

# The regrets of procrastination in climate policy

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## Abstract

Anthropogenic carbon dioxide (CO<sub>2</sub>) emissions are projected to impose economic costs due to the associated climate change impacts. Climate change impacts can be reduced by abating CO<sub>2</sub> emissions. What would be an economically optimal investment in abating CO<sub>2</sub> emissions? Economic models typically suggest that reducing CO<sub>2</sub> emissions by roughly ten to twenty per cent relative to business-as-usual would be an economically optimal strategy. The currently implemented CO<sub>2</sub> abatement of a few per cent falls short of this benchmark. Hence, the global community may be procrastinating in implementing an economically optimal strategy.

Here we use a simple economic model to estimate the regrets of this procrastination—the economic costs due to the suboptimal strategy choice. The regrets of procrastination can range from billions to trillions of US dollars. The regrets increase with increasing procrastination period and with decreasing limits on global mean temperature increase. Extended procrastination may close the window of opportunity to avoid crossing temperature limits interpreted by some as ‘dangerous anthropogenic interference with the climate system’ in the sense of Article 2 of the United Nations Framework Convention on Global Climate Change.

**Keywords:** climate change, climate threshold, economically efficient climate change strategies

This paper is dedicated to the memory of David Bradford.

## 1. Introduction

Is the world waiting too long to start serious action to abate carbon dioxide (CO<sub>2</sub>) emissions? To answer this question we need a model of what ‘the world’ is trying to do. An economic model of climate change may provide a useful framework to analyse this question. In this framework, the world’s economic equilibrium is interpreted as though it were the solution of an optimization problem, a utilitarian balance of the interests of people in the present and in the future. One instrument to achieve this balance is investment in capital stock. Investment

in capital stock involves balancing the interests of people in the present with those in the future because economic output can either be consumed now or invested in capital stock to increase future economic output. An increase in future economic output increases future potential consumption. Historical data allow inference about how the balance between present and future consumption has been struck. The historical data hence provide a description of the observed value judgment about intertemporal welfare distribution.

The climate problem adds a second instrument to affect the balance of the interests of people in the present and the future: investment in abating CO<sub>2</sub> emissions. The economic model can be used to derive optimal investments in abating CO<sub>2</sub> emissions that are consistent with the observed value

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judgment. The model hence allows statements about how the world might deal consistently with the problem of controlling CO<sub>2</sub> emissions. This framework can, of course, not prescribe the value judgment of how society is to allocate welfare across time. The economic model can, however, be used to test for the consistency of two investment strategies given a simple but transparent model of the relevant trade-offs and observations about past value judgments.

Here we estimate regrets about procrastination in implementing optimal investment strategies for abating CO<sub>2</sub> emissions. A climate policy is optimal in our analysis framework if it treats climate-related investments in the same way as ordinary economic investments have been treated in the past. Procrastination is defined as following a business-as-usual strategy (i.e. zero abatement of CO<sub>2</sub> emissions), rather than the optimal path, until some future time. After this point the strategy follows an optimal path. Procrastination increases future climate change and the resulting climate change damage. Procrastination can also increase the required future investment in CO<sub>2</sub> abatement to achieve a given climate objective. Procrastination hence results in future costs, or regrets.

We adopt a very simple model of the coupled natural-human system to derive such optimal policies. This simple model provides a transparent and parsimonious analysis framework, but also imposes several caveats on the conclusions. We will return to these caveats in the discussion section below.

This analysis is arguably closest in nature to Yohe *et al* (2004). We expand on the benchmark study by Yohe *et al* (2004) in three main aspects. First, we allow for a higher temporal flexibility in the choice of strategies. Yohe *et al* (2004) analyse the choice of an initial carbon tax (which then grows at the rate of interest). Our study, in contrast, optimizes the abatement trajectory over the full time horizon, which can lead to lower overall abatement costs. Second, our choice of the social rate of time preference is arguably more consistent with the observed discount rates than Yohe *et al* (2004). Finally, we expand the range of considered procrastination periods.

