Eric Neumayer

Preserving natural capital in a world of uncertainty and scarce financial resources

Article (Accepted version)
(Refereed)

Original citation:
Neumayer, Eric (1998) *Preserving natural capital in a world of uncertainty and scarce financial resources. International journal of sustainable development and world ecology*, 5 (1). pp. 27-42. ISSN 1350-4509

DOI: 10.1080/13504509809469967

Preserving Natural Capital in a World of Uncertainty and Scarce Financial Resources

Published in:

International Journal of Sustainable Development and World Ecology

5 (1), 1999, pp. 27-42.

Eric Neumayer

Department of Geography and Environment, London School of Economics and Political Science, Houghton Street, London WC2A 2AE, UK

ABSTRACT

Natural capital should be preserved because it exhibits features that distinguish it from all other kinds of capital. Natural capital provides basic/fundamental life-support functions, is a necessary input into production due to the first law of thermodynamics and is often unique in that its destruction is irreversible. The notorious prevalence of risk, uncertainty and ignorance makes it difficult, however, to state which parts of natural capital should be preserved. Some forms of natural capital are more likely to be substitutable than others. A good case can be made for preventing large-scale biodiversity loss, protecting the ozone layer, restricting emissions that cause global warming, limiting the accumulation of toxic pollutants and for restricting over-harvesting and soil erosion.

Another difficult question is how, to what extent and for how large costs certain forms of natural capital should be preserved. Both the 'precautionary principle' and the concept of 'safe minimum standards' are rather elusive, especially on the question of costs. Policy measures are discussed that allegedly preserve natural capital at low, or even negative, costs: the abolishment of environmentally and economically harmful subsidies, the substitution of market-based for command-and-control instruments, the substitution of ecotaxes for labor and capital income taxes and the so-called 'Porter'-hypothesis that tighter environmental regulation will increase firms' productivity. It is argued, however, that while there is some scope for policies that are good for the environment and for economic development at the same time, the relationship between the environment and the economy is likely to remain one of a fundamental trade-off. Resolving this trade-off is beyond scientific reach and should be left to democratic decision making. What science can do, is to help basing democratic decisions on rational grounds.

1. INTRODUCTION

If society is committed to sustainable development, or sustainability for short, should it preserve any natural capital? The answer to this apparently 'heretic' question is not as easy and intuitive as many environmentalists think. Indeed, the now dominant view among neoclassical economists is the perfect substitutability paradigm: What matters for future generations is only the aggregate total capital they inherit — be it human-made, natural or any other form of capital (Hartwick 1990, Solow 1993). According to this view which comes under the name of 'weak sustainability', the depletion of natural capital does not matter for future generations as long as enough other forms of capital are built up instead.

I define sustainability here as economic development that leaves future generations at least as well off as the current generation. Obviously such a definition is anthropocentric in that it denies any intrinsic relevance of nature for questions of sustainability. Nature has value if and only if humans value nature. Note, however, that humans might value nature for whatever reasons and not merely because it contributes to the production of consumption goods or directly produces utility through environmental amenities. Humans might very well value nature as such in attributing 'intrinsic' value to nature, but it is still humans who determine the value.

What is natural capital? Capital is defined here broadly as a stock that provides current and future flows of service. Natural capital is then the totality of nature, i.e. resources, plants, species and ecosystems, that is capable of providing human beings with material and non-material flows of service.

This paper argues that to contest the perfect substitutability paradigm of weak sustainability one first needs to explicate the distinctive features of natural capital. There are three aspects — basic life-support function, necessity for production, irreversibility of destruction — that distinguish natural from other forms of capital. Also, one must differentiate and move beyond this abstract term 'natural capital': Some forms of natural capital are more likely to be substitutable than others.

If that was all, however, sustainability would be an easy task, the prescription simply being to preserve all those forms of natural capital that exhibit distinct features and are not likely to be substitutable by other forms of capital. But the actual world we are living in is one of imperfect information where risk, uncertainty and ignorance abound and financial resources are scarce. The absence of certainty and perfect information frustrates any attempt to give clear-cut answers on which forms of natural capital should be preserved.

The following three sections of this paper develop this argument. Section 2 starts out with highlighting distinctive features of natural capital. Section 3 discusses the implications of the notorious prevalence of risk, ignorance and uncertainty concerning the environment. Section 4 brings the first two threads together and states which forms of natural capital are most likely and which are less likely in need of an explicit preservation policy.

The next question is how, to what extent and for how large costs should certain forms of natural capital be preserved, given that finance is scarce. Section 5 discusses two famous policy principles, namely the precautionary principle and the concept of safe minimum standards that were developed to deal with situations of uncertainty and ignorance. As it turns out, both principles are very elusive on whether and how much preservation should be undertaken if it is costly to do so. Section 6 therefore discusses preservation when financial resources are scarce. It asks whether preservation of natural capital can be achieved at low, or even negative, economic costs. It analyses the abolishment of wasteful subsidies, the substitution of market-based for command-and-control instruments, the substitution of ecotaxes for labor and capital income taxes and the so-called 'Porter'-hypothesis that tighter environmental regulation will increase firms' productivity. It argues that although there is some scope for undertaking measures at minimal costs, the relationship between the environment and the economy is likely to remain one of a fundamental trade-off rather than a 'free lunch'. A resolution of this trade-off is beyond scientific reach, however, and is rightly to remain in the political realm, because science cannot tell society how risk-averse it should be as regards the preservation of natural capital. The social and natural sciences can help in making the choices transparent and rational — but how much the current generation is willing to sacrifice for preserving natural capital is ultimately a matter of democratic decision making. Section 7 concludes.

2. DISTINCTIVE FEATURES OF NATURAL CAPITAL

What makes natural capital distinct from other forms of capital? There are three aspects that can justify such a distinction:

- Natural capital provides very basic and fundamental life-support functions that no other form of capital can provide. It is multifunctional in a way and to an extent that is not shared by other forms of capital (Ehrlich and Ehrlich 1992). Natural capital is the basis of all life, human and non-human: It is the world ecosystem that contains the economy, not the economy that contains the world ecosystem (Daly and Townsend 1993, p. 3). Mankind can exist and indeed has to a large extent existed in the past without major human-made or other forms of capital, but it cannot live without some minimum level of natural capital. The outstanding value of natural capital is not that we can use fossil fuel, e.g., but that nature enables the very existence of human life. Nature might cope with piece-meal destruction for a long time, but if a certain threshold is exceeded, the whole system could break down. There are ‘limits to meta-resource depletion’ (Ehrlich 1989). These life-support ‘resources’ really are non-substitutable and their degradation would often lead to irreversible catastrophes. Their ‘basicness’ makes it difficult to estimate accurately or even approximately their specific value. In some sense, they are simply priceless: their value to humans is infinite.

