WPS 1417

POLICY RESEARCH WORKING PAPER

1417

Uncertainty and Global Warming

An Option-Pricing Approach to Policy

Andrea Baranzini
Marc Chesney
Jacques Morisset

How does uncertainty about the extent of global warming affect decisionmaking to reduce it? Which policy options to choose and how long to delay implementing them?

The World Bank
Latin America and the Caribbean, Country Department I
Country Operations Division
February 1995

Summary findings

Uncertainty is inherent in the analysis of global warming issues. Not only is there considerable scientific uncertainty about the magnitude of global warming, but even if that problem were resolved, there is uncertainty about what monetary value to assign to the costs and benefits of various policies to reduce global warming.

And yet the influence of uncertainty in policymakers' decisions is ignored in most studies of the issue.

Baranzini, Chesney, and Morisset try to explicitly incorporate the effect of uncertainty on the choice of global warming abatement policies. The approach they develop draws on the emerging literature on investment under uncertainty — in particular, that on the option-valuation approach.

Their numerical applications focus on Cline's (1992) analysis of global warming, but it may be applied to a range of global warming analyses.

First, they assess whether it is optimal to implement Cline's strategy of limiting global warming today, or whether it should be postponed, and for how long.

Then, they identify the optimal policy to be implemented today for different levels of uncertainty about the costs and benefits of policies to reduce global warming.

This paper — a product of the Country Operations Division, Latin America and the Caribbean, Country Department I — is part of a larger effort in the region to understand the role of uncertainty in environmental policy issues. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Celinda Dell, room Q7-106, extension 85148 (30 pages). February 1995.

Produced by the Policy Research Dissemination Center

Uncertainty and Global Warming

An Option-Pricing Approach to Policy[1]

Andrea Baranzini[a]
Marc Chesney[b]
Jacques Morisset[c]

a. University of Geneva, Department of Economics, 102 bd Carl-Vogt, CH-1211 Genève 4, Switzerland
b. Department of Finance, HEC-ISA Centre, F-78350 Jouy-en-Josas, France
c. World Bank, 1818 H Street NW, Washington, DC 20433, USA

---

[1] We would like to thank Antonio Estache and Danny Leipziger for helpful comments and William Cline for providing us data on the costs and benefits of global warming.

UNCERTAINTY AND GLOBAL WARMING

TABLE OF CONTENTS

SUMMARY

Uncertainty is an inherent phenomena in global warmning issues. First, there is considerable scientific uncertainty around the magnitude of global warming, and second, even if this problem was resolved, it remains difficult to measure in monetary terms the benefits and the costs associated with the policies aimed at reducing global warming. Although uncertainty affects the policy-makers' decision to reduce (or not) global warming, such an influence is ignored in most existing studies.

The aim of this paper is to explicitly incorporate the effect of uncertainty on the choice of global warming abatement policies. The approach developed in this paper is related to the emerging literature on investment under uncertainty, and in particular to the option-valuation approach. Our numerical applications will focus on Cline's (1992) analysis of global warming, but our approach may be applied to a wide range of global warming analyses presented in the literature. We are able to obtain two kind of results. First, we assess whether it is optimal to implement a given strategy of limiting global warming today or whether it should be postponed, and for how long. Second, we identify the optimal policy to be implemented today, for different levels of uncertainty around the costs and benefits of limiting global warming.

1 Introduction

Global warming has received considerable attention in the last few years, yet few concrete actions have taken place. Recently, Cline (1992) and Nordhaus (1993) have shown that, from an economic perspective, the resulting recommendations greatly depend on some key issues. First, it is necessary to evaluate the costs and benefits of limiting global warming. Second, these benefits and costs should be evaluated in a reference period and discounted accordingly. Third, one should consider uncertainties about evolving scientific knowledge and economic environment.

This paper focuses on the issue of uncertainty. In the context of global warming uncertainty affects the decision-making through two kinds of irreversibilities, that work in opposite directions. First, uncertainty, as already pointed in the seminal work by Weisbrod (1964), Arrow and Fisher (1974) and Henry (1974), delays the decision on an irreversible action if the passage of time is likely to bring significant new information. This is particularly true for global warming, in which the political and economic repercussions of abandoning policy actions once they are well under way are so high as to make abandonment impracticable. Second, uncertainty biases the traditional cost-benefit analysis against policy adoption. It may be desirable to adopt a policy now, even though the traditional analysis declares it uneconomical, because greenhouse gases possess long lifetime, increasing the level of irreversible damages compared to that if the action was taken from the start.

The approach developed in this paper will be related to the emerging literature on investment decision under uncertainty, in particular to the option-valuation approach. In this paper, we will obtain two kinds of results. First, we will assess whether it is optimal to implement a given strategy of limiting global warming today or whether it should be postponed, and for how long. Second, we will identify the optimal policy to be implemented today, for different levels of uncertainty around the costs and benefits of limiting global warming.

The option pricing approach developed in this paper can be applied to a wide range of global warming projections presented in the literature, but our numerical applications will focus on the recent aggressive policy proposed by Cline (1992). The impact of changes in uncertainty on the optimal date of intervention of this proposal will be closely examined throughout the paper. In the face of uncertainty, the optimal strategy could be to wait, or, eventually, to proceed with a less aggressive policy. Cline's proposal is to limit the level of CO_2 emission to 4 GtC annually, but a ceiling of 5.5-6.5 GtC --about the existing level in 1990-- seems more appropriate for a level of uncertainty ranging around 8-10 percent annually. This results, we believe, have high policy content and are in line with European Union's recent proposals.

The paper proceeds as follows. In section 2 we review the basic theory of the option pricing model. Section 3 introduces Cline's cost-benefit analysis and integrates the option pricing model in this approach. Section 4 concludes and presents some qualifications.

2 The Option-Pricing Model

The economically optimal decision to invest depends on the benefits and costs associated with a given project or policy proposal. Typically, the discounted benefits (V) and costs (F) of reducing global warming are expressed as follows:

$$V = \sum_{t=0}^{T} \frac{B_t}{(1 + r)^t} \qquad (1)$$

$$F = \sum_{t=0}^{T} \frac{C_t}{(1 + r)^t} \qquad (2)$$

where r is the appropriate discount rate, and T the time horizon. The discounted costs are the monetary costs of abatement policies, while discounted benefits are the level of damage avoidance --the difference between the cost of global warming in the absence of intervention and the costs of global warming which can not be avoided because greenhouse gases possess many years of life once they are emitted.

In conventional models, a policy will be implemented when discounted benefits are greater than discounted costs ($V/F > 1$). Although this approach is typically applied in the global warming context, it suffers from two major shortcomings. First, it does not account for the uncertainty surrounding the costs and benefits of limiting global warming. One way around has been to calculate different scenarios and assign probabilities, but only a few number of outcomes can be considered. Second, it does not consider the possibility of waiting to take advantage of better information. As discussed in the introduction, the decision to invest can be considered as irreversible because it requires initial investments on the order of hundreds of billions of dollars a year (see Cline (1992) for some detailed figures). Therefore, the policy-makers have strong incentives to wait in order to acquire additional information and thus the decision to wait has a value. The question is how to derive the value (or the price) to wait and to determine the optimal time of intervention.

The financial literature provides useful tools to calculate the price of waiting and the critical threshold ratio of benefits to costs which renders the policy efficient.

