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Global warming:
Discounting is not the issue, but substitutability is.

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Abstract

The cost-benefit study of Nordhaus (1994) is representative for the neoclassical approach towards global warming. Nordhaus found that no substantial emission cuts are warranted. Most of his critics have concentrated on the issue of discounting and demanded that a lower discount rate should be applied. These criticisms first miss the point and second lead to ethically dubious, inconsistent conclusions and inefficient policy choices. They miss the point because the real problem of Nordhaus's methodology is his implicit underlying assumption of perfect substitutability between natural and other forms of capital. Given the validity of this assumption, lowering the rate of discount is inconsistent with current savings behaviour, is ethically dubious because future generations will be much richer than the current one anyway, and is inefficient because scarce financial resources are channelled into emissions abatement that exhibits rates of return far inferior to alternative public investments. Any call for aggressive emission abatement must therefore *directly* attack the perfect substitutability assumption of neoclassical economics and show that man-made capital and natural capital are complementary. The real disagreement is about whether consumption growth can compensate for environmental degradation caused by global warming. Discounting is not the issue, but substitutability is. Unfortunately, proponents of aggressive emission abatement have so far failed to provide either convincing evidence or con-

vincing *a priori* reasons that man-made capital and natural capital should indeed be regarded as complements rather than substitutes.

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Short title:

Substitutability, not discounting, is the issue.

1. Introduction

Global warming is an ideal object of study for questions of the interlinkage between intra- and inter-generational distribution and questions of sustainability under uncertainty.[1] Its essential features are that current economic activity has large-scale long-term future consequences on both environmental amenities and the capacity to provide material well-being. While there is some (contested) evidence that global warming is already under way and water cycles as well as ecosystems react upon it (Environmental Protection Agency 1997, p. 8), the bulk of impacts of global warming will clearly not be felt for another 50 years or so (Fankhauser and Tol 1996, p. 665; Mendelsohn and Neumann 1999). That is, global warming will impact mainly upon future generations but mostly not the current one. Hence the benefits of abating greenhouse gas emissions will be enjoyed by future generations, while the costs of abating greenhouse emissions are borne by the current generation.

But the members of future generations will rather unequally gain from abating greenhouse gas emissions. As a general rule, the closer a country to the equator the higher its damage from global warming is likely to be and hence its gain from emission abatement (Mendelsohn and Neumann 1999). The specific vulnerability towards climate change depends on a range of factors including a country's geophysical characteristics, but also its socio-institutional and infrastructural capacity. Low-level islands are more at risk than highlands, developed countries with their advanced ca-

pacity to adapt and prevent are less vulnerable than developing countries. Interestingly, some members of future generations who happen to live in cold countries close to the poles, as for example Russia, might even gain from warming and be hurt by abating greenhouse gas emissions (Fankhauser and Tol 1996, p. 669).

To make things still more complicated, the likely size of gains from emission abatement is a highly contested matter as well. Older estimates of damage due to a doubling of CO_2 in the atmosphere range between 1 and 2.5% of GDP (IPCC 1996b, p. 203). More recent studies which better take into account sectors that might benefit from warming (such as citrus cropping and summer recreational activities) and the possibilities for efficient adaptive behaviour to reduce potential damages come to much smaller estimates. Indeed, they do not exclude the possibility that modest global warming might be beneficial — even for those countries that earlier studies expected to be damaged by warming (see Mendelsohn and Neumann 1999).

In this paper I discuss the relevance of the issues of discounting and substitutability on addressing global warming.[2] The neoclassical approach towards global warming has tended to recommend only minor abatement policies for greenhouse gases. Nordhaus (1994, p. 94), e.g., suggests an optimal reduction rate of greenhouse gases in 2025 of 11.1% of uncontrolled emissions and of 13.4% in 2075. Note that because uncontrolled emissions are expected to grow tremendously over time, Nordhaus's optimal policy recommendation does not call for any emission cuts relative to, say, the

1990 level, but for further and substantial increases in greenhouse gas emissions over time that are only slightly lower than uncontrolled emissions (see Nordhaus 1994, p. 87).[3]

Environmentalists and ecologically oriented economists have criticised the neoclassical approach towards global warming. Mostly, they have concentrated on the question of discounting and demanded to apply a lower rate of discount for reasons of intra- as well as inter-generational fairness (e.g. Broome 1992, Azar and Sterner 1996). Because the distribution of the net costs of global warming is heavily skewed towards the distant future, using a lower rate of discount would warrant higher emission abatement (Fankhauser 1994; Chapman, Suri and Hall 1995).

This paper argues that the demand for a lower discount rate misses the point and leads to inefficient policy choices. It misses the point because it fails to address the real issue which is the underlying assumption of perfect substitutability of natural through other forms of capital rather than the appropriate selection of a discount rate. It leads to inefficiencies because, given perfect substitutability, lowering the discount rate in general or for global warming in particular would channel scarce resources away from their most productive uses. Maybe surprisingly, the demand for a lower discount rate is dubious on ethical grounds as well since it calls to give greater weight to future generations who, given perfect substitutability, are likely to be substantially better off than the current generation anyway.

