/$)	10	12	23	15
	Steel (g/$)	43	37*	44	25*
	Aluminium (g/$)	0.70	1.65	1.23	0.98
Total resource consumptions	Energy (EJ)	1.2	3.1	64.8	66.8
	Steel (Mt)	5.2	9.3*	124.5	103.8*
	Aluminium (Mt)	0.1	0.4	3.5	4.3

* Figures for 1984

Sources: Author's own calculations, using nominal GDP per capita, total population and US GDP deflator from World Bank (1991, 144-5 & 604-5); energy consumptions from WRI (1988, 306); steel and aluminium consumptions from WRI (1988, 311-2).

TABLE 1.
Resource intensities and resource consumptions, Brazil and USA 1970 and 1986

There were remarkable falls in the intensity of energy, steel and aluminium use in the USA over the 16 year interval; but nevertheless growth in GNP (from rises in both living standards and population) was enough to increase total consumptions of energy and aluminium, if not of steel. Steel intensity fell in Brazil, but energy and aluminium intensities rose, and total consumption of all three resources rose dramatically as its GNP more than doubled in value. So as far as it goes, Table 1 does not paint an encouraging picture for sustainable resource use.

The debate about resource scarcity remains contentious. At the broad global level, optimists like Simon (1981) and pessimists like Ehrlich and Ehrlich (1990) again tend to use opposing parts of the vast available data sets to reach very different conclusions. In a much more confined area, econometric techniques have so far failed to prove whether physical capital (tools) and energy are complements or substitutes (Berndt and Field 1981, Solow 1987). A frequent problem in the debate is the wide range of measures of resource scarcity, such as unit prices, unit extraction costs or reserve lifetimes (MacKellar and Vining 1989). Nevertheless, some fairly sophisticated studies have concluded that several resources are now becoming scarcer (Slade 1982, Hall and Hall 1984). A rather simpler but still striking result is that in the USA (whose domestic energy resources are now severely depleted) the amount of energy input needed to produce a unit of energy output rose sharply in the 1970s (Hall, Cleveland and Kaufmann 1986, 88). So the long-term declines in scarcity calculated by Barnett and Morse (1963) may now have been reversed, as substitutions of tools and knowledge finally fail to keep pace with the inexorable physical depletion of the resource base. But we can never be sure: many dire predictions of imminent physical exhaustion have turned out to be wrong in the past because they underestimated the potential of technical progress (Baumol, Blackman and Wolff 1989, 214).

The future balance between environmental pollution and the accumulation of tools and knowledge is no easier to predict. There have been dramatic reductions in sulphur dioxide emitted *per unit* of electricity generated in some rich countries, but *total* global emissions rose steeply until 1980 (WRI 1990, 4 & 208). Similarly, despite falling intensities in some rich countries (as shown in Table 3), world emissions of carbon dioxide continue to rise (WRI 1992, 350).

To sum up: at least until recently, overall decreases in resource use or pollutant emissions per real dollar of GNP have been outweighed by increases in GNP, so that most total resource uses and pollutant emissions are still rising, often swiftly, which bodes ill for local or global sustainability. In the medium term of about fifty to one hundred years ahead, technical progress and fresh resource discoveries may continue to alleviate non-renewable resource scarcity, so cumulative environmental pollution probably poses a more serious threat to global sustainability. This is because, unlike most non-renewable resources, the environment (a) may suffer from catastrophic threshold effects, (b) is mostly not owned, so that there is no world price mechanism to warn of increasing environmental scarcity, and (c) allows few 'discoveries' of untapped assimilative capacity.

4.7 *Sectoral sustainability*

We have so far considered the sustainability of a single, isolated economy or society. Given that almost all parts of the world economy affect each other, it is important to ask now what can be said about the sustainability of its different sectors, such as individual product industries or nations. Can one, and should one, achieve 'sustainable agriculture', or 'sustainable forestry'? Can Japan develop sustainably, while the poorer countries from which it imports its raw materials are developing unsustainably? Can Bangladesh develop sustainably even if global warming raises the sea-level and drowns vast swathes of its land?

