INTERTEMPORAL ACCOUNTING OF CLIMATE CHANGE – HARMONIZING ECONOMIC EFFICIENCY AND CLIMATE STEWARDSHIP

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Abstract. Continuing a discussion on the intertemporal accounting of climate-change damages initiated by Nordhaus, Heal and Brown in response to the recent demonstration of Hasselmann et al. that standard exponential discounting applied uniformly to all goods and services invariably leads to a 'climate catastrophe' in cost-benefit analyses, it is argued that (1) there exists no economically satisfactory alternative to cost-benefit analysis for the determination of optimal climate protection strategies, and (2) it is essential to allow for the different long-term evolution of climate damage costs relative to mitigation costs in determining the optimal cost-benefit solution. A climate catastrophe can be avoided only if it is assumed that climate damage costs increase significantly in the long term relative to mitigation costs. Cost-benefit analysis is regarded here in the generalized sense of optimizing a social welfare function that incorporates all relevant 'quality-of-life' factors, including not only consumption and the value of the environment, but also the ethical values of equitable intertemporal and intrasocietal distribution. Thus, economic efficiency and climate stewardship are not regarded as conflicting goals, but as synonyms for a single encompassing economic optimization exercise.

The same reasoning applies generally to the problem of sustainable development. To quantify the concept of sustainable development in cost-benefit analyses, the projected time evolution of the future values of natural resources and the environment (judged by the present generation, acting as representative agents of future generations) must be related to the time-evolution of all other relevant quality-of-life factors. Different ethical interpretations of the concept of sustainable development can be readily operationalized by incorporation in a generalized cost-benefit analysis in which the evolution paths of all relevant material and ethical values are explicitly specified.

1. The Discounting Problem

In recent editorial comments in this journal, Nordhaus (1997), Brown (1997) and Heal (1997) have reviewed various approaches to the intertemporal accounting of climate change. The comments were stimulated in part by an article by Hasselmann et al. (1997) in the same journal issue, in which it was demonstrated that the application of normal economic discount rates to future climate damages in a standard cost-benefit analysis of optimal greenhouse gas emission paths generally leads to a 'climate catastrophe' in the long term. The intertemporal accounting of long-term environmental impacts is a standing subject of controversy between environmentalists and economists (see, for example, Cline, 1992; Arrow et al., 1996; Toman et al., 1995; Hackett, 1998), and, as pointed out by Heal, the discount debate has an even longer history in economics. Thus, it is helpful for the interdisciplinary

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interaction between climatologists and economists that the economic reasoning on this issue has been presented in some detail from three different viewpoints.

The source of the debate is simply stated. Climate has a long memory. Thus, the severest climate impacts of continuing greenhouse gas emissions will accrue several centuries in the future. However, the application of an inflation adjusted standard discount rate of, say, 5%, to climate damages occurring 200 years in the future implies that the damage costs are discounted by a factor $\exp(-10) = 4.5\,10^{-5}$ when translated into equivalent present-day costs. Thus, expressed as present-day costs, climate damages in the long term appear acceptable at almost any level. Clearly, this does not correspond to most people's evaluation of the climate problem. So how should the cost-benefit analysis be modified? The question is not straightforward. It leads ultimately to the fundamental problem: how should 'sustainable development', a much interpreted yet notoriously elusive concept, be quantified in establishing an optimal climate protection strategy?

Hasselmann et al. resolve the problem by applying different discount rates to mitigation and climate damage costs. They argue that mitigation costs are normal economic costs that should be discounted at standard market rates, while climate damage costs are largely nonmarket social costs and should be discounted at very much smaller rates, or not at all.

The editorial comments on this approach are mixed. Heal reviews various proposals for introducing weaker disount factors for long-term costs, but comments that none of these contemplate different discount factors for different sectors of the economy. However, this has, in fact, been frequently advocated (cf. Pigou, 1932; Krutilla and Fisher, 1975; Hackett, 1998), and Henderson and Bateman (1995), cited by Heal, present abundant evidence that the application of social discount rates differing from one another and from the market discount rate is the norm rather than the exception in the planning of public projects.

Nordhaus also regards differential discounting as legitimate when considering the different time evolution of prices for different goods (as was argued by Hasselmann et al.), but regards this as only one of several equally legitimate alternatives. He expresses some skepticism whether differential discounting is the best approach, but finds that a uniform weakening of the long-term discount factor for all costs is still less satisfactory. On the other hand, the alternative approach he suggests, the prior establishment of fixed targets on the permissible levels of climate change, or, more stringently, on greenhouse gas concentrations or emissions, no longer corresponds to an overall cost-benefit optimization.