  Examples that come to one’s mind are the ozone layer and the biogeochemical cycle of the atmosphere. The same applies more generally to basic ecosystem functions. Costanza et al. (1997) recently have given a conservative estimate of the value of the world’s ecosystems. They suggest this value to lie in the range of US$ 16-54 trillion as a minimum estimate. For comparison, global gross national product is about US$ 18 trillion per year, so the value of the world’s ecosystems is very large indeed. (Note that in Costanza et al.’s (1997) estimates the values for specific items whose magnitude is likely to be infinite as for the global climate have been deliberately truncated to make them finite and to provide a lower bound estimate of the real value.)

- Natural capital is to some extent a necessary input for production. The first law of thermodynamics tells us that nothing can be produced without some resource input and that nothing can be destroyed. As long as the energy from solar influx is by and large not used, energy and material become invariably transformed from low entropy to high entropy. Recycling and re-use can delay this entropic transformation, but it can neither stop nor reverse it according to the second law of thermodynamics. There is some minimum level of natural capital that we need for resource input and for taking up the unwanted side-products of output (pollution and waste). The conjecture that we could live without any natural capital contradicts fundamental physical laws. In contrast, it is possible in principle to live without any human-made capital such as factories, machineries, roads etc.

- Some forms of natural capital are unique in that they cannot be rebuilt once they have been destroyed. That is, destruction of some forms of natural capital is irreversible or quasi-irreversible. Some environmental assets are fundamentally non-substitutable which is in general not the case for other forms of capital. Human-made capital can always be reconstructed if it has been destroyed. Reconstruction is costly, of course, and it may take some time, but at least it is possible in principle. Admittedly, this is not true for unique historical buildings which provide non-material value, but certainly for human-made capital used in production.

  An example for irreversible natural capital loss is the destruction of biodiversity: it is impossible to bring an extinct species back to life. Examples for quasi-irreversibility are the ozone layer destruction and global warming: Both the ozone layer and the climate may 'regenerate' to their former state if allowed to do so, but it takes 'too much time' (from a human perspective) to wait for the natural regeneration. The consumption of 'non-renewable' resources is another example of quasi-irreversibility.

3. RISK, UNCERTAINTY AND IGNORANCE

If we are aware of the distinctive features of natural capital, why can't we simply preserve all those forms of natural capital that provide basic life-support functions, are necessary for production and irreversibly lost after destruction? If we lived in a world of certainty and limitless financial resources, there would not be any problem. But unfortunately we are living in a world that is plagued by ubiquitous risk, uncertainty and ignorance. Therefore we do not know for certain which forms of natural capital we should preserve. Also, finance is scarce, an issue which is discussed in later sections.

Risk

Risk refers to a situation where the set of all possible states of the world, the probability distribution over the set of possible states and the resulting payoffs can be objectively known. Buying a lottery ticket is a good example for engaging in a risky action, because the odds of winning can be objectively known as can the costs of buying the ticket and the value of potential prizes — hence the expected gain or loss can be computed without any remaining doubt.

In order to cope with risk, economists have included so-called option values into their traditional cost-benefit analyses. In the environmental context, option value is the expected value of refraining from an action that leads with some given probability to irreversible environmental destruction in order to keep the option open of using the environmental resource in the future. Option value can thus be interpreted as a kind of risk premium: it lowers the net benefit of the considered action, it reflects an additional opportunity cost and the 'price' society is ready to pay in order to keep the option of future use of the environmental resource open. The more risk-averse society is, the higher will the option value be. In case of extreme risk aversion, the option value can be infinite and the action that could result in environmental destruction should not be undertaken whatever its likely other benefits. On the other hand, if society is risk-preferring, it will be more inclined to take the action and risk the irreversible environmental destruction.

Note that we are typically not confronted with a 'risky' situation when we are trying to judge the validity of running down natural capital because in most cases we do not know either the probability distribution of all possible states nor do we know the potential outcomes resulting from the different states of the world. What is worse: often we do not even know the complete set, that is, we are ignorant of the total number of possible states of the world.

Uncertainty

Uncertainty refers to a situation where the probability distribution over a set of possible states of the world and the resulting payoffs cannot be known objectively, but agents have subjective beliefs about the objective distribution and the payoffs. Those beliefs can be updated (and in many cases improved) over time, i.e. they are not static as is the case in the context of risk, but dynamic. Agents can learn to improve their beliefs on the basis of Bayesian decision theory rules (Faucheux and Froger 1995).

Option values can be used in a context of uncertainty as well, only that this time it is the subjectively expected value that counts. Additionally, economists have included so-called quasi-option values into their traditional cost-benefit analyses. In the environmental context, quasi-option value is the value of delaying an irreversible environmental destruction in order to acquire improved information and to make a better informed future decision. For quasi-option values to make sense, we have to expect that either future information will tend to favor environmental preservation for given preferences or that the preference for environmental resources will increase over time. Only then is there a positive value, otherwise there would be a cost in keeping the environmental option open (Beltratti, Chichilnisky and Heal 1993, Chichilnisky and Heal 1993). Note that quasi-option value, contrary to option value, does not depend on society being risk-averse; even a risk-loving society can exhibit a positive quasi-option value for preserving an environmental resource.

Uncertainty comes rather close to our present state of knowledge about many rather novel and complex, but most pressing environmental problems such as global warming. We know something about the effects of dumping greenhouse gases in the atmosphere, we know something about the climatic consequences, we can imagine different states of the world following and we have some idea about the probability distribution over these different states of the world. Our knowledge about climate change is still rather poor, however.

Ignorance

Ignorance refers to a situation where we have no idea whatsoever about the set of possible states of the world, about the probability distribution over the set and about the resulting payoffs. A weaker definition would allow for subjective beliefs where those beliefs are largely arbitrary, however, and lack a sound foundation.

It seems fair to say that our knowledge about the extent and the likely consequences of large-scale biodiversity destruction resembles more a situation of ignorance than of uncertainty. Estimates from the United Nations' Environmental Program of the number of existing species vary between seven and twenty million (Schuh 1995) of which about 1.4 million are named by biologists (Brown et al. 1994, p. 4). Our knowledge about most of the named species is only rudimentary (Norton 1986). Estimates of expected loss of species over the next 25 years vary between 2 and 25% (Schuh 1995) and we are arguably miles away from knowing anything about the loss in value terms of this destruction of biodiversity. As Norton (1986, p. 203) rightly argues, ‘it is an understatement to refer to this level of ignorance as mere ‘uncertainty’’. We are — almost necessarily — so much ignorant of the complex interlinkages within ecosystems that we cannot know the value of either single species or the whole of biodiversity to any reasonable extent of precision.

Climate change is another example for ignorance. We have introduced it under the heading of uncertainty above, but IPCC (1996, p. 161) rightly claims that ‘when dealing with many of the effects of climate change, ignorance is perhaps a more appropriate concept than uncertainty’. The lesson is that often environmental problems have aspects of both uncertainty and ignorance.

Also, ignorance has in the past been quite common for environmental problems: DDT and CFCs were both thought to be benign for the environment before their detrimental effect was discovered. And ignorance is arguably a pretty good description of the quality of our knowledge about the consequences of human activity on the state of the environment beyond the very immediate future.

