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Bumping Against a Gas Ceiling Hadi Dowlatabadi *

Abstract

The adoption of physical thresholds as a ceiling for permitted climate change sidesteps contentious issues such as: policy cest, impact valuation, discounting and equity. In this paper I offer some reflections on the concept of tolerable climate change. I also use an integrated climate assessment model (ICAM-3) to demonstrate how uncertainties in our understanding of socio-economic and earth systems reduces the probability of success in keeping climate change within a pre-defined tolerable range. Finally, I explore the implications of socio-economic thresholds for welfare loss in pursuit of a climate policy (e.g., tax rebellions). Crossing such regional socio-economic thresholds will lead to local failures to pursue climate change mitigation policies – increasing the probability of straying beyond the tolerable window of global climate change. Given various uncertainties and the dynamics of the socio-economic and the earth systems, the odds of success in staying within the a climate change window of $\Delta T \le 2^{\circ}$ C, and $\Delta T/yr \le 0.015 ^{\circ}$ C are estimated to be no higher than 25% over the next century. A risk-risk tradeoff approach appears to hold promise, but while adoption of a larger window of tolerance increases the probability of success it also opens the window specification criteria to contention.

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Introduction

Attribution of recent trends in climate change to anthropogenic activities has led to considerable concern about the future extend of anthropogenic climate change (Houghten, Filho *et al.* 1996). This has led to a desire to define limits for such climate change. In general, economists have argued for striking a balance between the costs of mitigation of greenhouse gas emissions and averted climate change impacts (Nordhans 1992). Natural scientists, on the other hand, have argued for the definition of physical thresholds to tolerable climate change. Such thresholds are often defined in terms of the adaptive capacity of natural ecosystems. In one such exercise, the boundaries to tolerable climate change have been defined in terms of inviolable thresholds for the rate of and total temperature change (WBGU 1995). A number of studies are underway to define "safe windows" of climatological change, and translate them into a permissible range of greenhouse gas emission trajectories (Toth. Bruckner *et al.* 1997).

Here, four issues are considered in more detail:

- Characterizing climate impacts and defining Tolerable Windows the presumption of
 intolerance is that the existing managed or natural system is somehow optimized to
 current conditions. Long-term climate oscillations, and rapid land cover changes due to
 human activity have led to regional climate changes in excess of 1°C. The natural
 ecosystems respond with various lags (depending on growth forms and location) and
 path dependency. The current distribution of ecosystems can neither be defined in
 terms of an equilibrium, nor is it an optimum in the traditional sense of the term. In
 defining future thresholds of intolerable loss, we need to consider these issues with far
 greater care.
- Regional climate anomalies and oscillations although often ignored by climate
 modelers, the earth's climate system has long-term oscillations which exhibit century
 scale regional rates of temperature change often between 0.1 and 0.2°C/decade. These
 high regional rates of change in mean temperature have been observed over three to
 seven decades. Strictly speaking then, even nature violates the defined Tolerable
 Window in rate of temperature change. In defining thresholds it is important to
 consider the dynamics of ecosystem adjustments in relation to such change, and the
 combined impact of secular trends in climate change *and* long-term natural oscillations.

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- Translating Tolerable Windows to emissions given uncertainties in the state and dynamics of the earth-human system, meeting the target with certainty is intolerably expensive.
- Thresholds for policy implementation there are thresholds in the political feasibility
 of pursuing a strict climate policy. The probability of such a policy failure on a regional
 level and implications for meeting the TW approach are calculated.

The rest of this paper is divided into three sections. The first section is devoted to a discussion of the challenges inherent in defining Tolerable Windows and impact thresholds. The second section is devoted to a brief description of an integrated assessment model (ICAM) and exploration of the Tolerable Windows Approach under conditions of imperfect knowledge and partial control. In the final section some concluding remarks are offered.