Finally, Brown supports the view that the impacts of future climate change should not be discounted, but argues, rather in the spirit of the fixed-target option of Nordhaus, that the appropriate method for establishing greenhouse gas emissions should be one of a 'stewardship' in climate rather than a classical cost-benefit exercise. However, while Brown suggests that an efficient stewardship in climate is beneficial for economics as a whole, Nordhaus appears to regard the requirements of sustainable development as in conflict with economics, stating that the requirements can be met only by overriding economic efficiency criteria.

For a climatologist, this plethora of apparently conflicting economic viewpoints is rather bewildering. With regard to the ethical issue of the ‘value’ of preserving our present climate, or the ‘damages’ ensuing from a climate change to future generations, it is unavoidable and healthy that there should be discussion and differences of opinion. However, this was not the issue of the debate: it was implicitly assumed in all commentaries that some agreement on this question had been reached. But once the value judgements have been settled, the problem of optimizing the economic path to meet the specified normative objectives should be a purely mathematical exercise over which there should be no basic controversy (apart from the usual technicalities regarding the construction of economic and climate models). So what is the origin of these differences of opinion?

A closer inspection reveals that many of the disagreements are, in fact, not real, but can be attributed to differences in terminology. However, there remain also genuine incongruities. I shall try in the following to develop a consistent synthesis of the various viewpoints. In the process, I shall respond to the criticisms of our differential discounting approach by proposing a reformulation that is in accord with this synthesis (and more accepted economic terminology).

Since the views expressed in the specific editorial comments span rather well the general debate on the perceived conflict between economic efficiency and climate stewardship that pervade the literature on environmental economics, an attempt has been made to place the following arguments also in a broader frame. The general objective is to translate the qualitative concept of sustainable development into a quantitative operational formalism that is amenable to economic optimization procedures. This, of course, has been the goal of many previous treatises on sustainable development. However, most previous work has ignored the implications of differential discounting. It is argued that this feature is essential for the meaningful application of economic optimization methods to sustainable development.

I conclude that if one wishes to (1) stay within the framework of a standard neoclassical growth model, or some other model that yields interest rates that do not collapse with time, and (2) determine the optimal greenhouse gas emissions path as the solution of a general cost-benefit problem (rather than as a partial optimization exercise under the restraints of prior specified climate-change, greenhouse-gas-concentration or emission targets), the only feasible resolution of the environmental discounting dilemma is to apply differential discounting. However, I propose a rewording of the approach of Hasselmann et al. in terms of ‘relative value discounting’, following Krutilla and Fisher (1975), Harvey (1986), Arrow et al. (1996), Horowitz (1996) and Nordhaus (and in the spirit of the arguments presented by Hasselmann et al.). Rather than introducing different discount rates, a standard common discount factor is applied to all sectors of the economy, and one consideres instead the different time evolution of the relative prices of different goods and services.

The resolution of the above stated dilemma that the application of a standard exponential discount factor implies that ‘climate damages in the long term appear acceptable at almost any level’ is then found to lie in the word ‘almost’. If it is assumed that the value attached to the preservation of climate represents a constant or even gradually increasing fraction of GDP, or, expressed in instantaneous currency, rises at least as fast as the real discount factor falls, one obtains essentially time independent (or even slightly increasing) discounted climate damage costs – as assumed by Hasselmann et al. in their baseline scenario.

In the following, I expand on this conclusion, but discuss first the various alternative approaches considered by Nordhaus, Brown and Heal – and proposed in numerous variants in the environmental economic literature.

2. Market and Social Values

A central issue is the distinction between values established by transactions on the market place and ethical or social values set by other mechanisms. The state of our climate is clearly a common asset of humankind whose value is not established by market transactions, but by governments in response to public value judgements. (I do not discuss here the important question of how these public values are formed and transmitted to decision makers, but simply assume that they exist, and that decision makers translate them into policy as responsible representative agents of society as a whole.) In contrast to the value attached to our present and future climate, which depends strongly on non-monetary factors such as the quality of life and an ethical commitment to future generations, the means by which our present climate can be preserved – primarily by reducing net greenhouse gas emissions – is mainly a problem of technology. Given the regulatory framework (taxes, subsidies, emission permits etc.) established by governments to achieve the desired climate protection goals, the ensuing mitigation actions are largely governed by market forces. However, both adaptation and prevention measures involve mixed costs of both categories: building higher dykes in response to rising sea levels is a purely monetary cost (although borne by the public), while the carbon-free restructuring of industry involves social adjustment costs as well as technological investments. Thus, an optimal climate protection strategy must take a wide spectrum of costs of different categories into account.

One of the origins of the apparent divergence of views on the climate protection issue is the use of different terminologies in the treatment of these mixed-cost categories. In some cases, economic costs are assumed to refer only to market costs, in other cases, to the sum of market and social costs.