4. IMPLICATIONS FOR THE IMPORTANCE OF NATURAL CAPITAL

The combination of risk, uncertainty and ignorance with the distinctive characteristics of natural capital (basic life-support functions, necessity for production, irreversibility of destruction) frustrates any attempt to draw any general conclusions on which forms of natural capital should be preserved. Some forms carry more of the distinctive features than others, some are more prone to uncertainty and ignorance than others. It is therefore necessary to go one step beyond this abstract notion 'natural capital' and to distinguish which forms are more and which forms are less in need for explicit preservation.

Biodiversity and global environmental resources

Take ecosystems and the biodiversity they exhibit first. It is a well established fact in ecology that ecosystems are characterized by highly nonlinear, discontinuous and discrete changes in their ecological 'resilience', that is, in their ability to 'recover from and thus absorb' (Barbier, Burgess and Folke 1994, p. 17) external and internal shocks. The stability of ecosystems ultimately depends on the extent of its resilience and not so much on the stability of individual components. The complexity of ecosystems is still poorly understood and not easy to understand anyway. 'Ecosystems do not have single equilibria with functions controlled to remain near it. Rather, destabilizing forces far from equilibria, multiple equilibria and the absence of equilibria define functionally different states' (Holling 1995, p. 49). Due to this fact, an ecosystem might be able to cope with piecemeal destruction for quite a long time, but it can break down unexpectedly fast after some (often unknown) threshold has been transgressed (Perrings and Pearce 1994). In some sense, every small-scale destruction of an ecosystem increases the likelihood of unraveling the whole ecosystem (Randall 1991, p. 65). While not undisputed (see Perrings, Folke and Mäler 1992), there is a large body of evidence from ecological studies suggesting that 'resilience increases with system complexity, and complexity can be measured by biological diversity. In that way, the more diversity there is, the more resilience there is and hence the more sustainable the system is.' (Pearce 1994, p. 148). Ceteris paribus, the more biodiversity there is, the bigger is the opportunity set open for future generations (Perrings 1994). Hence, there is a good case for preventing biodiversity loss.

There is also, more generally, a good case for protecting the 'global environmental system' (Clark 1995, p. 146) such as the global climate and the ozone layer. Both are fundamental life-support resources whose destruction would endanger the welfare if not the existence of coming generations. While a certain rise in atmospheric concentration of carbon dioxide seems inevitable, precautionary action should be undertaken to prevent large and unpredictable changes in the global climate. Since we do not know exactly beyond which concentration these catastrophic changes will occur we must make sure that our emissions stay well below the limit that best available science suggests to be the critical level.

Accumulating toxic pollutants

A good case can also be made for not letting emissions, especially highly toxic and health-damaging emissions, accumulate in the environment. The aim should be to not letting emissions exceed 'critical loads' after which the capacity of the receiving media to dissipate and diffuse emissions would be damaged. This prescription would rule out the use of highly toxic chemicals if they cannot be prevented from entering the environment. It would also rule out the use of nuclear power with its highly damaging by-products on all stages of the nuclear circle and its accumulating highly toxic nuclear waste radiating for tens of thousands of years.

Natural resources

One might wonder why so little has been said about the necessity of resources for production. The reason is that in a context of risk, uncertainty and ignorance it seems likely that the distinctive features of natural capital are especially relevant when it comes to the global environmental system and accumulating toxic pollutants as opposed to the global resource system. Property rights over resources are often much better defined and the global environmental system, unlike the global resource system, lacks an 'automatic self-correcting feedback loop' (Clark 1995, p. 146) and especially lacks a functioning price system. There are good reasons to presume that the global resource system will be much better taken care of in some way or other than the global environmental system. It is the waste absorbing function of the environment that is most under threat and least protected. That is not to say, that resource availability might never pose a problem, but the frequent falsification of alarms about immediate resource exhaustion presents a case in point (e.g. Meadows et al. 1972). The world economy has so far exhibited a most remarkable capability to overcome resource constraints via substitution and technical improvements.

Food resources

What about food resources? To feed more people there are two basic strategies. One is extensification: It is estimated that the amount of land usable for growing crops is three times larger than current usage (Preston 1996, p. 96). Alternatively, land could be used more intensively. In Europe, for example, usage of cropland fell by one quarter and the total forested area grew by 30 percent in spite of increased food production (Preston 1996, p. 99). Table 1 shows the trend in per capita world food production alongside production in Africa and Asia.

Table 1. Index of per capita food production (1979-81 = 100).

	1964-66	1979-81	1982-84	1984-86	1992-94
WORLD	95	100	102	104	104
AFRICA	109	100	94	95	94
ASIA	92	100	108	113	127

Source: WRI (1988-89, p. 272f.; 1996-97, p. 238f.)

The figures reveal that while food production has caught up with growing world population and has even increased in per capita terms in Asia and the world as a whole over the last thirty years or so, it has dramatically declined in Africa. What this suggests is that the availability of food is more a problem of intra-generational distribution than of inter-generational sustainability as such. However, where there are clear signs of over-harvesting, soil erosion and land degradation a good case can be made to enforce 'sustainable' harvesting, that is harvesting within the limits of natural regeneration, and to maintain soil fertility. The availability of food is most basic to ensure non-decreasing future welfare and where there are clear signs that danger to food security is imminent, conservatory steps should be undertaken.

Nature as such does not seem to impose limits on increasing food production enough to feed many more people. Waggoner (1994, p. 1) in a Task Force Report for the American Council for Agricultural Science and Technology comes to the conclusion that 'the global totals of sun on land, CO_2 in the air, fertilizer, and even water could produce far more food than ten billion [people] need' . For other cautiously optimistic views on the availability of food for a human population rising up to ten or twelve billion people see Ruttan (1991) and Bongaarts (1994).

In summary, a good case can be made

- for conserving 'rather more than less' natural capital in the form of biodiversity,
- for protecting the ozone layer and restricting emissions that cause global warming,
- for limiting the accumulation of toxic pollutants and

- for restricting over-harvesting and soil erosion.

The case is strengthened by the fact that examples abound where there are negative interlinkages between environmental problems: Deforestation often worsens loss of topsoil and land degradation and contributes to global warming. Acid rain not only kills forests but also contaminates freshwater sources. Ozone depletion contributes to global warming and some of the substitutes for CFCs have high global warming potentials.

But how to put these prescriptions into practical policy-making? Even if we knew exactly which forms of natural capital we should preserve, the question is still how much preservation should there be and how much cost should be incurred for preservation? There exist two famous policy principles, namely the precautionary principle and the concept of safe minimum standards. Do they give clear answers to what extent and at what costs the critical forms of natural capital should be preserved? Note that the following arguments cannot, for reasons of space, discuss all critical forms of natural capital. Discussion is limited to biodiversity protection and, albeit less so, to global warming.

