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Climate policies under climate model uncertainty: Max-min and min-max regret☆

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ABSTRACT

Temperature responses and optimal climate policies depend crucially on the choice of a particular climate model. To illustrate, the temperature responses to given emission reduction paths implied by the climate modules of the well-known integrated assessments models DICE, FUND and PAGE are described and compared. A dummy temperature module based on the climate denialists' view is added. Using a simple welfare-maximising growth model of the global economy, the sensitivity of the optimal carbon price, renewable energy subsidy and energy transition to each of these climate models is discussed. The paper then derives max-min, max-max and min-max regret policies to deal with this particular form of climate (model) uncertainty and with climate scepticism. The max-min or min-max regret climate policies rely on a non-sceptic view of global warming and lead to a substantial and moderate amount of caution, respectively. The max-max leads to no climate policies in line with the view of climate sceptics.

1. Introduction

The complex interactions between greenhouse gas emissions (GHGs) and the earth's climate are still highly uncertain, as has become clear from the excellent work by the Intergovernmental Panel on Climate Change (IPCC) on comparing the temperature responses resulting from various emission reduction paths to different Integrated Assessment Models (IAMs). Much effort has gone into elucidating the effects of the many uncertainties (about key parameters such as the climate sensitivity or the transient climate response, positive feedback loops such as release of CH_4 from ocean floors, catastrophic shocks, etc.) in the climate models of these IAMs by generating fan charts for the temperature responses to emission reduction paths for each of the main climate models. It is important, however, to distinguish between all the *statistical* uncertainties concerning the parameters, equation errors, shocks and initial conditions of a particular model, on the one hand, and *scientific* uncertainty about which particular climate model with all the scientific uncertainties that are associated with it is the right one, on the other hand (cf. Arrow, 1951).[1] Our objective in this paper is to analyse the effects of the second type of uncertainty, scientific or more precisely climate model uncertainty, on the optimal price of carbon and optimal energy transition and to suggest suitable ways of dealing with these fundamental uncertainties.

To create a testbed to illustrate the effects of climate model uncertainty on optimal policy formulation, we use the carbon cycles and temperature modules of three prominent IAMs that are used most by economists and in policy debates: the “Dynamic Integrated model of Climate and the Economy” or DICE (Nordhaus, 2014); the climate “Framework for Uncertainty, Negotiation and Distribution” or FUND (Anthoff and Tol, 2013); and the “Policy Analysis model of the Greenhouse Effect” or PAGE (Hope, 2006, 2011). For purposes of our analysis we abstract from the many statistical uncertainties captured by these models by using their deterministic versions of the carbon cycle and temperature responses. We justify this, since we wish to illustrate how to deal with climate model uncertainty and therefore focus on this type of scientific uncertainty only. To make our testbed more

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[1] See Heal and Millner (2014, 2015) for an overview of the different types of uncertainty facing climate policy.

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relevant for the current policy debate, we also add a fourth climate model, namely the one adhered to by climate sceptics. President Trump has elected one of the most prominent climate sceptics, Scott Pruitt, to be in charge of the Environmental Protection Agency and has nominated the CEO of ExxonMobil, Rex Tillerson, to be Secretary of the State Department. He has also claimed that climate change is a (Chinese) hoax and the expectation is that the United States will withdraw from the Paris climate change agreement or treat it as a dead letter. Many share Trump's opinion and believe that global warming is not caused by humans, so we add a model, contrary to the main body of scientific evidence, which states that burning fossil fuel does not contribute to global warming at all. It is not relevant whether we believe climate sceptics are scientifically correct or not. Neither does it matter whether climate sceptics are driven or captured by fossil fuel business interests or not. These views are clearly present, so one needs take of such views when formulating policy.

To illustrate our interpretation of the climate modules of DICE, PAGE and FUND, we discuss their special features and compare the temperature responses to pre-specified business-as-usual and de carbonisation emission paths taken from the IPCC for each of these three models. We also compare these temperature responses to those generated by the MAGICC emulator based on a large ensemble of detailed large-scale carbon and temperature models (cf. Meinshausen et al., 2011). To study how such different temperature responses affect the optimal global price of carbon and transition from fossil fuel to renewable energy, we specify a very simple welfare-maximising Ramsey economic growth model with these two types of energy and a specification of temperature-dependent climate damages. Our economic module also allows for two market failures resulting from not internalising global warming damages caused by burning fossil fuel and not internalising learning by doing externalities in the production of renewable energy. Hence, the globally first-best optimal policies require a carbon price *and* a renewable energy subsidy (cf. Rezai and van der Ploeg, 2017).

