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TIME PREFERENCE IN GLOBAL WARMING CALCULATIONS: A PROPOSAL FOR A
UNIFIED INDEX

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Abstract

Many aspects of the calculation of the impacts of greenhouse gas emissions and the costs and benefits of possible response options are highly sensitive to the way in which time preference is incorporated into the computations. The Intergovernmental Panel on Climate Change (IPCC) used global warming potentials to standardize inputs of different gases with differing radiative forcings and atmospheric lifetimes; in the results emphasized by the IPCC's Second Assessment Report, a 100-year time horizon and no discounting is used, and this has been adopted by the Kyoto Protocol for use in the first commitment period (2008-2012). Here an alternative unified index is proposed that assigns explicit weights to the interests of different generations. In contrast to discounting (including the zero discount rate used by the IPCC), the generationally weighted index forces policy makers to face the moral assumptions that underlie their choices related to global warming.

Key words: carbon accounting, climate change, global warming, global warming potentials, mitigation, time preference, ton-year accounting

1. Introduction

     Greenhouse gas (GHG) emissions today can be expected to warm
the globe over a period spanning several human generations.
Actions taken today, such as tropical forest clearing, also imply
"committed emissions" that will occur over a long time period,
and response options imply either "committed uptakes" or
emissions reductions that also will occur over long time periods.
 The way that time preference is incorporated into the
calculations, either through discounting or an alternative
scheme, strongly affects the resulting policy conclusions. The
decision as to the relative weight to be given to short-term
versus long-term effects is a policy--rather than a scientific--
question. The choices made can have greater impact on the
overall conclusion of the calculations than the range of
scientific doubt surrounding emissions, uptakes and other
components of the climatic system. These choices affect the
relative advantages of different mitigation options based on
differences in the timing of uptakes and releases of gases, and
based on the atmospheric behavior of the gases that each option
adds to or removes from the atmosphere. Greater weight to
radiative forcing, or the absorption of outgoing radiation (heat)
by the atmosphere, in the relatively near future decreases the
advantage of avoided fossil-fuel emissions over temporary
sequestration of carbon in silvicultural plantations. It also
increases the advantage of avoiding deforestation as compared to
both silvicultural plantations and to avoided fossil fuel
emissions, and decreases the global warming benefits of
hydroelectric, wind, solar and nuclear power supply.

     Discounting, or decreasing the weight given to future real
costs and benefits by a fixed percentage each year, is the
traditional way of incorporating time preference into financial
calculations. "Time preference weighting" refers to the weight in
decision-making that is given to future events at each point in
time. Application of a discount rate achieves a time preference
weighting by adjusting the present value of future events by a
factor based on a simple negative exponential relationship to
time.

     In calculating global warming potentials (GWPs) of
greenhouse gases, or the impact of each gas relative to carbon
dioxide (expressed either by molecule or by weight of gas),
discounting was proposed by Lashof and Ahuja (1990). The
Intergovernmental Panel on Climate Change (IPCC) has instead
adopted a procedure of time horizons, whereby no discounting is
applied over a given period of years, after which no
consideration is given. Calculations in the IPCC reports
(Houghton et al., 1990, 1992, 1996, 2001) are made for 20-, 100-
and 500-year time horizons. This represents what is known as the
"Goldilocks approach," whereby one option is offered that is
obviously too high, one that is obviously too low, and one in the

middle that policy makers will inevitably pick. The executive
summaries of the IPCC reports emphasize the 100-year scenario,
presenting graphical results only for this option. The 100-year
global warming potentials from the Second Assessment Report have
been adopted by the Kyoto Protocol for use in the first
commitment period from 2008 to 2012 (UN-FCCC, 1997).

The time horizon method is easier to explain to politicians
and to the general public than are discount rates. The two
systems are roughly equivalent, in that the weight will be the
same when the area under the curves is equal (Fig. 1). The
equivalence between the length of the time horizon and the annual
discount rate represents the decision-making weight attached to
events that are assumed to be of equal magnitude at each point in
time (Fearnside, nd). However, the magnitude of the climate-
change events themselves are not expected to be constant over
time, including the magnitude of the impacts associated with each
unit of carbon emission (Tol, 1996), a feature that significantly
affects mitigation decisions (Richards, 1997).

(Figure 1 here)

Considering the equivalence between discount rate and time
horizon as in Figure 1, the 5% annual discount rate that has been
used by the US Environmental Protection Agency (Lashof and Ahuja,
1990) is roughly equivalent to a 30-year time horizon that has
been used by the World Bank (Arrhenius and Waltz, 1990). The
100-year cutoff emphasized by the IPCC is equivalent to a 0.9%
annual discount rate.