I. Characterizing Climate Impacts

It is tempting to think of ecosystems as systems in equilibrium, in the absence of external perturbations. Climate is often considered the dominant determinant of land cover, and was used by Holdridge as a means of characterizing global land cover (Holdridge 1947). More recently, the Holdridge and similar schemes have been used to estimate the impacts of climate change on unmanaged ecosystems (Emanuel, Shugart *et al.* 1985; Smith and Shugart 1993). The spatial prevalence of vegetation does not fit such simple schemes (Prentice 1990; Shewliakowa 1996).

Paleontological evidence reflects long periods of quiescence in the composition of ecosystems in each region of the earth. These periods of quiescence are punctuated by eras of rapid change (Mayr 1954). Hence, the term punctuated equilibrium was coined to characterize the pattern of such evolutionary change (Eldredge 1971; Eldredge and Gould 1972). This suggests that the entities constituting a community (whether the community is a human society or an ecosystem) develop around locally stable configurations, rather than following a process of continual change, adopting the optimal ensemble and form, as exogenous environmental conditions evolve (Gould 1977; Stanley 1979). There is no reason to reject this paradigm as characterizing the world around us, except in that it makes the life of scientists more difficult. Life grows more difficult, because at any given time we do not know if the quasi-equilibrium system is close to or far away from its "idealized" state. In this paradigm we are hard-pressed to argue that a future condition will necessarily lead to change, or where the threshold of such change may be.

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Impacts of environmental change can be due to extreme events or secular changes. In persistent systems there is generally a level of robustness to extreme events. All else being equal, the longevity of the system is related to the return period of devastating extreme events. When all other factors are not being held constant, the system's resilience to extreme events may change dramatically.

The arguments above highlight two issues:

- first, in order to define impacts we tend to resort to an over-simplified characterization
 of current land cover being optimal for current conditions. This is unlikely to be true
 for managed or unmanaged systems;
- second, because natural systems exhibit punctuated equilibria, estimation of thresholds is likely to be difficult, and projection of impacts after the threshold has been crossed is a matter of speculation rather than knowledge.

Regional Climate Anomalies and Oscillations

The WBGU (1995) have used historic evidence of climate change to establish threshold values for climate change in terms of ΔT and ΔT /decade. Their argument being that a record of pre-industrial climate change can be used to define the range of "natural climate change" for which ecosystems have been relatively robust. There is much to recommend this approach, except that at the time of the analysis, our knowledge of climate change on century time-scales was limited. In the past three years, three separate studies have identified natural climate oscillations of significant magnitude (Schlesinger and Ramankatty 1994; Mann, Park *et al.* 1995; Mahasenan, Watts *et al.* 1997). In each study actual or proxy records of local temperature show annually averaged mean temperature anomalies with amplitude of = 1°C. These natural oscillations have periods of = 70 yrs., = 160 yrs., and ≈250 yrs. Thus, for the shortest period oscillation, identified by Schlesinger and Ramankutty from the instrument record, the historic regional rates of temperature change have been approximately 1°C/40 years. In the study by Mahasenan Watts and Dowlatabadi, the pre-industrial natural rate of temperature change has approached 1°C/80 years.

Identification of large regional oscillations in temperature anomalies in the proxy and instrument records call into question presumptions about the dynamics of regional ecology and climate. Perhaps it is appropriate to consider the time constant for the dynamics of different components of the ecosystem. This would imply coupling between system components of different times-cales on a discontinuous basis (Gunderson, Holling et al.

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1995). The interaction of system components of different time-scale and their implications can be seen in many regions, a most vivid example being the impact of spruce buworm on the forest dynamics of New Brunswick (Baskerville 1995).

The faster components of the system are likely to be influenced by the measured climate anomaly since 1880. Thus, the issue of threshold identification is made more complicated than a simple presumption of equilibrium between the current ecosystems and climate. The dynamics of forests does not appear to be directly related to climate anomalies, but to the dynamic interaction of faster system components, which may be sensitive to climatic conditions.