Indeed, an irreversible investment is similar to a financial call option where in exercising the decision to invest, the policy-maker forgoes the potential gains of postponing the decision. We use the model developed by Samuelson (1965) and McDonald and Siegel (1986) and known as the perpetual option model, also called: the option to wait to invest.

The benefit to cost ratio is defined as Y = V/F. The critical level at which it becomes optimal to implement the policy is Y^{*}, which is greater than 1 because of the value to wait to invest. For simplicity, we assume that Y follows a geometric Brownian process:

$$\frac{dY}{Y} = \mu dt + \sigma dz \tag{3}$$

where μ is the drift of the process, σ its volatility, and z a Brownian motion.

We assume that the drift and the volatility are constant over time. In our numerical simulations, the first variable will be determined by Cline's analysis, while the second one will be defined exogenously. One major caveat is that disasters cannot be analyzed because this stochastic process assumes that the benefit/cost ratio is continuous (on this topic, see Drepper and Mansson (1993)).

Assuming a perpetual and american option, McDonald and Siegel (1986), following Samuelson (1965), have demonstrated that the option value (W) at time u can be written as[2]:

---

[2] W is the discounted expected pay-off in a risk-adjusted economy. In equation (4), $(Y^{*}-1)F$ is equivalent to the pay-off of early exercise. $(VY^{*}/F)^{\gamma}$ is an expected discount factor.

$$W_u = (Y^* - 1)F(\frac{V}{F}Y^*)^\tau \qquad if\ \frac{V}{F} < Y^* \tag{4}$$

with

$$\tau = (0.5 - \frac{(r_F - r_V)}{\sigma^2}) + \sqrt{(\frac{(r_F - r_V)}{\sigma^2} - 0.5)^2 + 2\frac{r_F}{\sigma^2}} \tag{5}$$

$$Y^* = \frac{\tau}{(\tau - 1)} \tag{6}$$

$$\sigma^2 = \sigma^2_V + \sigma^2_F - 2\theta_{VF}\sigma_V\sigma_F \tag{7}$$

where $r_V = (r - G_V)$ and $r_F = (r - G_F)$ denote the effective discount rates, G_V the growth rate of benefits, G_F the growth rate of costs, σ_V and σ_F the standard deviations of benefits and costs respectively, σ^2 the total variance associated with the variable Y, and Θ_{VF} the correlation coefficient[3].

The investment decision is optimal when the benefit to cost ratio is greater than the critical ratio ($Y > Y^*$) as the value to invest in the future is lower or equal than that of investing today ($W \leq F - V$). Yet the value of the option to wait to invest could be large enough to invalidate the usual decision rule, to invest when benefits exceed costs. In effect, the correct decision rule under such circumstances should be to invest when benefits exceed the costs by an amount at least equal to the value of the lost (foregone) option.

The influence of (exogenous) uncertainty is explicitly taken into account in the decision making process. Overall, an increase in uncertainty (σ^2) augments the value

---

[3] Here the risk premium is assumed to be zero.

to invest in the future as compared with that of investing today; ($dW/d\sigma^2 > 0$).[4] If uncertainty is higher, the value of waiting to receive more information is indeed higher and the required flexibility premium should be higher too. In the numerical application, we will see that the investment decision is very sensitive to the estimate or perception of the underlying uncertainty. One caveat is in order at this point. The uncertainty is assumed to be exogenous, but it can be influenced by the damages from global warming and the degree of policy intervention --uncertainty may increase (or alternatively decrease) with the level of cumulative emission from the use of fossil fuel.[5]

As discussed in the introduction, not only is the optimal investment timing influenced by the possibility of waiting for better information, but also by the evolution of irreversible damages during the waiting period. Two basic assumptions can be tested in the model. First, it can be assumed that irreversible damages would remain constant, whatever is the starting date of intervention. The advantage is that the expected time when the investment will take place can be directly deduced from the option-pricing approach:[6]

$$\begin{aligned} E(T) &= \frac{\ln(Y^* F/V)}{G_V - G_F} \qquad && \text{if } G_V - G_F > 0 \quad \text{and } \frac{V}{F} < Y^* \\ E(T) &= 0 && \text{if } G_V - G_F > 0 \quad \text{and } \frac{V}{F} > Y^* \end{aligned} \tag{8}$$

Second, it is certainly more realistic to assume that the level of irreversible damages is correlated positively with the length of the waiting period. Postponing the intervention will therefore translate into a higher level of CO_2 emission which, in turn,

---

[4] Note that this is not always true for the individual standards deviations, since the total effective standard deviation is a quadratic function of the two standard deviations and the correlation, see the Appendix.

[5] On this issue, see the recent paper by Chichilnisky and Heal (1993).

[6] For a proof see World Bank (1991).

will increase the temperature and irreversible damages, shortening the waiting period in comparison to that suggested by equation (8). In that case, we will determine the optimal timing by simulating the Cline's proposal with different dates of intervention, starting from 1990 (as proposed by Cline). The optimal timing will be determined by the first date when the benefit to cost ratio is greater than the critical ratio ($Y > Y^*$). This exercise will be done in the next section.

In short, the model can thus be used (i) to determine if governments should intervene to reduce global warming; (ii) to examine the influence of uncertainty on the process; (iii) to determine the optimal date of intervention; and (iv) to identify the optimal level of CO_2 cutback to be implemented today.

3 An Application

The objective of this section is to apply the option-pricing model developed in the preceding section. In order to proceed with application we need two types of data:

- The estimated costs and benefits associated to the abatement in global warming, as well as the relevant discount rate. This data will be extracted from Cline's analysis.

- Variables relevant to the option model, such as quantitative measures for the underlying uncertainty (on costs and benefits), specifically the standard deviation of uncertain variables and the correlation between these variables.

3.1 The Baseline Scenario

The analysis presented by Cline (1992) is certainly the most thorough study of climate change and, therefore, it will be used as a reference for our baseline scenario in the absence of uncertainty. However, it is worth underscoring that two aspects from the original model have been modified: First, the expected increase in temperature from global warming will be explicitly linked to the CO_2 emission rather than to be determined by a linear approximation between the long-term global warming and the current level of temperature. Second, the ratio of unavoidable damages to total damages in the absence of intervention will not be fixed during the entire period, but it will vary over time in response to the variations in the stock of CO_2.

Expected Costs

In the recent literature, the cost of abatement policies are generally determined by: (i) afforestation or diminishing deforestation; (ii) energy substitution --non-fossil fuel for fossil fuel energies; (iii) non-energy inputs substitution --capital and labor for energy; (iv) change in product mix; (v) adaptive measures such as population migrations; (vi) 'climatic engineering' such as ocean fertilization.

Accordingly, Cline considers that the costs of abatement policy basically arise from the reduction in fossil fuel emissions due to output reduction (Q), the need to set aside land for afforestation (FA), and the need to curtail frontier agricultural land use and thereby carbon release from deforestation (FD). These costs are expanded by the proportion (w) to take into account likely costs associated with curtailing all greenhouses gases in a way commensurate with reducing carbon dioxide emissions. This cost is further increased by considering the portion of the cost that would have gone into investment (x). Therefore, the costs of abatement polices at time t (in percent of World GDP) can be estimated by:

$$\frac{C_t}{GDP_t} = (Q_t + FA_t + FD_t)(1 + w)x \tag{9}$$

where GDP_t is world GDP at time t.