Parts of the argument against changing the rate of discount can already be found in Lind (1995) and Schelling (1995). What these authors do not explicate, however, is that their objections are only valid if the underlying assumption of perfect substitutability is valid. Most authors seem to be unaware of the crucial importance of this assumption for policy implications on global warming. It is the aim of the paper therefore to highlight this importance.

Differing assumptions about the substitutability of natural capital are closely linked to the quarrel between two competing paradigms of sustainability: weak and strong sustainability.[4] Weak sustainability is based on the work of Robert Solow (1974, 1993a,b) and John Hartwick (1977, 1990) and can be called the 'perfect substitutability paradigm'. Weak sustainability requires keeping *aggregate total net investment*, suitably defined, above or equal to zero (the so-called *Hartwick-rule*). Loosely speaking, this requirement is equivalent to keeping the *aggregate total value* of man-made capital *and* natural capital at least constant.[5] Natural capital and man-made capital are seen as substitutes for each other both in production and utility functions. This means that natural capital can be safely run down as long as enough human-made capital is built up in exchange: it does not matter whether the current generation uses up non-renewable resources or dumps CO_2 in the atmosphere as long as enough machines, roads and ports are built up in compensation. In the words of Solow: „Earlier generations are entitled to draw down the pool (optimally, of course!) so long as

they add (optimally, of course!) to the stock of reproducible capital" (Solow 1974, p. 41).

Strong sustainability, instead, calls for keeping **both** the *aggregate total value* of man-made capital *and* natural capital **and** the *total value of natural capital itself* at least constant. This paradigm was mainly developed by Herman Daly and Robert Costanza (Daly 1992, 1996; Daly and Costanza 1992). The reason for emphasising the need to keep the total value of natural capital at least constant is as follows: First, man-made capital and natural capital are thought of as being complementary and not substitutable to each other. Strong sustainability can therefore be labelled the 'complementarity paradigm'. Second, due to population growth, past environmental degradation and resource depletion, natural capital is regarded as the limiting factor. Strong sustainability also holds that rising consumption cannot compensate future generations for environmental degradation, i.e. it cannot substitute for a declining stock of directly utility relevant renewable resources and a rising stock of pollution.

This paper is structured as follows: Section 2 presents the neoclassical approach towards global warming for which Nordhaus's well-known models are representative. Section 3 argues that the question of discounting, on which most of the critics of Nordhaus have concentrated, is not the relevant issue. Section 4 shows that to challenge the neoclassical approach towards global warming, one must instead *directly* attack the heart of the assumption on which its way to discount the future rests: the assumption of perfect substitutability of natural capital. Section 5 concludes.

2. The neoclassical approach towards global warming: The Nordhaus-models

Discussing global warming is no easy task: The science and economics of global warming is complex (see IPCC 1996a,b), there are numerous highly technical models for cost-benefit analysis (IPCC 1996b, pp. 374-396) and there is a vast and continually growing literature discussing the pros and cons of action. Quite clearly, I cannot and do not want to discuss all the details of this debate. Indeed, I will concentrate on those few aspects that are directly relevant to the issues of discounting and substitutability. Furthermore, I will restrict my discussion to the cost-benefit analysis of the 'DICE-model' in Nordhaus (1994), the updated and expanded version of Nordhaus (1991a), because this is the best known and best documented study and is representative in many respects of other studies using similar models which are reviewed in Toth (1995). The model in Nordhaus (1994) is itself updated in Nordhaus and Popp (1997) which is „basically a version of the DICE model that adds another dimension, that of different uncertain states of the world“ (p. 3). All the fundamental objections that apply to Nordhaus (1994) are valid for Nordhaus and Popp (1997) as well.

Nordhaus's (1994) DICE-model — the Dynamic Integrated Model of Climate and the Economy — is a dynamic optimisation economic growth model based on Ramsey (1928) in which a social planner maximises the

integrated sum of the utility of per capita consumption.[6] Output is produced by a constant returns to scale Cobb-Douglas production function. Output production generates greenhouse emissions which lead to global warming which leads, in turn, to losses in output. For a quick overview of the model see Nordhaus (1994, chapter 2, pp. 7-21).

Nordhaus implicitly assumes the validity of 'perfect substitutability' which is the centre of the paradigm of weak sustainability. He does so in two closely related ways: First, benefits and costs are meshed together and computed as shares of total output — regardless of whether they are connected to environmental amenities or consumption related. The only costs due to global warming are costs in the form of output losses. This is valid only if future generations do not care about whether, say, the costs of global warming are connected to environmental amenities that provide them with direct utility or restrain their capacity to consume material goods. Second, Nordhaus presumes perfect substitutability in the way he discounts the future. His formula for discounting is the well known Ramsey (1928) formula:

$$r = \rho + \eta(C) \cdot \frac{\dot{C}}{C}$$

The social discount rate r should be equal to the sum of the pure rate of time preference ρ and the product of the elasticity of the marginal utility

of consumption $\eta(C)$ and the per capita growth rate of consumption $\frac{\dot{C}}{C}$. If $\rho > 0$, this is called (pure) utility discounting. Nordhaus (1994, p. 123) calls discounting because of $\eta(C)\frac{\dot{C}}{C} > 0$ „growth discounting".