The approach of separate calculations, such as the 20-, 100-
and 500-year GWP calculations of the IPCC, inevitably leads to
one of the options being chosen. The concerns embodied in the
other calculations, although mentioned in passing in the text of
the reports, do not enter into decision-making in the end. What
is needed is a single index that combines the various concerns
with short- and long-range impacts in a way that reflects the
value judgments of society. These value judgments will thus be
made explicitly rather than being hidden in the calculation.

Both cutoff times and discount rates affect one of the two
ends of the distribution in ways that may not reflect the values
that decision makers intend to guide their choices on global
warming. If a long cutoff time is used--say 500 years--the
weight attached to short-term impacts becomes almost nothing. If
a discount rate is used to represent long-term concerns, the
weight given to events far in the future (reflected in the area
under the curve, as in Fig. 1, curve b) becomes very little after
only a few decades, even with a discount rate as low as one
percent annually.

2. Purposes and effects of time-preference weighting

It is important that impacts of global warming be assessed together with the evaluation of costs of reducing emissions, as the current concentration of most effort on estimating costs of responses implicitly leads to the conclusion that responses are expenses--when, in fact, they may be very cheap as compared to the costs of inaction. Time-preference weighting has a great effect on mitigation decisions, as responses to global warming generally require investments on the short term in order to avoid impacts that will only appear years in the future.

Discounting or other forms of time-preference weighting can be done for a variety of purposes, with unique considerations applying to each. Best known is the dichotomy between financial decisions by individuals and societal decisions on policies involving the interests of both the entire present population and future generations. The high discount rates used in financial decisions frequently lead to perverse decisions that destroy potentially sustainable systems, such as tropical forest management for timber (e.g., Clark, 1976; Fearnside, 1989).

The idea of discounting losses of "natural capital," such as natural ecosystems, is to be rejected in principle (Daly and Cobb, 1989). Irreversible losses such as these cannot be adequately adjusted for by lowering the discount rate, and are better handled through intergenerational transfers (Howarth and Norgaard, 1993), such as preserving large areas of tropical forests (Crowards, 1997).

Global warming has unique features that distinguish it from many other kinds of environmental impacts, and virtually all environmental impacts involve losses not well represented by money. In the view of this author it is inappropriate to use the same discount rate for calculations of money and for carbon. However, some have argued that the same discount rate should be used for carbon as for money (van Kooten et al., 1997), while others have argued that pure rate of time preference component of the discount rate should be zero (e.g., Cline, 1992). Another view is that a two-step procedure should be used, discounting short-term (<30 year) effects using a social discount rate based on financial behavior, and discounting long-term (>30 year) effects at an expected rate of real economic "growth" of 2-3% per year (Rabl, 1996). Weitzman (1998) presents the same novel theoretical argument for a variable discount rate over time. Problems with using non-market discount rates have been reviewed by Horowitz (1996), who favors explicitly assigning "prices" (values) to future environmental goods and then discounting these to the present at market discount rates.

Two broad categories of discount rates exist: those based on the opportunity cost of capital and those based on the social rate of time preference. Social rate of time preference is

calculated from components representing the pure rate of time preference and the expectation that one will be richer (or poorer) in the future and so will attach a different marginal utility to wealth, more wealthy people attaching lower importance to the loss or gain of a unit of wealth. The pure rate of time preference is that which is based solely on an event's position in time irrespective of how wealthy we expect to be. Weighting by the pure rate of time preference is also called "time discounting," while weighting by the utility of expected future wealth is called "growth discounting" (Azar and Sterner, 1996).

The pure rate of time preference is often described as being based on the "impatience" of individuals, mainly because of their own mortality. However, whole societies are quasi-immortal (Daly and Cobb, 1989) and cannot be described as "impatient," thus providing a rationale for using a zero or very low pure rate of time preference for climate change issues (Azar and Sterner, 1996). This is the principal reason for the present value of global warming monetary impacts being estimated by Azar and Sterner (1996) at 50-100 times higher per ton of carbon emission than the values calculated by Nordhaus (1993) using his Dynamic Integrated Model of Climate and the Economy (DICE) and a 3% pure rate of time preference. The pure rate of time preference is the parameter to which DICE is most sensitive in identifying optimal responses to global warming (Nordhaus, 1997).

Assumptions are critical regarding the relationship between wealth and utility and the expected level of future wealth. The utility of a given amount of money is generally assumed to decrease as one becomes wealthier. The finite nature of the Earth's resources invalidates the common assumption that per capita consumption of physical resources can continually increase--a realization that results in a significantly lower value for social rate of time preference for long-term discounting and greatly increases the present value of damages from expected climate change (Azar and Sterner, 1996).