These observations about natural rates of regional temperature anomaly and ecosystem dynamics have two implications for the WBGU thresholds:

- first, past natural oscillations in regional temperature anomalies approximate the upper bound of the identified thresholds, leaving no room for any anthropogenic change;
- second, snap-shots of ecosystems are not in a stable equilibrium with regional climates and cannot offer a basis for definition of a threshold for temperature anomalies.

Interactions, Uncertainties and Inversion of Tolerable Windows

Beyond the difficulties of characterizing possible climate change thresholds, is the challenge of inverting tolerable windows of climate change into a corridor of permissible emission paths. In the ICLIPS project this inversion process is being implemented for a system of decoupled filters (Toth, Brackner et al. 1997). Thus, while impacts of climate change on a valued outcome are used to define the tolerable window, the implications of climate change mitigation policies on the same valued outcome are ignored.

Let us consider a specific impact to illustrate the need for an integrated approach to assessment of impacts from both climate change and climate policy. The study on food security by Parry and Livermore (1997) has projected a response surface for the number of people at risk of severe hunger through time, for different levels of temperature anomaly above 1990 normals. They suggest that higher global temperatures will lead to more hunger. Clearly this should be avoided. But if the study is interpreted as: "if climate change is limited, there will be *less* hunger" we would have fallen prey to a severe oversimplification of the issues involved and lulled into a sense that *climate policy* will not be creating hunger.

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Hunger today is not caused by inadequate global food production, it is most often caused by political failure to distribute food, or by consumers not having the means to procure it. It is clear that measures to control climate will have to limit CO₂ emissions. This will involve an increase in the price of fossil energy. Commercial agriculture is an energy intensive activity. Agricultural products are likely to become more expensive to produce and to distribute. Hence, unless specific measures are taken to isolate food distribution and procurement from these "knock-on effects" of climate policy, hunger cases will be generated by the climate mitigation policy. I do not know if the number of these cases will exceed the number of hunger cases averted by limiting climate change. Nevertheless, I do know that de-coupling the *target*, from the *process* in translating TW to permissible trajectories of emissions can lead to counter-productive policies.

Translation of a tolerable window into a corridor of permissible CO₂ emission trajectories needs to consider one last challenge: uncertainty about the dynamics of the natural and social systems. This uncertainty is a reflection of our current state, in which despite all empirical evidence at our disposal, we are unable to characterize the world with certainty. Projection of socio-economic trends, their response to interventions, the response of the climate system to further emissions of greenhouse gases and acrosols, and the impacts on managed and natural systems is uncertain,

Inversion procedures that include uncertainty will show that there is always a probability of crossing thresholds in the tolerable window. By being cautious, this probability can be minimized but being cautious cannot eliminate it.

The observations above lead to two conclusions:

- that the inversion process requires coupling of the various filters, for example the implications of the policy on the impacts of concern cannot be ignored;
- uncertainties in our understanding of elements making up the socio-economic and natural systems will mean that prospective policy measures towards the target will never guarantee that the thresholds will be respected.

II. A Quantitative Exploration of the WBGU Using ICAM-3

Discussions above have highlighted the challenge of defining climate impacts, and thresholds. Nonetheless, integrated assessment models can be employed in performing the inversion of tolerable windows into climate change mitigation policies.

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A brief overview of ICAM-3

Over the past seven years the ICAM-3 model has been developed to capture the salient interactions and uncertainties described above, ICAM-3 is a simulation framework with a focus on: completeness, representation of uncertainties (parametric and structural), and diversity (regional demographics, economics, elimate and multi-criteria impacts). The model uses 2000 parameter uncertainties and over 2¹² structural uncertainties to reflect our state of knowledge. It has 11 world regions, impacts that range from market damages in coastal areas to health effects in urban areas. The simulations are run for the period 1975 to 2100, in 5-year time intervals.

The drivers of change in ICAM-3 are population growth and productivity of capital and labor. Demographics are modeled to respond to changes in various socio-economic factors and calibrated to reproduce the range of population projections by the United Nations and IIASA (Lutz *et al.*, 1997). Productivity growth is an exogenous target parameter, defined for each region according to the scenario design published by the Energy Modeling Forum (EMI²-14 1995). A complete description of ICAM can be found elsewhere (Dowlatabadi and Morgan 1998).

