SHORT-TERM DECISIONS UNDER LONG-TERM UNCERTAINTY

Richard S.J. Tol
Institute for Environmental Studies, Vrije Universiteit Amsterdam

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Abstract

The behaviour of future policy-makers substantially influences future greenhouse gas emissions. Uncertainty about the motives of future policy-makers may thus strongly influence the climate policy strategies of current policy-makers. Analytical and numerical analyses in this paper confirm this hypothesis. If current policy-makers want to constrain emissions accumulated over a prolongued period of time, and if future policy-makers tend, with a certain chance, to a less ambitious climate policy, then current policy-makers should intensify their efforts to reduce emissions and the costs of emission reduction. In this setting, if current policy-makers want to meet a cumulative emission contraint in expectation, then the preferred policy trajectory does not qualitatively deviate from one suggested by a standard cost-effective trajectory. If, however, the constraint is to be met with a certain probability, then the importance of early action is enhanced relative to that of postponed action. Costs substantially increase if current policy-makers want to set long-term goals without the full cooperation of future policy-makers.

Keywords: **greenhouse gas emission reduction, cost-effectiveness analysis, uncertainty**

JEL Classification: D80, Q40

Non-technical summary

An effective climate policy requires the cooperation of all significant policy-makers, not only the present ones, but also the policy-makers of the future. When advicing policy on long-term issues, analysts typically assume either that future policy-makers will do exactly what current policy-makers tell them to, or that the behaviour of future policy-makers is fully predictable. This paper drops that assumption. The current policy-makers is assumed to want to stabilize the atmospheric concentration of greenhouse gases. Future policy-makers may share that desire and agree to the strategy set out by the current policy-maker, but they also disagree and settle for a less ambitious emission reduction. The behaviour of both types of future policy-makers is fully known, as is the chance of observing one instead of the other. Although this only slightly deviates from the typical assumption described above, the optimal strategy of the current policy-maker is substantially different. Efforts to reduce emissions and to lower the costs of emission reduction should be intensified. If the current policy-maker wants to meet the target with a specific chance, then early action would be more important than if the target needs only be met in expectation. Higher costs will be incurred should current policy-makers want to realize long-term goals without the full cooperation of future policy-makers.

1. Introduction

Uncertainty prevails in climate change. Not surprisingly, many studies have attempted to find a strategy for climate policy (essentially, carbon dioxide emission reduction) which is in some sense rational under uncertainty, by means of cost-benefit analysis (Kolstad, 1994, 1996; Nordhaus, 1994; Peck and Teisberg, 1995; Tol, 1997a), cost-effectivenss analysis (Manne and Richels, 1992, 1995; Yohe and Wallace, 1996), or adaptivity (Dowlatabadi, 1997; Lempert *et al.*, 1996). Some of these studies consider more than one agent, others consider the effects of learning about the nature of climate change; a few studies (Ulph and Ulph, 1996) analyze the interactions between multiple agents and learning. No study, within my knowledge, addresses the problem that the decisions of future policy-makers are uncertain. Current-day policy-makers may set out a strategy for climate policy over the next century aiming at, say, maximum net present welfare or a stable atmosphere. Future policy-makers may have entirely different purposes, however, and there is only so much that the present generation of policy-makers can do to influence their actions.

To illustrate this point, Figure 1 displays the median atmospheric concentration of carbon dioxide and its 5 and 95-percentiles, according to the no-intervention scenario of *FUND*, an integrated assessment model of climate change (cf. Tol, 1997a-c), and contrasts this with the median concentrations of two policy-interventios scenarios, namely a non-cooperative, repeated game (9 players, 21 generations) and the WRE trajectory towards stabilization at 550 ppm (cf. Wigley *et al.*, 1996). The collective abatement effort of future policy-makers has an effect that is about as large as the combined effects of uncertainties in population growth, economic development, technological progress and the carbon cycle. Assuming that future policy-makers will follow the strategy decided upon by current policy-makers (as cost-effectiveness analysis implicitly does) or that we have a perfect model of the behaviour of future policy decisions (as cost-benefit analysis implicitly does), is a simplification which may lead to misinformed policy advices on the short term. Sequential decision-making under uncertainty and learning, be it in a setting of cost-benefit or a cost-effectiveness analysis, similarly assumes that the goals and motives of future policy-makers are known and equal to those of current policy-makers.