## 2. Methods

We adopt the DICE-94 model (Nordhaus 1994) as a simple tool. The DICE model is a globally aggregated model of optimal economic growth (cf. Ramsey 1928), amended with simple representations of anthropogenic climate change, the associated impacts and the economic trade-offs associated with investments to reduce CO<sub>2</sub> emissions. The model has been used in several previous studies (e.g. Nordhaus 1992, Tol 1994 or Keller *et al* 2004) to analyse questions about efficient timing or extent of abating CO<sub>2</sub> emissions. Here we give a brief overview of the model. A more detailed description is given in Nordhaus (1994).

Economic production in the model is determined by a Cobb–Douglas production function with inputs of capital stock, labour and technology. Economic production results in CO<sub>2</sub> emissions which drive a simple carbon cycle model.

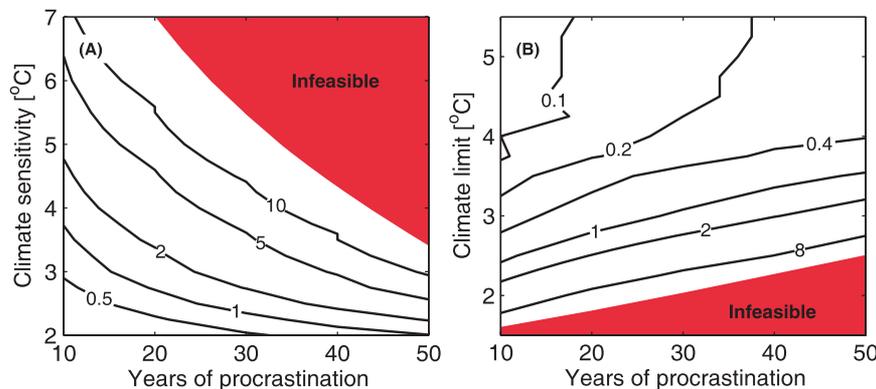
The carbon cycle model translates the CO<sub>2</sub> emissions into atmospheric CO<sub>2</sub> concentrations. Changes in atmospheric CO<sub>2</sub> concentrations cause changes in the global mean temperature, which are taken as a proxy for anthropogenic climate change. Changing global mean temperatures cause economic damages, which, in turn, decrease economic output. The stylized decision-problem in the model is to maximize welfare, which is approximated by a weighted sum of the utility of consumption over time. Utility is defined as the logarithm of per capita consumption. The flows of utility over time are weighted by population size and a discount factor determined by a social rate of time preference. The decision-maker can maximize welfare by choosing optimal trajectories of investments in capital stock and in CO<sub>2</sub> emission abatement.

The model is implemented over a finite time horizon with decadal time-steps. We analyse strategies between 1965 and 2155. Numerical artefacts due to the finite time horizon are reduced by extending the model time domain by another 280 years. The objective to limit the increase in global mean temperature below certain levels is represented as an optimization constraint. We solve the optimization problem using a genetic algorithm (Runarsson and Yao 2000). We assess the convergence of the optimization algorithm by comparing two independent solutions (cf. Moles *et al* 2004). Specifically, we randomly initialize the population of the genetic algorithm and compare the resulting strategies after the optimization step. Solutions with basically identical abatement strategies (root mean squared error < 2%) are accepted as converged. Following McInerney and Keller (2007), we approximate the optimization problem by a sequential approach. In the first step, we determine the optimal investment in capital stock for a business-as-usual strategy. We then fix the investments in capital stock and optimize the investments in abating CO<sub>2</sub> emissions.