Nordhaus sets the pure rate of time preference ρ equal to 3% (Nordhaus 1994, p. 11). He assumes a logarithmic utility function for which $\eta(C)$ is equal to 1 (ibid., p. 11f.) and projects $\frac{\dot{C}}{C}$ to be about 3% in the first few years, declining slowly in later years (ibid., p. 125). Hence his overall discount rate is approximately 6%.

Setting the pure rate of time preference equal to 3% is controversial and Nordhaus's reasons as well as the criticism thereof will be discussed later on. The rate of pure time preference is of no particular relevance for our argument that Nordhaus implicitly assumes the validity of the 'perfect substitutability paradigm', however. Setting $\eta(C)$ equal to 1 is somewhat arbitrary, but so is more or less any assumption about the algebraic form of the representative consumer's utility function from which the elasticity of the marginal utility of consumption follows. Instead of simply assuming a specific utility function, one can also try to infer values for $\eta(C)$ from actual consumption decisions. Pearce and Ulph (1995, p. 17) have reviewed studies that have done this and provide a best estimate for $\eta(C)$ of 0.8 with a lower bound of 0.7 and an upper bound of 1.5. Nordhaus's selection of $\eta(C) = 1$ appears to be acceptable therefore. The more problem-

atic part is $\frac{\dot{C}}{C}$. Nordhaus estimates output to grow at about 3% p.a. This is a rather high estimate and others have come up with lower figures — see the discussion further below. Naturally, predicting *future* growth rates is never easy and always reflects a best guess that can turn out to be wrong *ex post*.

The specific value of $\frac{\dot{C}}{C}$ is not relevant for our discussion here, however. Whatever its value, the underlying assumption is invariably that environmental costs and benefits are substitutable by material benefits and costs. To see why, recall the ethical rationale for the inclusion of $\eta(C)\frac{\dot{C}}{C}$ in the Ramsey-formula: Given that $\eta(C)\frac{\dot{C}}{C}>0$, the future should count less because it is then presumed to be *better off* due to the increase in consumption (weighted by the elasticity of the marginal utility of consumption). That is, future losses arising from global warming, e.g. in the form of environmental amenities, are implicitly assumed to be perfectly compensable by increased consumption! Natural and other forms of capital are perfect substitutes!

One might think that if the current generation was committed to weak sustainability, i.e. to ensuring that the welfare of future generations is at least as high as the current generation's welfare, this would demand higher emission abatement than found by Nordhaus since he does not ex-

plicitly take weak sustainability as a side-constraint to his cost-benefit analysis. This is not true, however. *Solely* judged from the requirements of non-declining welfare it is most likely that no explicit abatement policy whatsoever is warranted![7] The reason is that if, as all estimates seem to agree upon, damages from unrestricted emissions are to be less than 10% of GNP (IPCC 1996b, p. 218) by the middle of the next century and future generations are likely to be materially better off by much more than 10%, then there is no need to combat global warming in order to ensure non-declining welfare into the future — given the validity of the 'perfect substitutability paradigm'. In this sense, Nordhaus's computations are more friendly to future generations than a *mere* commitment to keep welfare at least non-declining would be![8]

3. Critiques of the Nordhaus-models: why discounting is not the issue

Many aspects of Nordhaus's methodology have been attacked. To give but a few examples:

- Ayres and Walter (1991) contend that Nordhaus's land prices and vulnerability coefficients are too low.
- Cline (1996) criticises Nordhaus's method of computing agricultural costs as biased towards producing low estimates.

- Ekins (1996) suggests that taking into account beneficial side-effects of restricting CO_2-emissions such as reductions in SO_x- and NO_x-emissions (so-called secondary benefits), which Nordhaus ignores, would warrant much higher abatement.
- Howarth (1996) criticises Nordhaus for ignoring people's non-use values for the protection of biodiversity and ecosystems and, more generally, for largely neglecting negative impacts of global warming on ecosystems.
- Tol (1994) suggests that intangible goods should directly enter the utility-function rather than the production function.
- Chapman, Suri and Hall (1995) examine the consequences of a doubling of the CO_2-concentration in the atmosphere causing higher temperatures than expected by Nordhaus.
- Price (1995) contends that Nordhaus overestimates the uptake of CO_2-emissions in the oceans.
- Mendelsohn and Neumann (1998), on the other hand, come to the conclusion that Nordhaus rather overestimates damage from global warming since he underestimates the possibilities for adaptation opportunities.

I cannot discuss these criticisms here for reasons of space. Rather I will concentrate on the question of discounting on which most critics of Nordhaus have focused. Lowering the applied discount rate would drastically increase the warranted emission abatement, as confirmed by Fankhauser

(1994) and Chapman, Suri and Hall (1995), because the distribution function of the net costs of global warming is heavily skewed towards the distant future.