Such questions can be classified in three main ways. Firstly, they may concern *product sustainability* or *national sustainability*. Secondly, they may concern the threat to a sector's sustainability from dependence on imports of non-renewable resources, or from transboundary pollution. Thirdly, they may concern relations between similar or highly unequal nations.

4.7.1 *Product sustainability*

Why should the output of a particular economic sector such as steel, forestry or food – perhaps worldwide, but usually within one country – be sustained? The only sensible way to define sustainability here is in terms of output, since sectors do not have utility functions. A concern for the optimality of the whole economy requires that each sector is fully optimised; but a concern for the sustainability of the whole economy does *not* require the sustainability of any particular sector, unless that sector's product is essential at its current level (Pezzey 1989a, 55-9).

So there can only be two reasons for seeking product sustainability, as noted by Toman and Crosson (1991). Firstly, because it is believed that a particular product has an intrinsic right to be sustained. This is often the view that ecologists hold, not so much about an economic product, but about a species or an ecosystem. Secondly, because it is believed that a particular product is so important to the economy as a whole that it is non-substitutable (or, in an uncertain world, that the risk of its being non-substitutable cannot be taken).

The second reason is probably what motivates most writing on sustaining primary sectors like agriculture, forestry, fishing, energy and water supply (see for example CJAE 1991 and WRI 1992); one does not hear so much about sustainable steel-making. Primary sectors are the ultimate source of all economic activity, because they import free and inexhaustible solar energy into the economy, and we depend on them for sheer survival; we therefore want to guarantee sustainable supplies of them. Moreover, these sectors *could* in principle sustain some constant level of output (not necessarily the current level) without imports of non-renewable resources like petroleum or artificial fertilisers.

However, several other questions remain about product sustainability. Even agriculture would always need to import some tools, so its sustainability still has some link with the sustainability of industry. And pollution effects like acid deposition or global climate change might make production biologically impossible in some sectors, no matter what inputs they import from the economy.

Also, does sustaining a sector's output mean sustaining the *physical quantity* or the *value* of its output? Both are mooted by Pearce, Markandya and Barbier (1989, 43), and the difference may be crucial. If the product is a necessity and its quantity of output is falling, its price may be rising so fast that the value of output (price times quantity) is actually rising. This could be seen as sustainable for the producer, but unsustainable for the consumer.

Finally, if we are looking at one country in an international setting, why cannot food, timber and fish be imported once domestic supplies have been exhausted? One answer might be that we are interested in a poor country whose sole source of foreign exchange is natural resource exports, which leads on to our next topic.

4.7.2 *National sustainability*

A simple, if slightly crude way of defining a nation is as a geographical area within a 'boundary of caring', which therefore has a separate utility function. Its inhabitants care about each other to a considerable extent, and their government enacts policies which reflect this mutual care (e.g. by redistributing income within the nation). They care much less about other nations, and have no governmental power over them, although they will have both some concern about, and some means of influencing, those nations with which they exchange goods or bads (i.e. pollution).

Many new questions about sustainability immediately spring to mind in the real world of separate and unequal nations. Take for example an imaginary four-nation world (inspired by Ulph and Ulph 1988) where Industria and Machinia, two competing industrialised nations, both import oil from small, rich Petrolia and wood from large, poor Forestia, and export manufactured goods in return. All oil use causes global CO_2 pollution in this world, and some nations may seek sustainability for themselves, while others may not. We might then for example ask:

(1) If Industria seeks sustainability by controlling its CO_2 emissions, how effective will this be if Machinia does not also control its emissions?

(2) If Industria seeks sustainability by reducing its oil imports, does it help or hinder Industria's quest if Machinia or Petrolia do not seek sustainability?

(3) Does the current trade in wood allow Industria and Machinia to achieve sustainability at the expense of Forestia's unsustainability?

(4) Does it help Industria's sustainability if Forestia reduces its population growth?

(5) Does it help Forestia's sustainability if Industria and Machinia reduce their consumption of wood, or of oil?

(6) What is the effect on sustainability of allowing unrestricted migration of people between countries?

(7) Should Forestia protect itself from transboundary cultural pollution that is spread by the mass media: from the influences of 'Dallas in Delhi', or high-technology rock concerts seen by hundreds of millions of people, which generate unachievable material wants and make it harder to be contented with life?