Unlike optimization frameworks, the challenge of meeting a climate change target such as the WBGU, is treated as a control problem in ICAM-3. In optimization frameworks, the objective function is maximized (in this case probably mitigation costs) while meeting constraints such as those specified by the WBGU. Thus, there is no question of violating the climate change threshold.

When the problem is defined in terms of a control problem, we need to define a control algorithm within ICAM that responds to available measures of system conditions at each time period and steers it towards some objective (in this case away from defined thresholds).

Two aspects of the system need to be defined: a) what measures of system state are observed? h) how is the control mechanism implemented and revised through time?

In the version of the model used in this exercise I employed the observation and control strategy found most efficacious in numerous past experiments. The TWA is about the ΔT and $\Delta T/yr$, state variables. Consequently, monitoring of these is the basis of the control algorithm. At any given time t, ΔT_r and its rate of evolution is observable within the model. Future projections of ΔT_{ren} are based on extrapolation of current state indicators

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 $(\Delta T_t + n \Delta T_t)$. Based on these projections, it is possible to estimate whether the TW of temperature ΔT anomaly or its rate will be violated.

The system is "controlled" via a carbon tax. This tax is revised at each period in accordance with whether the TW is projected to be observed or violated. A simple quadratic penalty function is used to determine the response of the control (carbon tax) to projected variance between the TW limits and projections based on current trends.

$$\tau_{i} = \tau_{i-1} \cdot \alpha \left[\left[\left(\Delta T_{i-1} + n \cdot \Delta \dot{T}_{i-1} \right) - \Delta T^{*} \right] \right] \Delta T^{*} \right]$$

where :

 τ_i is the calculated level of tax in period t;

 ΔT_{r-1} is the level of the variable observed in the previous period;

 $\Delta \hat{T}_{r-1}$ is the rate of change in the variable observed in the previous period;

 ΔT^* is the negotiated target:

n is the time for socio-economic planning and response; and,

is a constant of proportionality; the sign of which changes depending on whether the projections are above or below the target.

Observations of the key indicator are averaged over five years. Revisions to the tax occur once every five years. There may be superior models of behavior, but I have not been able to find them.

Whenever more than one more than one state variable has to be monitored (e.g., WBGU), the control variable with the largest value is used to steer the system. If the penalty for exceeding the target is set to be more severe, for example the use of the 4⁺ power in equation above, there is a probability of not exceeding the target, but the magnitude of interventions and their variability from one time period to another is unacceptably large. Therefore, the chosen control algorithm does not assure least cost solutions, and does not guarantee that the thresholds are not exceeded.

The challenge of meeting targets such as WBGU are compounded by two additional features of nature reflected in ICAM-3:

 First, the system responds to interventions with a lag. Thus, a carbon tax introduced to limit CO₂ emissions will lead to a response diffused in time and of uncertain efficacy. The lag in time arises from the socio-economic response to prices through demand

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adjustments and structural change in the economy (0-5 years) inter-fuel substitution (10-15 year lag) technological innovation and diffusion (5-20 years). The relative magnitude of these effects is not well known. There are further lags in the system, in that the carbon cycle is incompletely known, and that the climate system responds with a lag to changed radiative forcing.

Second, the uncertainty in many aspects of the system involves the rate of response to intervention and the equilibrium response to the intervention. Not knowing either of these with assurance leads to possible misinterpretations of empirical evidence. For example, let us assume that we are sure that there has been a change in net radiative forcing of 1Wm⁻², and an observed global temperature anomaly of 0.5°C. Does this mean that the system has no lag and an equilibrium response of 0.5°CW⁻¹m²? Or does it mean the system has a 10 year lag and an equilibrium response > 5°CW⁻¹m²? Continued observation, and anomalies such as Mt Pinatubo will allow disentanglement of such jointly distributed uncertainties. But for the present, we cannot disentangle these uncertainties and are thus unable to define the walls of a corrider of emissions towards ΔT elimate change thresholds with confidence (Dowlatabadi 1996).