5. POLICY PRINCIPLES TO COPE WITH RISK, UNCERTAINTY AND IGNORANCE

5.1 THE PRECAUTIONARY PRINCIPLE

The most basic principle is the so-called ‘precautionary principle’. It has two important elements: First, preventive measures for environmental conservation should be undertaken before there are definite scientific results ‘proving’ that protection of the environment is necessary. The motivation is to avoid regretting environmental inaction after unacceptable irreversible environmental destruction has already taken place. One good example is global warming. As environmentalists emphasize: It is better to be vaguely right in time than precisely right too late. Second and related to the first point, the burden of proof should shift to those who believe that an action has only negligible detrimental consequences on the environment. That is, the new default position should favor environmental preservation, whereas current practice still favors economic activity over environmental preservation. The precautionary principle can thus be interpreted as an insurance scheme against uncertain future environmental catastrophes.

The precautionary principle was first integrated into official policy statements in the 1970s in former Western Germany in the form of the so-called Vorsorgeprinzip (Boehmer-Christiansen 1994). It soon found its way in virtually every official document on the environment and in countless international environmental treaties (Cameron and Wade-Grey 1995). It should come as no great surprise that this seeming ‘success’ of the precautionary principle was largely due to the fact that it does not provide any clear operationable guidelines or a rigorous analytical scheme. As Bodansky (1991) observes, the precautionary principle is not able to give a clear answer on when it should be applied, that is, what are acceptable and unacceptable environmental dangers, at what costs it should be applied and what types of precautionary actions should be undertaken.

5.2 SAFE MINIMUM STANDARDS (SMS)

Another principle that seemingly takes better account of the question of preservation costs is the Safe Minimum Standard (SMS). Propositions to introduce SMS date back to Ciriacy-Wantrup (1952) and were originally reserved for issues of species preservation and biodiversity protection. Recently, however, the notion of SMS has been increasingly used for other environmental topics as well. IPCC (1996, p. 159), e.g., speaks of an ‘affordable safe minimum standard’ for reduction of greenhouse gases.

SMS in the context of species preservation calls for granting a species some minimally viable standard, as long as the economic costs of doing so are not ‘unacceptably high’. The reason for adopting SMS is that because of risk, uncertainty and ignorance the exact value of biodiversity cannot be measured. Hence, to avoid potentially high future costs, biodiversity should be conserved — to repeat: as long as the costs of doing so are not 'unacceptably high'.

The concept of SMS has been officially embraced by UNEP's Global Biodiversity Program (Crowards 1996, p.16). The Endangered Species Act in the U.S. has many characteristics of a SMS (Castle and Berrens 1993, p. 122). The U.S. Fish and Wildlife Service has considerable leeway to intrude into property rights and impose conservation of endangered species on private agents. Economic actions that threaten the existence of endangered species are only allowed if 'the benefits of such action clearly outweigh the benefits of alternative courses of action consistent with conserving the species on its critical habitat' (Endangered Species Act Amendments of 1978, public law 95-632).

One of the most fundamental problems of SMS is that it cannot define what 'unacceptable costs' are. The reason why many people would support SMS is presumably that everyone can have his or her own idea of what unacceptable costs are. Another major problem is that the SMS gives no guidance to which species or habitats scarce financial resources should be allocated and there can be no doubt that the available resources are limited. Stevens et al. (1991, p. 399) claim that since we do not know which particular species are worth while protecting, applying the SMS with its focus on the costs of preventing species extinction is superior to cost-benefit analysis since it can do without making estimates of the potential benefits of protecting a specific species. But Stevens et al.'s (1991) claim is not true: the awkward and often badly informed choices are simply transferred to another level of decision-making. While it seems likely that more species will be protected under a SMS regime, selections still have to be made where financial resources are scarce.

Note that the protection costs are likely to be high even in terms of direct management costs due to the complexity of safeguarding the resilience of an ecosystem. The main costs arise in terms of opportunity costs, however, due to blocking economic development in a large part of a nation's area. There are <u>definite</u>, <u>present,</u> <u>real</u> costs for <u>uncertain,</u> <u>future</u> and perhaps <u>intangible</u> benefits in applying SMS. Also, the actual protector will not be able to reap all of the potential future benefits because some of the benefits are positive externalities to other people in other countries, i.e. the protection of biodiversity has to some extent the characteristics of a global public good. Consequently, there are powerful incentives to free ride on others' effort for biodiversity protection. Since every potential protector has the incentive to free ride, none of them might have sufficient impetus to protect biodiversity.

The financial constraints are exacerbated by the fact that the vast majority of the world's biological diversity exists in only a few nation-states that belong to the poorest of the world, with the notable exception of Australia (Swanson 1994, p. 806). There will be no way to protect biodiversity without considerable financial transfers from rich to poor countries, as confirmed by initial, albeit small, transfers under the Global Environmental Facility (GEF) fund and UNEP's Biodiversity program where the rich countries pay poor countries for biodiversity protection.

Time and again, we have reached the point where preserving some critical components of natural capital — while desirable for good reasons — appears to be a costly endeavor to undertake. It is therefore unavoidable to discuss the preservation of natural capital in a world of scarce financial resources now.

6. PRESERVING NATURAL CAPITAL WHEN FINANCE IS SCARCE

To get a taste of the problems policy-makers wanting to preserve critical components of natural capital are faced with, it is worth while further discussing biodiversity protection. As long as there are no sufficient international financial transfers from rich donor countries (as seems likely to be the case), giving priority to biodiversity protection and other environmental problems can lead to awkward choices whose consequences we might not be very comfortable with. It is worth quoting Beckerman (1994, p. 194f.) at some length here:

> Given the acute poverty and environmental degradation in which a large part of the world's population live, one could not justify using up vast resources in an attempt to preserve from extinction, say, every one of the several million species of beetles that exist. For the cost of such a task would be partly, if not wholly, resources that could otherwise have been devoted to more urgent environmental concerns, such as increasing access to clean drinking water or sanitation in the Third World.

Jacobs (1995, p. 63) claims that in practice we are not faced with many choices of the 'preserve some obscure species' versus 'improve basic health care' type, but at least they cannot be ruled out in principle. While we might not want to preserve every beetle as such, we might well want to preserve the totality of remaining tropical rainforests where the vast majority of beetles resides. Hence there will remain cases where fundamental ethical conflicts arise and the sustainability criterion in itself is not well equipped to deal with those problems.

This fact is neglected by Costanza (1994, p. 394) who believes that uncertainty and ignorance are reasons enough for preserving the complete stock of natural capital:

> While a lower stock of natural capital may be sustainable, given our uncertainty and the dire consequences of guessing wrong, it is best to at least provisionally assume that we are at or below the range of sustainable stock levels and allow no further decline in natural capital. This 'constancy of total natural capital' rule can thus be seen as a prudent minimum condition for assuring sustainability, to be abandoned only when solid evidence to the contrary can be offered.