We cannot begin to answer so many difficult questions here, and can only note a few of the attempts that have been made so far on (1)-(3) (and see Section 5 for further discussion of (7)). One general thought is that many of the questions involve mutual or one-way externalities between many or all nations, which therefore need to be controlled by international co-operation, often at the global level. Without this, sustainability will be much harder or even impossible (hence the importance of understanding the causes of co-operation – see Sections 3.4 and 5.2). This may also be true even when there are no externalities, and the sole threat to a nation's sustainability is its reliance on imports of non-renewable resources.

Regarding question (1), Pezzey (1992b) suggests that interactions on world resource markets mean that unilateral curbs on global pollution may be ineffective, and Hoel (1991) suggests they may even be counter-productive. Questions like (2) are addressed by the conventional literature on trade in non-renewable resources, which worries mostly about unsustainability in the resource *importing* country (Kemp and Long 1984, 414), although Pezzey (1992c) considers the case of two countries which trade resources with each other. In contrast, 'alternative' thinking is more likely to address (3) and worry about unsustainability in the resource *exporting* country (see Pearce, Markandya and Barbier 1989, 45-7); and to claim for example that Industria has an obligation to see that its imports of tropical hardwoods are not the result of unsustainable logging in Forestia. One argument for such an obligation is that it will make up for past exploitation of Forestia by Industria which has led to such gross inequity in development between the two countries, an assertion which we now consider in more detail.

4.7.3 *Exploitation and equity*

Many writers (for example UNDP 1992, ch.4) claim that poor countries are getting poorer (i.e. their utility is declining) because they are kept that way by the global trading system. They are said to have little choice but to deplete their natural resources unsustainably, because that is the only way they can earn enough foreign exchange to pay the interest on their debts to rich country banks. Moreover, natural resource prices are felt to be too low because of rich country domination of world markets. The underlying sense is that poor countries are *exploited* by rich countries. However, 'exploitation', like 'need', is a concept that is largely ignored or rejected by conventional economic analysis, which regards the market price of (say) tropical hardwoods as fair *if* it reflects not only free competition between poor exporters (which drives the price down), but also free competition between rich importers (which drives the price up).[16] And if too much of the money that poor countries borrowed in the 1970s was spent on armaments, unwise prestige projects and profligate consumption by corrupt and elitist governments, why should that be seen as the fault of the lending countries?

Developing a dispassionate, non-Marxist theory of exploitation, which squarely addresses all the above issues, is in my view vital for debating these issues fruitfully. Such a theory will surely involve the roles of *constraints on borrowing that is needed to realise productive potential, monopoly power,* and *retrospective justice*, as follows. Poor countries are often simply prevented, by their inability to borrow, from making highly profitable investments in their own physical or human capital; or if they can borrow, they may not know how to invest wisely. Much of the extraction of Third World resources is carried out by multinational companies which appear to face very little competition. And past pollution by rich countries has been the main cause of global environmental degradation, especially the accumulation of greenhouse and ozone-depleting gases in the atmosphere. One might therefore show that poor countries have been and continue to be 'exploited' in some well-defined way, and that justice arguably requires rich countries to redress this exploitation and achieve greater international equity in development, by means of disinterested foreign aid and reform of the global trading system.

Even if rich countries remain unmoved by these arguments and are concerned only with their own long-term sustainability, their need for natural resource imports and desire to avoid damaging climate change may mean that more equitable development is in their own interests, insofar as it is essential for reducing population growth and resource degradation in poor countries, and thus for achieving global sustainability. But the problem of how to get all rich countries to co-operate in pursuit of this common goal would still remain. As reluctantly concluded in Section 3.4, the threat to global sustainability may have to be quite severe before a strong ethic of international environmental co-operation emerges.