Before examining the demand to use lower discount rates in detail, let us first look at why Nordhaus sets the pure rate of time preference equal to 3%. He does so because he believes in economic efficiency. Estimates of the real rate of return to investment, which is also called the opportunity cost of investment, vary, but they usually lie in the range of 4% to 10% p.a. in developed countries (Nordhaus 1991a, p. 926). Manne and Richels (1995, p. 5) believe that 5% represents a lower bound, Pearce (1993, p. 60) thinks that 7% comes close to the long-run average real rate of return, Cline (1992, p. 262) estimates it to be about 8%. The World Bank usually does not accept a project with a rate of return of less than 10% (Markandya and Pearce 1991, p. 140). So Nordhaus's estimate of 6% represents a good, conservative guess of the real return. Now, efficiency requires that the government does not use a discount rate different from the opportunity cost. Hence with $\eta(C)\frac{\dot{C}}{C}$ to be estimated as 3%, it can be inferred that society's pure rate of time preference must be 3% because only then is the social discount rate equal to the opportunity cost of investment: 3% + 3% = 6%.[9]

The reason why the government should not use a discount rate different from the opportunity cost of investment is that using a different, say lower, rate would channel scarce financial resources away from invest-

ments that provide the future with a higher real rate of return. This inefficiency can arise within the limits of a given public budget in that resources are channelled away from highly productive public investments in primary education, say, towards emission abatement with a lower real rate of return. It can also arise with an endogenously determined public budget in crowding out highly productive private investments for the sake of low-return public investments into emission abatement. No doubt, the reader will realise that this argument is valid only if the 'perfect substitutability paradigm' is valid.

Let us now turn to the critique towards Nordhaus's approach towards discounting. Many economists and philosophers have since long demanded to set the pure rate of time preference equal to zero for reasons of inter-generational fairness: being later in time should as such be no reason for counting less (e.g. Ramsey 1928, Pigou 1932, Rawls 1972, Broome 1992, Cline 1992, Azar and Sterner 1996). The main argument is that future generations are excluded from today's market and political decisions (e.g. Broome 1992, p. 89f.). If future generations could reveal their preferences they would surely opt for higher investments for the benefit of the future, thus driving down the real rate of return on investment. Since we cannot know counter-factually what the real rate of return on investment would be if future generations were not excluded from today's market and political decisions, it can be said to be fair to set the pure rate of time preference equal to zero: Being later in time should be no reason for counting less. Hence the discount rate would be down to 3% from 6%.

But that is not the end of the story. Critics have also argued that Nordhaus's projection of $\frac{\dot{C}}{C}$ might be too high (Rabl 1996, p. 143). Cline (1992, p. 284ff.), in remembrance of the dismal per capita growth performance of many developing countries in the 1980s, projects worldwide $\frac{\dot{C}}{C}$ to be about 1.5% in the middle of the next century, 1% by 2100 and 0.5% by 2275 which would bring down the rate of discount to 0.5%-1.5%. Azar and Sterner (1996, pp. 177ff.) have further abandoned the assumption of a worldwide representative consumer and have examined the consequences of *intra*-generational unequal distribution. They argue as follows: If it is right to apply the Ramsey-formula to future generations and ask what their marginal utility of rising consumption is, then it must also be right to ask for the marginal utility of the much poorer people in the present-day developing world. It was taken as a justification for discounting that future generations are expected to be better off in Ramsey's formula. For the same reason Azar and Sterner (1996, p. 178) argue „that a given (...) cost which affects a poor person (in a poor country) *should be valued as a higher welfare cost than an equivalent cost affecting an average OECD citizen* [italics in original, E.N.]".

Because the costs of global warming are relatively higher in developing countries than in developed countries because of their greater vulnerability and their more restricted capacity for adaptation (IPCC 1996b, p. 218),

adjusting $\frac{\dot{C}}{C}$ along the lines of Azar and Sterner (1996) substantially increases the level of abatement that is warranted by a cost-benefit analysis of global warming. The same holds true for reducing the pure rate of time preference (possibly to zero) or lowering estimates of $\frac{\dot{C}}{C}$ for the representative world consumer.

Although I have some sympathy for these criticisms I will now argue that they first miss the point and second lead to ethically dubious and inconsistent conclusions and inefficient policy choices. The two points are linked together, as I will also show.