Related to this ambiguity are different uses of the terms economic efficiency and cost-benefit analysis. The terms are sometimes used in the narrow sense of referring only to the costs and benefits associated with the market place, at other times in the more general context of optimizing the overall system, including all conceivable monetary and non-monetary values. The conflict seen by Nordhaus (and many others, see for example Arrow et al., 1996; Howarth and Norgaard, 1995; Howarth, 1996; and references cited in Toman et al., 1995) between sustainable development and economic efficiency can be understood only if the term economic efficiency is restricted to market costs (or, more generally, if the objective 'social welfare' function that is being maximized fails to correctly include one's concern for 'sustainable development'). On the other hand, most environmental cost-benefit analyses (including Nordhaus, 1993) consider both market and nonmarket costs. This inconsistency runs through much of the controversy over environmental cost accounting, see IPCC (1996). It can probably be attributed in part to the problems associated with the use of a single discount factor, with an assumed parallel price evolution for all goods and services. This necessarily leads to the aforementioned climate-catastrophe dilemma in cost-benefit analyses. Instead of addressing the problem at the core, the response is often to simply reject cost-benefit analyses as such – thereby forsaking the primary optimization objective of economics.

In the following, I shall use the terms economic costs, economic efficiency and cost-benefit analysis always in the encompassing sense of including costs of all categories. Thus, the classical definition of economics as the 'optimal allocation of scarce resources' is interpreted as including all monetary and non-monetary resources that affect the quality of life.

3. The Target Approach

Critiques of cost-benefit analyses often propose as alternative a target approach. It is argued that acceptable climate-change limits should be set a priori, on the basis of ethical arguments divorced from economic considerations. If desired, the optimal greenhouse gas emissions path can then still be determined subsequently as a separate cost-minimization exercise, given the climate-change constraints (or permissible greenhouse-gas concentration or emission levels) set by governments.

This approach is undoubtedly helpful in clarifying the economic impacts of prescribed targets. It is also rather close to the current political process. If pursued as an investigation of the impact of various control measures, it reduces to a normal forward-integrating scenario analysis. If combined with a subsequent cost-minimization calculation to determine the optimal emissions path under the prescribed target constraints, as illustrated by Nordhaus, the approach represents a partial optimization inverse-modeling exercise in the spirit of Wigley et al. (1996), Tahvonen et al. (1994) or the tolerable window approach of Petschel-Held et al. (1999). However, as already pointed out, the target approach is fundamentally inconsistent with the basic economic objective of determining the optimal overall allocation of all human and natural resources to achieve a given set of objectives. For the optimal allocation of all resources, targets should be derived as the output of a comprehensive optimization exercise, rather than prescribed as an input.

Although basic economics, this view is by no means prevalent in the environmental economic literature. Since it is nevertheless fundamental for the argument developed below, some explanatory words may be appropriate. Although the goal of preserving the present climate state for future generations is largely motivated by ethical values, the human endeavors devoted to realizing this ethical objective must nonetheless compete with other demands on human resources. This is clearly expressed in Article 2 of the United Nations Framework Convention on Climate Change: '… [the goal is the] stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame … to enable economic development to proceed in a sustainable manner'. The prior establishment of a climate-change limit on ethical principles, independent of other demands on human resources, preempts the necessary trade-off between preserving the climate and the general goal of 'economic development'. Prior ethical commitments can be justified only if they are based on clear-cut moral imperatives (like 'thou shall not kill'), independent of other considerations (but even this example must be qualified: the number of people killed on highways could be reduced by more investments in highway safety). Unfortunately, climate change is not a clear-cut off-on process, but a problem of gradually increasing risks that must compete with other urgent problems and attendant risks in an economic world of finite resources.

In fact, decoupling ethics from economics, even if desired, is not feasible. The establishment of a climate-change limit implicitly defines the costs one is willing to pay to restrict climate change – namely, the ensuing abatement costs. But one can then legitimately ask: why cannot one accept a larger climate change by, say, 10%, or, alternatively, tighten the climate-change target by 10%? The rational answer can only be that, in the former case, the climate-change impact costs (loss in 'ethical value') would be greater than the savings in abatement costs, while in the latter case, the additional abatement costs would be greater than the reduction in climate impact costs. In other words, the prescribed climate change target is claimed to be judiciously chosen such that the incremental costs of climate damages and mitigation exactly balance. Thus, starting from a 'purely ethical' principle, one has, in fact, implicitly presented the solution of a classical cost-benefit problem and established both the total and marginal (shadow) price of limiting climate change. Rather than introducing these costs implicitly, would it not be more constructive to state one's assumptions regarding climate-change costs explicitly? This would provide the necessary quantitative basis for a rational discussion of whether these assumptions, in fact, reflect public value judgements.