Costanza's reasoning completely ignores the fact that there is rarely a 'free lunch', that there is almost always a price you have to pay, here the (opportunity) costs of preserving the whole stock — so the benefits and the costs of preservation still have to be balanced in some way. Unfortunately, there is no easy answer to how this trade-off should take place. If the benefits of conserving natural capital are largely uncertain and speculative, economic theory cannot tell us how much conservation should be undertaken because it cannot tell society how risk averse it should be. It has to leave answering this question to democratic decision-making. What it can do, however, is to help finding out measures which lead to a desired environmental objective at least cost. Therefore we are turning our attention to ways to protect the environment at minimal economic cost now.

Abolishing environmentally and economically harmful subsidies

What can be said rather unambiguously is that actions that both protect the environment and improve economic efficiency should be undertaken. In many instances governments have introduced subsidies, fail to establish and protect property rights, invite rent-seeking behavior etc. that lead to both environmental destruction and to growth-retarding distortions in the economy. Abandoning these practices, so the argument, would be good for the environment in dramatically easing the pressure on the remaining ecosystems and good for economic growth at the same time. These are the World Bank's (1992) famous 'win-win-situations'. They indeed open the way for a 'free lunch': Society can have both a better environment and higher economic growth at no or even negative net cost.

The prospect for these situations is, at least in principle and theory, higher than one might expect. Roodman (1996, p. 6) estimates environmentally damaging and economically distorting subsidies for water use, energy use, agriculture etc. to be at least 500 bn US$. Pearce (1996, p. 8) states an upper estimation bound of 1,000 bn US$. The latter figure comes close to 5% of world GNP!

Note, however, that often behind these subsidies stand vested political interests, as for example with the European Union's Common Agricultural Policy, which means that they are difficult to abolish (see Roodman 1996, pp. 52-56, for more detail). The abolition of these subsidies would come at negative economic costs, but at high political costs and would create immense distributional conflicts. Sometimes there are also good reasons for the subsidies and in some cases, as in agricultural subsidies in Northern countries, the environmental impacts of abolishing the subsidies and liberating agricultural trade are ambiguous (Lutz 1992). Nevertheless, the reported figures give a rough idea of what could be done to make some progress towards sustainability.

In many countries there are also likely to be many cases where environmental pollution directly harms economic productivity, either via damaging production inputs or via undermining the health of the labor force. Systematic evidence on this question is scarce, but many case studies have shown that often some level of environmental production is self-financing because it leads to higher economic productivity (see World Bank 1992, ch. 2, pp. 44-63). Of course, policy makers have to intervene in order to get something done since the environmental pollution is most often the consequence of some economic agent externalizing environmental costs on someone else and he or she is therefore not likely to abate emissions on his or her own just because this would be in the social interest.

Substituting market-based for command-and-control instruments

Another possibility to enhance sustainability while at the same time limiting the negative consequences on economic growth is using market-based instruments like emission taxes and tradable permits for environmental protection instead of the still much more widely used command-and-control instruments. Unfortunately, economists in the past have been over-optimistic as concerns the advantages of market-based instruments and have often overlooked administrative and political economy problems with applying taxes and permits (see Hanley, Hallett and Moffatt 1990, Hahn 1990, Hahn and Axtell 1995, Stavins 1995). Indeed, the static efficiency advantages have often been exaggerated by comparing a theoretical ideal of market-based instruments with real world examples of command-and-control and by ignoring the preponderance of uncertainty about the costs and benefits of environmental protection measures (Stavins 1996).

However, the static advantages are of minor interest in a sustainability context. What is more relevant here is the dynamic advantage of market-based instruments. Both taxes and tradable permits are dynamically efficient in that they induce firms not only to reduce resource consumption or pollution emission to the desired level but to explore and develop new and even less pollution- or resource-intensive technologies in order to pay less taxes or earn additional revenues via selling permits. Command-and-control instruments, whether demanding a specific environmental performance or prescribing a certain technical standard, are dynamically inefficient because over-compliance would not save money to the firm and developing new technologies risks inducing the environmental authority to tighten the standard without the firm being able to reap the benefits of its improvement.

Technical progress plays an important, if not the most important, role in overcoming resource constraints and in mitigating the pollution side-effects of economic activity — so market-based instruments with their built-in dynamic efficiency have clear advantages over command-and-control instruments. There has been some increase in the use of market-based instruments in OECD-countries over the last decade or so, but their extent remains modest and they have rather supplemented than replaced command-and-control instruments (Pearson 1995, p. 357). More research should go into the question of what the political economy problems in applying market-based instruments are and how they could be overcome. This recommendation gains additional justification when, as is not duly recognized yet, the positive effects on sustainability of replacing existing command-and-control instruments with taxes or permits are also taken into account.

Changing the tax-base of the economy?

Taxes and permits, if initially sold to firms and not 'grandfathered', also raise revenues for the public authority. No wonder then that economists have come up with the idea of using market-based instruments also to raise public revenues in order to reduce other distortive taxes — going as far as proposing a grand-design change in the base of the tax system of a country away from taxing labor or capital income towards taxing resource and energy input and pollution emission (e.g. Daly and Costanza 1992, p. 45).

There would be ample space for such large-scale changes since it is estimated that roughly fifty per cent of all state revenue in EU-countries comes from taxes that are directly or indirectly levied on labor whereas less than ten per cent comes from taxes on natural resource use and pollution taxes (Tindale and Holtham 1996, p. 64). Figures for other OECD-countries are similar (McCoy 1996, p. 211). So far, only Norway and Sweden and, to a lesser extent, Denmark, Finland and the Netherlands have undertaken some preliminary steps in the direction of deriving state revenue from 'ecotaxes' rather than other taxes — for an overview over environmental taxation in OECD-countries see Barde (1996).

Changing the tax-base of the economy towards replacing ecotaxes for taxes on labor has also gained some wider support among economists in recent years as a 'no regret'-policy to combat global warming, because it is believed that raising taxes on carbon emissions and compensating fully with reductions in other distortive taxes will be good for both the climate and the economy, especially for fostering employment (Pearce 1991, Jaeger 1995). This is the so-called 'double dividend hypothesis'.

If the hypothesis was true, this would be excellent from an environmental point of view. The reason is that the benefits from environmental protection are often uncertain, as argued in former sections of this paper, in contrast to the direct costs of doing so. The optimal internalization of environmental externalities via Pigouvian taxes as presented in the neat little diagrams of environmental economics textbooks is very often virtually impossible in reality. If the double dividend hypothesis was true, many more measures to protect the environment could be justified since it would not be necessary anymore to know the exact magnitude of the environmental benefits. It would be enough to know that the environmental benefits are positive, however big, since due to the double dividend environmental protection will come at no or even negative net economic costs.

Also, many environmentally harmful emissions cannot be measured because of the sheer number of emission sources or because measurement is prohibitively expensive. It would then be sufficient to tax inputs such as energy and resources which are much more easy to monitor than pollution emissions. Doing so makes sense as long as the link between energy or resource input and pollution is sufficiently strong. Referring back to carbon emissions, it would be sufficient to tax different energy inputs approximately according to their carbon content rather than trying to measure carbon emissions exactly at the 'end of the pipe'. In short, the double dividend hypothesis seems to open the way for a much bigger 'free lunch' than the abolition of environmentally and economically harmful subsidies. But does it really hold?

