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# Counting Only the Hits? The Risk of Underestimating the Costs of Stringent Climate Policy

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*Abstract*: This paper warns against the risk of underestimating the costs -and the uncertainty about the costs- of achieving stringent stabilization targets. We argue that a straightforward review of integrated assessment models results produces biased estimates for the more ambitious climate objectives such as those compatible with the 2°C of the European Union and the G8. The magnitude and range of estimates are significantly reduced because only the most optimistic results are reported for such targets. We suggest a procedure that addresses this partiality. The results show highly variable costs for the most difficult scenarios.

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# Counting Only the Hits? The Risk of Underestimating the Costs of Stringent Climate Policy

## Introduction

As the predictions about climate change are becoming direr and support for climate policy is growing across the political spectrum, the long-term goals for greenhouse gas emission reduction are getting more ambitious. The targets that are now on the political agenda were deemed unlikely only five years ago. As a result, there is only a thin body of literature on the costs of meeting these aspirations. This has led to an inadvertent bias in policy advice: the most policy-relevant part of the literature is dominated by a few studies only. This note estimates the size of this bias.

The bias in policy advice comes about as follows. Analysts run their model using a central scenario that is considered to be most relevant to policy. Sensitivity analyses are done with more stringent and more lenient targets, but results are reported in less detail. A conscientious modeler would realize that more stringent targets would take the model further away from its domain of calibration and validation, and would hesitate to publish such results so as to maintain academic credibility. In addition, without modifying the underlying model structure, stringent scenarios are often not attainable or infeasible, and simply do not appear in the literature. Until recently, the standard choice for a central scenario aimed at stabilizing atmospheric carbon dioxide at a concentration of 550 ppm (Weyant et al. 1999;Weyant 2004;Weyant et al. 2006). The policy debate has now moved to a stabilization of greenhouse gas concentrations at 450 ppm $CO_2$ equivalent as a central case (MEF 2009;CEC 2005). In order to be able to satisfy this new policy demand, models have been pushed towards implementing more optimistic assumptions about the range and availability of their mitigation portfolio, which has the effect of lowering the costs of climate policies. In summary, published results for stringent emission targets are fewer and tend to be disproportionally based on cheap models and low baseline scenarios.

This is best illustrated with the Summary for Policy Makers of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Barker et al. 2007;IPCC 2007). Emission reduction costs are reported for three alternative targets. While 118 results were available for targets in the range of 3.2 to 4.0°C warming, there were only 6 estimates of the costs of keeping warming in the range of 2.0 to 2.4°C. According to the reported results, moving from a 3.6°C to a 3.0°C target would double the abatement costs. Moving from a 3.0°C to a 2.2°C target would increase costs by 37.5% only. As the underlying models are correctly specified – that is, more stringent targets mean higher and accelerating costs – the IPCC results can only be explained by selection bias: only models with low emission reduction costs reported results for the most stringent targets. Such selection bias is potentially misleading for policy makers (Tol 2007).

This paper proceeds as follows. We first discuss the data used in this paper, and then present a method to correct for selection bias. We apply this method and analyze the results before drawing conclusions.

## Data and selection bias

We avail of a recent data set of model results. The data result from the 22nd round of model comparison led by the Energy Modeling Forum (EMF22). We focus on the international scenarios as this is the richest set of data[1]. Details of the scenarios and of the main implications can be found in (Clarke et al. 2010). Ten models[2] from across the rich world ran ten scenarios (some models reporting more than one version). The scenarios had three alternative levels of atmospheric stabilization in 2100 (2.6 $Wm^{-2}$, 3.7 $Wm^{-2}$, 4.5 $Wm^{-2,}$ corresponding to 450, 550 and 650 CO2-eq ppm), allowed or disallowed overshooting the target in the intermediate run, and had two alternative specifications of international participation (global emission reduction from 2012 onwards versus delayed participation by developing countries). The modelers were explicitly asked to run all scenarios, including the more stringent ones; although they did not report results in case of infeasibility or unrealistically high initial carbon price (above 1000$/tCO2 in 2012), they did report the fact that the target was "infeasible" according to their model.