The observation that 'ethical' values become monetized when confronted with alternative options of action that can be priced on the market place is, of course, not limited to climate change. It is a standard experience of everyday life. Individuals are continually defining their personal price of ethical values when deciding on how much to save for their children's education, to contribute to a charity, or when voting on welfare policies (although in this case the impact on the market place is indirect, through the action of public decision makers). The main distinction between the climate problem and other ethical issues is that effective stewardship in climate requires concerted political action on an international level. Thus, individuals are not able to express the value they attach to the protection of climate through personal market actions, and only in a restricted manner by voting in communal or national elections.

However, responsible decision makers will nevertheless endeavor to establish how much people are willing to pay today to preserve our present climate for future generations. Acting as representative agents of the public, they will then presumably incorporate these values in a general (normally intuitive) cost-benefit analysis that considers both climate-change impacts and the costs of mitigation measures. This is, of course, an altruistic idealization of the complexities of multi-player national and international politics. A less sanguine picture is painted, for example, by Norgaard (1994). However, for the present conceptual discussion, this need not concern us. It is assumed that a single conscientious decision maker, or decision-making group, uninhibited by Arrow's (1970) theorem on the non-existence in general of a consistently defined, democratically determined social welfare function, simply postulates a social welfare function that is deemed best for humanity (thereby conveniently violating Arrow's condition that no single person or group should dominate the voting process). Decision makers therefore face the same trade-off problem as an individual in deciding on how many resources should be assigned to the achievement of an ethical objective in competition with other goals. The only difference is that they form their value judgements by responding to public opinion.

Thus, a generalized cost-benefit trade-off, whether implicit or explicit, is inescapable. A common misunderstanding of critiques of the cost-benefit approach is a too narrow interpretation of the social welfare function that is being maximized. For example, it has been stated that cost-benefit analyses optimize only the allocation, not the distribution of resources (cf. Howarth and Norgaard, 1995; Howarth, 1996, and further references cited therein), or that cost-benefit solutions accept a decrease of the welfare of future generations, provided the total welfare over all generations is maximized (Pearce and Atkinson, 1995). We adhere here to the broader view of Toman et al. (1995), that the social welfare function can and should have a very general form that incorporates all relevant value judgements. These can include, in particular, the social costs of perceived inequitable intergenerational or intrasocietal distribution, or high penalty costs (or simply a hard side condition) ensuring that the social welfare is nondiminishing. Stated simply: if one is dissatisfied with the outcome of the optimization exercise, one has not defined the social welfare function properly such that it accurately reproduces one's complete set of value judgements.

The general formulation of such a comprehensive social welfare function will not be considered here. This is an important ethical issue beyond the present conceptual analysis. The discussion here will be limited rather to the simpler question:

having decided, on ethical grounds, that 'sustainable development' is a desirable objective, how does one incorporate this as yet unspecified value judgement into an otherwise arbitrarily prescribed social welfare function? Specifically, how should one relate future costs to present costs in the definition of the time integrated social welfare function that one wishes to maximize?

4. Exponential Versus Non-Exponential Discounting

According to conventional economics, the intertemporal cost relation is determined for market goods and services by the discount rate, which is identical to the interest rate r. This is established by the balance between the credit supplied by savers willing to defer consumption and the credit demands of investors and impatient consumers (Fisher, 1907). For a constant-growth-rate economy, $r = \text{const}$, so that an initial savings stock established at time $t = 0$ grows by the compound interest growth factor $I = \exp(rt)$. Thus a given sum of money S_t at time $t > 0$ is equivalent to the sum $S_0 = D\,S_t$ at time $t = 0$, where the discount factor D is the inverse of the compound interest factor, $D = I^{-1}$ (all values are assumed to be corrected for inflation).

Since everything that can be traded on the market place can be expressed in prices, the exponential discount factor must apply generally for all market values. For to buy a good or service valued at a price P_t at time t, one can deposit the smaller amount $P_0 = D\,P_t$ at time $t = 0$ in a savings account, and can withdraw the savings at time t to carry out the purchase. For a constant-growth-rate (sometimes misleadingly termed 'steady state') economy, there is no time limit on this conclusion. Savings accounts, stocks or treasury bonds can be passed on through many generations. The fact that interest rates differ depending on risk can be ignored in the present context; r may be interpreted as the interest rate on low-risk government bonds.

As pointed out, environmentalists are not happy with the application of exponential discount factors based on the real interest rate to environmental damages. An extensive environmental literature (see, for example, Krutilla and Fisher, 1975; Toman et al., 1995; Arrow et al., 1996; Hackett, 1998) argues that it is not appropriate to equate the social discount rate for public goods such as the environment to the market interest rate. Starting from the classical Ramsey factors that govern the willingness of an individual to defer consumption (the pure rate of time preference, the growth rate of per capita consumption, and the elasticity of marginal utility) one arrives, in the terminology of Nordhaus, at a 'prescriptive' net social rate of time preference (social discount rate) for environmental values that can well differ for an individual from the 'descriptive' rate of time preference (market discount rate) set by the interest rate. However, the distinction between an 'ethical' discount rate for environmental goods and an 'economic' discount rate for market goods violates the basic principle expounded by other environmental economists – and adopted here – that all values, both market and non-market, can and should be monetized in common currency or consumption units. The question whether or not the interest rate, which is set by the balance between supply and demand, corresponds to an 'ethically acceptable' discount rate is irrelevant: the market expresses what trading economic actors actually want. Governments can modify market relations by internalizing the external costs of climate change, thereby impacting also the interest rate. But the optimization of the overall economic system, given the internalization measures of government policy, is achieved within the framework of market laws. Since ethical values become monetized in the unavoidable competition with market goods and services, one cannot escape the simple logic of the classical exponential discounting argument by negating the demands of overall economic efficiency. One must look for other arguments.