Results

Many different thresholds can be defined, each would be specific to an impact in a region, and evaluated using relatively arbitrary criteria. None would have global salience. Nevertheless, we need to define alternatives to the economic paradigms involving costbenefit analysis in order to explore the different aspects of the available policy choices. In order to explore the TW concept, I will use ICAM-3 to simulate the challenges involved in observing the WBGU thresholds using prospective and iterative control. The quantitative studies carried out explored four issues:

- The implication of parameter uncertainty on the success of control toward the WBGU thresholds when only considering a relatively simple model of socio-economic dynamics and CO₂ emissions.
- The implication of structural uncertainty on the success of control toward the WBGU thresholds.
- The implication of a more complex model including other greenhouse gases, aerosols, and natural climate oscillations on the success of control toward the WBGU thresholds.
- The implication of possible socio-economic thresholds in policy cost for successful pursuit of policies aimed at observing the WBGU thresholds.

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In all the case studies presented here the control objective is to limit CO₂ emissions in order to observe a combined ΔT and ΔT /yr, threshold of 2°C and 0.015°C/yr. As noted earlier, the model has over 2000 uncertain parameters. In order to capture the implications of these parameter uncertainties the simulations are repeated 100 times using Latin Hypercube Sampling from the probability distributions of the uncertain parameters. The results presented here are the summary statistics from the ensemble of results generated by these runs. Extensive sensitivity and uncertainty analyses can be conducted in this framework in order to learn the key contributors to failure of a control strategy to meet its target and other outcomes of interest (Dowlatabadi, Morgan *et al.* 1995).

CO2 emissions only - exploring the implications of parameter uncertainty

In order to explore parametric uncertainties, a simplified variant of ICAM is used in which only radiative forcing due to CO₂ is considered. A further simplification of the natural system involves omission of long-term climate oscillations. Simplifications are also made in the socio-economic module, by eschewing endogenous modes of technical change in energy production and consumption in favour of exogenously specified parameters. More detailed explanations of the variants of the energy-economics module in ICAM-3 is presented elsowhere (Dowlatabadi *in press*).

In the panels of Figure 1 we can see the 10th, through 90th percentile range of key outcomes in both *the business as usual* (BAU) and *control* scenarios. The wide range of values encompassed by trajectories in each panel reflects the sensitivity of results to parameter uncertainties. In the BAU scenario, Figure 1a, we can see that in the absence of interventions the temperature anomaly has an 80% chance of growing to be between 2 and 5°C. There is a 10% chance that BAU will lead to a globally averaged temperature anomaly of less than 2°C, and there is a 10% chance that it will exceed 5°C. Thus, in terms of prospective controls we may need no control for the AT threshold in 10% of cases. The BAU range of the rate of temperature change. Figure 1c, shows a similarly broad range of potential outcomes, again with a 10% chance than no control may be needed.

When we consider the control trajectories we find that the control nimed at limiting temperature change to 2°C, only succeeds in 75% of cases, see Figure 1b. Furthermore, in 75% of cases, the threshold for the rate of temperature change is exceeded for the first three decades of the 21st century, see Figure 1d. Finally, the level of control, expressed in terms of the shadow price of carbon, leading to these results is presented in Figure 1e. It would be a mistake to interpret this panel as a failure to meet the targets despite high control levels. In a fraction of the simulations, failure to respect thresholds is due to the prior expectations.

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shaping the control path being erroneous, and the system's dynamics being unforgiving of such mistakes.

It is evident that parameter uncertainties, even in this simple variant of ICAM-3, lead to a significant probability of failure in controlling CO_2 emissions to meet the climate change thresholds with assurance. Furthermore, uncertainties in economic growth, population growth, autonomous energy efficiency improvements, elasticity of demand, inter-fuel substitution, availability and price of non-fossil energy sources, and climate sensitivity can lead to the need for extreme levels of control. In the case of this simple model, for 10% of the simulated cases, the shadow price of carbon exceeds \$700/TC.