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[1] Data is publicly available at the following website http://emf.stanford.edu/events/emfbriefing_on_climate_policy_scenarios_us_domestic_and_international_policy_architectures/

[2] ETSAP-TIAM,FUND, GTEM, IMAGE, MERGE, MESSAGE, MINICAM, POLES, SGM and WITCH.

We focus our attention on the economic implications of climate stabilization scenarios, as this is one of the most relevant information summarizing the requirements needed to comply with the climate policy. Nine out of ten[3] models reported economic output expressed either -or both- as GDP and abatement costs, two common metrics for macro-economic and energy system models respectively. To maximize consistency in the use of the cost metrics, we have used change in GDP for all the (seven) models that reported it and total abatement cost in the remaining (two) cases. Policy costs have been calculated relative to the baseline, actualized in net present values using a 5% discount rate.

Since some models reported more than one case for each scenario, we have 11 runs for each of the 10 scenarios, for a total of 110 potential observations. However, only 68 are observed in reality, since some scenarios could not be run by some models. Table 1 shows the distribution of model runs that were completed, by scenario; it indicates that the more ambitious the scenario, the fewer the observations. The density of observations is particularly low for the 2.6 $Wm^{-2}$ scenarios, which is troubling because these are the only ones consistent with the 2°C objective that has been adopted by the European Union and most recently by the G8. Surely, policy driven research in the near future will try to remedy this imbalance and arguably more effort will be (and is already being) diverted to the analysis of more stringent scenarios. As of now, though, an account of the risks of relying on such sparse data has not been thoroughly carried out.

The important feature to notice in Table 1 is that since stringent scenarios can be simulated only by the models that are more optimistic (in terms of technology substitutability, mitigation portfolio, baseline etc.), a meta-analysis of model results would inevitably be plagued by selection bias. This could lead to a distortion in the statistical analysis, with important repercussions for policy advice.

## Accounting for the bias

Correcting for the bias is not straightforward since replacement methods such as imputation cannot be used precisely because there is a systematic relation between the causes of data being missing and the missing data, that is the values are not missing at random. In such cases, a model for filling in the missing observations needs to be devised. Essentially, we conduct a meta-

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[3] With the exception of POLES

analysis (Barker et al. 2002;Fischer et al. 2006;Kuik et al. 2009;Repetto et al. 1997) and use the estimated model to impute the missing observations. We propose a simple OLS regression[4] between the (log) of the policy costs and a series of independent variables that include the stringency of the climate target in radiative forcing, model dummies, a delayed participation dummy, and an overshoot dummy. The results shown in Table 2 confirm the intuition that the climate objective, the possibility to temporarily overshoot the target, and the rate of participation of developing countries are main driving forces of policy costs.

This simple estimation allows us to predict policy costs for those models that were unable to run the more stringent scenarios, thus addressing the selection bias issue. Figure 1 compares the original dataset with the one augmented with predictions. It shows that correcting for selection bias leads to a significant upward revision of the estimates of macro-economic implications of stringent climate policies. Policy costs for the 2.6 $Wm^{-2}$ (450 CO2-e) cases rise several fold, especially for the two more ambitious scenarios, that were originally dealt with by only two models.

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[4] We also experimented with the Heckman sample selection technique, a model for heteroskedasticity, and kernel density estimators but did not find significant results. There are too few data given the number of model/scenario combinations, so that we can only estimate a basic model.