This paper is a first attempt to advice a current policy-maker what she should do, given that she has a long-term goal for climate policy and that she does not know what her successors will do. The analysis is simple. The only uncertainties considered are those regarding the motives of future policy-makers. Only two types of policy-makers exist: stabilizers (wanting to stabilize the atmospheric concentration of carbon dioxide) and optimizers (wanting to maximize net present welfare). Only two instruments exist: emission reduction, and research and development (reducing the costs of future emission reduction). If the current policy-maker is a stabilizer, successing policy-makers will either follow her strategy or switch to a policy which maximizes then-current net present welfare. The probability of a switch is constant over time so that the probability of having switched grows over time. The current policy-maker minimizes the net present costs of emission reduction, given certain conditions on the chance of meeting the

stabilization target. This situation is contrasted with the situation in which the future policy-makers are all stabilizers, and the current policy-maker minimizes net present emission reduction costs.

The mirror analysis, i.e., the current policy-maker is an optimizer, is omitted because current policy-makers seem little interested in this paradigm (cf. Article 2 of the Framework Convention on Climate Change) and because the analysis is rather straightforward (in the model chosen in this paper). Current stabilizing agents need later-generation would-be optimizers to reach their goal, and therefore actively seek to influence optimizing behaviour by increasing short-term emission abatement and lowering the costs of emission reduction. Current optimizing agents lack an active interest in the future, as they only want to maximize expected net present welfare given their model of the behaviour of future policy-makers. They may want to discourage future agents from switching to stabilizing behaviour (as this would cause a welfare loss), but analyzing this requires a more sophisticated (and rather speculative) model than used in the analysis below.

The paper follows this route. The next section develops some analytical insights into the problem described above. Section 3 presents a numerical model, which is used in Section 4 to illustrate the effects of not knowing what future policy-makers will do. Section 5 concludes.

2. Some analytical insights

The analytical framework is similar to the one used in Tol (1997d), with learning-by-doing omitted. In general, a cost-effective path towards a certain constraint on

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cumulative emissions follows from something like:

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subject to
where R_t denotes emission reduction at time t, D denotes investments in RD&D, Y is income, δ is the discount rate, E are business-as-usual emissions, W is their weight in cumulative emissions which should be less than M. For simplicity, $f(\bullet)=0$ for $R=D=0$ so that the business as usual scenario is optimal bar greenhouse gas

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emissions. Further,
so that relative costs are increasing in abatement and RD&D effort, but decreasing in past RD&D.

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The first order conditions for R are

so that R is increasing over time (cf. Tol, 1997d).

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The first order conditions for D are

so that little general can be said about the time profile of D. Although the number of terms in (5) declines as t gets higher, one would have to know the relative size of the derivatives of f to D at all times in order to come to unambiguous conclusions about the optimal investment path in RD&D.

Above, the situation is described where all policy-makers are stabilizers. If there is a chance that future policy-makers deviate from the path the first policy-makers

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sets out, (2) is replaced by
at least, if the current policy-maker wants to meet the target in expectation. R_t^* is emission reduction according to the optimizing policy-maker at time t. As

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outlined in the introductory section,
so that the optimizers abate less than their contemporary stabilizers, but more should past stabilizers invest more in RD&D. p_t denotes the chance that the policy-maker in time t is a stabilizer, following the path set out in period 1. Since stabilization has a ring of sub-optimality, $p_t < p_{t-1}$, so that optimizers do not switch back to stabilizing behaviour.