Prima facie the hypothesis appears to be convincing: Substituting the taxation of 'bads' such as pollution for the taxation of 'goods' such as labor and capital while keeping the overall tax burden of an economy the same should enhance economic activity rather than reduce it. On closer inspection, however, economists using highly complex general equilibrium models have contested this view. The point is that a tax on, e.g., energy input works its way through other markets and in the end amounts to an implicit tax on labor (tax interaction effect). This implicit tax has to be set higher than the direct tax on labor, however, because a successful environmental tax erodes its own base if the addressed firms partially reduce energy input or use less polluting inputs (erosion effect). Thus, substituting ecotaxes for labor taxes cannot but exacerbate existing distortions in the economy (Bovenberg and Mooij 1995, Bovenberg and Goulder 1995). The effects on employment depend largely on whether the implicit fall in relative labor costs due to decreasing the taxes on labor income will be fully compensated by higher real wages or not. If they are, then no beneficial effects on employment are to be expected (Carraro, Galeotti and Gallo 1996). Results are less clear-cut if the revenues from environmental taxation are used to reduce capital taxes which are generally presumed to be highly distortive. Under certain, fairly restrictive conditions a double dividend is possible (Goulder 1994, pp. 12ff.).

Other economists have insisted that a double dividend is much more likely to hold. They have based their arguments more on logical reasoning than theoretical modeling, however, which weakens their case since the effects of taxation are usually so difficult to assess that they can only be captured in complex models. Jaeger (1995, p. 56), e.g., argues that taxing pollution should be regarded as broadening the tax base of the economy via taxing a hitherto untaxed ‘commodity’. Since it is a standard result in public finance economics that second-best taxation is the less distortive the wider is the tax base one should expect the overall welfare burden due to taxation to decline and thus the double dividend hypothesis to hold. Similarly, Ekins (1996, p. 158) argues that the environmental externality should be considered as distorting other markets as well through market-interaction effects. Internalizing this externality via a pollution tax should make other markets less distorted rather than exacerbating existing distortions since the distortion due to the environmental externality is abolished.

The debate on the double divided is unlikely to be resolved over the next decade or so. It might actually never be resolved since the conclusions are highly dependent on the modeling approach and every model can be contested for not including important aspects whose inclusion would alter the model results. It seems fair to say, however, that the double dividend hypothesis has not been really proven so far and that the relationship between the environment and the economy is more likely to remain one of a fundamental trade-off rather than a free lunch where both environmental protection and economic growth can be achieved at the same time at zero or even negative net cost. That does not mean that environmental protection should not be undertaken, but rather that it has to be justified more for its environmental benefits alone rather than for its alleged additional beneficial effect on the general economy.

Totally uncontroversial, however, is the fact that the economic costs of environmental protection will be lower (but still positive) if the revenue is used to reduce other distortive taxes rather than increasing the overall tax burden of the economy or returning the taxes to consumers via lump-sum transfers. Creating revenues that can be used to reduce other distortive taxes also represents an advantage of market-based instruments over command-and-control instruments in addition to the advantages already presented in the last sub-section.

Regulating tighter for increasing productivity?

Equally contested as the call for a large-scale change in the tax base of an economy is the proposition put forward by Porter and van der Linde (1995) (the so-called ‘Porter’-hypothesis) that there are many cases in which tightening environmental regulations would at the same time increase firms’ economic profitability, i.e. cases in which tighter environmental standards come at no economic costs or even at economic benefits. The idea is that tighter regulation, if properly designed, would trigger firms to innovate and thus to become more productive.

Economists have not found this argument very convincing (see Oates, Palmer and Portney 1993; Palmer, Oates and Portney 1995), for mainly two reasons: First, the ‘Porter’-hypothesis assumes that firms are foregoing opportunities to increase their profitability, i.e. they are working inefficiently. They need a government to tell them how to improve their productivity, so to speak. In a competitive context firms working inefficiently will be outcompeted by their more efficient rivals, however, which implies that the foregoing of profitable opportunities can at most be a transitory and marginal phenomenon. Second, even if those opportunities existed and were not seized by private firms it is still doubtful whether the government can know any better and is able to design environmental regulation such that firms’ profits increase. If the ‘Porter’-hypothesis was true, then why do we see firms lobbying against environmental protection programs instead of lobbying for tighter environmental regulation? Porter and van der Linde (1995) cite dozens of examples which allegedly buttress their case. But ‘examplerism’ is no substitute for systematic empirical evidence and Jaffe, Peterson and Stavins (1995) in a survey of the existing evidence did not find any systematic support for the ‘Porter’-hypothesis.

That is not to say that firms, and even less so consumers who are not faced with constant competitive pressure, are always operating efficiently. If that was the case, how could we explain the existence of business consulting? One area where it has been shown that opportunities for environmental protection exist that are not widely exploited and could save money at the same time is energy conservation — both within firms and private households (Jochem and Gruber 1990, Jaffe and Stavins 1994, Jackson 1995). The reasons for this failure are presumably a mixture of lack of information and awareness, lack of technical expertise and lack of strong incentives because of the low share of energy costs among total expenditure. Here, policy-makers could help to overcome these obstacles via providing information and expertise and via inducing electric utilities to ‘sell’ energy efficiency improvements. Thus some cheap if not costless steps towards environmental protection could be made.

One must beware not overestimating the prospects for these costless opportunities, however. The claim that 20% and more of carbon emissions in industrialized countries can be cut at no economic costs due to energy conservation measures — a claim which is often found in so-called bottom-up engineering studies of the costs of carbon emission abatement (IPCC 1996, pp. 303-343) — is rather dubious because it neglects the many informal transaction costs that prevent firms and consumers alike to seize these self-paying opportunities. That something is costless in theoretical Nirvana does not mean that it will be costless in the actual world we are living in. It seems fair to say, therefore, that while there are some unexploited options and informed policy-makers can help to realize these options, it is nevertheless true that substantial environmental protection will have its economic price.

7. CONCLUSION

In this paper I have made explicit why natural capital is different from other forms of capital and is not likely to be perfectly substitutable as the concept of ‘weak sustainability’ holds. On the other hand, due to risk, uncertainty and ignorance it is no easy task to name those forms of capital which are indispensable for the welfare of future generations. I have argued that a good case can be made for preserving ‘rather more than less’ natural capital, especially in the form of protecting biodiversity and global environmental life-support ‘resources’ such as the ozone layer and the global climate, in the form of limiting the accumulation of toxic pollutants and in the form of preventing unsustainable harvesting and soil erosion. However, I was not able to give exact boundaries.