Clearly, the cost associated with Q varies with the level of abatement as shown by Cline. This basic equation is defined as follows:[7]

$$Q_t = [\frac{(E_t - K - R_t^{FA} - R_t^{FD})}{(E_t - E_0^F)} - Z_0][\alpha + \gamma(t - 35)] \tag{10}$$

with:

Z_0 = percentage carbon reduction at zero cost (set a 22 percent).

E^F_0 = Base year deforestation emissions (set a 1 billion ton of Carbon (GtC).

α = Abatement cost parameter (set at 0.0678)

γ = Abatement cost parameter (set at -0.00039)

K = target ceiling emission (set at 4 GtC)

E_t = Level of global carbon emission at time t (baseline)

R^{FA}_t = Emission reduction from afforestation (set at 1.6 GtC per year, 1991-2020)

R^{FD}_t = Emission reduction from lower deforestation (set at 0.7 GtC per year, 1991-2275)

Finally, the parameters w and x are defined to be equal to 0.2 and 1.12 of total

---

[7] Note that equation (10) is slightly different over the period 1990-2025 (see Cline (1992), p. 282 for details).

costs respectively, following the arguments proposed by Cline.[8]

For the aggressive policy of 4 GtC of CO_2 emissions annually proposed by Cline, the estimated costs for the period 1990-2275 are depicted in Figure 1 and in Table 1.[9] The estimates assume that a reduction of up to 22 percent of emissions can be achieved at zero cost, on the basis of the body of engineering estimates. The overall pattern that emerge is one in which there is a phase of initially low cost carbon reductions, followed by a period when these costs rise to a peak of 3.5 percent of World GDP, a level that then tapers off to some 2.5 percent of GDP as the passage of time should permit the development of a wider range of technological alternatives.

It is worth underscoring that these projections are calculated on the basis of the costs measured by Cline (1992), but a considerable debate is taking place currently in the literature. For example, important additional damage estimates have been made by Titus (1992) and Fankhauser (1992), the first author author arguing that potential damages in forest loss are much more important than estimated by Cline, while the second one have extended Cline's analysis by including a more extensive set of countries. The model can be easily extended to include alternative measures of damages costs.

Expected Benefits

Expected benefits are defined as the damages that can be avoided by a policy

---

[8] The parameter x is defined by Cline as follows:

$$x = (1 - \pi^c_k) + p^*_k \pi^c_k$$

with π^c_k the portion of the cost that would have gone into investment, and p^*_k a shadow price of capital to convert investment in consumption-equivalents.

[9] The time horizon of 2275 is fixed by Cline, because at that time, it is believed that resources will be exhausted under a scenario of high fossil fuel consumption.

or, in other terms, as the differences between the damages in the absence of intervention and the unavoidable damages. The first requirement is therefore to determine the damages of global warming in the absence of intervention. Damages from global warming are determined by the estimated increase in temperature; which largely depends on the so-called climate sensitivity parameter.

In expression (11) is specified the linkage between the increase in temperature from global warming and the level of CO_2 emission. Two scenarios are successively examined (the central and the high cases) which correspond to an increase in temperature in the long term of about 10 C° and 18 C° respectively.[10] The increase in the level of temperature is assumed to depend on (i) the degree of radiative force above industrial level, which in turn is influenced by the level of CO_2 concentration at time t, (ii) the relationship between the degree of radiative force and the increase in temperature, and (iii) the feed-back effect caused by water vapour, snow and ice albedo. In short, global warming is defined as follows:

$$W_t = 6.3 \ln \left[\frac{0.476 \left(Z_0 + 0.5 \sum_{i=0}^{t} E_{t-i} \right)}{C_0} r \right] \lambda \beta \qquad (11)$$

where Z_0 is the initial atmospheric concentration of carbon dioxide in 1990, E_t the C02 emission at time t, λ warming per unit of radiative forcing before taking account the feedback effect (set a 0.3), and ß is the feedback multiplier (set at 1.9 in the central case and 3.4 in the high case). The values of these parameters are those used by Cline (1992).

The increase in temperature will produce world damages that are estimated

---

[10] The "central case" is in line with the IPCC estimates, while the "high case" is relatively pessimistic.

on the basis of studies on the U.S. economy.[11] The central estimate for economic damage from global warming is set by Cline at 1 percent of world GDP at benchmark of doubling CO_2 concentration. Finally, the function relating damage to warming is assumed to be geometric with an exponent of 1.3. Therefore, non-discounted damages (in percent of world GDP) from global warming in the absence of intervention are given by:

$$\frac{B_t}{GDP_t} = (d_0 \frac{W_t}{2.5})^{\gamma} \qquad (12)$$

where d_0 is the benchmark economic damage for carbon-dioxide-equivalent doubling (set at 1 and calibrated for a climate sensitivity of 2.5 C°), W_t the projected temperature at time t as defined by equation (11), and γ the exponent in the geometrical function (set a 1.3).

Equations (11) and (12) can be used to determine the costs of global warming in the absence of intervention --the accumulation of carbon dioxide leads to an increase in temperature which, in turn, produce damages to the world economy.

In Cline's approach, the benefits from an aggressive abatement policy are fixed at 80 percent of the costs of global warming in the absence of intervention during the entire period. This fraction, equivalent to the unavoidable damages in the long term, overestimates the benefits from intervention in the beginning of the period since the level of greenhouse gases is higher in 1990 (6.7 GtC) than the ceiling proposed by Cline (4 GtC). A more precise approach is here followed since the benefits are

---

[11] The general approach has been to analyze the different economic sectors affected by global warming. Some problems arise for agriculture, with the controversial so-called fertilization effect, according to which CO_2 concentration may, up to a certain level, improve photosynthesis. Other major problems concern the monetary value of non-market damages, such as health effects, changing amenities, species extinction and social costs of migrations due to sea-level rise. The indirect damages, due to greenhouse gases and conventional air pollutants should also be included in the estimates (Ayres and Walter, 1991).

measured as the difference between the costs of global warming in the absence of intervention (B^{wi}_t) and those if the global CO_2 emission is limited at 4 GtC (B^i_t). Thus:

$$b_t = \left(\frac{B_t^{wi}}{GDP_t} - \frac{B_t^{i}}{GDP_t}\right) \eta + T_t \qquad (13)$$

The benefits from intervention are further expanded to take into consideration the fact that some of these gains accrue to production going into investment (the parameter η is set a 1.06 following Cline's analysis) and the benefit from reduction of the excess tax burden (T_t).

The evolution of the expected benefits of an aggressive abatement in global warming is described in Figure 1 and Table 1. It is worth underscoring that the fraction of avoidable damages is not constant over time as originally assumed by Cline. As depicted in Figure 2, this fraction is only 45-50 percent in the first decades and gradually increase up to 82 percent in 2275. Benefits of limiting global warming would be considerably higher in the long-term than in the short-term because of the importance of the irreversible accumulation of CO_2 and thus unavoidable damages in the first decades.

Cost-Benefit Analysis

As discussed by Cline, the results of the cost-benefit analysis are greatly influenced by the discount rate (r) because of the long time horizon (up to 285 years). Although there is an ongoing debate on this issue, we remain attached to Cline's analysis by using a relatively low discount rate of 1.5 percent.[12] The ratio of

---

[12] By incorporating the influence of the portion of resources diverted from capital investment by applying a shadow price on capital and converting these resources to consumption equivalents, the overall discount rate is close to 2 percent. For an extensive discussion on the issue of the discount rate, see for example, Birdsall and Steer (1993).

actualized benefits to costs is:

$$Y = \frac{\sum \frac{b_t}{(1 + r)^t}}{\sum \frac{C_t}{(1 + r)^t}} \tag{14}$$

with C_t and b_t defined in equations (9) and (13) respectively.