Such high shadow prices for carbon are worthy of special mention because, in today's economy, the economic value of carbon use in some regions of the world is below \$600/TC. The imposition of a large shadow price on carbon in these regions could drive their economies beyond the threshold of collapse. This existence of and probability crossing this threshold is examined below.

CO2 emissions only - exploring the implications of structural uncertainty

In Figure 2 the key BAU and control projections are estimated for a significantly different model of the energy-economy. In this model, fuel scarcity driven price hikes for fossil fuels can lead to new fossil fuel discoveries and subsequent price collapses. Price hikes and interventions to limit CO₂ emissions lead to innovation in energy and carbon efficiency. There are economies of learning, hence the cost of CO₂ control and non-fossil energy production declines with experience. More detailed exploration of this and other energy economy variants is presented elsewhere (Dowlatabadi 1996).

This structural model of the energy economy leads to significantly higher emissions of CO_2 . This can be detected in the higher trajectories of the BAU Δ T and Δ T/yr, projections. However, the economy is much more responsive to control measures. Hence, the overall impact of higher BAU emissions does not necessitate a higher level of control. A comparison of the panels in Figures 1 and 2 reveals the results are broadly similar. This suggests that, in the context of this problem, parameter uncertainties are more significant contributors to uncertainty in meeting objectives, that widely different structural models of the energy-economy. It should be added however, that in the second variant of the energy-economy model climate change control imposes welfare losses only one quarter as large as those of the first model structure (Dowlatabadi 1996).

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GHG & aerosol emissions, plus natural climate oscillations — estimating the probability of exceeding the climate change threshold

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So far, CO₂ control towards the WBGU tolerable window of temperature change has been examined using a model excluding greenhouse gases other than CO₂, nerosols, and long-term natural oscillations in the climate system. Inclusion of these factors leads to the following three complications in meeting the climate change targets:

- controls are exercised over CO₂ emissions while other greenhouse gases are also increasing;
- control of fossil CO, emissions will reduce the flux of aerosels, leading to a temporary increase in net radiative forcing and AT/yr.;
- natural oscillations in the climate system are going to lead to changes in \Delta T and \Delta T/yr. inrelated to emissions and controls, making observations more ambiguous and monitoring the efficacy of control measures more uncertain.

In the Figures 3a-e, the probabilistic projections from a model including these complicating factors are presented. The additional greenhouse gases lead to ΔT for BAU between 0.5 and 2°C higher than in the earlier models. The inclusion of aerosols leads to a spike in $\Delta T/y_{T,*}$ possibly as large at 0.015°C/y_T, when controls are imposed. The natural oscillations lead to greater difficulty in staying within the ΔT thresholds. Prospective control is unable to deliver a temperature anomaly of less than 2°C in more than 50% of cases. Finally, the cost of controls is considerably higher, exceeding \$500/TC in 50% of cases towards the end of the projection period. Realistically speaking, these very high control costs are unlikely to be realized. Their simulation in ICAM reflects the absence of controls over CH₄ and N₅O emissions, and innovations in non-carbon energy supply and CO₂ management. It is more reasonable to expect that these would be forthcoming in response to opportunities created by high control costs.

GHG & aerosol emissions, plus natural climate oscillations — estimating the probability of exceeding the socio-economic threshold

Earlier, in conjunction with the impacts of climate change on hunger, I urged the use of integrated assessments that can assess the impact of the climate policy on hunger also. Here, ICAM-3 is used to assess whether the cost of meeting the climate thresholds leads to crossing of socio-economic thresholds.

What may be considered a socio-economic threshold? Historic evidence indicates that major wars lead to loss of welfare > 20%. Usually, wars can be sustained by having a

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strong publicly supported agenda. It is difficult to imagine socio-economic conditions where climate change control would fit this mold. Thus, it is likely that when the loss of welfare in pursuit of climate change thresholds mounts, there will be forces in each region urging rebellion.