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The first order conditions for R' are
so that the increase of R' over time is dampened (since $p_t < p_{t-1}$), perhaps even reversed, compared to R. Indeed, if the chance of stabilizing behaviour becomes very low, it makes little sense to plan a lot of abatement as the expected cumulative emissions are little affected whereas net present costs are.

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The first order conditions of (1)-(2) and (1)-(6) compare as follows
where λ and λ' are the respective LaGrange multipliers. Little definite statements can be deduced from (9). $1/p > 1$ so the constraint on cumulative emissions has to bite much harder in case of the possibility of optimizers ($\lambda/\lambda' \gg 1$) for emission abatement to go up ($R' > R$). The constraint is definitely stricter as optimizing emission reduction is less than stabilizing reduction ($R^* < R$). The constraint bites harder as p gets smaller, which works against the tendency resulting from (8). This

comparison and that of (8) only hold if technologies are the same in the two cases, $\partial f/\partial R = \partial f/\partial R'$, which they are not as investments in RD&D also change.

Above, optimizing and stabilizing emission abatement are assumed to be independent of one another. This is not realistic since there are inertia switching to and fro carbon- and energy-intensive economies. The inertia of emission reductions are captured by the convex cost function. The inertia of emission increases are ignored, which is no problem since stabilizers reduce emissions ever faster. However, the switch from stabilizing to optimizing behaviour could lead to

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an emission increase.If optimizing abatement depends also on stabilizing abatement

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for s > 0, then the first-order conditions become
so that early (stabilizing) abatement gets an additional bonus. On the other hand, the cumulative emissions constraint becomes less strict, as optimizing abatement increases.

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The first order conditions for D' are
so that investments in RD&D are probably greater than in the case without optimizers (p = 1). This conclusion is unambiguous if the derivatives of f to D_t are independent of RD&D investments at other times and emission reductions at all times. Adding a positive effect of stabilizing emission reduction on optimizing emission reduction decreases the need for RD&D.

Alternatively, the current policy-maker may be interested in meeting the target with a certain chance. The consequences of this are as follows. Since optimizers are assumed not to invest in RD&D, an optimizer's emission reduction is higher the later the switch from stabilizing behaviour occurs (and even more so if stabilizing abatement positively influences optimizing abatement). Thus, an RD&D policy has to set out so that the emission reduction path which switches at time T-s falls below the cumulative emission constraint. The reduction paths switching at times T-s+1, T-s+2,..., T automatically fall below the constraint. So, compared to the situation with stabilizers only, the RD&D policy has to be more aggressive in the period 1 to T-s-1. Emission reduction influences the chance of meeting the target since optimizing and stabilizing trajectories share a common (stabilizing) start. Higher emission abatement in the short-term thus increases the chance of meeting the target. This effect is dampened if stabilizing reduction positively influences optimizing reduction, since the cumulative emissions of an optimizing path are lower in this case.

Overall, the analytical insights obtained in this section do not allow for firm statements. Further guidance is sought by the numerical analyses of the next section.

3. A numerical model

The numerical model used for this analysis is a simplified version of the model used in Tol (1997d) -- learning-by-doing is omitted from this analysis -- extended to include the possibility of future policy-makers switching to optimizing behaviour.

Income is 100 in period 0, increasing with 20% per period (a period could be thought of as a decade). The discount rate is 20% or 30% per period. Emissions are 100 in year 0, increasing with 10% per period. Emission reduction costs $\alpha_t R_t^2$, where $\alpha_t = \alpha_{t-1}\exp(-\gamma D_{t-1})/(1+\tau)$. $\tau = 0.1$ per period. $\gamma = 1$. RD&D costs βD_t^2. The weights of the carbon emissions are $W_t = 0.16 + 0.04t$. The number of periods is 20. Unconstrained emissions accumulate to 4500. The emission constraint is put at two-thirds of this: 3000.

