Robust selection of climate policies under current knowledge of uncertainties

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31st March 2014

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In the context of climate change, decision-making frameworks have to consider a broad range of potential futures by exploring the space of uncertainties. In this space of possible futures, selection rules of optimal policies can be based on probabilities or degrees of belief, on the existence of multiple priors or can be based on non-probabilistic criteria [Heal and Millner, 2013]. In this research, we apply a set of selection rules to the results issued from a large number of scenarios generated by an integrated assessment model. These scenarios capture the uncertainties from the socio-economic drivers, the delay of action, the climate system and the economic impacts from climate change.

Uncertainty representation and propagation In our framework, we decompose the integrated assessment in three components: the socio-economic scenarios, the climate system (including the carbon cycle) and the impacts at global levels. We use the best available knowledge to account for uncertainties in each of this component. Baseline socio-economic scenarios are defined as linear combinations of the Shared Socioeconomic reference Pathways and a delay of the beginning of the policy action vary betweeen 2015 to 2030. The climate model, SNEASY [Urban et al., 2010], is producing probabilistic temperature projections, calibrated on the CMIP5 temperature's spread using an inverse Bayesian technique based on a Monte Carlo Markov Chain. Each vector of the Markov chain represents a state of the climate system. Finally, we fit three probabilistic damage functions from global impact cost estimates issued from the literature: a "quadratic" function, an "exponential" and a "catastrophic" one.

Utility function The policy action is characterized by a carbon budget, which is defined as the cumulative Kyoto greenhouse gases emissions over the 21st century. We denote the carbon budget $c \in \mathcal{C} \subset \mathbf{R}^+$ and the states of the world $s \in \mathcal{S}$. The total discounted utility function

$$U(c;s) = \sum_{t \in T} \frac{1}{1+r}^{(t-t_0)} \left[M(c,t;s) + I(c,t;s) \right],$$

where the mitigation costs are $M(c,t;s)$ and the economic impacts costs are $I(c,t;s)$ in period t. r is the discount rate.

The mitigation costs are computed by the WITCH integrated model [Bosetti et al., 2006], by imposing a constraint on the cumulated emissions. The WITCH model also computes the associated optimal emission pathways. These emissions are sent to the SNEASY model which produces probabilistic temperature projections. The economic impacts are produced subsequently.

Decision rules We apply several decision making frameworks in order to select the best climate policies according to their respective criteria. First, we apply the *subjective expected utility* framework [Savage, 1954]. In this framework, the knowledge of the decision maker is represented as subjective probability distributions over the possible states of the world. Then, as it is unlikely to know the likelihood of the damage function shapes, we consider the *maxmin expected utility* framework which introduces the notion of multiple priors [Gilboa and Schmeidler, 1989]. Each damage function function shape is a different prior. We also apply the α*-maxmin expected utility* criterion [Ghirardato et al., 2004] which is an extension of the precedent rule, introducing uncertainty aversion. Within this rule, the lowest expected damage from climate change (maxmax) is retain for each policy strategy as opposed to the highest expected damage (maxmin), amongst the priors.

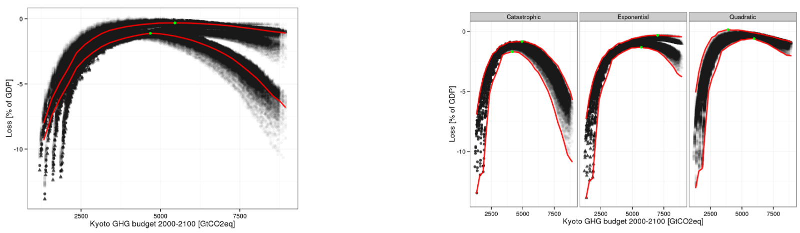
We also consider non-probabilistic approaches. First, the *maxmin* framework [Wald, 1945] is looking for the best amongst the set of worst-case outcome of each policy action. Secondly, the α*-maxmin* criterion from Arrow and Hurwicz [1972] is also considered. Finally, we apply the *minimax* regret criterion [Savage, 1951] which minimises the max regret corresponding to the difference between the worst and the best outcome of each policy.

Results Preliminary results show a trade-off between mitigation costs and damage costs (Figure 1). Low carbon budget policies, on the one hand, have benefits or no impacts from climate change but may suffer high mitigation costs. High carbon budget policies, on the other hand, have very low mitigation costs but the risk of very high damage is not negligible, as the probability distribution of the damage costs has a very long tail. The selected policy will be located in between these two alternatives. The value of the utility discount rate, reflecting the time preference of the decision maker, is then a key element, as the damages from climate change will occur later in the century. Table 1 shows the results using a discount rate of 2%. Generally, we observe that the level of abatement is increasing with ambiguity aversion. However, when using a "quadratic" damage function, there is the possibility of benefits from climate change at low warming and, in this case, optimistic decision makers would select a lower carbon budget than the pessimistic ones.

Conclusion A number of decision rules has been applied to the results coming from a probabilistic integrated assessment model. The addition of probability distributions within an integrated model helps to better represent the current scientific knowledge. Using many decision rules, allows us to inform the decision makers on the level of uncertainty they are facing but also on the level of ambiguity in the available knowledge.

Decision rule	Kyoto carbon budget [$GtCO_2eq$]
Maxmin	4 167
Maxmax	3 779
Minimax regret	5 920
Expected Utility (EU)	6 492
Maxmin EU	4 684
Maxmax EU	5 458

Table 1: Selection of Kyoto carbon budgets. Utility discount rate is 2%.



(a) Maxmin and maxmax expected utility (b) Maxmin and maxmax criteria

Figure 1: Application of the decision rules over the utility values as a function of the Kyoto carbon budget. Black points are the generated utility values.The red lines are the search paths of each decision rule and the green points are the best criterion values.

Acknowledgements The authors thank Klaus Keller for providing the SNEASY climate model and his support in the calibration phase. The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n°282846 (LIMITS)

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