The results that emerge from the traditional cost-benefit analysis are that the aggressive policy should be rejected in the central case because the ratio Y is lower than 1 (Y=0.94). In contrast, in the high case, the aggressive abatement policy should be implemented since the discounted benefits are largely greater than the discounted costs of intervention (Y = 1.94).[13]

Therefore, the results of the traditional cost-benefit analysis do not permit to support or to reject aggressive abatement policies. However, Cline concludes that these empirical results support his policy proposal to the extent that policy-makers are risk averse and apply a higher weight to the high case scenario than the central case scenario.

3.2 Parameters for the Option Pricing Model

As explained in the preceding sections, our objective is to introduce uncertainty in the analysis of global warming. The principal questions to be answered are: should we invest now in the aggressive abatement policy advocated by Cline or should we

---

[13] These ratios slightly differ from those found by Cline because the temperatures and so the benefits from intervention are not defined in the same ways. If we use the same approach than Cline, the benefit-cost ratios are 0.77 and 1.59 for the central and high cases respectively, close to the results obtained by Cline (chapter 7, scenarios 1 and 9).

wait, and if yes how long? Finally, what would be the appropriate policy to be implemented today?

There appears to be much more uncertainty about the benefits of global warming abatement than about costs in the literature (as reflected in TAbles 2 and 3). The major source of uncertainty regarding the benefits lies in the uncertainties and imponderable impacts of climate change (scientific uncertainty), but major doubts also remain on the magnitude of the damages, and their conversion in monetary values. The uncertainty about the costs of limiting global warming principally lies in the choice of instruments to be implemented (e.g. carbon tax, regulations).[14]

To illustrate the degree of uncertainty, Tables 2 and 3 report the estimates of recent studies on the expected costs and benefits. The estimated costs of a 40 percent abatement policy from baseline in 2025 range from only 0.26 percent of World GDP for Edmonds-Burns to 3.52 percent for Whally-Wigle, while the estimated benefits (of eliminating the damages of CO_2 doubling)[15] vary between 0 and 5.5 percent of GDP.[16] The overall uncertainty of costs and benefits in 2025 is 74 percent and 107 percent respectively, equivalent to a standard deviation of about 3.2 percent and 3.8 percent annually.

The correlation coefficient between discounted benefits and costs of global warming also influences greatly the optimal timing of intervention --the critical ratio

---

[14] See Nordhaus (1993), for a good summary of the uncertainties of limiting global warming.

[15] Which is expected to occur as early as 2025 (IPCC, 1990).

[16] Although Nordhaus (1993) reports that most studies give quite similar results and find damages ranging between 1.0-1.5% US 1988 GDP for a CO_2 doubling and a survey of scientific and economic experts by Nordhaus (1993) shows that a 3 C° increase of average temperature in 2090 would cost on average 1.8% of GDP, an order of value close to the preceding ones, the great dispersion of the answers, ranging from 0 to 5.5% of GDP, illustrates the uncertainty surrounding these estimations.

(Y^*) is a decreasing function of this coefficient. If benefits and costs are poorly correlated, the effect of uncertainty would increase since there will always be the possibility of having simultaneously higher than expected costs and lower than expected benefits. The correlation coefficient, calculated by the standard formula, equals 0.065 (see Table 4).

From equations (9) and (13), we infer that the annual average growth rate of benefits (G_V) is 0.9 percent in the high case and 0.8 percent in the central case, while the annual growth rate of costs (G_F) is 0.02 percent.[17] The discount rate (r) remains the one applied by Cline (1.5 percent).

All parameters are summarized in Table 4. The option-pricing model is successively applied to the central and high cases. The introduction of uncertainty does not delay the investment decision in the high case scenario, but accentuated the non-profitability of policy intervention in the central case scenario. Below are some details.

> High Case : In the face of uncertainty, the decision to proceed now remains optimal. However, as discussed below in detail, this result is quite sensitive to the volatility associated with the costs and benefits.
>
> Central Case : Policy intervention is even less attractive, when analyzing it in the face of uncertainty. The optimal time of investment would be in about 133 years from now. This result may appear redundant, knowing the deterministic result, but it reveals option prices (i.e. the variable W in Table 4).

---

[17] Defined as geometric average growth rates per annum for the period 1990-2275.

Sensitivity Analysis

The decision to invest is sensitive to the degree of uncertainty as depicted in Table 5 for the high and most pessimistic case of global warming. When the volatility of benefits and costs is lower than 6 percent annually, it remains optimal to invest now in aggressive policies against global warming. In contrast, these aggressive policies should be deferred for about 35 years with a volatility of 6 percent, 72 years with a volatility of 8 percent or 115 years with a volatility of 10 percent.

As explained earlier, the optimal date of intervention will depend on the evolution of irreversible damages during the waiting period. Following the assumption that the level of irreversible damages would remain the same as if the action was taken from the start, the optimal waiting period is defined by equation (8). The results from this assumption are summarized in Table 5 (denoted by E(T)). However, if the irreversible damages increase over time, the waiting period will be shorter. To illustrate, assuming a volatility of 10 percent per year, the optimal delay would be about 115 years compared to 152 years with constant irreversible damages.

Optimal Policy

In the face of uncertainty, the aggressive policy proposed by Cline may appear sub-optimal. The response could be to wait, as examined earlier, or, eventually, to proceed with a less aggressive policy. The second option is actually recommended by Nordhaus (1993) who, based on the Dynamic Integrated Climate-Economy (DICE) model, proposes an initial abatement policy of 10-15 percent rather than 40 percent as proposed by Cline.[18]

---

[18] Recently, Cline (1993) has however shown that the DICE model can reproduce his results if the discount rate is appropriately chosen.Although the selection of the discount rate is fundamental for a period of time over 300 years, our objective remains to examine the impact of uncertainty.

Using the approach developed in this paper, it is relatively easy to identify the optimal policy to be implemented today for a given degree of uncertainty. Notice that, for simplicity, we assume that the degree of uncertainty on costs and benefits are equivalent, so that the resulting impact on the option value is unambiguously positive as demonstrated in Appendix. The results of this exercise are presented in the last line of Table 5 in terms of CO_2 ceiling. For example, the optimal ceiling would be only 6.4 GtC for a volatility of 10 percent, while it would decline to 4.8 GtC for a volatility of 6 percent. As expected, higher is the uncertainty around the cost and benefits, lower should the CO_2 cutback.

Figure 3 depicts the optimal path of CO_2 emission over the period 1990-2275 for different degree of uncertainty.[19] The optimal path is sensitive to the degree of uncertainty, specifically in the beginning of the period. The optimal path, when the uncertainty is around 8 percent annually, would cut emissions by 15-20 percent in the first decades from baseline, rising gradually to 80 percent in the next century. However, when the uncertainty rises to 10 percent, the CO_2 cutback would be only 5-10 percent in the first decades. These results can be compared with the 40 percent cutback recommended by Cline in the next few decades, and are close to the level proposed by Nordhaus and those recommended recently by the European Union.

4 Concluding Remarks

Uncertainty is an inherent phenomena in global warming issues, and thus it must be explicitly taken into account in the evaluation of policies. Although the major concern remains the uncertainty around the scientific evidence of climate changes, the economic analysis provides some guidance whether governments should intervene in

---

[19] The abatement ratio is defined as the CO_2 cutback from baseline.

the foreseen future.

