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Analysis

Climatic Cost-benefit Analysis Under Uncertainty and Learning on Climate Sensitivity and Damages

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ABSTRACT

Cost-benefit analyses on climate change have drawn considerable critique, primarily due to contestable choices of discounting and high uncertainties in climate sensitivity and climatic damages. Consequentially, it is argued that cost-benefit analysis can suggest mitigation rates that are nearly arbitrary. This article investigates how firm conclusions can be made from cost-benefit analysis if the main uncertainties are considered endogenously in the analysis and an extensive sensitivity analysis is carried out regarding the contestable assumptions.

The SCORE model is used to calculate optimal emission pathways and carbon prices that hedge against climate sensitivity and damage risks using a wide range of plausible parametrizations. In a vast majority of cases the near-term emissions fall between 1.5 °C and 2 °C emission pathways, giving thus support for the Paris Agreement targets. Sequential decision-making allows hedging against uncertainties and readjusting mitigation efforts over time to reflect new information, leading to diverse stabilization temperatures in the long-term. Assumptions on mitigation costs, climate sensitivity and damages affect optimal near-term mitigation and long-term stabilization temperature more strongly than the discount rate choice. The consideration of parametric uncertainty on climate sensitivity and damages adds a substantial risk component to carbon pricing, while learning can induce significant price volatility in a decadal timescale.

1. Introduction

Cost-benefit analysis (CBA) aims to specify the economically optimal strategies for mitigating climate change through minimizing the sum of costs from mitigation action and ensuing climate damages. As such, it could suggest to what level greenhouse gas emissions should be reduced, or how they should be priced at different points of time. The analysis is commonly carried out with integrated assessment models (IAMs), numerical simulation models combining aspects from economics, climate science and technological development.

Past analyses have yielded very differing suggestions on how ambitious the mitigation efforts should be (see e.g. Tol, 2009), rendering the overall conclusions from climatic CBA rather unclear. As a single draw from this lot, the latest incarnation of DICE (Nordhaus, 2017) – perhaps the best-known and highly cited model in this context – yields an optimal policy of limiting temperature increase to levels around 4 °C within the next 200 years. This conflicts starkly with the currently stated aims in global climate policy. The Paris Agreement of the United Nations' climate convention aims to keep global temperature increase “well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C”.

However, notable critique has been presented against climatic cost-benefit analysis and IAMs (Weitzman, 2009; Pindyck, 2013; van den Bergh and Botzen, 2015). The most severe argument highlights the limitations of our current knowledge on what impacts climate change might have on ecosystems and the society, including the possibility of a total catastrophe; and how such climate impacts should be valued. Disagreement exists also on how the costs and benefits of different generations should be aggregated (Dasgupta, 2008). Further challenges in this setting arise from uncertainties in climate sensitivity (Knutti and Hegerl, 2008) and the cost of future emission reductions (Rogelj et al., 2013).

The objects of the criticism have very different characteristics. The uncertainty on climate sensitivity is epistemic.[1] Climate damages also carry epistemic uncertainty on the realized impacts, but also involve normative judgments on how the impacts are valued. Discounting involves normative judgement about intergenerational equity. Future mitigation costs entail epistemic uncertainty on what might be physically achievable, but also depend strongly on how much the society invests in developing and deploying new technologies, and therefore this uncertainty cannot be separated from the mitigation action considered in a cost-benefit model.

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[1] However, one should note that the estimation of climate sensitivity involves also aleatory uncertainty, due to the natural variations embedded in observations.

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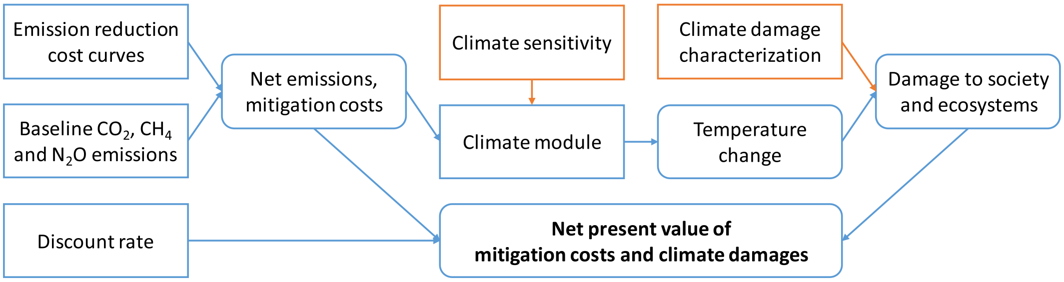

Fig. 1. A graphical outline of the SCORE model. Uncertainty and learning is assumed for the input parameters in boxes with orange outline. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The epistemic uncertainties may be reduced over time through new observations and research, which can be termed ‘learning’. However, learning is not inevitable, for example if there exist structural errors or omitted effects in models that explain the phenomenon being investigated (see e.g. Leach, 2007; Oppenheimer et al., 2008). Learning might be even less straightforward with normative judgements with no objective value, such as discounting or the valuation of climate impacts. Therefore the uncertain and contestable elements need to be addressed using different methods in IAMs.