Optimal emission abatement is assumed to be very simple: marginal net present benefits equal marginal direct costs (recall that emission abatement does not interfere with the assumedly exogenous economic growth, and that technology changes through learning-by-doing are omitted). In addition, marginal benefits are

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assumed to be constant over time. Thus, optimal emission reduction R_t^* equals where MD denotes marginal damage. In order to enhance the contrast between optimizers and stabilizers, and in line with the cost-benefit literature (Manne *et al.*, 1995; Nordhaus, 1991, 1992, 1994, 1996; Peck and Teisberg, 1991, 1993, 1994, 1995; Tol, 1997a,e), MD is small (0.001).

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Optimal investments in RD&D are set to zero. The derivative of R_t^* to D_{t-1} equals

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leading to a marginal benefit of
so that the marginal net present benefits of investing in RD&D are in the order of MD^2, which is small by assumption, justifying very little investment.

Equation (13) describes optimal abatement if that were path-independent. It is not, since moving from a carbon- and energy-extensive economy to an intensive one is about as costly as moving in the opposite direction. Interpreting (13) as an

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attractor, actual optimizing behaviour follows
where s is the time of switching, so that optimizing reduction falls gradually from the stabilizing path to the optimizing path, at speed ρ; $\rho = 0.9$. The assumption

behind (16) is that there will always be a fossil source of energy (e.g., coal) that is cheaper than its alternatives. Stabilizing paths have a similar constraint, which is ineffective in most cases.

The switch between stabilizing and optimizing behaviour is modelled as follows. The first decision-maker is a stabilizer. In each period, a switch to optimizing behaviour occurs with a probability of 10%. Once switched, all succeeding decision-makers are optimizers. Thus, the chance of finding a stabilizers declines with 10% per period. The chance of changing in the second period is 10%; the chance of changing in the third period is 9%, 8.1% in the fourth and so on.

4. Results

In the first experiment, the policy-maker in the first period sets out a cost-effective path restricting cumulative emissions to a total of 3500 (unrestrained 4408) without bothering about the possibility of future policy-makers switching to optimizing behaviour. Emission abatement starts low and increases monotonically over time (cf. Figure 2). Investments in RD&D slope gently upwards during the first 15 periods, and fall ever more rapidly after that (cf. Figure 3). This is typical of this model, and arguably of any such cost-effectiveness analysis (Tol, 1997d). Net present costs are 2.

Cumulative emissions are considerable higher should future policy-makers switch to optimizing behaviour, even in case the switch occurs relative late, because later baseline emissions are relatively high and count heavily in cumulative emissions, and because the deviation of optimizing emission reduction from stabilizing reduction is so large. Cumulative emissions in these cases vary between 4400 and 3797. The mean of all paths (stabilizing and optimizing) is 4240, and the chance of meeting the 3500 target is only 13.4% (which is the chance of staying on the stabilizing path).

In the second experiment, the expectation of the cumulative emissions should stay below 3500 as an additional constraint. The optimizing policy-makers do not care about this, but they do react to the stabilizing first part of their emission trajectory and to the lower emission reduction costs in the second part. Nevertheless, the stabilizers act by drastically increasing abatement: cumulative emissions fall to 833 (cf. Figure 2). Net present costs rise to 26 (a 13-fold increase; cf. Figure 4). For the optimizing cases, cumulative emissions range between 4344 and 1376. The change is partly the result of additional investments in RD&D (cf. Figure 3), but mostly the result of the fact that the stabilization path is followed for a short or long while. The chance of meeting the 3500 target is still only 28.2% (cf. Figure 4). The logic behind this behaviour of the stabilizing policy-makers is that the optimizers react only a little to changing costs of emission reduction, so that the best bet is to drastically reduce the stabilizing share in the mean cumulative emissions.