On the basis of the option-valuation approach, this paper has examined the impact of uncertainty on the costs-benefits analysis. The major conclusions are the following:

- The aggressive proposal presented by Cline (1992) appears to be optimal for a relatively low degree of uncertainty around the costs and benefits of limiting global warming. This result is valid in the case where the increase in temperature in the long term is about 18 C° (high case scenario), and the discount rate is equal to 1.5.

- However, the action should be delayed if the uncertainty is higher than 6 percent per annum. The optimal date of intervention calculated in the paper, ranging from 35 years to 126 years from now, accounts for the possibility to accumulate future information and for the increase in irreversible damages during the waiting period compared to those which would have prevailed if the action was taken from the start.

- In case of relative high uncertainty, it may be optimal to implement today a less aggressive policy. If the Cline's proposal is to limit the level of CO_2 emission to 4 GtC annually, a ceiling of 5.5-6.5 GtC --about the existing level in 1990-- seems more appropriate for a level of uncertainty ranging around 8-10 percent annually.

Finally, we would like to conclude that the approach followed in this paper could be improved in numerous ways. As discussed earlier, uncertainty around cost and benefits is assumed to be exogenous and constant over time. It would be certainly more realistic to consider uncertainty as endogenous, varying, for example, with the increase in global warming or the magnitude of the policies to limit global carbon emissions. Clearly, additional work is required in this area in both an analytical and empirical perspectives.

Appendix

In this appendix, the impact of changes in uncertainty on the option value (W) is discussed in more detail. While an increase in the overall uncertainty on costs and benefits (σ^2) will unambiguously increase the option value and thus delay the implementation of policies against global warming, the impact of variations in individual components --uncertainty on benefits (σ_V) or on costs (σ_F)-- remains ambiguous. Below is a detailed description.

A. The Impact of a Change in Overall Uncertainty

Substituting equation (4) into equation (6), the option value can be written as:

$$W = (Y^* - 1)F\left(\frac{V}{F}Y^*\right)^{Y^*/(Y^* - 1)}$$

All variables have been defined in the main text. The impact of a change in overall uncertainty is therefore equal to:

$$\frac{dW}{d\sigma^2} = \frac{dW}{dY^*}\frac{dY^*}{d\tau}\frac{d\tau}{d\sigma^2}$$

The sign of dW/dσ^2 is unambiguously positive, as demonstrated below:

$$\frac{dY^*}{d\tau} = -\frac{1}{(\tau - 1)^2} < 0$$

$$\frac{dW}{dY^*} = \frac{W}{(Y^* - 1)}\left[2 - \frac{\ln(\frac{VY^*}{F})}{(Y^* - 1)}\right] > 0 \text{ , } \textit{because } \frac{V}{F} < Y^*$$

$$\frac{d\tau}{d\sigma^2} = \frac{2(r_V - r_F)}{\sigma^3} - 2\left[\left(\frac{(r_F - r_V)}{\sigma^2} - 0.5\right)^2 + 2\frac{r_F}{\sigma^2}\right]^{-0.5}\left[\left(\frac{r_F - r_V}{\sigma^3}\right)\left(\frac{r_F - r_V}{\sigma^2} - 0.5\right) - \frac{r_F}{\sigma^3}\right] < 0 \text{ ,}$$

$$\textit{because } \frac{\sigma_F\,\sigma_V}{(\sigma_F - \sigma_V)^2} > 0$$

B. The Impact of a Change in Individual Components of Uncertainty

The impact of a variation in the uncertainty around benefits and costs on the option value can be expressed, respectively, as follows:

$$\frac{dW}{d\sigma_V} = \frac{dW}{d\sigma^2}\frac{d\sigma^2}{d\sigma_V} = \frac{dW}{d\sigma^2}2(\sigma_F - \theta_{VF}\sigma_V) > 0 \quad \mathit{if}\ \frac{\sigma_F}{\sigma_V} > \theta_{VF}$$

$$\frac{dW}{d\sigma_F} = \frac{dW}{d\sigma^2}2(\sigma_V - \theta_{VF}\sigma_F) > 0 \quad \mathit{if}\ \frac{\sigma_V}{\sigma_F} > \theta_{VF}$$

σ is the volatility of Y, which is a ratio of benefits (V) over costs (F).

From these two equations, we can observe that the impact of a change in the individual uncertainties on the value of the option is ambiguous. For example, the sign of the impact of a change in σ_V on W depends on the values of: (i) the correlation between the costs and the benefits associated with the policies against global warming; (ii) the uncertainty on benefits; (iii) the uncertainty on costs. To illustrate, the option value is more likely to be influenced positively by an increase in the uncertainty on benefits ($dW/d\sigma_V$) if the correlation between costs and benefits is low and if the uncertainty on benefits is low relative to the uncertainty on costs.

The numerical exercise simulated in Table 5 of the main text assumes that the variation in the uncertainty on costs equals that in the uncertainty on benefits ($d\sigma_F = d\sigma_V$). In this case, the resulting impact on the option value is unambiguously positive, as demonstrated below:

$$\begin{aligned} dW &= \frac{\partial W}{\partial \sigma_F}d\sigma_F + \frac{\partial W}{\partial \sigma_V}d\sigma_V \\ &= 2\frac{dW}{d\sigma^2}(\sigma_V + \sigma_F)(1 - \theta_{VF})d\sigma_F > 0 \end{aligned}$$

Bibliography

Arrow, K.J. and A.C. Fisher (1974), 'Environmental Preservation, Uncertainty and Irreversibility', Quarterly Journal of Economics, 88(2), 312-319.

Ayres, R.U. and J. Walter (1991), 'The Greenhouse Effect: Damages, Costs and Abatement', Environmental and Resource Economics, 1(3), 237-270.

Birsall, N. and A. Steer (1993), 'Act Now on Global Warming -- But Don't Cook the Books', Finance and Development, 30.

Cline, W.R. (1992), The Economics of Global Warming, Washington, The Institute for International Economy, 399 p.

Cline, W.R (1993), Modelling Economically Efficient Abatement of Greenhouse Gases, Institute for International Economics, September.

Daily, G.C., P.R. Ehrlich, H.A. Mooney, and A.H. Ehrlich (1991), 'Greenhouse Economics: Learning Before You Leap', Ecological Economics, 4(1), 1-10.

Dixit, A. (1992), 'Investment and Hysteresis', Journal of Economic Perspectives, 6(1), 107-32.

Drepper, F.R. and B.A. Mansson (1993), 'Inter-temporal Valuation in an Unpredictable Environment', Ecological Economics, 7(1), 43-67.

Fankhauser S. (1992), "Global Warming Damage Costs: Some Monetary Estimates", London: Center for Social and Economic Research on the Global Environment, mimeo, August.

Hanley, N. and C.L. Spash (1993), Cost-Benefit Analysis and the Environment, Edward Elgar Publ., Hants.

Henry, C. (1974), 'Investment Decisions Under Uncertainty: the Irreversibility Effect', American Economic Review, 64(6), 1006-1012.

McDonald, R. and D. Siegel (1986), 'The Value of Waiting to Invest', Quarterly Journal of Economics, November, 707-727.

Morgenstern, R.D. (1991), 'Towards a Comprehensive Approach to Global Climate Change Mitigation', American Economic Review, 81(2), 140-145.

Nordhaus, W.D. (1991a), 'To Slow or not to Slow: the Economics of the Greenhouse Effect', The Economic Journal, 101, 920-937.