The time-preference weighting mechanism proposed in the present paper is designed for a specific purpose—adjustment of global warming calculations to better reflect the interests of society. While it might be adapted for other purposes, its appropriateness would depend on the characteristics of each.

3. Rationale for time-preference weighting

One of the greatest questions in addressing the problem of time preference in global warming is dealing with impacts on human life. It should never be forgotten that the impacts of global warming at the levels predicted by such scenarios as the 1-3.5°C average global temperature rise by the year 2100 presented by the IPCC in its Second Assessment Report (Houghton et al., 1996, p. 6) translate into millions of human deaths

(e.g., Daily and Ehrlich, 1990). The IPCC's Second Assessment Report (Pearce et al., 1996, pp. 197 and 218) uses Fankhauser's (1995) estimates for a jump to double the pre-industrial CO_2 concentration with the world (including its population size) as it was in 1990, the result would be a loss of US\$ 221 billion (in 1990 prices) annually, exclusive of human life losses, plus loss of 138,000 lives per year (115,000 of which would be in non-OECD countries). A separate means of dealing with human life impacts is needed (Fearnside, 1998). The IPCC's Third Assessment Report increases the estimated warming by 2100, especially at the high end, to 1.4-5.8°C (Houghton et al., 2001).

The impacts on human life represent a moral justification for assigning a value to time. This justification is independent of the selfish interests of the current generation. Delaying global warming impacts has a value because global warming does not represent a one-time catastrophe, like a volcanic eruption. Rather, increasing global temperature by a given amount increases the probability of floods, droughts and other "natural" sources of impacts on human populations from that point onwards. If mitigation efforts can delay, say by ten years, the date at which we reach any given global-warming milestone (such as the doubling of pre-industrial CO_2 levels that would occur in approximately 2070 in a "business as usual" scenario: Schimel et al., 1996, p. 83), then all loss of life and other impacts that would have been sustained during that ten-year period must be considered to be a permanent gain. Giving a value to time requires discounting or some other time-preference weighting arrangement.

Much of the debate on discounting of environmental impacts has been couched in terms of "how individuals trade off current for future consumption" (e.g., Arrow et al., 1996). However, in the case of global warming, more than "consumption" is at stake, as decisions on time preference determine who lives and who dies. In addition to the effect of losses cascading forward, including losses of human life (creating a permanent value for delay), financial losses in the future are valued less than those today because of what can be done with the money in the interim (e.g., Lyon, 1996). However, even in the case of monetary impacts, it has been argued that one cannot use money earned now to "compensate" future generations for greater damages later (Spash, 1994). On the other hand, some argue that such investments as building hospitals and doing research on AIDs provide something partly akin to compensation.

A distinction between the discounting of money and discounting the utility that money represents is critical. The usual assumption of a constant discount rate for utility need not be made: reducing the discount rate over time better reflects the views of many who have considered the question of intertemporal fairness (Heal, 1997). However, the use of discount rates, whether constant or variable, is not the best way to achieve

specific objectives related to maintaining climate and other environmental goals. Decision-making based on viewing the present generation as a trustee or steward of the interests of future generations (Scott, 1999), as in the case of decisions on creation of national parks, can be more effective (Brown, 1997; Nordhaus, 1997).

It is important to realize that there is no option for avoiding a choice on time preference. A zero rate of discount is just as much a choice as any other discount rate or equivalent time-weighting arrangement. I propose that an explicit choice be made between the weight to be attached to short- and long-term concerns (or to present and future generations), and that this be combined into a single index. A generationally weighted index is derived later in Section 6.

4. Global warming potentials and tropical deforestation

The impact of tropical deforestation is understated by the IPCC through its treatment of GWPs. Deforestation releases trace gases such as methane (CH_4), carbon monoxide (CO) and nitrous oxide (N_2O) in greater proportions relative to CO_2 than does the burning of fossil fuels (Fearnside, 2000). For short-lived gases like CH_4 and CO, time preference may make a substantial difference. Discounting or other forms of time-preference weighting would increase the weight given to tropical deforestation, thereby adding to already strong indications that priority should be given to deforestation avoidance as a global warming mitigation strategy (Fearnside, 1995).

The impact of trace gases is not fully reflected in the GWPs (the global warming impact of a ton of gas relative to a ton of CO_2) for three major reasons. First, the indirect effects (effects other than absorption of outgoing infrared radiation by the gases themselves) have been only partially included in the calculations. In the 1990 IPCC report (Shine et al., 1990, p. 60), numerical values were presented for indirect effects, although they were left out of the calculations of global warming. In the 1992 supplementary report (Isaksen et al., 1992, p. 56), numerical estimates of indirect effects were dropped completely, and only the sign of the effect was indicated. Even for methane, where a major effect through the hydroxyl radical (OH) was recognized as having a probable magnitude equal to the direct effect, no indirect effect was included--not even the small and obviously certain effect of the CO_2 molecule that will be formed when the CH_4 is later oxidized.