5 PSYCHOLOGICAL AND SOCIAL PERSPECTIVES ON SUSTAINABILITY

Section 4 assumed that utility is determined by the quality of life, which itself reflects the absolute level of environmental amenity as well as the absolute level of consumption. But even the most far-reaching incorporation of environmental values into economic policies and GNP accounting methods will still tell us little about how happy we are. There is overwhelming evidence that *relative* variables – one's relationship to and status within a group, and changes relative to one's past experience (motivations M3, M5, M6 and M7 in Section 3.1) – also profoundly influence utility, and hence must be included in any debate on sustainability as a whole, even if they remain hard to quantify. We now examine these further 'psychological' or 'social' influences on sustainability (although neither word is an ideal label).

5.1 *Evidence of adaptation, comparison and loss aversion effects*

There is a wealth of psychological evidence that "the maintenance of a state [is] associated with a decreasing response to that state", because people adapt to that state (Kahneman and Varey 1991, 136). The same authors also note (p.143) the further possibility that "any beneficial effects of improved circumstances may be cancelled by adaptation". If such total adaptation does happen, then life is a 'hedonic treadmill': as long as basic survival needs are provided for, any quality of life will give the same utility, if people are sufficiently isolated in both space and time to adapt to it. But people are not isolated: they can make comparisons with others in their current 'social reference group' (Wärneryd 1988 reviews this concept), and comparisons with their own past. So we get pleasure merely because our quality of life is higher than others', or because it is rising (motivations M5 and M6; the former creates a 'positional treadmill', since if everyone tries to increase their relative position, they will all stay in the same position). But these comparisons are not symmetric: the displeasure caused by a given loss of quality of life or relative status outweighs the pleasure gained from a rise of the same amount (motivation M7, generally known as 'loss aversion'). An objectively neutral 'binge-purge' cycle may therefore leave people feeling subjectively worse than before, until they adapt to the new situation.

Like so much else, adaptation and comparison effects can be found in the 'bible' of economics:

> *Custom*… has rendered leather shoes a necessary of life in England. The poorest creditable person of either sex would be *ashamed* to appear in public without them. (Smith 1776/1937, 822, emphasis added)

People need shoes here not to protect their feet, but to maintain the company of their fellow citizens. Thus comparisons affect utility not just because people have come to enjoy status for its own sake (motivation M5), but also because they need it to *participate* in society to achieve other things (motivation M3). For example, people still need economic status for biological reasons. To attract a mate, the average young person in Los Angeles needs access to a car, a telephone, a shower and an underarm deodorant. The average Nepali does not – although he or she may think so, if his or her social reference group is expanded by exposure to the 'cultural pollution' of Western mass media.

Starting with the pioneering contribution of Duesenberry's (1949) relative income hypothesis, impressive research results on adaptation, comparison and loss aversion effects have been accumulated (see Frank 1989 for a useful short survey,[17] and Lewis and Ulph 1988 specifically on participation). Important (albeit subjective) evidence for the first two effects is found in Easterlin's (1974) survey of self-assessments of happiness, which found that:

(a) within one country, at any one time, rich people consider themselves to be happier than poor people do;

(b) within one country, long term growth in living standards has little effect on how happy either rich or poor people feel, as long as their relative (income) position remains unchanged; and

(c) at any one time, people in rich countries feel hardly any happier than people in poor countries (where living standards are maybe fifteen times lower) who have the same relative position within own their country.

Similar evidence has been produced by extensive surveys in the Netherlands and elsewhere (see Kapteyn 1985).

5.2 *Evidence of community erosion*

Being able to participate at all in society is important to utility, for reasons just given; but only *repeated* participation with the same local family, friends, colleagues and customers can create a *community* and give 'amenity' benefits such as friendship, love and a sense of belonging, and 'productivity' benefits such as a climate of honesty and co-operation in business and leisure, and a low crime rate.[18] Recent theoretical and empirical research has shown how a high enough probability that the same people will meet repeatedly, and thus face the consequences of any past cheating or hostility, is a crucial requirement for a culture of altruism and honesty to evolve (Axelrod and Dion 1988).