The analysis of policy principles such as the precautionary principle and the concept of SMS has failed to provide clear-cut policy recommendations for cases where environmental protection can only be achieved via incurring real economic costs. Both principles are unable to provide guidelines on what should be regarded as ‘excessive costs’ of preserving natural capital. I have therefore highlighted some measures that could be undertaken without major, if any, real economic costs. Realizing these measures would mean to establish and protect property rights, to abolish environmentally and economically harmful subsidies, to substitute market-based for command-and-control instruments, to use the revenues from environmental taxation such that their economic costs are minimized and to help overcome obstacles for realizing self-paying efficiency improvements. Putting these measures into practice would also mean to substantially roll back the current destruction of all kinds of natural capital. If it turned out afterwards, that the world would still be unsustainable, additional measures for the preservation of certain forms of natural capital can be undertaken even if this is costly to do.

It has to be admitted that the analysis of this paper was not able to give clear-cut answers on how much and which forms of natural capital at what costs to preserve in order to insure against the non-achievement of sustainability and to prevent ex post surprise. There is always the possibility that we run down too much natural capital in spite of our ex ante expectation that this depletion of natural capital would not endanger sustainability. Overall then, ensuring sustainability in a world of uncertainty and scarce financial resources is no easy task. On the other hand, there is also the clear danger to either spent too many scarce financial resources on the preservation of natural capital and thereby to significantly reduce the consumption possibilities of the current and future generations or to channel the resources available for preserving natural capital into the wrong channels and thereby ‘preserve’ forms of natural capital that are not really threatened.

How risk-averse society should be in making decisions on preserving natural capital and how much economic costs it would be willing to incur for doing so is not a question economic (or any other) theory can tell us. It is a question that has to be decided in the political arena. What science can do is to highlight the prevalent issues and to provide some rough estimates of benefits and costs of some action as well as looking for least-cost measures to reach a certain environmental objective. But the setting of the objective itself is outside the scientific realm. There are limits to what science can and should do.

Acknowledgement

I thank James Putzel, Mathias Hafner and Michael Jacobs for helpful comments. All errors are mine. Financial assistance from the German National Scholarship Foundation and from the European Commission is gratefully acknowledged.

REFERENCES

Barbier, Edward B., Joanne C. Burgess, and Carl Folke (1994). Paradise Lost? — The Ecological Economics of Biodiversity. (London: Earthscan)

Barde, Jean-Philippe. (1996). Environmental Taxation: Experience in OECD Countries. In Timothy O'Riordan (ed.) Ecotaxation, pp 223-245. (London: Earthscan)

Beckerman, Wilfred. (1994). 'Sustainable Development': Is it a Useful Concept?. Environmental Values 3, pp. 191-209

Beltratti, Andrea, Graciela Chichilnisky and Geoffrey Heal. (1993). Preservation, Uncertain Future Preferences and Irreversibility. Working Paper 59-93 (Milano: Fondazione ENI Enrico Mattei)

Bodansky, Daniel (1991). Scientific Uncertainty and the Precautionary Principle. Environment 33, pp. 4-5 and 43-44

Boehmer-Christiansen, Sonja (1994). The Precautionary Principle in Germany — Enabling Government. In Timothy O'Riordan and James Cameron (eds.) Interpreting the Precautionary Principle, pp. 31-60. (London: Earthscan)

Bongaarts, John (1994). Can the Growing Human Population Feed Itself? — As Human Numbers Surge Toward 10 billion, some Experts are Alarmed, others Optimistic. Who is Right?. Scientific American March, pp. 18-24

Bovenberg, A. Lans and Lawrence H. Goulder (1995). Costs of Environmentally Motivated Taxes in the Presence of Other Taxes: General Equilibrium Analyses, Working Paper No. 5117 (Cambridge (Mass.): National Bureau of Economic Research)

Bovenberg, A. Lans and Ruud A. de Mooij (1995). Do Environmental Taxes Yield a Double Dividend?. In Gianna Boera and Aubrey Silberston (eds.) Environmental Economics: Proceedings of a Conference held by the Confederation of European Economics Association at Oxford, pp. 52-69. (London: Macmillan)

Brown, Katrina, David W. Pearce, Charles Perrings and Timothy Swanson (1994). Economics and the Conservation of Global Biological Diversity, Working Paper No. 2 (Washington D.C.: Global Enironment Facility)

Cameron, James and Will Wade-Gery (1995). Addressing Uncertainty: Law, Policy and the Development of the Precautionary Principle. In Bruno Dente (ed.) Environmental Policy in Search of New Instruments, pp. 95-142. (Dordrecht: Kluwer)

Carraro, Carlo, Marzio Galeotti and Massimo Gallo (1996). Environmental Taxation and Unemployment: Some Evidence on the 'Double Dividend Hypothesis' in Europe. Journal of Public Economics 62, pp. 141-181

Castle, Emery N. and Robert P. Berrens (1993). Endangered Species, Economic Analysis, and the Safe Minimum Standard. Northwest Environmental Journal 9, pp. 108-130

Chichilnisky, Graciela and Geoffrey Heal (1993). Global Environmental Risks. Journal of Economic Perspectives 7, pp. 65-86

Ciriacy-Wantrup, S.V. (1952). Resource Conservation: Economics and Policies (Berkeley: University of California Press)

Clark, Colin W. (1995). Scale and the Feedback Mechanism in Market Economics. In Timothy Swanson (ed.) The Economics and Ecology of Biodiversity Decline — The Forces driving Global Change, pp. 143-148. (Cambridge: Cambridge University Press)

Costanza, Robert (1994). Three General Policies to Achieve Sustainability. In A. Jansson, M. Hammer, C. Folke and R. Costanza (eds.) Investing in Natural Capital: The Ecological Economics Approach to Sustainability, pp. 392-407. (Washington D.C.: Island Press)

Costanza, Robert, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton and Marjan van den Belt (1997). The Value of the World's Ecosystem Services and Natural Capital. Nature 387, pp. 253-260

Crowards, Tom M. (1996). Addressing Uncertainty in Project Evaluation: The Costs and Benefits of Safe Minimum Standards, Working Paper GEC 96-04 (University of East Anglia and University College London: Centre for Social and Economic Research on the Global Environment)

Daly, Herman E. and Kenneth N. Townsend (1993). Introduction. In Herman E. Daly and Kenneth N. Townsend (ed.) Economics, Ecology, Ethics, pp. 1-10. (Cambridge (Mass.): MIT Press)

Daly, Herman E. and Robert Costanza (1992). Natural Capital and Sustainable Development. Conservation Biology 6, pp. 37-46

Ehrlich, Paul R. and Anne H. Ehrlich (1992). The Value of Biodiversity. Ambio 21, pp. 219-226

Ehrlich, Paul R. (1989). The Limits to Substitution: Meta-Resource Depletion and a New Economic-Ecological Paradigm. Ecological Economics 1, pp. 9-16

Ekins, Paul (1996). On the Dividends from Environmental Taxation. In Timothy O'Riordan (ed.) Ecotaxation, pp. 125-162. (London: Earthscan)