Take setting the pure rate of time preference equal to zero. The first thing to note is that such a proposal is inconsistent with current savings behaviour. Applying such a low rate of discount for policies to maximise social welfare would imply far more public investment and would require a far higher savings rate than is actually prevalent in any existing country (IPCC 1996b, p. 133).[10] The second thing to note is that while it is true that future generations are not present in today's markets, the actual rate of discount used by the present generation does not violate the sustainability constraint (at least non-declining welfare over time) *if* consumption is rising over time. If future generations were around and could reveal their preferences in today's markets, investment into man-made capital would be higher, the real rate of return to investment and hence the discount rate would be lower and consumption would rise *still faster* over time. But

given the validity of perfect substitutability, there is no justification to lower the rate of discount for reasons of sustainability if non-declining utility is already ensured by the actual rate of discount. The third thing to note, related to the last point, is that the proposal to lower the rate of discount is, somewhat surprisingly at first sight, contestable on ethical grounds as well. The reason is as follows: Even with a conservative estimate for $\frac{\dot{C}}{C}$ of 1.5%, future generations will be almost 4.5 times better off 100 years from now. Even if the costs of global warming by that time were, say, 50% of GNP, a future generation 100 years hence will still be 2.25 times better off than the present generation. If that is the case, then setting the pure rate of time preference equal to zero and forcing the current generation to make more sacrifices for emission abatement than with a pure rate of time preference of, say, 3% is dubious for reasons of intergenerational fairness. As Lind (1995, p. 384) has put it:

> Can we justify current generations sacrificing 2-3% of GWP [Gross World Product, E.N.] to increase the wealth of future generations who even after deduction for the high damage scenario are 2-15 times richer than the present generation? The answer is clearly no on the basis of intergenerational equity, which must weigh in favour of the current generation.

Ironically, given the validity of the 'perfect substitutability paradigm', inter-generational fairness instead of calling for a zero pure rate of time preference would rather call for quite a high pure rate of time preference.

What about the argument of Azar and Sterner (1996)? Here things are somewhat different. If we discount future values because they accrue to richer people in the future then it is consistent to count values that accrue to the future *intra*-generational poor differently from those that accrue to the rich. With global warming, there will be winners and losers and it could be argued that the future beneficiaries of emission abatement are mainly located in some of the future developing countries whereas those who are likely to undertake the abatement investments are mostly located in the present developed countries. Furthermore it could be argued that due to this difference in location the future beneficiaries will not be better off (very much) than the current people asked to undertake sacrifices: Even if the now poor will be, say, 4.5 times better off in 100 years they will not be much better off, if at all, than the currently rich. Hence it would follow that, given a zero pure rate of time preference, the discount rate should be equal to 0% or only slightly above. It might even be negative!

Azar and Sterner's (1996) reasoning is consistent with the spirit of the Ramsey-formula. But it still leads to inconsistent conclusions and inefficient choices. Their reasoning is inconsistent with the actual provision of aid from the current rich to the current poor which is of a rather limited magnitude.[11] As Schelling (1995, p. 397) has put it:

> It would be strange to forgo a per cent or two of GNP for 50 years for the benefit of Indians, Chinese, Indonesians and others who will be living 50 to 100 years from now — and probably much better off than today's Indians, Chinese, and Indonesians — and not a tenth of that amount to increase the consumption of contemporary Indians, Chinese, and Indonesians.

But such a policy would also be hugely inefficient, even if the current rich were ready to make large sacrifices for the sake of people living in developing countries either now or in the future. Given perfect substitutability, there are many much more attractive investment options from the viewpoint of the beneficiaries than investing in emission abatement. As Nordhaus (1991b, p. 57) notes, real rates of return to investment into education are extraordinarily high in poor countries: somewhere in the region of 26% for primary education, 16% for secondary and 13% for higher education. No doubt, poor people would be much better off if scarce finance was invested in these opportunities rather than in combating global warming. Given perfect substitutability, Schelling (1995, p. 401) is right in expecting that „if offered a choice of immediate development assistance or equivalent investments in carbon abatement, potential aid recipients would elect for the immediate" — as would their future descendants if they had a voice.

4. The real issue: substitutability of natural capital

The problem with all these propositions to lower the discount rate is that they do not attack the real problem with Nordhaus's methodology, namely the underlying assumption of perfect substitutability. Given this assumption, lowering the discount rate to justify large-scale emission abatement is *either* ethically dubious because future generations are better off than the present generation anyway and inconsistent with the observed magnitude of current savings, *or* it is inconsistent with the behaviour of the currently rich towards the currently poor and imposes upon the poor inefficient investments whose financial resources they would rather use for different purposes if given a choice. Any call for more stringent emission abatement must therefore directly address the question of substitutability and assume, implicitly or explicitly, that man-made capital and natural capital are less than perfect substitutes. This is because substitutability is the implicit underlying theoretical foundation for discounting.

There have been some proposals in the literature to treat environmental costs and benefits differently from other values. One is the so-called Krutilla-Fisher-approach. Krutilla and Fisher (1975) presume that environmental benefits are likely to increase *relative* to other benefits in the economy — for example because future richer people will appreciate relatively more environmental amenities if the income elasticity of environmental appreciation is bigger than one (the environment as a superior good). *De facto*, this increase in relative value means that environmental

benefits are discounted at less than other values or maybe even not at all. If the relative importance of environmental benefits grew sufficiently strong, they could even count more than their nominal value so that, *de facto*, they would be 'discounted' at a negative rate. Krutilla and Fisher also presume that some of the benefits from environmental destruction are likely to depreciate over time. The developmental benefits from dam construction, e.g., are likely to depreciate over time as superior technologies become available. *De facto*, this depreciation in relative value means that these benefits are discounted heavier than other, especially environmental, values. Note the words *de facto*: Formally, the same uniform discount rate is applied to all values, it is rather the values that appreciate or depreciate, respectively, before they are uniformly discounted to present values.