We approximate the historic climate policy as following a business-as-usual strategy before 2005. Abatement strategies can change from 2005 onwards. Procrastination is represented in the model as a continuation of the business-as-usual strategy beyond the year 2005. For example, a procrastination period of twenty years implies following a business-as-usual strategy until the year 2025. After the procrastination period, the carbon dioxide abatement strategy follows an optimal path. The deviation from the economic optimal path due to the procrastination decreases welfare. The regrets of procrastination are expressed as the hypothetical consumption change in the year 2005 that would cancel out the welfare loss due to the procrastination. Regrets are given in 2005 US\$, adjusted from the base-year in the model using the consumer price index (BLS 2007).

## 3. Results and discussion

We first analyse climate policies designed to limit globally averaged warming below 2.5 °C (figure 1(A)). This climate limit has been suggested as the temperature at which a collapse of the West Antarctic Ice Sheet might be triggered (O'Neill and Oppenheimer 2002). A collapse of the West Antarctic Ice Sheet is an example of a potential climate threshold



**Figure 1.** The costs of procrastination in trillions of US dollars (2005 base). Shown are results for the objective to limit globally averaged warming to 2.5 °C as a function of the climate sensitivity (panel A) and for a range of possible climate objectives, given the expected value of the climate sensitivity (Andronova and Schlesinger 2001) (panel B). The shaded areas illustrate the regions where the procrastination has rendered the climate objective infeasible in the model.

response that might correspond to the language of Article 2 of the UN Framework Convention on Climate Change (UNFCCC 1992): ‘dangerous anthropogenic interference with the climate system’. Procrastinating for just 10 years can carry regrets on the order of hundreds of billions to several trillions US\$, depending on the currently uncertain climate sensitivity (Andronova and Schlesinger 2001). For high climate sensitivities and long procrastination periods, the objective to avoid the 2.5 °C limit becomes infeasible (figure 1(A)). The infeasible regions in figure 1 show where the procrastination has resulted in a committed warming exceeding the temperature limits. The committed warming is the maximum of the future temperature trajectory given the maximum feasible CO<sub>2</sub> emissions abatement. At a given time, the committed future warming can exceed the observed present warming because the carbon and climate system show a considerable inertia (cf. Wetherald *et al* 2001).

Future generations may, of course, choose different temperature limits (cf. Keller *et al* 2007b). Our current procrastination may render low temperature limits infeasible (figure 1(B)). The infeasible region expands from approximately 1.5 °C for a procrastination of a single decade to roughly 2.5 °C for a procrastination of five decades. Choosing a higher climate limit reduces the regrets. So-called overshoot trajectories may allow us to return to temperatures below such limits, but the consequences of such strategies are uncertain (O’Neill and Oppenheimer 2004).

The simplicity of our model introduces several important caveats. First, a cost-efficient policy may not be a good predictor of what eventually will be implemented (Bradford 1999). Furthermore, the model contains several biasing structural assumptions (cf. Nordhaus 1994, Nordhaus and Boyer 2000). Our analysis could be improved, for example, by representations of (i) uncertainty and (partial) learning (e.g. Hammitt *et al* 1992, Nordhaus and Popp 1997, Yohe *et al* 2004, O’Neill *et al* 2006, Keller *et al* 2007a), (ii) incomplete participation of nations in climate management strategies (Fankhauser and Kverndokk 1996, Keller *et al* 2003), (iii) socioeconomic inertia (Grübler *et al* 1999) and (iv)

endogenous technological change (cf. Arrow 1962, Argote and Epple 1990). For example, the fact that the model neglects socioeconomic inertia likely underestimates the regrets of procrastination. Reducing the likely biases introduced by these approximations is an area of active research (e.g. McInerney and Keller 2007, Nordhaus 2007).

Given these caveats, the economic analyses of climate change seem to agree, however, that non-negligible cuts in near-term CO<sub>2</sub> emissions constitute an economically sound balance between the costs of action and the costs of inaction. The currently implemented CO<sub>2</sub> emission cuts fall short of this balance. Procrastination may be purchased at substantial costs. The regrets are sizeable for the current best estimate of economic damages of climate change. Limiting the increase in global mean temperature to reduce the risks of climate threshold responses increases the regrets considerably.

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