In the third experiment, an additional constraint is that the chance of meeting the target should equal 38.7% (that is, 13.4% for the stabilizing path plus 25.3% for the optimizing paths). Now, emission abatement in the stabilization path is reduced (cumulative emission 932) and the time profile changes, with a slower start, and heavier reduction occuring in periods 7 to 13 (cf. Figure 2). Investments in RD&D

are increased, particularly in the early years (cf. Figure 3). Net present costs increase further to 29 (cf. Figure 4). In the optimizing paths, cumulative emissions range from 4371 to 1474. The logic behind the behaviour of the stabilizers is that with these constraints the early switches to optimizing also have to be influenced; this is partly achieved by early emission abatement, and partly by drastically lowering the costs of abatement.

In the fourth experiment, the constraint on the mean cumulative emissions is abandoned. The mean increases to 3714. Net present costs of the stabilizing path fall to 26 (cf. Figure 4). The main difference between this and the previous experiment is that later emission abatement (cf. Figure 2) and investment in RD&D (cf. Figure 3) fall. This is revealed in the cumulated emissions in the stabilizing case (2158 compared to 932) and the optimizing cases (minimum 2364 compared to 1474).

As a sensitivity test, the desired chance of meeting the target is increased to 72.3%, a reasonably safe bet. The net present costs increase from 26 (29 if the mean target is also to be met) to 63 (64). The additional effort lies entirely in the first 10 periods. Both emission reduction and investments in RD&D increase substantially.

In another sensitivity test, the influence of current on future abatement (ρ in equation (16)) is varied between 0.8 and 0.99. If this influence is larger, the mean and probabilistic targets are more easily met. If the influence is smaller, the targets are harder to meet. For a higher influence, the mean target is tougher than is the probabilistic target. For a lower influence, the probabilistic target is tougher. Similarly, if the chance of switching to an optimizing regime increase, the targets are harder to meet. Should this chance depend on the distance between optimizing and stabilizing abatement, than RD&D gains in attractiveness compared to abatement.

5. Conclusions

Climate change is a very uncertain phenomenon. An important, but to date largely ignored part of that uncertainty is the behaviour of future policy-makers. A current policy-maker wanting to stabilize the atmospheric concentration of greenhouse gases faces the problem that this is unlikely to be a welfare maximizing policy, and that therefore future policy-makers have an incentive to switch to less ambitious emission controls.

This possibility strongly influences the trajectory set out by a current policy-maker wanting to constrain cumulative emissions. Investments in emission reduction and technological development to reduce future emission reduction costs both have to increase if the current policy-maker wants to meet her target in expectation or with a certain chance. Intensification of climate policy should occur in all periods should meeting the cumulative emission target in expectation be the objective. Intensification should occur in all periods should a probabilistic target be the objective, but the intensification is distinctly more pronounced in the first periods. In this case, the cost-effective trajectory deviates qualitatively from the one suggested by Wigley *et al.* (1996).

The costs faced by the stabilizing policy-makers increases, in the examples here by an order of magnitude. This indicates that it is in the interest of current policy-makers to design strategies that are acceptable to future policy-makers, even if the desired environmental goals may be compromised.

This paper demonstrates that uncertainty about the motives of future policy-makers is a serious concern to current policy-makers, in that the preferred strategy and its costs differ substantially. Research to further spell out and quantify the consequences is warrented.

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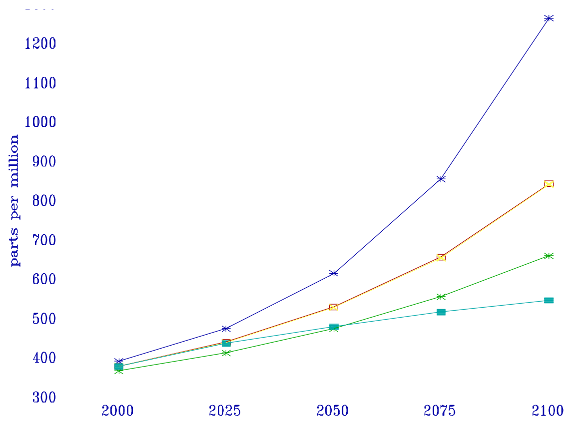

Figure 1. Atmospheric concentration of carbon dioxide in the period 1990-2100 according to *FUND*1.6. Displayed are the median of the business as usual scenario (open squares) and its 5 and 95-percentiles (asterisks); the median of the non-cooperative optimal path (crosses); and the median of the WRE trajectory to a 550 ppm stabilization (filled squares).