That the relative value of environmental goods might be rising over time has found the approval of the leading economist experts on global warming — see IPCC (1996b, p. 130). Recently, Rabl (1996) has applied the Krutilla-Fisher rationale to global warming under the presumption that the environmental benefits of combating global warming are likely to rise over time. Similarly, but without recourse to the Krutilla-Fisher approach, Tol (1994) examines the effect of letting intangible goods whose value increases over time with per capita income enter the utility function. Not surprisingly, Rabl and Tol find that higher emission abatement is warranted than Nordhaus did.

The Krutilla-Fisher approach does not go a long way in departing from the 'perfect substitutability paradigm', however. What it says is that envi-

ronmental and other values are still perfectly substitutable for each other, if only their value has been appreciated or depreciated beforehand. The approach does not attack the heart of the 'substitutability paradigm' therefore.

Such an attack is undertaken by proponents of strong sustainability — not surprisingly so given their belief in the 'complementarity paradigm'. At first glance the expected consequences of global warming seem to buttress their view. This is because while not every effect of global warming will be detrimental to natural capital and human health,[12] a consensus is emerging (see IPCC 1995, pp. 28-36 and Environmental Protection Agency 1997) that, for some regions at least, it will lead to or at least can lead to

- a change in the species composition of forests with the possible loss of species and the disappearance of entire forestry types.
- an increase in the frequency and the range of pests, pathogens and fires.
- an increase in desertification and soil drying.
- a disruption in mountain resources of food and fuel for indigenous people.
- an increase in the salinity of estuaries and freshwater aquifers and an increase in drinking water scarcity.
- a disruption of saltwater marshes, mangrove ecosystems, coastal wetlands, coral reefs, coral atolls and river deltas due to, among others, increased coastal flooding.

- an increase of heat waves with damaging effects on ecosystems and human health.
- an exacerbation of air pollution and an increase in airborne pollens and spores that lead to increased incidences of respiratory disease, asthma, and allergic disorders.
- an increase in the potential transmission of infectious diseases like cholera, malaria, encephalities, dengue and yellow fever.

In putting ecosystems under severe stress, global warming can therefore damage the capacity of natural capital

- to provide food, fibre, medicines and energy.
- to process and store carbon and other nutrients.
- to assimilate waste, purify water, and regulate water runoff.
- to control floods, soil degradation and beach erosion.
- to provide opportunities for recreation and tourism.

Since natural capital as such should be kept intact, strong sustainability calls for aggressive policies to combat global warming. While some warming might be unavoidable, strong sustainability would try to ensure that the future is harmed as little as possible, even if it is materially better off than the present. According to this view, global warming will degrade natural capital and since natural capital cannot be substituted for, global warming has to be prevented quite regardless of the costs of doing so.[13]

Not surprisingly the position of the proponents of strong sustainability to undertake drastic action against global warming is shared by environmentalists (see for example Leggett 1990). Their position stands in marked contrast to Schelling's (1991, p. 221) belief that „any disaster to developing countries from climate change will be essentially a disaster to their economic development".

But is it really true that damages to natural capital cannot be compensated for? Proponents of aggressive emission abatement would have to show that first adaptive behaviour cannot avoid these damages and second individuals exhibit utility functions in which consumption and environmental amenities are complements (since most damages relate to environmental amenities which enter utility functions directly). As concerns the first point, the already mentioned study by Mendelsohn and Neumann (1999) shows that adaptive behaviour can drastically reduce the expected damages from global warming. To be fair, however, it has to be conceded that neither this nor many other studies take into account health, aesthetic and nonmarket ecosystem impacts like species loss and loss of coastal wetlands. As concerns the second point, the proponents of strong sustainability would have to show that individuals have lexicographic preferences with respect to environmental amenities, i.e. damage to environmental amenities cannot be compensated for by consumption growth, however big the increase.

Unfortunately, there is hardly any reliable empirical evidence on this point. To my knowledge, the only available evidence comes from some

contingent valuation studies where minorities of interviewees have stated that they want environmental amenities to be preserved whatever the cost — 14% of the sample in Hanley and Milne (1996), 23% of the sample in Spash and Hanley (1995) and 24% in Stevens et al. (1991), to give some examples. Given that the validity of these hypothetical surveys is highly contested by many economists (e.g. Hausman 1993) and that, if at all, only minorities seem to exhibit preferences that can be interpreted as lexicographic, one cannot infer that damage to environmental amenities and human health cannot be compensated for with consumption growth.