One obvious possibility is to question the validity of a constant interest rate over the long time periods relevant for climate change. There exists an abundant literature on economic growth under the constraints of finite natural resources, beginning with the early fundamental treatises of Malthus (1798) and Ricardo (1821), followed in this century by the classical analysis of Hotelling (1931), the influencial but controversial 'limits to growth' investigation of Meadows et al. (1972), the seminal work of Krutilla and Fischer (1975) on natural environments, and, in recent years, the flowering of an impressive bouquet of neo-classical, overlapping-generation and other types of growth models (see, for example, Howarth and Norgaard, 1995; and the comprehensive review of Toman et al., 1995). Many of these models predict a reduction of the interest rate with time as finite natural stocks become depleted or the environment is degraded. A central issue in these analyses is the degree of substitutability between limited natural resources and the assets accruing from technological progress. Although global climate can be viewed as simply one of many growth-limiting factors in a finite world, it differs from other factors, such as natural material resources, in representing a global-scale common good. Thus Hotelling's result that the 'invisible hand' will automatically secure an optimal allocation of privately owned natural resources over time is not applicable: a visible government hand, guided by some insight into the interrelation between climate and economics, is needed.

As pointed out by Heal, there exists also ample empirical evidence that individual rate-of-time preferences are not constant, but tend to decrease in the longer term. On the micro-level of individual choice, many people are simply not *homini economici*. They ignore the equivalence of the interest rate and discount rate for all costs and values that can be calibrated, either directly or indirectly, by market transactions and apply their own individual (in the short term, normally significantly higher) discount factors (Strotz, 1956; Thaler, 1981; Lowenstein and Thaler, 1989; Winston and Woodbury, 1991). In general, an individual rate-of-time preference may be some more or less arbitrary monotonically decreasing function of time (subject to some rather general constraints, cf. Koopmans, 1960; Chichilnisky, 1996). It can depend, among other factors, on the magnitude of the choice and differences between losses and gains (‘savoring’ and ‘dread’, Lowenstein and Thaler, 1989). However, the rate-of-time preferences tend to approach the classical interest rate level in the macro-level limit of major options: ‘People tend to get the big decisions right’ (Thaler, 1981). It can therefore be assumed that the decision maker defining the social welfare function will be guided solely by rational considerations. Nevertheless, the distortion of individual rate-of-time preferences (relative to a rational, purely economic value judgement) on the micro-level of choice may tend to lower the resultant long-term interest = discount rate in the balance between the supply of savings and the demand for capital.

However, for the present discussion, the multiplicity of factors affecting the discount rate and the wide spectrum of growth models designed to take these and other factors into account need not concern us. It is sufficient to divide the models into two classes: those that allow for a different evolution with time for the value of the environment relative to the values of other goods, and the essentially single-sector models that do not make this distinction. The first class will be discussed in the following section: with appropriate assignment of the relative time evolution of the values for the environment and for market goods, this model class can resolve the ‘climate-catastrophe’ dilemma in cost-benefit computations. For the second class, however – assuming the models do not predict economic collapse, but envisage a feasible long term economic development path maintained by an appropriate technological-economic response to climate change – this is not feasible.

This can be readily demonstrated as follows. Consider as reference a simple model with a constant interest rate r_0, exponential discount factor $D_0 = \exp^{-r_0 t}$, and instantaneous net specific costs (per year) $c(t)$, composed of the sum of the costs for emissions abatement and climate-change damages. A cost-benefit analysis is then applied to determine the optimal path of some control variable (for example, a carbon tax, or simply the greenhouse gas emission level itself) such that the total discounted cost C_0, integrated over time, is minimized:

$$C_0 = \int c(t) D_0(t) dt = \min .$$

Assume that (because the differences in the time evolution of climate-damage and mitigation costs are not considered), the optimal control solution leads to a ‘climate catastrophe’.