The IPCC's Second Assessment Report or SAR (Houghton et al., 1996) recognizes the indirect global warming impact of CH_4 through production of tropospheric ozone and stratospheric water vapor. CO, however, has a GWP of zero assumed in the Second Assessment Report. CO has no direct impact on radiative forcing,

but it removes hydroxyl radicals from the atmosphere, thereby slowing the natural removal of CH_4 and lengthening the atmospheric lifetime of this potent greenhouse gas (Schimel et al., 1996). Each molecule of CO is oxidized to a molecule of CO_2 after only three months, on average, and even this source of impact is not currently recognized. Counting the CO_2 generated from CO would give CO a GWP of 1.57. CO also makes a contribution to tropospheric ozone, giving an additional GWP of 1 to CO on a mass basis (Shine et al., 1990, p. 60). Inclusion of the OH-removal effect would increase the weight given to CO much more: if one assumes that each molecule of CO leads to a molecule of CH_4 not being removed from the atmosphere (an upper bound for the effect, but probably not far off), then the GWP of CO from hydroxyl radical removal is 21 × (16/28) = 12 on a mass basis. Ignoring ozone effects (to avoid any double counting), the total GWP of CO would therefore be 1.57 + 12 = 13.57. Since the calculated impact of the methane that remains in the atmosphere as an indirect result of CO emission from tropical deforestation is highly sensitive to time preference, the impact of deforestation could change tremendously depending on the choices made.

The second major assumption that leads to underestimating the effect of trace gases emitted by deforestation is the future composition of the atmosphere. The GWPs used by the IPCC all assume that the atmosphere will remain indefinitely at its present chemical composition (Albritton et al., 1995, p. 214). The concentrations of different gases in the atmosphere will continue to change, leading to an increase in the impact of all non-CO_2 gases (Isaksen et al., 1992, p. 56). This effect would increase the GWPs of trace gases by 19-32% for a 100-year time horizon, depending on the carbon dioxide emission scenario chosen (Wuebbles et al., 1995). Greater emissions of CO_2 enhance the rate at which CO_2 is removed from the atmosphere to sinks in the ocean and in the terrestrial biosphere, thereby decreasing the integrated radiative forcing of CO_2 and increasing the impact of trace gases relative to the CO_2 standard on which GWPs are based.

The third way that trace gas impacts are minimized is in the choice of a time horizon for the calculation. Short-lived gases such as methane have a major impact in the near term, but this diminishes rapidly in the longer term calculations such as the 100-year horizon emphasized by IPCC. A ton of methane is 21 times more potent in provoking global warming than a ton of CO_2 in the 100-year calculation, but 56 times more potent in the 20-year calculation (Schimel et al., 1996, p. 121). The 100-year time horizon with no discounting that is the preferred option of the IPCC is probably a poor solution for expressing a balance between short- and long-term concerns reflecting the values of society. For a variety of reasons, both selfish and not, most people care much more about what will happen in the next year than what will happen in any given year up to a century in the

future. By giving them the same weight, the IPCC understates the importance of processes like tropical deforestation that release potent but short-lived gases. One result of this is to understate the global warming benefit of slowing deforestation as compared, for example, to planting trees or reducing fossil fuel combustion.

5. Carbon sequestration

What different people mean by "sequestering carbon" varies tremendously--from simply fixing it (even if only for an instant) to holding it locked up for all eternity. The most logical solution to the problem of definition would be to make the criterion for "sequestration" consistent with the time horizon and/or discounting scheme used to reflect time preference in other aspects of global warming, such as the calculation of GWPs for the various greenhouse gases.

The Global Environment Facility (GEF), currently charged with distributing international funds for combating global warming, does not apply any discounting to physical quantities, such as tons of carbon. I suggest that the discounting or other time-preference weighting procedures applied need to be made consistent between the calculation of GWPs, the weight of physical benefits such as carbon, and the monetary costs and returns of response options from the point of view of international efforts to combat global warming.

6. A unified index for time preference

It is useful to examine an example of an alternative to the discounting mechanism of assigning weight to future events. For concreteness, the example that follows uses one set of parameters to distribute decision-making weight among generations. Alternative results could be obtained by assuming different weights for each generation, by considering a different number of generations, or by using demographic parameters to represent age distribution and overlapping generations or cohorts. If considered appropriate, projections of population growth could be added. The example presented here is therefore just one among many possibilities, but serves to illustrate the method's ability to make the component moral choices explicit and understandable.