Maybe because of this rather shaky evidence, some of the proponents of aggressive emission abatement seem to suggest therefore that the question of substitutability can be answered *a priori*. Barry (1991, p. 264) argues that any environmental damage imposed on coming generations represents a harm that is first unjustified and second not amenable to compensation:

> We will all agree that doing harm is in general not cancelled out by doing good, and conversely that doing some good does not license one to do harm provided it does not exceed the amount of good. For example, if you paid for the realignments of a dangerous highway intersection and saved an average of two lives a year, that would not mean that you could shoot one motorist per year and simply reckon on coming out ahead.

Sen (1982, p. 347) provides a similar line of reasoning. He regards 'lasting pollution' as a kind of oppression of future generations that cannot be compensated for by increased material well-being:

> Even if the future generation may be richer and may enjoy a higher welfare level, and even if its marginal utility from the consumption gain is accepted to be less than the marginal welfare loss of the present generation, this may still not be accepted to be decisive for rejecting the investment when the alternative implies long-term effects of environmental pollution.

The problem with such wide-ranging arguments is that there is a virtual infinity of actions of the present generation that affect the future and often the same action will have both beneficial and harmful aspects. The verdict that any action that inflicts some harm on coming generations is unjustified and cannot be compensated for calls for a virtual standstill in economic actions of the present generation. Radical environmentalists might be happy with such a scenario — but future generations will presumably be less fond of it. The point is that not imposing any harm on the future carries with it a tremendous opportunity cost. The world we live in is full of trade-offs and decisions on how to cope with these trade-offs can sometimes be quite awkward. Simply ignoring the existence of these trade-offs is not a viable position.

This becomes clear in examining a further argument by Barry (1991, p. 248) who states that „while it is true that we do not know what the precise tastes of our remote descendants are, they are unlikely to include a desire for skin cancer...". Whether this argument makes sense or not depends on what you mean by 'tastes'. Surely, nobody has a desire for skin cancer as such, but whether future generations will accept an increase in the rate of skin cancer or not depends on what they get in exchange for it. Given the choice between no change at all and a society with hugely increased consumption opportunities and increased life expectancies but a somewhat higher chance to develop skin cancer at some age, I would not be too sure that future generations would prefer the former option to the latter.

It is therefore not so much a question of whether doing harm can in general be compensated by doing good, as Spash (1994) seems to suggest. To a certain extent this must be possible or else we are doomed for inactivity. The real question is, again, whether large-scale damage to natural capital caused by global warming can be compensated for by higher consumption levels or not.

5. Conclusion

It was argued in this paper that the predominant critique of Nordhaus's methodology leads to nonsensical conclusions if the underlying assumption of perfect substitutability is not addressed. Lind (1995, p. 384) is wrong in suggesting that

> the real disagreement between the environmentalists who advocate an all out programme to reduce greenhouse gas emissions, and economists and others who may be more sceptical, is a disagreement over (...) what the rate of per capita income growth will be and how severe the consequences of global warming will be.

The real disagreement is about the validity of the 'perfect substitutability paradigm'. The proponents of strong sustainability and the environmentalists regard the disturbance of the global atmospheric cycle as a harm to future generations that cannot be compensated for by higher consumption even if future generations are as much as 20 times materially better off.

If substitutability is the real issue, but discounting is not, what are the implications for global warming? Weak sustainability calls for laissez-faire, strong sustainability calls for aggressive abatement policy, but which paradigm of sustainability is 'correct'? Answering this question is beyond the scope of this paper, but Neumayer (1999, chapter 3) argues in detail that neither paradigm of sustainability can be falsified under scientific standards. As mentioned, there is hardly any reliable evidence on whether natural and man-made capital are substitutes or complements in utility functions. Whether one believes in one paradigm or the other is ultimately just that: a matter of belief. Hence there is no clear-cut answer on what to do with global warming.

In spite of this ambiguity, however, a good case can be made for precautionary action towards global warming. The reasons are uncertainty and ignorance about the likely future consequences of global warming. On the other hand, abating greenhouse emissions is costly. Channelling scarce financial resources into combating global warming drags them away from other investment opportunities and possibly even from other environmental protection measures.

It would be optimal therefore to do two things: Firstly, a lot more research should go into finding more empirical evidence on whether individuals exhibit something close to lexicographic preferences with respect to environmental amenities or not — difficult as that might be. One should beware not expecting too much from such research, however. This is because proponents of strong sustainability seem to regard the question of substitutability more as a *normative* than a *positive* one. In other words, they seem to believe that consumption growth *should* not be allowed to compensate for damage to natural capital. Hence there might not be a lot to be gained from more research. Secondly therefore, and given the ambiguity, it seems to be reasonable to realise those options first that protect the environment at minimal, if any, economic costs. This would imply, as laid down in more detail in Neumayer (1998), 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 minimised and to help overcome obstacles for realising

self-paying efficiency improvements, especially in the energy sector. If correctly targeted, many of these measures would help to reduce emissions causing global warming substantially.[14]