Now consider a more sophisticated model with variable discount factor $D(t)$, corresponding to a time dependent interest rate $r(t) = -d(\ln D(t))/dt$, but otherwise the same cost expression. The minimization problem

$$C = \int c(t) D(t) dt = \min$$

for the total costs C for this model can then be transformed to the same form as the reference model, with constant interest rate r_0, but with modified specific costs, by transforming to a new time variable $t' = t'(t)$, where

$$D(t)dt = D_0(t')dt' \quad \text{or} \quad \frac{dt'}{dt} = \frac{D(t)}{D_0(t')}.$$

This yields

$$C = \int c'(t')D_0(t')dt' = \min,$$

with the same discount factor as in the reference case, but a modified specific cost expression $c'(t') = c(t(t'))$.

Provided the change in the time axis is not dramatic, i.e., that the interest rate does not collapse as $t \to \infty$, one faces for the modified specific costs the same problem as in the reference case: climate-change damages several hundred years in the future are almost completely discounted, and the minimal-cost solution again yields very large (instantaneous) future climate-change damages.

5. Relative Value Discounting

However, if, as in Hasselmann et al., one drops the requirement of a uniform application of a single discount factor to all sectors of the economy or, alternatively, in the terminology of Krutilla and Fisher (1975), Harvey (1986) and Horowitz (1996), uses a common discount factor, but allows for the different time evolution of the costs of emission abatement relative to the climate-damage costs, there is an alternative simple resolution of the climate catastrophe problem that does not require dramatic modifications of the market interest rate. This is based on the observation that the real discount factor applies for average prices, after application of a correction factor for inflation that is defined with respect to the price index for some reference basket of goods and services. Since the relative prices of individual goods and services change with time, one obtains different effective discount factors for different goods.

In particular, it can be argued that the average costs of the impacts of climate change may be expected to increase more rapidly than the costs of mitigation measures. The former tend to be strongly dependent on human services and quality-of-life factors (such as health costs or the enjoyment of nature), whose values traditionally increase more rapidly than average prices, while the latter are strongly governed by technological progress (such as the development of solar energy), which is normally associated with falling costs relative to average costs. Expressed differently, a ‘real’ discount rate obtained by normalizing all values with respect to a reference goods and services basket containing only climate impact quantities may be expected to be significantly smaller than a ‘real’ discount rate obtained by using as numeraire a goods and services basket consisting entirely of the technical costs of mitigation.

In the following, however, this is expressed in terms of Krutilla and Fisher's (1975), Harvey's (1986) and Horowitz's (1996) terminology: only a single discount factor is introduced. This is identical to the market interest rate, which is inflation-adjusted with respect to some conventional (non-environmentally weighted) goods and services basket. But allowance is made for the different time evolution of the costs of mitigation and climate-change damages. For simplicity, a traditional constant-growth-rate model with exponential compound interest growth factor is assumed. However, as pointed out above, this is not essential. The baseline optimal emission scenario of Hasselmann et al., with no discounting of climate damage costs (in their terminology), is equivalent then to the assumption that the mitigation costs decrease with time relative to the climate-change damage costs, and, specifically, that the instantaneous climate-damage costs rise at the same rate as the market discount factor falls.

It is not claimed that this assumption necessarily corresponds to the value judgement of the general public, or even of all environmentalists. Our point is simply that a rejection of the 'climate catastrophe' solution of a standard cost-benefit analysis using uniform cost discounting must be argued in terms of an increase in climate damage costs relative to abatement costs. Environmentalists that intuitively reject 'climate catastrophe' solutions can rationally justify their rejection only on the basis of a quantitative assessment of the future evolution of climate damage costs relative to mitigation costs. This will not be attempted here, since our goal is to clarify basic interrelationships rather than argue for or against a particular policy. However, a qualitative argument can be given as follows:

The divergence of the evolution paths of climate-damage and mitigation costs is best explained in terms of percentages of instantaneous GDP, rather than instantaneous (inflation adjusted) currency units (cf. Figure 1). The impact of climate change on the quality of life may be measured in terms of the efforts people are willing to expend to maintain a given level of personal health and life expectancy, to enjoy an unspoiled environment, to have access to adequate water supplies, to preserve species, and, generally, to avoid the risks of social strife and other unforeseeable consequences of irreversible environmental change. It is assumed that these efforts, expressed as a percentage of GDP, or as workhours per day per individual, remain more or less constant in time, or even increase, as growing technical proficiency reduces the efforts needed to satisfy normal material needs. On the other hand, the efforts required to modify our industrial infrastructure to mitigate climatic change can be expected to decrease with time as decarbonization technologies and industry in general become more efficient.