In this example, an index is constructed based on the following assumptions: present-day adults have an average age of 40 years; the average child is born to parents 25 years of age; life expectancy of all generations is 75 years. Only four generations will be considered: present-day adults and their children, grandchildren and great-grandchildren.

In this example a weight of 40% is given to the present generation, 35% to the children of present-day adults, 15% to

grandchildren and 10% to great-grandchildren (Fig. 2). No
discounting is done over the lifetime of each generation. A
possible improvement would be to distribute the weight for each
generation's allocation over the lifespan of that generation
based on actuarial statistics, so that the relatively small
number of old people who reach the age of 75 do not receive the
same weight as the larger number of people alive during the
earlier years.

(Figure 2 here)

The weight given to each generation can be represented by a
rectangle (Fig. 3a), the area of each rectangle being equal to
the relative weight. The height of each rectangle is therefore
equal to the area (the percent weight assigned to the generation
from Fig. 2) divided by the number of years from the present to
the end of the generation in the case of already existing
generations (adults and children) and from the beginning to the
end of the generation in the case of future generations
(grandchildren and great-grandchildren). The height of each
rectangle is then summed with the others over the year ranges for
which the rectangles overlap. These totals can be represented in
a histogram, with the units for the ordinate standardized to
consider the value at present as 1.0 (Fig. 3b).

(Figure 3 here)

The area under the curve with the relative weights assumed
here is approximately equal to that obtained with a 1% annual
discount rate (the equivalent area is attained at a 1.24% annual
discount rate). If one ignores the effect of the decay of CO_2 in
the atmosphere, avoiding an emission of one ton of carbon now
would result in 100 ton-years of carbon "credit" over a century
(Fig. 4a), whereas if a 1% annual discount rate were applied it
would represent 57 carbon ton-years of credit (Fig. 4b), and the
equivalent figure for the generation-weighted time preference
example is 58 carbon ton-years over the same period (Fig. 4c).

(Figure 4 here)

The decay of atmospheric carbon stocks as carbon is
transferred to the oceans and the terrestrial biosphere creates a
value for time that is independent of time preference. This is
because temporary removal of carbon from the atmosphere, for
example by sequestration in a silvicultural plantation, reduces
global warming by an amount that depends on the amount of
additional heat that would have been trapped by the atmosphere
had the carbon been emitted instead of having been sequestered.
This amount depends on the natural removal rate of additional
increments of carbon given the atmosphere's current composition.
 This value can be expressed through ton-year accounting, where
the impact of an emission is represented by the integral under

the carbon-decay curve up to the time horizon. Holding one ton
of carbon out of the atmosphere for 100 years has a value of 46
ton-years (Fig. 4d), considering the revised Bern model used in
the IPCC's Second Assessment Report, or 55 ton-years considering
the earlier Bern model used in the 1990 IPCC report (see
Fearnside et al., 2000). Discounting or other weighting for time
preference is an adjunct to ton-year accounting. A 1% annual
discount rate for time preference combined with the revised Bern
model decay path results in a value of 32 ton-years over a
century, or 68% of the value without discounting (Fig. 4e), while
the generation-weighted time-preference mechanism proposed by
this author with the sample parameters in the example given above
results in a value of 31 ton-years, or 67% of the value with no
time preference (Fig. 4f).

The shape of the curve for generation-weighted time
preference is significantly different from the discounting curve
in two ways: (1) the weight given to the last part of the curve,
although much less than for the earlier years, does not decline
to virtually zero, and (2) the peak is not at the immediate
present, but rather about ten years in the future. The
displacement of the peak is important, in that many response
options that require immediate investments to receive returns a
few years in the future will be favored more than they would be
by discounting.

7. Decision-making on time preference

Time preference has a dramatic effect on sequestration costs
and plantation benefits (see Fearnside, 1995 for examples). It
can also affect choices of energy sources, such as that between
hydroelectric power (which has high short-term emissions) versus
thermoelectric generation from fossil fuels (Fearnside, 1997).
The example of generation-weighted time preference given above
reflects the personal preferences of the author (an adult with
two small children, all, hopefully, with life expectancies
characteristic of developed countries). The scheme adopted, and
the weights assigned to each generation in applying the scheme,
should be decided upon democratically after extended public
debate. Public involvement is essential to ensure that societal
values are accurately represented, and would still be essential
even if technocrats were capable of assessing public preferences
without error. For example, discount rates derived from
financial market data are based on the subjective preferences of
those with financial assets—hardly majority rule or one-person-
one-vote. Public discussion helps ensure that later, when
taxpayers must bear the cost of global warming responses, such
expenses will not be viewed as unwanted burdens mandated by
government bureaucrats. Combating global warming is in our own
self-interest as a means of maintaining a livable world for
ourselves and our descendants.