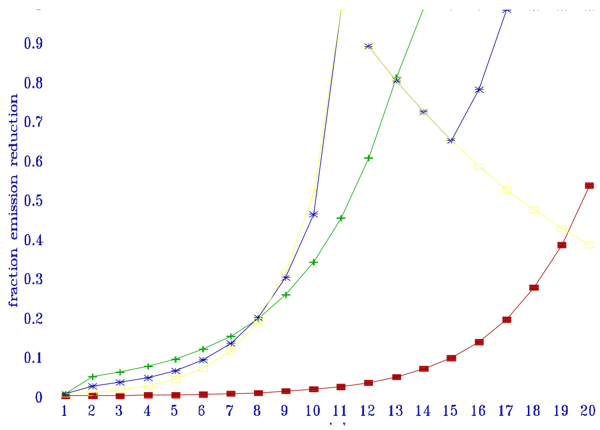

Figure 2. Emission reduction as fraction of the business as usual emissions. Displayed are the standard cost-effectiveness case with a certain target on cumulative emissions and only stabilizers (filled squares); mean target (plusses); mean and probabilistic target (asterisks); and probabilistic target (open squares).

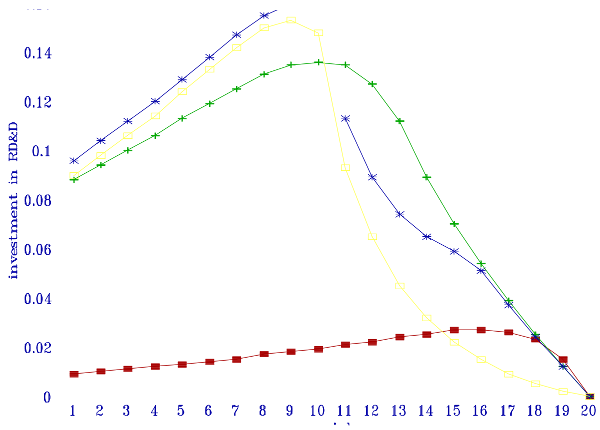

Figure 3. Investments in research, development and demonstration. Displayed are the standard cost-effectiveness case with a certain target on cumulative emissions and only stabilizers (filled squares); mean target (plusses); mean and probabilistic target (asterisks); and probabilistic target (open squares).

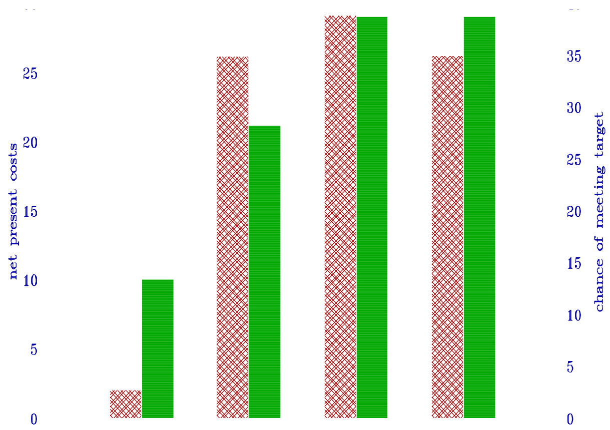

Figure 4. **Net present costs of the stabilizers (left), and the change of meeting the target (right) for the four experiments.**