We thus use a simple common economic module rather than the different economic modules of the DICE, FUND and PAGE models, again to focus all our attention at climate model uncertainty. The common economic block of our IAM is hooked up with our best possible interpretation of the deterministic versions of the carbon cycle and temperature modules of each of the three climate models. Our choice of economic module and of temperature modules is somewhat arbitrary. We justify this on the grounds that we are more interested in the illustration of our proposed methods for deriving optimal carbon prices under climate model uncertainty than in the precise value of the numbers that are generated by our optimal policy simulations. Previous studies have focused on comparing outputs across standardised inputs and IAMs (cf. IAWG, 2016; Gillingham et al., 2016) but have not addressed climate model uncertainty within a uniform welfare-maximising framework.[2]

First, we show the sensitivity of the optimal climate policies and timing of the optimal energy transition to the particular climate model that is used. We then substitute the optimal climate policies derived from each of the four climate models into the other three models and see how well or badly they perform. This is not a trivial task, since the fundamental theorem of welfare economics no longer holds and therefore one is required to maximise welfare subject to the constraints of the decentralised market economy instead of the easier approach of solving for the command optimum (cf. Kalkuhl et al., 2013; Rezai and van der Ploeg, 2016, 2017). In this sense, our approach is an illustration of second-best welfare economics.

Second, we use our framework of an economic module with four climate modules to derive robust climate policies. So we do not maximise expected welfare, but consider and derive the max-min optimal climate policy. This is the policy that yields the highest welfare if the welfare of each policy is evaluated under the worst possible outcome as has been originally suggested by Wald (1945) and has been given an axiomatic foundation by Gilboa and Schmeidler (1989). For each climate module we first calculate the optimal climate policy, then evaluate the welfare under each of the other climate modules, and then note the lowest of these welfare outcomes (i.e., the worst possible outcome for that policy). The max-min policy then corresponds to the one that gives the highest welfare under the worst possible outcome. An early application of max-min to climate policy can be found in Woodford and Bishop (1997), who consider a catastrophic and a non-catastrophic scenario in DICE and find that the max-min policy is to assume that the catastrophic scenario holds (until it is proven not to hold any longer). Strictly speaking, this is an exercise not in climate model uncertainty but in statistical uncertainty and techniques have since been developed to deal with catastrophic Poisson shocks in versions of the DICE integrated assessment model (e.g., Lemoine and Traeger, 2014; Lontzek et al., 2015; van der Ploeg and de Zeeuw, 2017). Climate model uncertainty or scientific uncertainty is, however, conceptually very different from statistical uncertainty and we analyse for the first time the use of max-min to derive optimal climate policy in this context.

We find that the max-min policy is the optimal policy derived from the model with the climate model of DICE. This is not surprising, since the DICE model has in our calibration of the various temperature modules the most adverse temperature responses and the max-min policy is a prudent policy that avoids bad outcomes when the world turns out to be different. In contrast, the max-max policy assumes that every policy rule is evaluated in the best possible view of the world, i.e. President Trump's climate sceptic view, in which case it is best not to price carbon at all. Arrow and Hurwicz (1977) suggest some average of max-min and max-max policies, which introduces some robustness into the optimal climate policy but less than for the max-min policy.

Less conservative policies are obtained under the min-max regret policy. Regret is defined as the difference between the welfare that would have been obtained if the right optimal climate policy was used for the climate model under consideration minus the welfare that prevails under this climate model with the climate policy under consideration. Clearly, regrets are zero if the right optimal climate policy is implemented for the climate model that happens to be correct. The min-max regret policy is then the policy that gives least regret across all the different climate models and was originally proposed by Savage (1951, 1954). So the objective is not to do as well as possible under the worst outcome as with max-min, but to minimise how much better one could have been off. Min-max regret thus leads to less ambitious climate policies than max-min, since what could have been had rather than the worst possible outcome is highlighted. The min-max regret policy in our simulations corresponds to the optimal price of carbon under the PAGE or FUND climate model depending on whether the sceptic view is included or not. Optimal policy based on President Trump's climate sceptic view, i.e. not pricing carbon at all, never prevails under min-max regret or max-min.

Section 2 discusses the climate and temperature models of DICE, FUND, PAGE and the denialists' and compares temperature responses for each of these to IPPC emission-reduction and business-as-usual paths and compares them with the emulated responses in MAGICC. Section 3 describes the common economic block of our integrated assessment model. Section 4 compares the optimal climate policy and energy transitions across these three different climate models. Section 5 derives and discusses the optimal max-min, max-max and min-max regret climate policies under climate model uncertainty. Section 6 concludes with a summary of results and a discussion of alternatives for calculating robust climate policies.

2. Temperature modelling in three prominent IAMs

Integrated Assessment Models (IAMs) combine sets of economic and geophysical assumptions in order to understand the complex

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[2] Cai and Sanstad (2016) use a similar decision framework to study the policy implications of uncertainty over technological change in an energy-climate system.

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