8. Conclusions

   1. The means of expressing time preference needs to be made consistent for assessing global warming impacts and the benefits of response options.

   2. The 100-year time horizon without discounting currently used by the IPCC for global warming potentials that have been adopted by the Kyoto Protocol for the first (2008-2012) commitment period is a poor reflection of the time-preference perspectives of society.

   3. A generation-weighted index allows flexibility in allocating concern to the short-term versus the long-term. The form of the curve is likely to differ from the simple decay assumed in discounting, the peak of greatest weight being displaced several years into the future. Greater weight is likely to be given to long-term concerns than would be using discounting, but less weight is given than under the IPCC's 100-year no-discounting scheme for global warming potentials.

   4. Use of a generation-weighted index would force decision-makers and the public to examine the moral choices underlying their decisions. The public debate needed to arrive at a societal decision on time preference could help increase willingness to bear the cost of taking effective steps to combat global warming.

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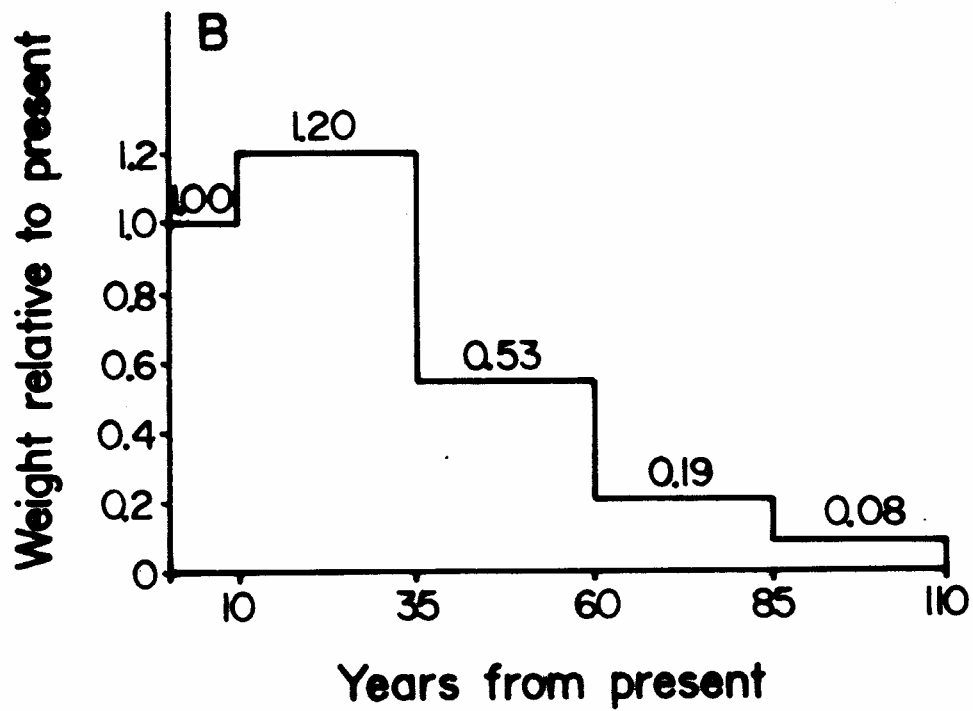UN-FCCC (United Nations Framework Convention on Climate Change), 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change, Document FCCC/CP/1997;7/Add1. Available at http://www.unfccc.de.
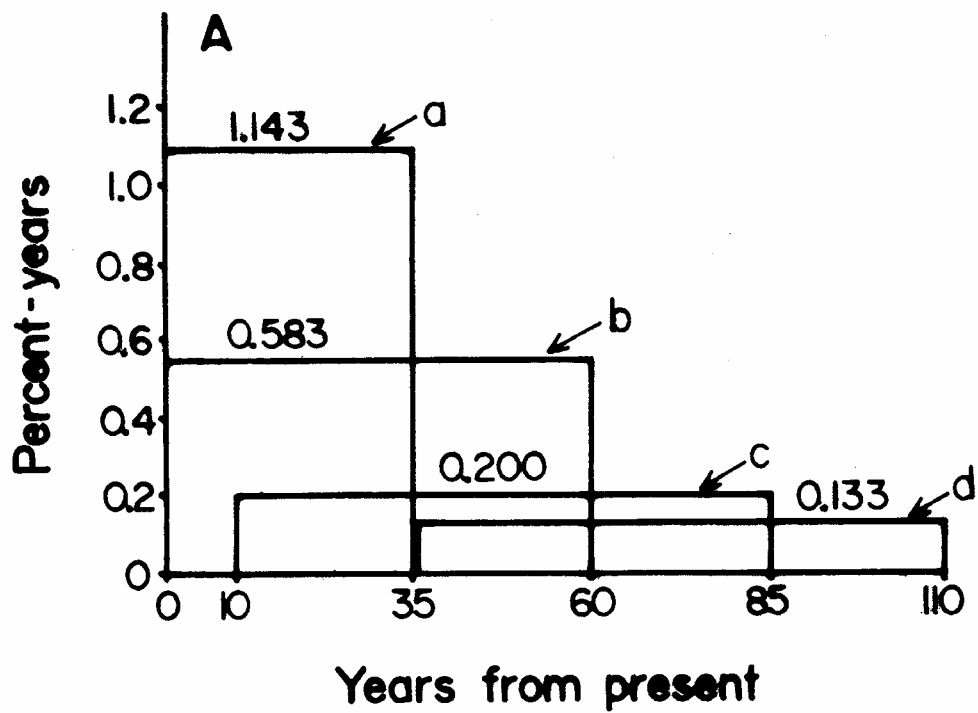
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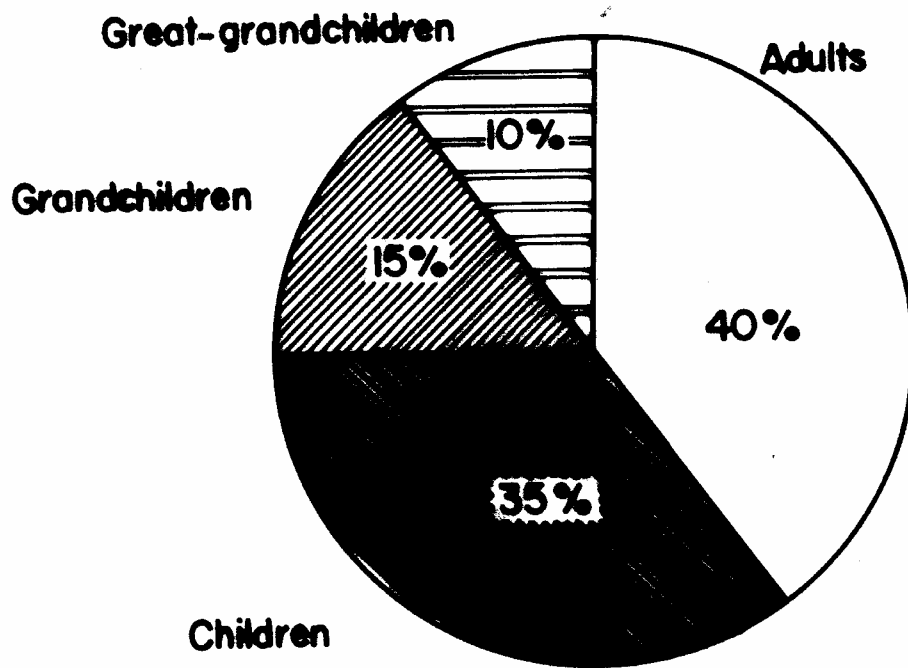
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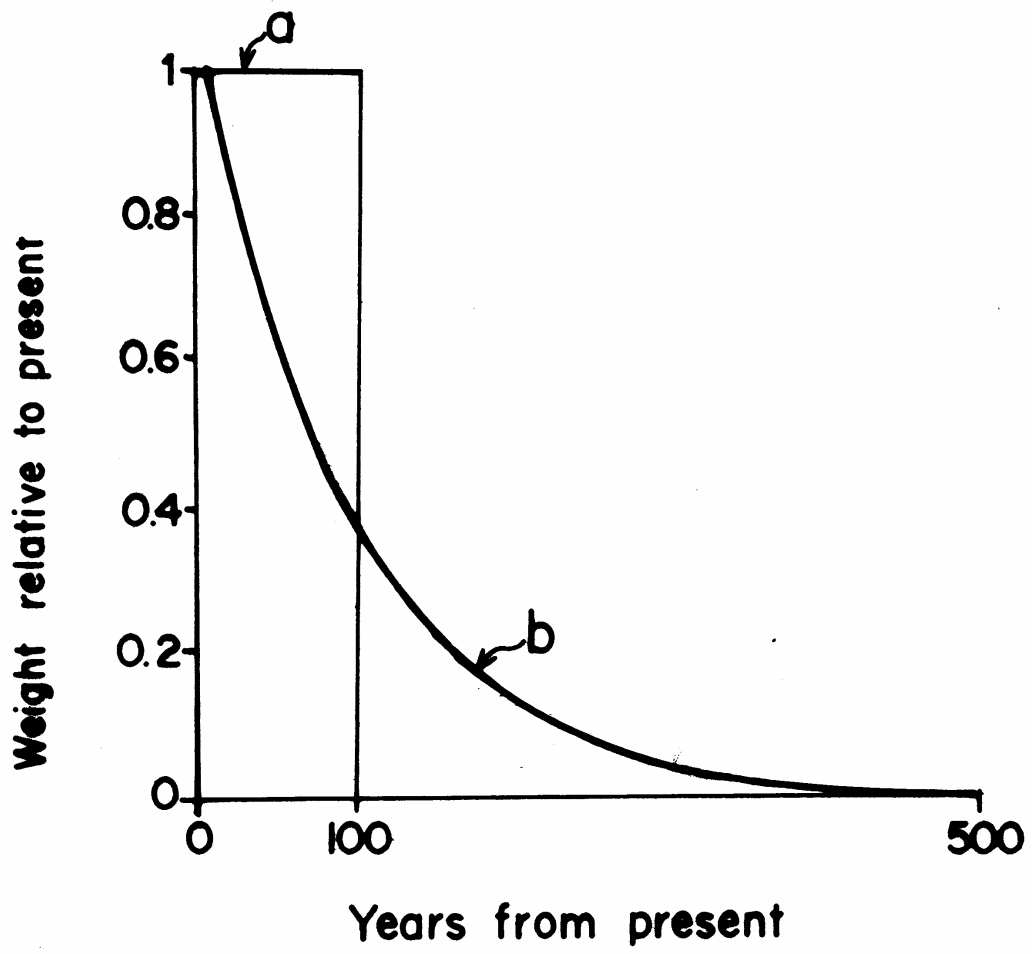
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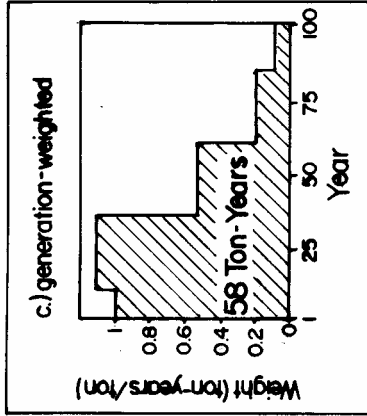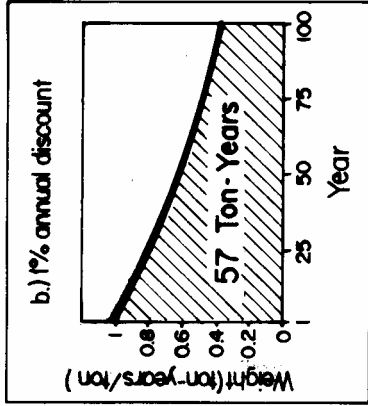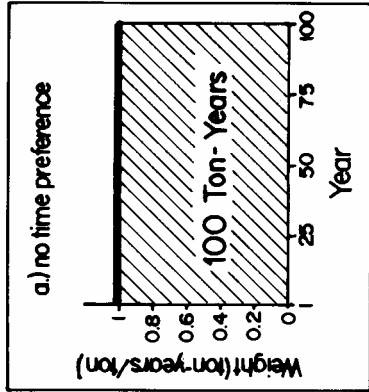
Figure captions