Faucheux, Sylvie and Géraldine Froger (1995). Decision-Making under Environmental Uncertainty. Ecological Economics 15, pp. 29-42

Goulder, Lawrence H. (1994). Environmental Taxation and the 'Double Dividend': A Reader's Guide, Working Paper No. 74 (Munich: Center for Economic Studies University of Munich)

Hahn, Robert W. and Robert L. Axtell (1995). Reevaluating the Relationship Between Transferable Property Rights and Command-and-Control Regulation. Journal of Regulatory Economics 8, pp. 125-148

Hahn, Robert W. (1990). The Political Economy of Environmental Regulation: Towards a unifying Framework. Public Choice 65, pp. 21-47

Hanley, N., S. Hallet and I. Moffatt (1990). Why is More Notice not Taken of Economists Prescriptions for the Control of Pollution?. Environment and Planning A 22, pp. 1421-1439

Hartwick, John M. (1990). Natural Resources, National Accounting and Economic Depreciation. Journal of Public Economics 43, pp. 291-304

Holling, C.S. (1995). Sustainability: The Cross-Scale Dimension. In Mohan Munasinghe and Walter Shearer (eds.) Defining and Measuring Sustainability: The Biogeophysical Foundations, pp. 65-75. (Washington D.C.: The World Bank)

IPCC (1996). Climate Change 1995 — Economic and Social Dimensions of Climate Change — Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press)

Jackson, Tim (1995). Price Elasticity and Market Structure — Overcoming Obstacles to Final Demand Energy Efficiency. In Terry Barker, Paul Ekins and Nick Johnstone (eds.) Global Warming and Energy Elasticities, pp. 254-266. (London: Routledge)

Jacobs, Michael (1995). Sustainable Development, Capital Substitution and Economic Humility: A Response to Beckerman. Environmental Values 4, pp. 57-68

Jaeger, William K. (1995). The Welfare Cost of a Global Carbon Tax when Tax Revenues are Recycled, Resource and Energy Economics 17, pp. 47-67

Jaffe, Adam B., Steven R. Peterson and Robert N. Stavins (1995). Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?. Journal of Economic Literature 33, pp. 132-163

Jochem, Eberhard and Edelgard Gruber (1990). Obstacles to Rational Electricity Use and Measures to Alleviate Them. Energy Policy 18, pp. 340-350

Lutz, Ernst (1992), Agricultural Trade Liberalization, Price Changes, and Environmental Effects. Environmental and Resource Economics 2, pp. 79-89

McCoy, Daniel (1996). Reflections on the Double Dividend Debate. In Timothy O’Riordan (ed.) Ecotaxation, pp. 201-214. (London: Earthscan)

Meadows, Dennis, Donella Meadows, Erich Zahn and Peter Milling (1972). The Limits to Growth (New York: Universe Books)

Norton, Bryan (1986). Commodity, Amenity, and Morality — The Limits of Quantification in Valuing Biodiversity. In Edward O. Wilson (ed.) Biodiversity, pp. 200-205. (Washington D.C.: National Academy Press)

Oates, Wallace E., Karen Palmer and Paul R. Portney (1993). Environmental Regulation and International Competitiveness: Thinking about the Porter Hypothesis, Working Paper No. 93-11 (Washington D.C.: Resources for the Future)

Palmer, Karen, Wallace E. Oates and Paul R. Portney (1995). Tightening Environmental Standards: The Benefit-Cost or the No-Cost Paradigm?. Journal of Economic Perspectives 9, pp. 119-132

Pearce, David W. (1994). The Precautionary Principle and Economic Analysis. In Timothy O'Riordan and James Cameron (eds.) Interpreting the Precautionary Principle, pp. 132-151. (London: Earthscan)

Pearce, David W. (1991). The Role of Carbon Taxes in Adjusting to Global Warming. Economic Journal 101, pp. 938-948

Pearce, David W. (1996). Valuing the Environment, Lecture notes from a lecture in the Cambridge University series 'Valuing the Environment'

Pearson, Mark (1995). The Political Economy of Implementing Environmental Taxes. International Tax and Public Finance 2, pp. 357-373

Perrings, Charles and David W. Pearce (1994). Threshold Effects and Incentives for the Conservation of Biodiversity. Environmental and Resource Economics 4, pp. 13-28

Perrings, Charles (1994). Biotic diversity, sustainable development, and natural capital. In A. Jansson, M. Hammer, C. Folke and R. Costanza (eds.) Investing in natural capital: the ecological economics approach to sustainability, pp. 92-112. (Washington D.C.: Island Press)

Perrings, Charles, Carl Folke and Karl-Göran Mäler (1992). The Ecology and Economics of Biodiversity Loss: The Research Agenda. Ambio 21, pp. 201-211

Porter, Michael E. and Claas van der Linde (1995). Toward a New Conception of the Environment-Competitiveness Relationship. Journal of Economic Perspectives 9, pp. 97-118

Preston, Samuel H. (1996). The Effect of Population Growth on Environmental Quality. Population Research and Policy Review 15, pp. 95-108

Randall, Alan (1991). The Value of Biodiversity. Ambio 20, pp. 64-68

Roodman, David Malin (1996). Paying the Piper: Subsidies, Politics, and the Environment, Worldwatch Paper No. 133 (Washington D.C.: Worldwatch Institute)

Ruttan, Vernon W. (1991). Constraints on Sustainable Growth in Agricultural Production: Into the 21st Century. Canadian Journal of Agricultural Economics 39, pp. 567-580

Schuh, Hans (1995). Viele Arten, wenig Wissen. DIE ZEIT Nr. 48, p. 25

Solow, Robert M. (1993). An almost practical step toward sustainability. Resources Policy September, pp. 162-172

Stavins, Robert N. (1996). Correlated Uncertainty and Policy Instrument Choice. Journal of Environmental Economics and Management 30, pp. 218-232

Stavins, Robert N. (1995). Transaction Costs and Tradeable Permits. Journal of Environmental Economics and Management 29, pp. 133-148

Stevens, Thomas H., Jaime Echeverria, Ronald J. Glass, Tim Hager and Thomas A. More (1991). Measuring the Existence Value of Wildlife: What Do CVM Estimates Really Show?. Land Economics 67, pp. 390-400

Swanson, Timothy (1994). The Economics of Extinction Revisited and Revised: A Generalised Framework for the Analysis of the Problems of Endangered Species and Biodiversity Loss. Oxford Economic Papers 46, pp. 800-821

Tindale, Stephen and Gerald Holtham (1996). Green Tax Reform — Pollution Payments and Labour Tax Cuts (London: Institute for Public Policy Research)

Waggoner, Paul E. (1994). How Much Land Can Ten Billion People Spare for Nature?, Task Force Report No. 121 (Ames: Council for Agricultural Science and Technology)

World Bank (1992). World Development Report 1992 — Development and the Environment (New York: Oxford University Press)

WRI (various years). World Resources — a joint publication from the World Resources Institute, United Nations' Environment Programme, United Nations' Development Programme and the World Bank (Washington D.C.)