Using the model, the cases in which the cost of controls exceeds a given level of welfare loss can be estimated. In Figure 4, a histogram is presented where the height of each bar indicates the probability of welfare losses \geq 20%. The welfare loss estimates due to the climate policy are assessed for each 5-year period, and each of the 11 regions in ICAM-3.

Policy rebellion, is likely to lead to even higher probabilities of failure to meet climate change thresholds. In Figures 3a-e, the feet of citizenry in each region is kept firmly to the fire, enforcing the climate control policy regardless of regional welfare losses. If each region is allowed to drop $C\Omega_2$ controls if their costs exceed the 20% welfare loss, the ability to respect the climate thresholds is reduced by a further 15%.

Consideration of equity in distribution of the control burden can reduce the probability of regional rebellion. For example, a region with a lower carbon efficiency (\$/1C) economy would have lower control levels imposed. If controls are pro-rated in this way, the peak probability of rebellion declines to less than 5%, but the probability of respecting the WBGU thresholds declines to less than 15%. If the costs of controls in these regions are born by wealthier nations the probability of meeting the WBGU increases, but the chances of rebellion in these regions rises dramatically!

III. Conclusions

Defining what level of climate change is "tolerable" is a thorny question. However, it is a useful alternative to cost-benefit frameworks because it requires explicit assessment of and tradeoffs between multi-criteria impacts. Elsewhere, Morgan, Kandlikar, Risbey and I have argued why cost benefit analysis and other decision criteria based on utility theory are of limited applicability to the climate problem (in press).

Rights based approaches could be defined in terms of thresholds of tolerability. However, universal inviolable thresholds are impossible to establish as each activity and region would have its own criteria. It is unlikely that a universal climate change threshold can be defined assuring the survival of all ecological systems.

The translation of any threshold into a corridor of permissible trajectories cannot treat the different elements of this process as being independent of one another, or known with certainty. Prospective control of emissions towards meeting any climate change goal is a

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sequential decision-making process. There are many uncertainties in our knowledge of the socio-economic and climate systems, which make *ex ante* controls unable to *guarantee* thresholds being respected. The level of confidence in meeting thresholds can be increased through hedging strategy and risk aversion, but these are costly in terms of welfare loss.

The tradeoff between the probability of meeting climate change thresholds and the welfare loss due to the mitigation policy has led some investigators to consider larger "tolerable windows" of climate change. Thus, an arbitrarily larger window is tolerated and lower welfare losses are suffered in meeting these thresholds. Definition of this larger window involves an implicit loss of rights for some ecosystems, in a tradeoff for lower welfare losses. It is not clear to me, why this arbitrary tradeoff is methodologically or morally superior to benefit-cost analysis.

Tradeoffs across multiple criteria are the stock and trade of politicians – not economists. Market trades are the stumping grounds of economists – much of the impacts of climate change will be outside the marketplace. In cost-benefit analysis of climate change different impacts are valued (scrnetimes controversially) and it is assumed that money transfers can be used to compensate various parties for inequitable outcomes from collective decisions. By adopting a formal valuation and tradeoff approach. CBA sets a standard against which TWA will be measured.

For those familiar with CBA, the adoption of a larger window simply to facilitate a higher chance of observing its limitations is arbitrary. The larger window will increase the chances that some rights are preserved while explicitly accepting the trampling of others. In a sense this negates the contribution of TW approaches by trivializing the tradeoff processes. We only need to recall the difficulty faced by EU member countries in agreeing to revised national abatement targets after COP-3 to recognize the intricacies of political tradeoffs. Somehow, a less restrictive target after Kyoto was not a simple linear interpolation of the stricter negotiating position adopted before the Conference of the Parties.

The process of defining a TW, involves the generation of information about multi-criteria impacts and their potential non-linear relationships to climate change and climate policy. This information is critical to the political/democratic process of collective decision-making and addresses the shortcoming of CBA in trivializing valuation across and compensation for impacts. We are far front Ending an ideal strategy for addressing climate policy challenges, however with the addition of TWA we will be asking explicit questions often implicitly assumed to be easy to answer in the past.