Nordhaus, W.D. (1991b), 'A Sketch of the Economics of the Greenhouse Effect', American Economic Review, 81(2), 146-150.

Nordhaus, W.D. (1993), 'Reflections on the Economics of Climate Change', Journal of Economic Perspectives, 7(4), 11-25.

Pearce, D.W. and A. Markandya (1990), L'Evaluation Monétaire des Avantages des Politiques de l'Environnement, OCDE, Paris.

Pindick, R.S. (1991), 'Irreversibility, Uncertainty, and Investment', Journal of Economic Literature, 39, 1110-1148.

Reilly, J.M. and K.R. Richards (1993), 'Climate Change Damage and the Trace Gas Index Issue', Environmental and Resource Economics, 3(1), 41-62.

Samuelson, P.A. (1965), 'Rational Theory of Warrant Pricing', Industrial Management Review, 6: 13-31.

Schelling, T. C. (1992), 'Some Economics of Global Warming', American Economic Review, 82(1), 1-14.

Titus J. (1992), "The Cost of Climate Change to the United States", in S.K. Majumbar et al., eds, Global Climate Change" Implications, Challenges and Mitigation Measures.

UNEP (1991), Climate Change, UNEP, Geneva.

Weisbrod, B.A. (1964), 'Collective-Consumption Services of Individual-Consumption Goods', Quarterly Journal of Economics, 68, 471-477.

World Bank (1991), Decision-Making under Uncertainty, Washington, The World Bank, Industry and Energy Department Working Paper, Energy Series Paper No 39.

Table 1: Cost and Benefits of Aggressive Abatement Policies, High Case Scenario

	--Temperature a/--		---- Benefits b/----		Costs b/	Avoidable
	High Case	4 GtC	Cline	Revised c/		Damages Ratio d/
1990	2.43	1.51	0.82	0.47	0.09	0.46
1995	2.67	1.60	0.92	0.56	0.08	0.49
2000	2.91	1.68	1.03	0.66	0.07	0.51
2005	3.17	1.76	1.17	0.78	0.13	0.54
2010	3.44	1.85	1.40	1.01	0.83	0.59
2015	3.73	1.93	1.61	1.21	1.39	0.62
2020	4.03	2.01	1.79	1.39	1.87	0.64
2025	4.34	2.09	2.14	1.74	3.70	0.67
2030	4.65	2.16	2.29	1.88	3.78	0.68
2035	4.96	2.24	2.44	2.03	3.82	0.69
2040	5.27	2.32	2.59	2.19	3.84	0.69
2045	5.58	2.39	2.74	2.34	3.84	0.70
2050	5.89	2.47	2.90	2.51	3.82	0.71
2055	6.20	2.54	3.06	2.67	3.81	0.71
2060	6.52	2.61	3.22	2.85	3.77	0.72
2065	6.83	2.68	3.38	3.02	3.72	0.72
2070	7.13	2.75	3.55	3.20	3.66	0.73
2075	7.44	2.82	3.72	3.38	3.58	0.73
2080	7.74	2.89	3.90	3.56	3.51	0.74
2085	8.05	2.96	4.07	3.75	3.42	0.74
2090	8.35	3.03	4.25	3.94	3.33	0.74
2095	8.64	3.10	4.43	4.12	3.22	0.75
2100	8.94	3.16	4.61	4.31	3.10	0.75
2105	9.23	3.23	4.78	4.50	2.98	0.75
2110	9.51	3.30	4.96	4.68	2.85	0.75
2115	9.78	3.36	5.13	4.86	2.71	0.76
2120	10.06	3.42	5.31	5.04	2.68	0.76
2125	10.38	3.49	5.51	5.26	2.68	0.76
2130	10.70	3.55	5.73	5.49	2.68	0.77
2135	11.03	3.61	5.95	5.73	2.68	0.77
2140	11.36	3.67	6.17	5.97	2.68	0.77
2145	11.68	3.73	6.40	6.21	2.68	0.78
2150	12.01	3.80	6.62	6.46	2.68	0.78
2155	12.33	3.86	6.85	6.70	2.68	0.78
2160	12.66	3.91	7.07	6.95	2.68	0.79
2165	12.98	3.97	7.30	7.19	2.68	0.79
2170	13.30	4.03	7.53	7.44	2.68	0.79
2175	13.61	4.09	7.75	7.69	2.68	0.79
2180	13.93	4.15	7.98	7.94	2.68	0.80
2185	14.24	4.20	8.21	8.19	2.68	0.80
2190	14.55	4.26	8.44	8.44	2.68	0.80
2195	14.86	4.31	8.67	8.69	2.68	0.80
2200	15.17	4.37	8.90	8.94	2.68	0.80
2205	15.47	4.42	9.13	9.19	2.68	0.80
2210	15.77	4.48	9.36	9.44	2.68	0.81
2215	16.07	4.53	9.59	9.69	2.68	0.81
2220	16.37	4.59	9.81	9.94	2.68	0.81
2225	16.67	4.64	10.04	10.20	2.68	0.81
2230	16.96	4.69	10.27	10.45	2.68	0.81
2235	17.26	4.74	10.50	10.70	2.68	0.81
2240	17.55	4.79	10.73	10.95	2.68	0.82
2245	17.84	4.85	10.96	11.20	2.68	0.82
2250	18.12	4.90	11.19	11.45	2.68	0.82
2255	18.41	4.95	11.41	11.70	2.68	0.82
2260	18.69	5.00	11.64	11.95	2.68	0.82
2265	18.97	5.05	11.87	12.20	2.68	0.82
2270	19.26	5.10	12.09	12.45	2.68	0.82
2275	19.53	5.14	12.32	12.70	2.68	0.82

a/ Defined as the increase in temperature (measures in Celsius degree) from preindustrial level in the absence of intervention (Baseline scenario).
b/ In percent of World GDP, not discounted.
c/ Dertermined by equation (12) in the text.
d/ Defined as the ratio of avoidable damages to total damages from global warming.

Table 2: Cost Uncertainty a/
In percent of World GDP

Manne-Richels	2.00
Edmonds-Barns	0.26
Whalley-Wigle	3.52
OECD-Green	2.20
Cline	0.70
Standard Deviation	1.30
Mean	1.74
Uncertainty b/	74.71

Source: Cline (1992)

Table 3: Benefits Uncertainty c/
In Percent of World GDP

Nordhaus (A)	1.00
Cline	1.10
Fakhauser	1.30
Nordhaus (B)	1.80
Lowest	0.00
Highest	5.50
Standard Deviation	1.91
Mean	1.78
Uncertainty b/	107.30

a/ Based on estimated costs in 2025 and calibrated for a 40 percent abatement policy from baseline.
b/ Defined as the ratio of standard deviation to mean.
c/ Based on Damages of CO2 doubling.
d/ Based on a survey of specialists.

Table 4:
Option-Pricing Approach a/

	Central Case	High Case
Benefits volatility b/	3.80%	3.80%
Costs volatility b/	3.20%	3.20%
correlation	5.99%	5.99%
Discount rate	1.50%	1.50%
Benefits (V)	96.5	198.5
Costs (F)	102.3	102.4
Benefits growth rate	0.81%	0.69%
Costs growth rate	0.16%	0.38%
Eff. Benefits growth rate	0.69%	0.81%
Eff. Costs growth rate	1.34%	1.12%
Total volatility	0.23%	0.23%
τ	1.8	2.4
Y^*	2.2	1.7
$Y = (V/F)$	0.9	1.9
W c/	494.0	1313.0
E(T), in years d/	133.6	-36.9

All variables are defined in the text

a/ In percent of World GDP, otherwise specified.
b/As determined in Tables 2 and 3
c/ In trillions of 1990 US dollars.
d/ Optimal timing determined by equation (8) in the text.