Fig. 1.   Discounting and time-horizon methods of accounting for time preference. The area under the time curve with 0.9% annual discount rate (b) is equal to that under the 100-year time horizon with no discounting (a) adopted by the IPCC and the Kyoto Protocol for global warming potentials.

Fig. 2.   Weight given to each generation in the sample calculation of generation-weighted time preference.

Fig. 3.   a) Time-preference rectangles used in the sample calculation of time preference.

          b) Generation-weighted time-preference weighting over time in the sample calculation of time preference.

Fig. 4.   a) Weight given to one ton of C emission assuming no natural removal from the atmosphere and no time preference.

          b) Weight assuming no natural removal from the atmosphere and 1% annual discount.

          c) Weight assuming no natural removal from the atmosphere and the sample generation-weighted time preference.

          d) Weight assuming natural removal used by the SAR (revised Bern model) and no time preference.

          e) Weight assuming natural removal used by the SAR and 1% annual discount.

          f) Weight assuming natural removal used by the SAR and the sample generation-weighted time preference.

WITHOUT DECAY OF ATMOSPHERIC CARBON

a.) no time preference

Weight (ton-years/ton)

100 Ton-Years

Year

b.) 1% annual discount

Weight (ton-years/ton)

57 Ton-Years

Year

c.) generation-weighted

Weight (ton-years/ton)

58 Ton-Years

Year

WITH DECAY OF ATMOSPHERIC CARBON

d.) no time preference

Weight (ton-years/ton)

46 Ton-Years

Year

e.) 1% annual discount

Weight (ton-years/ton)

32 Ton-Years

Year

f.) generation-weighted

Weight (ton-years/ton)

31 Ton-Years

Year