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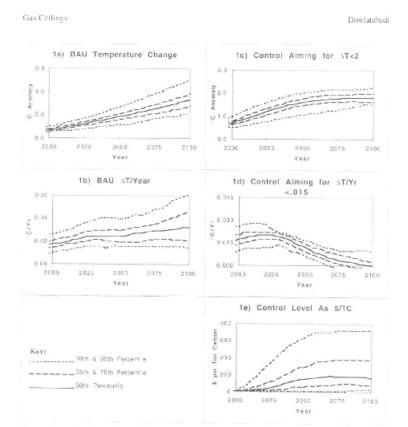
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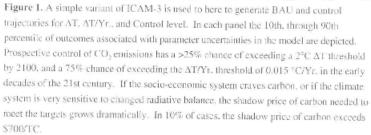
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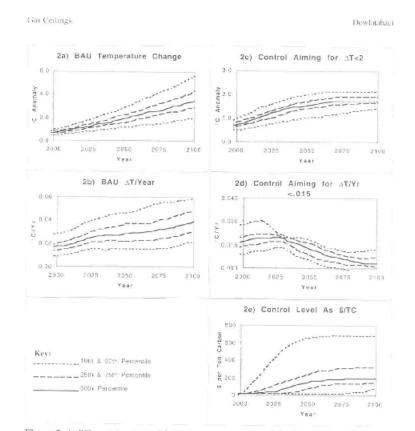


Figure 2. A different structure of the energy economy module leads to a different set of energy use and CO₂ emissions in the BAU projection (2a). Consequently, the controlled trajectory has a higher chance of exceeding the threshold (2c). The BAU rate of temperature change has a higher probably of exceeding 0.04°C/yr (2b). Finally, the shadow price of carbon reflects the implications of model structure variations on the responsiveness of carbon use to intervention. The upward trend in 10th percentile of carbon shadow prices hints at the long term implications of different energy-economic modules. In the short ten however, it appears that parameter uncertainties dominate the consequences of model structure uncertainties.

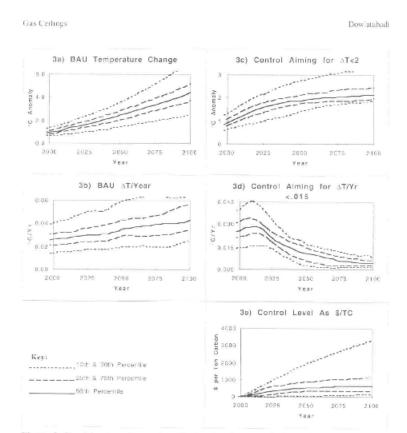


Figure 3. Consideration of natural oscillations in climate, emissions of GHGs other than CO_2 and sulfate and carbon aerosols leads to significant changes in the BAU and control projections. Without control, ΔT will increase by between 0.5 and 2°C more by 2100 (3a). With aerosols, the initial impact of control is to raise $\Delta T/yr$, by up to .015°C/yr, see (3d). As the controls are *only* on CO_2 emissions, unrealistically high shadow prices for carbon are required (3e).

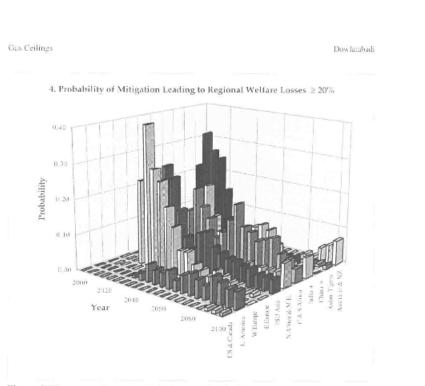


Figure 4. When control costs are high, there can be significant loss of welfare. A 20% loss of welfare is equivalent to the losses experienced by nations engaged in major wars. In such times, porsuit of climate change mitigation policies are likely to be abandoned unless greater losses from climate change are evident.

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