Figure 1 illustrates the original and rephrased descriptions, respectively, of the intertemporal relations for the climate-change impact and mitigation costs assumed in the baseline scenario of Hasselmann et al. The ordinate scale on the right shows the original discount factors for climate-change damage costs and mitigation costs,

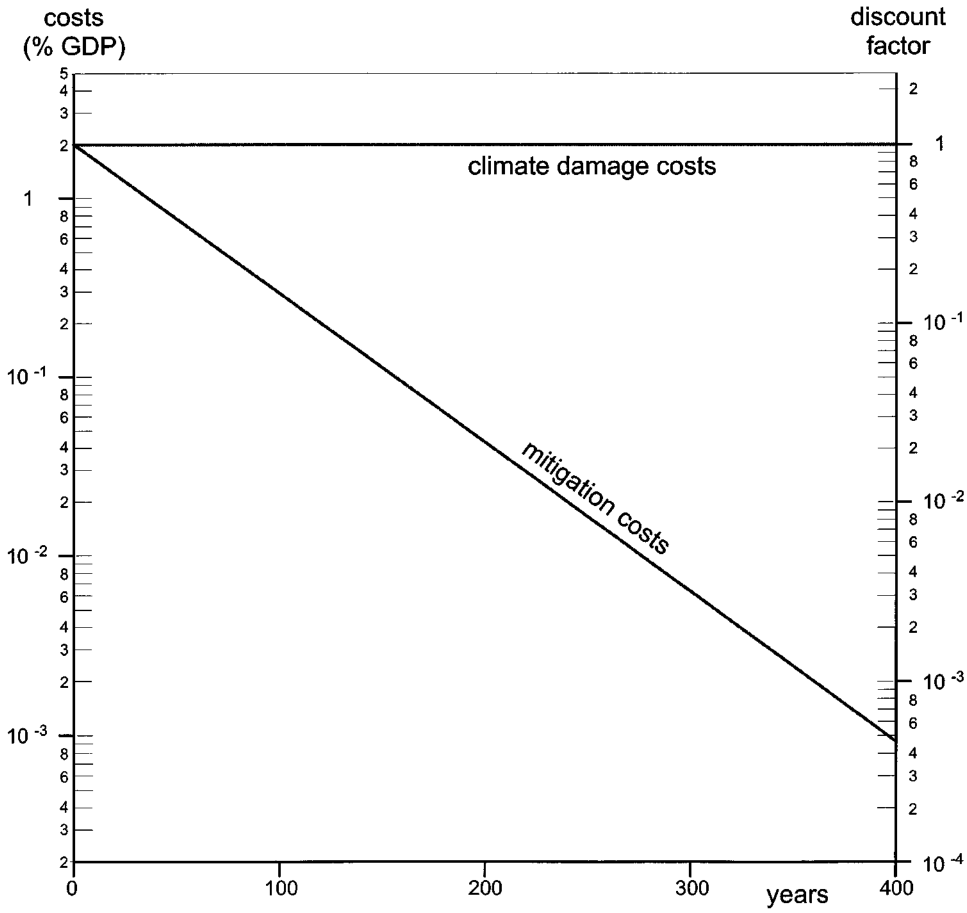

Figure 1. Ordinate scale on right: discount factors for climate-change damage and mitigation costs according to the original differential discounting terminology of Hasselmann et al. (1997). Discount rates are set at 2% and 0% for climate-change mitigation and damage costs, respectively, in accordance with their baseline scenario. Ordinate scale on left: Relative costs, expressed as percentage of GDP, of climate-change damages and mitigation actions (for a given level of climate change and mitigation) in accordance with the rephrased ‘relative value discounting’ terminology, applying a common discount rate of 2% for both cost categories. For simplicity, the real discount rate is assumed to be equal to the real growth rate of GDP.

the ordinate scale on the left the corresponding costs, for given levels of climate change and mitigation, in units of percentage of GDP, in the terminology of relative value discounting. The units of the left scale are essentially arbitrary, but the order of magnitude of the price the public is willing to pay to limit climate change was estimated as 2% of GDP by taking as reference the current U.S. expenditure of more than 15% of GDP on health and safety (Cropper et al., 1994).

Thus, the environmental dilemma resulting from the application of exponential discount factors is resolved by the assumption that the value attached to the preservation of our climate remains fairly constant (or even increases) with time when expressed as a percentage of GDP, or as the percentage of worktime that people are willing to expend on the preservation of the climate. Hence the climate-change impact costs, when expressed in terms of instantaneous currency, rise at least as fast as GDP. Assuming that the exponential growth in real GDP is approximately equal to or not much smaller than the inverse of the real discount factor, this yields roughly time independent climate damage costs in discounted equivalent present-value units.

6. Optimizing Climate Stewardship

The qualitative arguments underlying the particular baseline scenario of Hasselmann et al. have been summarized here only as illustration. A careful quantitative justification would clearly require detailed data surveys and extensive public polls, which lie beyond the present conceptual exposition. The central point is that, independent of the details of the assumed cost evolution paths, a necessary condition for the resolution of the climate-catastrophe dilemma in cost-benefit analyses is the more rapid evolution of climate damage costs relative to mitigation costs. Once this has been recognized, one can incorporate in the specification of the total climate-related costs within the definition of the social welfare function any desired interpretation of intergenerational equity, thereby operationalizing the general concept of sustainable development.