Many writers clearly feel that industrial growth has steadily eroded community bonds, and hence has seriously offset the utility benefits of rising consumption (Wilkinson 1973, 180-5, Seabrook 1978, Daly and Cobb 1989, Ch. 8).[19] However, there has been little attempt to quantify if this happens, and if so why, no doubt because 'community' is such a hard concept to measure. I suggest the following general explanation, based on Section 4.3 above. Even with constant output, industrialism requires non-renewable resource depletion and technical progress (the technological treadmill). Both these require increasing *transience* (faster changes of jobs and residential locations), and often larger-scale production. Transience, increased scale, and the cheaper telecommunications and transport brought by technical progress, encourage greater *dispersion* among where people live, work, shop and play. Both transience and dispersion make it harder to maintain the repeat rates of local social interactions, and thus erode communities. Now obtaining comprehensive data over a long enough time scale, and using them to test all the above causal links properly, is exceedingly difficult (see Dennis 1984, Chs. 8-9 for just one illustration why), and remains for future research; but must the default be that we have to prove that communities are being destroyed by industrialism before we take any preventive action?

5.3 Implications for sustainability policy

If the above evidence of adaptation, comparison, loss aversion and community effects on utility is accepted, then it will be socially optimal and better for sustainability if people strive less for status, avoid binge-purge cycles, and move house or job less often. But they cannot be expected to act alone, when to do so would be against their individual interests. So policies are needed to put some kind of price or discouragement on pervasive social externalities, just as with environmental externalities. What policies are available? Here are some rudimentary and no doubt controversial suggestions.

Relative consumption effects make a case for a more redistributive taxation system (Boskin and Sheshinski 1978). They also make a case for reducing the power of mass media to cause people to make envious comparisons, for example by taxing advertising and other vehicles of mass propagation of materialistic values. As for maintaining a sense of community, using a pre-announced policy of long-term tax increases on transport and telecommunications would discourage geographical transience and dispersion. The problem with this last policy (which often occurs when an evolutionary treadmill is thrown into reverse) is that *initially* such taxes would harm community life, because patterns of dispersion and land use change only very slowly. A further move on both fronts would be to use public education consciously to discourage materialism and transience, as suggested by WCED (1987, 44).

There is little economic analysis of adaptation effects over time (Frank and Hutchens 1992/3 being a rare exception), but their policy implications must surely be mixed. If an isolated society is currently unsustainable, the good news is that once they have adapted to a lower, sustainable standard of living, they might notice little difference in utility. The bad news is that the downward transition will be very painful, so it may be put off until too late and will then cause excessive pain. Also, any country which unilaterally reduces its living standard would face severe problems of transboundary cultural pollution, on top of the international environmental and trade problems noted in Section 4.7.2. The difficulties in achieving international coordination of cultural policies would be perhaps even more daunting than with environmental policies.

Many of the above policy suggestions run contrary to cherished Western values of freedom, mobility and *de gustibus non est disputandum*, the conventional economic doctrine of consumer sovereignty (which ignores all the ways in which teachers and especially parents consciously shape children's tastes and preferences). But these values have costs as well as benefits, and there needs to be serious debate about whether they are correctly 'priced' in today's societies. The above emphasis on economic incentives rather than regulatory controls is deliberate, so as to improve sustainability with the minimum impacts on personal choice; although reaching social consensus on such policies will hardly be easy.

6 SUMMARY AND CONCLUSIONS

Over millions of years on a hospitable and abundant planet, hominids evolved a unique combination of intelligence and dexterity and became biologically modern humans. With this evolved cleverness, humans have been able, in just a few thousand years, to control the planet's environment to an extraordinary degree, to explore their distant past, and to imagine their long term future. Yet they have not so far used these exceptional powers to maximise the chance of a future which can sustain their well-being for millennia to come.

Some of the groups into which we are divided are dependent on specialised knowledge which takes an ever longer time to acquire, and on 'tools' (machines), which consume large quantities of non-renewable resources, and eject correspondingly large flows of damaging and often untested wastes into the environment on which survival ultimately depends. Despite having made genuine progress in eliminating hunger, discomfort, drudgery and disease, these groups are committed to the 'technology treadmill': a never-ending and highly uncertain race to acquire better knowledge and tools to make up for continual resource depletion and environmental degradation. Other groups have not controlled their fertility, probably because of outside interference, and are experiencing either unsustainably growing populations, or painful population checks, such as famine and disease. Many intermediate groups face both technology and population problems at once. And because all three types of groups have expanded to exploit so much of the planet's natural endowment, they are now inescapably interconnected, albeit in very unequal ways, through global pollution and global resource trading. Their expansion has also annihilated most of the primitive tribes who had maintained a stable population and technology; those few that are left have no guarantee that outside interest in their untapped natural resources will not suddenly lead to their demise too. Except in these tribes, the pace of human and environmental change is constantly accelerating, so that the next couple of centuries will be geologically significant: for even if we avoid the twin threats of nuclear and environmental self-destruction, the predicted doubling of our population must surely alter the biota of the planet on a scale comparable to the mass extinctions observed in the fossil record.