If the current generation still thinks that additional precautionary action is warranted, it should do so. Woodward and Bishop (1997) argue from an extension of the Arrow-Hurwicz (1972) framework that basing such a decision on the aversion against unlikely, yet catastrophic outcomes can be a rational choice in dealing with uncertainty. Natural and economic science is able to guide in making this decision transparent and rational. It will not be able to give the answer in the society's stead, however. This is for two reasons: First, both the natural and economic science of global warming is unable to provide unambiguous answers about how much emission abatement is warranted. Uncertainty and ignorance are too widespread. I cannot elaborate on this point here, but the short list of criticisms against Nordhaus's methodology I have provided above gives some hints. As Fankhauser (1993, p. 22), one of the leading experts on global warming, has put it: „Through the choice of appropriate parameter values almost any abatement policy can be justified". Second, the answers are dependent on the underlying ethical decisions concerning how much to take the future welfare into account and whether one thinks that what future generations care about is only total capital or specific sub-categories like natural capital. Ultimately, it is on us to decide whether we think consumption growth can compensate future generations for damage to natural capital and human health or not.

It is a mistake to believe that there is a quasi-scientific answer on what to do with global warming. Proponents of weak sustainability and strong sustainability should argue for their case and natural and economic science can help in making the choices transparent and rational — as far as that is possible. But how much abatement is warranted is ultimately dependent on how risk-averse society is and which forms of capital it deems best for future generations, if it wants to make any discrimination at all. The question is rightly to be located within the political decision making process and should remain there.

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ENDNOTES

[1] Sustainability is defined here as non-declining utility over time: future generations should be no worse off than the current generation.

[2] Most of the paper's reasoning does not exclusively apply to global warming, however, but is relevant for similar global long-term environmental problems as well like ozone layer depletion and biodiversity loss.

[3] If uncertainty is also taken into account, then „the optimal policy (...) tends to raise control rates because of the asymmetry in the net damage function" (Nordhaus and Popp 1997, p. 10).

[4] The distinction between weak and strong sustainability should be credited to Pearce, Markanya and Barbier (1989).

[5] Capital is defined here as a stock that provides current and future (potential) 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.

[6] On page 10 of his book Nordhaus (1994) assures the reader that „by consumption we mean a broad concept that includes not only traditional purchases of goods and services like food and shelter but also non-market items such as leisure, cultural amenities, and enjoyment of the environment." This turns out to be an empty promise, however, since

on the following pages consumption is used in its traditional sense of consumption of marketed goods and services.

[7] Note, however, that weak sustainability should be regarded as traditional neoclassical economics (including cost-benefit analysis) plus the *additional* requirement to keep welfare non-declining over time. In that respect, weak sustainability would come to the same conclusion as Nordhaus does.

[8] Of course, the estimates about harm caused by global warming might be significantly wrong. Although its likelihood is very small, there is the possibility of a run-away climate catastrophe with dramatic damages if warming becomes extremely high (IPCC 1996b, p. 207f.). Alternatively, although not likely, the future economy might grow at only minimally positive rates or might even contract, as Woodward and Bishop (1995, p. 105) seem to fear. Then the requirement to keep welfare non-declining over time in itself would already call for some emission abatement. But currently best available guesses suggest that this is not the case.

[9] Note the following caveat, however: observable real rates of return to investment might be high because the economy is non-optimally managed. In particular, major environmental externalities might not be optimally internalised. The social discount rate should take these externalities into account, however. Hence the social discount rate would be lower than the private real rate of return to investment.

[10] My guess is that the advocates of setting the pure rate of time preference equal to zero if confronted with this argument would retort that policies to boost savings and public investment should be undertaken to maximise social welfare.

[11] Again, I would guess that Azar and Sterner (1996) would demand to raise this level of aid so as to maximise world social welfare, if only to remain consistent with their own approach.

[12] Warmer temperatures, for example, will mean reduced deaths from cold-related hazards which might be bigger in size than the increased deaths from heat waves (I am thankful to an anonymous referee for this suggestion). More generally, individuals seem to prefer, ceteris paribus, warmer climates as can be seen by the fact that many retired people in the United States move to the country's Southern parts.

[13] Unfortunately, the proponents of strong sustainability are not very clear on the question of discounting. Sometimes they seem to suggest abandoning discounting for certain social decisions (Daly and Cobb 1989, p. 155; Daly 1992, p. 142), but mostly they do not believe in adjusting discount rates for the benefit of the future and prefer „the more direct approach of guaranteeing sustainability by means of quantitative limits and safe minimum standards" (Daly and Cobb 1989, p. 152).

[14] This recommendation falls well short of the demands from the proponents of strong sustainability, but it is reaching further than the concensus 'Economists' statement on

climate change' (Hinrichs 1997) that was endorsed by over 2000 economists including William Nordhaus, Robert Solow and five other Nobel Laureates shortly before the United Nations' Environment Conference in New York in June 1997. And it is more radical than the community of nation-states could agree upon in the follow-up conference to Rio in Kyoto in December 1997. (The treaty is online available on the world wide web under the address http://www.unfcc.de).