The simplest approach (also used by Hasselmann et al.) is to treat all generations equally, i.e., to apply the same weighting to all present-value-equivalent costs. For an exponential discount factor, this normally yields finite time-integrated total costs even when the time horizon is extended to infinity. In the baseline scenario of Hasselmann et al., however, the instantaneous climate damage costs for a given level of climate change were taken as constant when expressed in terms of percentage of GDP – or grew exponentially when expressed in terms of instantaneous currency. It was therefore not immediately clear whether the total cost integral still converged. This was nevertheless assured in all scenarios studied through the impact of the exponentially discounted mitigation costs, which were taken as constant in instantaneous currency units (for a given abatement level). This yielded optimal greenhouse gas emission paths for which the emissions, and therefore the climate change, decreased asymptotically with time, securing the convergence of the cost integrals for both mitigation and climate-change damages. Although the economic model considered by Hasselmann et al. was very elementary (simple cost expressions for climate damages and mitigation, with some additional terms parametrizing economic inertia), the same qualitative result can be expected using a more sophisticated economic model.

Alternative formulations of intergenerational equity (cf. Pearce and Atkinson, 1995; Tol, 1999) can also be readily incorporated in cost-benefit analyses, once relative value discounting has been properly implemented. In his classical Theory of Justice, Rawls (1971), for example, proposes a maximin criterion: the welfare of the generation with the lowest welfare should be maximized. Alternatively, Chichilnisky et al. (1995) maximize the asymptotic level of indefinitely sustainable utility. Similarly, using an appropriate economic model, one can implement the strong criterion of sustainable development: no deteriation of the environment or reduction of non-renewable resources for future generations; or the more realistic weak sustainability criterion: no reduction in net welfare for future generations, allowing for some degree of substitutability between environmental deterioration or natural resource loss and the assets accruing from technological progress (see review by Kemp et al., 1984).

The 'proper' definition of intergenerational equity, and sustainable development in general, is an important ethical issue, which, as already mentioned, will not be addressed here. The purpose of this paper is simply to point out that, that once the normative issue has been decided, the determination of the optimal strategy to achieve the agreed-upon ethical objective is amenable to standard cost-benefit analysis. The frequently cited conflict between economic efficiency and climate stewardship disappears when social welfare is properly defined to include both conventional market and environmental values, and the different evolution of the costs of climate mitigation and climate damages is taken into account.

The derivation of realistic optimal cost-benefit solutions, requires, of course, more realistic economic models than the simple price expression used by Hasselmann et al. Thus, the assumed divergence of the time evolution of the climate damage and mitigation costs can be better justified and presumably enhanced by considering policies promoting induced technological change (ITC) or learning by doing, which decrease the mitigation costs curve relative to average costs, cf. Grubb et al. (1994), Morgan and Dowlatabadi (1996), Grubb (1997), Schneider (1997), Goulder and Schneider (1998).

A more realistic model would need also to distinguish more carefully between costs and welfare or utility, which were used more or less interchangeably in Hasselmann et al. (a decrease in costs corresponding to an increase in welfare) and in the present general discussion. However, it should be noted that, although the objective function that is maximized in cost-benefit analyses is the social welfare, the relevant marginal changes in welfare are expressed in costs. For the global optimization of the many different cost categories associated with climate change, cost units are generally more useful than utility, as they represent a universal, additive measure that can be intertemporally calibrated. In particular, the monetization of ethical values is expressed naturally, as the term implies, in terms of costs rather than utility.

Regardless of how the diverging branches of the relative costs for climate change and mitigation are quantified in a particular model, it is the divergence of the two branches as such that yields optimal emission path solutions of cost-benefit analyses that reflect environmentalist concerns regarding future climate change. It follows that a quantitative cost-benefit analysis of optimal greenhouse gas abatement strategies depends critically on the detailed assessment of the time evolution of the individual contributions to the net climate-change impact and mitigation costs.

This is a difficult task. Reliable predictions of the time evolution of relative costs over the multi-century time horizon relevant for climate change are clearly impossible. However, this should not be taken as a reason for abandoning the cost-benefit approach, but rather as a challenge to properly incorporate the role of uncertainty in cost-benefit analyses (cf. Morgan and Dowlatabadi, 1996; Schneider, 1997; Hasselmann, 1997). A responsible stewardship in climate must be based on an adequate assessment of the future impacts both of climate change and of the efforts to mitigate climate change. Indeed, it is only through the definition of the monetary equivalent of the values society assignes to future climate change that the concept of sustainable development attains an operational meaning. Cost benefit analyses based on improved coupled climate-socioeconomic models including uncertainty therefore represent indispensible tools for developing an effective climate protection strategy in accordance with the principles laid down in the Framework Convention for Climate Change.

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