From an evolutionary perspective, such developments have a chilling aura of inevitability. How else could the blind forces of natural selection have responded to the emergence of such a clever species, other than to have allowed it to expand, and possibly self-destruct (Diamond 1991, 194-5)? But natural selection has also given us consciousness and free will, which we can now use to ask how our cultural evolution can be controlled so that the technology treadmill can be sustained for millennia into the future. This is an almost impossibly complex question to answer, either scientifically or historically, for society as a whole. Scientifically, there are massive uncertainties about how the natural environment (especially global climate) and technology will evolve over the further future. Historically, do we look at the past two hundred years of industrial society, and conclude that something will always turn up? Or do we look at the last seven thousand years, when almost every centralised civilisation has eventually fallen, and conclude that the meteoric growth of industrialism merely presages an equally meteoric decline, this time on a global scale?

This paper leaves unresolved these difficult questions of feasibility. We focus instead on how the technology treadmill can be made to work more efficiently, since simple economic models suggest that this will help sustainability. This takes us into more conventional areas of economic analysis, and the resulting policy recommendations are unsurprising. Economic efficiency requires a pragmatic mix of regulation, environmentally compensatory projects, 'intergenerational transfers' of resources, and current economic incentives like pollution taxes and resource conservation subsidies, to make both public and private sector activities 'internalise' the external costs that people and businesses impose on each other without consent. And to control excessive population growth, more education and economic opportunities for women, better availability of birth control, and a more equitable distribution of income are all needed.

Given a definition of sustainability as non-declining welfare or 'utility', we are also concerned with the way that economic growth *creates* needs and wants. As growth makes society more transient, dispersed and mechanically complex, communities erode, and people need more consumption simply to participate in life. The ever-increasing ease of making envious comparisons with higher standards of living elsewhere makes people want more too. Economic efficiency requires that these social and psychological external costs also be internalised. Perhaps education and taxes on advertising should therefore be used to discourage the formation of materialist values, and taxes on telecommunications and transport should be used to discourage excessive transience and dispersion; such disincentives need not jeopardise essential freedoms.

All these environmental and social policies should improve sustainability, but still may not actually achieve it. This is especially true if individuals do not care much about the long-term future, and thus use high discount rates. Tougher policy actions would then be needed to reduce discount rates or otherwise to curb their effect on the future, and they could be justified only by regarding sustainability as a moral imperative.

No matter what sustainability policies are used, most of them will be ineffective unless they are implemented *internationally*. One nation on its own cannot now guarantee sustainability to its citizens, because it cannot easily insulate itself from global resource prices, from global climatic change, or from the dissatisfactions sown by the international mass media. Unfortunately, the chances of attaining effective international co-operation on sustainability are so far not promising. Some progress was made at the 1992 UN Conference on Environment and Development, but many proposals foundered in the mire of conflicting national interests.

An evolutionary view of history can offer some hope here. Remarkable feats of co-operation, without parallel in other species, have been achieved in huge groups of unrelated humans. The perception of a current outside threat from other groups appears to create, in ways still not fully understood, the moral systems which make such co-operation possible (Alexander 1987). So will the perception that the whole human species poses a threat to its future self therefore create a sustainability ethic just when it is needed? And will pressing resource or population constraints give rise to brilliant technical innovations, as has happened so often before, although sometimes after a period of considerable hardship (Wilkinson 1973)?