Table 5:
High Case: Sensitivity Analysis a/

Changes in Total Effective Volatility

Benefits volatility	0.00%	2.00%	4.00%	6.00%	8.00%	10.00%	12.00%
Costs volatility	0.00%	2.00%	4.00%	6.00%	8.00%	10.00%	12.00%
Correlation	5.99%	5.99%	5.99%	5.99%	5.99%	5.99%	5.99%
Discount rate	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%
Benefits (V)	198.5	198.5	198.5	198.5	198.5	198.5	198.5
Costs (F)	102.4	102.4	102.4	102.4	102.4	102.4	102.4
Benefits growth rate	0.69%	0.69%	0.69%	0.69%	0.69%	0.69%	0.69%
Costs growth rate	0.38%	0.38%	0.38%	0.38%	0.38%	0.38%	0.38%
Eff. Benefits growth rate	0.81%	0.81%	0.81%	0.81%	0.81%	0.81%	0.81%
Eff. Costs growth rate	1.12%	1.12%	1.12%	1.12%	1.12%	1.12%	1.12%
Total volatility	0.00%	0.08%	0.30%	0.68%	1.20%	1.88%	2.71%
τ	na	2.9	2.2	1.9	1.6	1.5	1.4
Y^*	1.4	1.5	1.8	2.2	2.6	3.1	3.7
Y =(V/F)	1.9	1.9	1.9	1.9	1.9	1.9	1.9
W	na	1252.1	1365.6	1715.1	2267.2	3044.6	4093.4
<u>Optimal Timing</u>							
E(T), in years b/	0	0	0	35.8	94.5	151.8	207.2
$E(T^*)$, in years c/	-	-	-	35.0	72.0	115.0	126.0
<u>Optimal Policy</u>							
CO2 Ceilings d/		2.4	3.5	4.8	5.7	6.4	7.0

a/ In percent of World GDP, otherwise specified

b/ Optimal timing is determined by equation (8) which assumes that the level of irreversible damages would remain the same than if the action was taken from the start.

c/ Optimal timing accounting for the increase over the waiting period of the irreversible damages.

d/ Optimal CO2 ceiling to be implemented from 1990 to 2275

Figure 1: High Case, Benefits and Costs

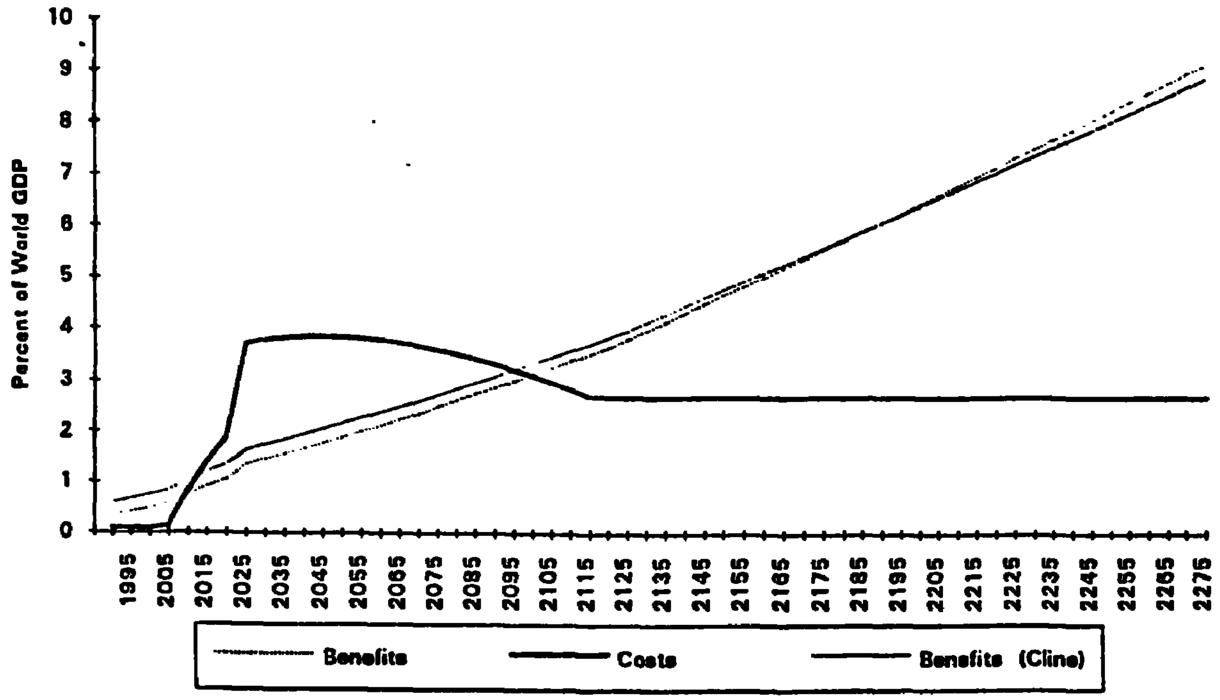
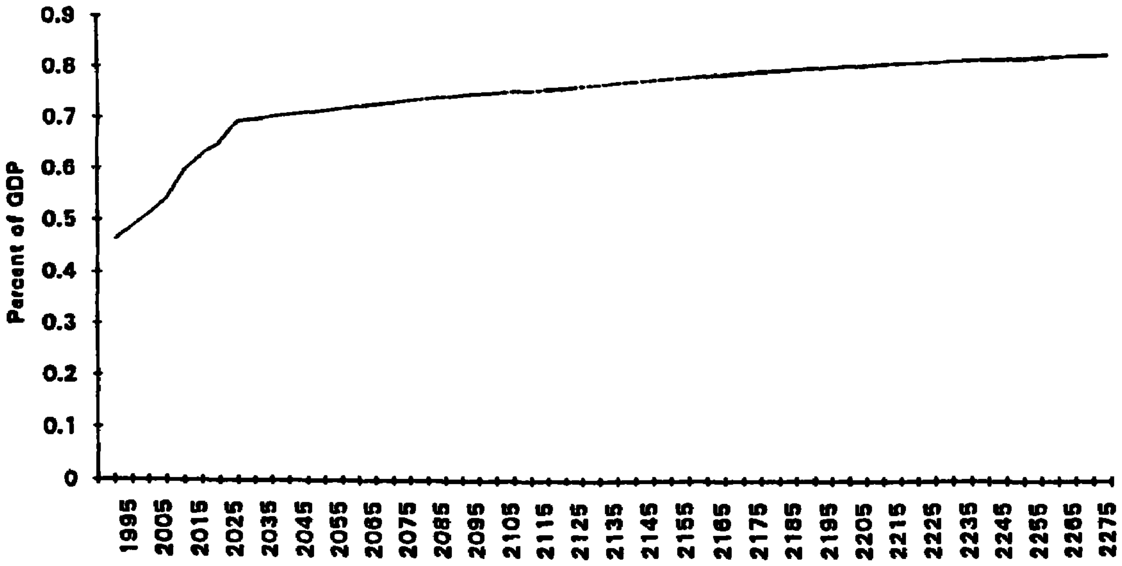