The Paris Agreement targets are more of a safe minimum standard than a result of deliberate CBA (Randalls, 2010). Because the underlying rationale differs, the moderate mitigation level suggested by many CBA studies (e.g. Crost and Traeger, 2014; Nordhaus, 2017) does not entirely refute the Paris Agreement targets as overly ambitious. Yet, some weighing between the achievable level of mitigation, the acceptable level of costs and the benefits from mitigation is required also in the determination of safe minimum standards.

This implicit reasoning is a conceptual problem with safe minimum standards (Crowards, 1998) due to the ambiguity over what are a safe level of climate change and acceptable costs. Formalizing the determination of targets through CBA makes the assumptions and valuations used in the analysis explicit, which facilitates understanding and transparent argumentation regarding the results. This is exactly the reason for the amount of criticism climatic CBA has drawn.

The critique must be nevertheless confronted. In order for CBA to be a usable tool for determining climate targets, it needs to provide some degree of robustness against uncertainty and alternative specifications. A number of analytical and computational approaches allow the consideration of uncertainty when deriving optimal policies (Golub et al., 2014). Also, the sensitivity of the modeling results to alternative parametrizations can be tested for elements for which probabilistic methods are not applicable. This approach can also be used to test alternative characterizations of probability for quantities that have little or no empirical foundation, such as the damages from climate change.

A number of past analyses have sought optimal mitigation strategies under uncertain climate sensitivity (Kelly and Tan, 2015; Hwang et al., 2017) or damages (Kolstad, 1996; Crost and Traeger, 2014). Some earlier studies have assessed these uncertainties jointly, but under a pre-defined set of policy responses (Lave and Dowlatabadi, 1993; Lempert et al., 1996; Yohe, 1996) or by finding non-adaptive strategies under a sampling of uncertain parameters (Plambeck and Hope, 1996). Robust decision approaches have also been used to address climatic responses under limited uncertainty information (Hall et al., 2012).

This paper investigates how well the criticism could be addressed by considering the uncertainties in climate sensitivity and damages within the CBA, and carrying out an extensive sensitivity analysis for the main parameters. An exogenous learning process is assumed to reduce the uncertainties over time. The computational approach finds mitigation strategies that adapt to the new information over time, minimizing the expected value of costs and benefits and hedging against both of these main uncertainties. Mitigation decisions are made while acknowledging the specified uncertainties, anticipated learning and the possibility to determine subsequent mitigation efforts in a sequential manner.

Three separate issues are addressed. First, the results portray how the consideration of uncertainty and learning regarding two main sources of uncertainty affects the outcomes of CBA. Second, the sensitivity analysis portrays how divergent the policy guidance gained from CBA can be, given the range of plausible parametrizations. Last, the results are reflected in relation to the Paris Agreement targets, discussing whether the targets are supported by the analysis presented here.

2. Methods

Scenarios are calculated with SCORE (Ekholm et al., 2013; Ekholm, 2014; Ekholm and Korhonen, 2016), a lightweight IAM with stochastic capabilities. A graphical overview of the model is presented in Fig. 1 and a more detailed description in the Supplementary material.

The objective of the model is to minimize the expected present value of mitigation costs and climate damages in long-term scenarios. Mitigation costs are portrayed through emission reduction cost curves, while climate damages are a function of temperature change. Uncertainty and learning over climate sensitivity and damages is described with scenario trees. Future costs and damages are discounted with rates of 1%, 3% and 5% in different cases, reflecting the range used in past prominent climatic cost-benefit analyses (Dasgupta, 2008).[2]

The marginal abatement cost curves were updated from the earlier versions of the model. The new cost curves are based on a multi-model study on the Shared Socioeconomic Pathways (SSPs) (Riahi et al., 2017): 82 scenarios with five different storylines and five climate policy cases, run with six large-scale IAMs. A single curve of the form $R_t = \alpha_t \, c_t^{\beta_t}$, where R_t is the emission reduction and c_t the marginal reduction cost at time t, was fitted in the middle of the scenarios' emission-marginal cost space for the year 2020. To reflect the broad range of future marginal costs in the scenarios, two sets of curves with either high or low costs were used beyond 2020, matching approximately to the higher and lower envelopes of the SSP scenario results. See the Supplementary material for details. As SCORE is implemented with the TIMES modeling framework (Loulou, 2008) employing linear programming, the curves are split into 100 discrete steps to allow a linear formulation.

Climate damages are based on the 2016 version of the DICE model (Nordhaus, 2017). Damages $D(t,\Delta T)$ are represented as a function of temperature change ΔT: $D(t,\Delta T) = Y(t) \; a \; \Delta T^b$, where $Y(t)$ is the world gross economic output. In SCORE, $Y(t)$ is defined exogenously and corresponds to the DICE optimal policy scenario, in which global per capita output grows by roughly 2% per annum between 2015 and 2100.

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[2] In common economic models used in this context, the social discount rate comprises of a pure rate of time preference and a rate of risk aversion, and prominent past analyses have used discount rates ranging from 1.4% to 4.4% (Dasgupta, 2008; Nordhaus, 2017).