We cannot be sure. Evolution shows that life proceeds by experiments, which fail as well as succeed, especially on islands. Evolution allowed the reindeer population on St Matthew Island to eat themselves to extinction. It allowed 5,000 people on the 150 square miles of Easter Island to ruin themselves, probably by deforestation (Ponting 1991, 1-7). And it will allow the 5,000,000,000 people on the 5,000,000 square miles of Earth Island today to ruin themselves. In spite of our ability to see so much further into time and space than the Easter Islanders, we are still very ignorant about the vastly complex environmental, economic and social systems on which our collective well-being depends, so we simply cannot know whether our current civilisation will succeed or fail of its own accord.

It will be an enormous challenge to detect and respond to any potential threat to sustainability in time. A starkly obvious threat to our *survival* will probably have a similar galvanising impact on our technical and moral systems as watching an enemy building warships had on our ancestors', but by then it may well be too late to stop considerable declines in *wellbeing*. And we cannot make purely scientific predictions about the threat: science requires repeated experiments, and civilisation is now effectively an unrepeatable global experiment, especially in its effects on climate. So if our species' future is to be more than a giant throw of the evolutionary dice, we need to use all our inherited capacity for taking far-sighted, co-operative precautions, as well as the cleverness which is both our crown and our curse. Until we do so, we should surely call ourselves *Homo ingeniosus*; for we have yet to earn the title *Homo sapiens*, the 'wise human'.

NOTES

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[1] By 'evolution', I always mean both genetic *and cultural* evolution, unless otherwise stated. I try to avoid any crude dichotomy between genetic and cultural determinants of behaviour, which Alexander (1987, 7) rightly criticises.
[2] Utility here refers to just one moment in time. A broader treatment includes preferences over time as part of utility, but for simplicity I treat time preferences as separate, and represented by discount rates, as analysed in Section 4.2.
[3] I ignore the possibly staggering implications for sustainability of human genetic engineering (and of nuclear warfare). Both subjects would require very different papers from this one.
[4] Ecology and evolution are highly interconnected subjects, but because environmental economists have concentrated on non-evolutionary aspects of ecology, they will be treated separately in this paper.
[5] I am following the view that happiness (i.e. utility) provides the "proximate mechanisms that lead us to perform and repeat acts that in the environments of history, at least, would have led to greater reproductive success" (Alexander 1987, 26); see also Frank (1987, 593).
[6] But M8 (time preference) will be treated separately from utility (see Note 2).
[7] Sustainability often has to be interpreted here simply in terms of survival, as it is hard to know how happy people were in past millenia, although some guesses will be hazarded.
[8] Recall from Section 1 that 'tools' means physical capital.
[9] 'Real' (as in real value or real interest rates) means that any purely monetary effects of inflation have been excluded.
[10] Examples of multiple resource use abound: water can provide a material resource input, environmental productivity, and/or environmental amenity.
[11] Discounting, especially in the presence of natural resource depletion, is a highly complex subject: see for example Broome (1992, Ch. 3) and Price (1993). Discounting has parallels with the chance of repeated social interaction - see Section 5.2.
[12] For a recent survey of this area, see Cropper and Oates (1992).
[13] Even if utility functions are unstable, so that the same objective quality of life produces

varying utility at different times, such variations would not concern many writers in the natural capital school, who focus on the *potential* for sustaining utility, rather than its actual achievement. They are thus adopting a 'resourcist' rather than a 'welfarist' approach to intergenerational equity (see Broome 1992).

[14] But see Hanemann (1989) for the conventional view of valuation under uncertainty.

[15] See Tilton (1989) for data on several other resources.

[16] Any environmental problems caused by deforestation are not relevant to this argument.

[17] For example, Frank concludes that "test after sophisticated test" have confirmed Duesenberry's prediction that if utility depends not only on absolute but also on relative consumption, then savings rates will rise with income in cross-section data.

[18] There are also undeniably some costs of small communities, such as "narrow interests, pressures for conformity, and prejudices" (Daly and Cobb 1989, 170), but a lot of these are felt mainly because of anti-community forces from outside.

[19] Norgaard (1988) also argues that industrialism and its mass communications erode the *diversity* of communities, and thus deprive the world of social adaptability in much the same way that species extinctions reduce biological adaptability.

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