Figure 2: Ratio of Avoidable Damages, High Case



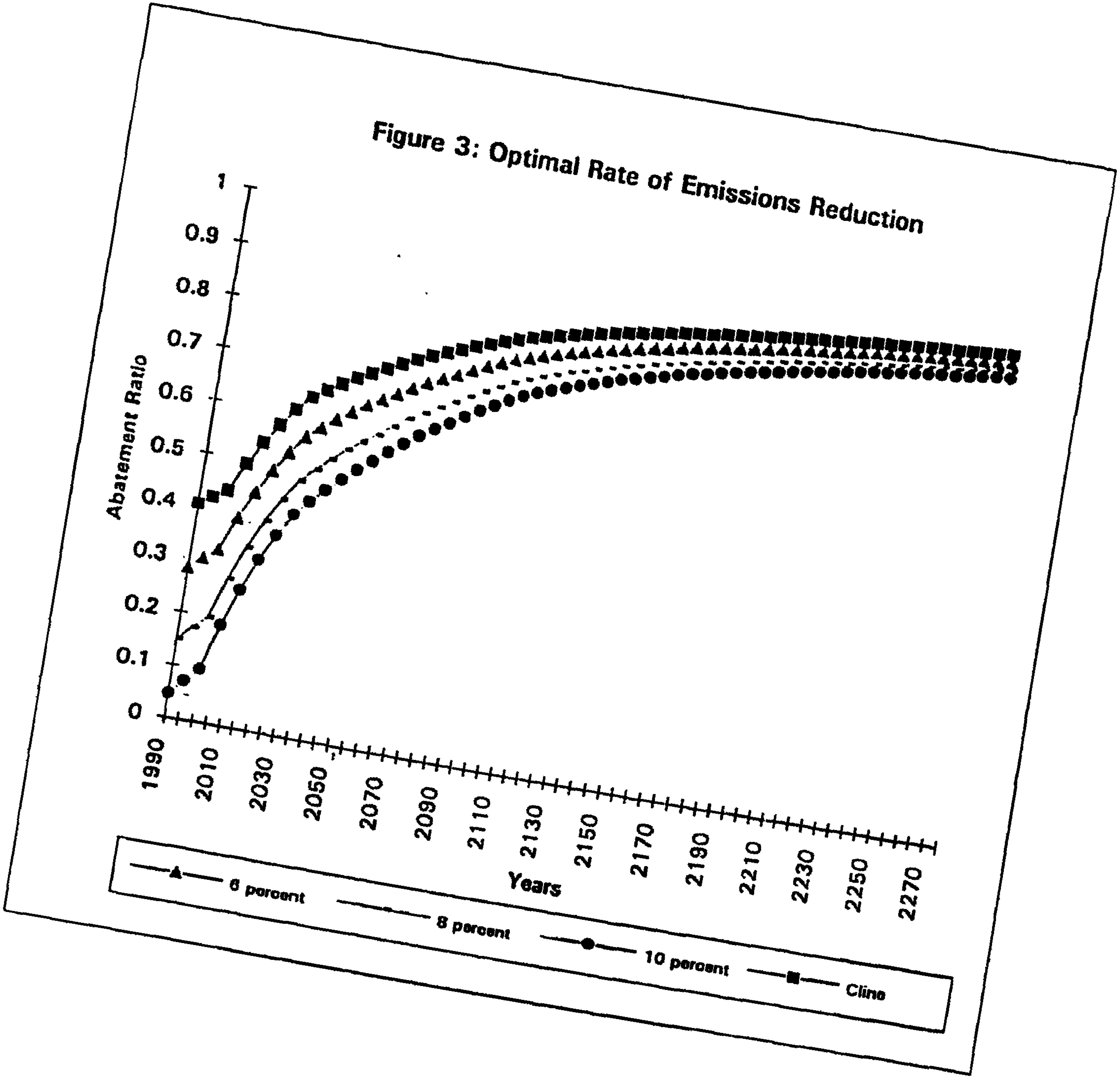


Figure 3: Optimal Rate of Emissions Reduction

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS1397	Are Private Capital Flows to Developing Countries Sustainable?	Uri Dadush Ashok Dhareshwar Ron Johannes	December 1994	J. Queen 33740
WPS1398	The Cost of Air Pollution Abatement	Raymond S. Hartman David Wheeler Manjula Singh	December 1994	E. Schaper 33457
WPS1399	How Important to India's Poor is the Urban-Rural Composition of Growth?	Martin Ravallion Gaurav Datt	December 1994	P. Cook 33902
WPS1400	Technical and Marketing Support Systems for Successful Small and Medium-Size Enterprises in Four Countries	Brian Levy with Albert Berry, Motoshige Itoh, Linsu Kim, Jeffrey Nugent, and Shujiro Urata	December 1994	D. Evans 38526
WPS1401	Colombia's Small and Medium-Size Exporters and Their Support Systems	Albert Berry Jose Escandon	December 1994	D. Evans 38526
WPS1402	Indonesia's Small and Medium-Size Exporters and Their Support Systems	Albert Berry Brian Levy	December 1994	D. Evans 38526
WPS1403	Small and Medium-Size Enterprise Support Policies in Japan	Motoshige Itoh Shujiro Urata	December 1994	D. Evans 38526
WPS1404	The Republic of Korea's Small and Medium-Size Enterprises and Their Support Systems	Linsu Kim Jeffrey B. Nugent	December 1994	D. Evans 38526
WPS1405	Growth and Poverty in Rural India	Martin Ravallion Gaurav Datt	January 1995	WDR 31393
WPS1406	Structural Breaks and Long-Run Trends in Commodity Prices	Javier León Raimundo Soto	January 1995	R. Luz 31320
WPS1407	Pakistan's Agriculture Sector: Is 3 to 4 Percent Annual Growth Sustainable?	Rashid Faruqee	January 1995	F. Willie 82262
WPS1408	Macroeconomic Management and Intergovernmental Relations in China	Jun Ma	January 1995	C. Jones 37754
WPS1409	Restructuring Uganda's Debt: The Commercial Debt Buy-Back Operation	Kapil Kapoor	January 1995	E. Spano 35538
WPS1410	Macroeconomic Effects of Terms-of-Trade Shocks: The Case of Oil-Exporting Countries	Nikola Spatafora Andrew Warner	January 1995	J. Queen 33740

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS1411	Income Inequality, Welfare, and Poverty: An Illustration Using Ukrainian Data	Nanak Kakwani	January 1995	G. Evans 85783
WPS1412	Foreign Technology Imports and Economic Growth in Developing Countries	Xiaoming Zhang Heng-fu Zou	January 1995	C. Jones 37754
WPS1413	Endogenous Distortions in Product and Labor Markets	Martin Rama Guido Tabellini	January 1995	S. Fallon 38009
WPS1414	The World Bank and Legal Technical Assistance: Initial Lessons	The World Bank Legal Department	January 1995	K. Mathernová 82782
WPS1415	China's GDP in U.S. Dollars Based on Purchasing Power Parity	Ren Ruoen Chen Kai	January 1995	E. O'Rielly-Campbell 33707
WPS1416	Informal Regulation of Industrial Pollution in Developing Countries: Evidence from Indonesia	Sheoli Pargal David Wheeler	February 1995	E. Schaper 33457
WPS1417	Uncertainty and Global Warming: An Option-Pricing Approach to Policy	Andrea Baranzini Marc Chesney Jacques Morisset	February 1995	C. Dell 85148