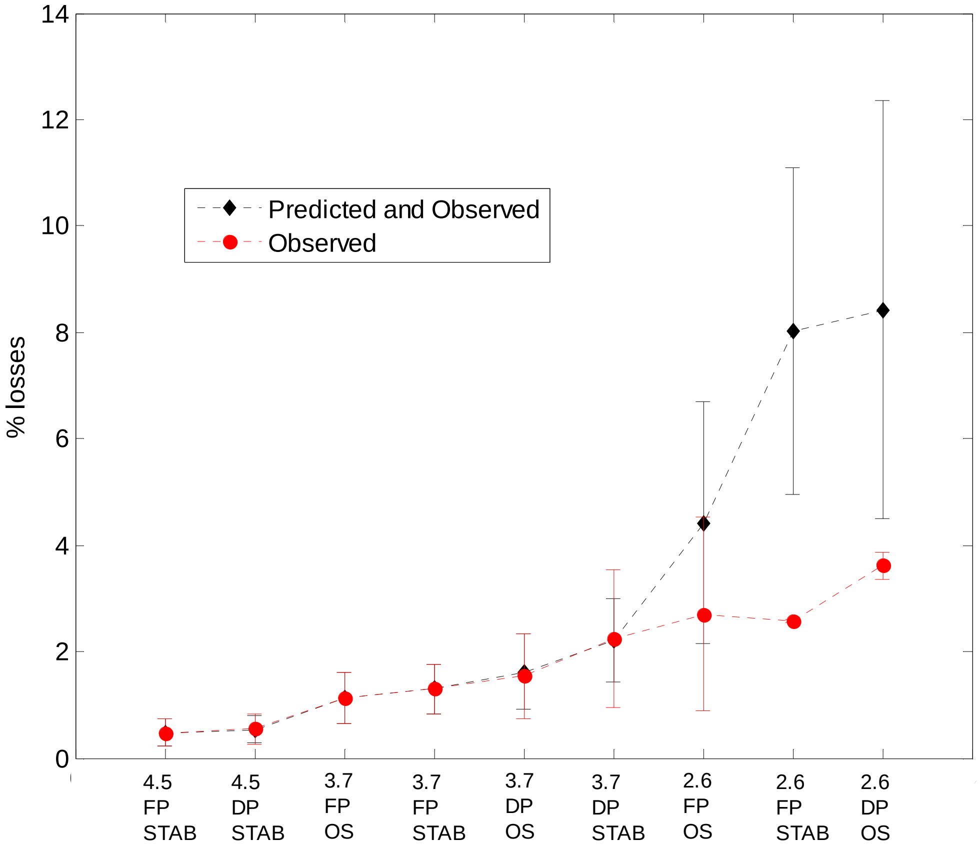

Figure 1. Mean policy costs for the original EMF22 data set (‘observed’) and the one where missing values have been predicted (‘predicted and observed’). Bars show 95% percentiles. Scenario legend as in Table 1.

Most importantly, accounting for the bias greatly increases the uncertainty around the costs. Relying on a subset of models is dangerous in that it can reduce the range of cost estimates, especially if the models share similar assumptions, which we have shown to be true for this experiment. Supplementing the data with our predicted values generates a much wider range of estimates. Table 1 reports standard errors and the coefficient of variation of results across models for the various scenarios. It shows that the variability across models tends to diminish in the observed datasets for the most ambitious scenarios, given that the low number of models that are able to solve them reported similar values. This feature is corrected when we predict the behavior of the more conservative models into the more ambitious schemes.

## What drives the costs difference?

Since we have shown that different subsets of models generate significantly different answers regarding the economic impact of climate policies, it is interesting to understand whether there is a main underlying force that drives the discrepancy. The distinction between bottom-up and top-down models has been emphasized in previous model comparisons such as the IPCC Fourth Assessment Report, since it is known that the former feature lower costs. The presence of no-carbon backstop technology has also been known to be a key driver of results (Repetto and Austin 1997). More recently, models have been including negative emissions technologies such as Biomass Energy with Carbon Storage (BECS) (Rhodes et al. 2005), which are particularly attractive when carbon is highly priced.

Figure 2 plots the average observed costs separating models into those that feature or do not feature BECS. Incidentally, in this dataset, this distinction coincides with the one of bottom-up versus top down. The two lines show that top-down/no-BECS models report significantly higher costs estimates and somewhat larger uncertainty around them. Since BECS is a necessary (albeit not sufficient) condition for running the most stringent scenarios, then it is possible that the cost range will get smaller as more and more models will implement it in order to run stringent scenarios.

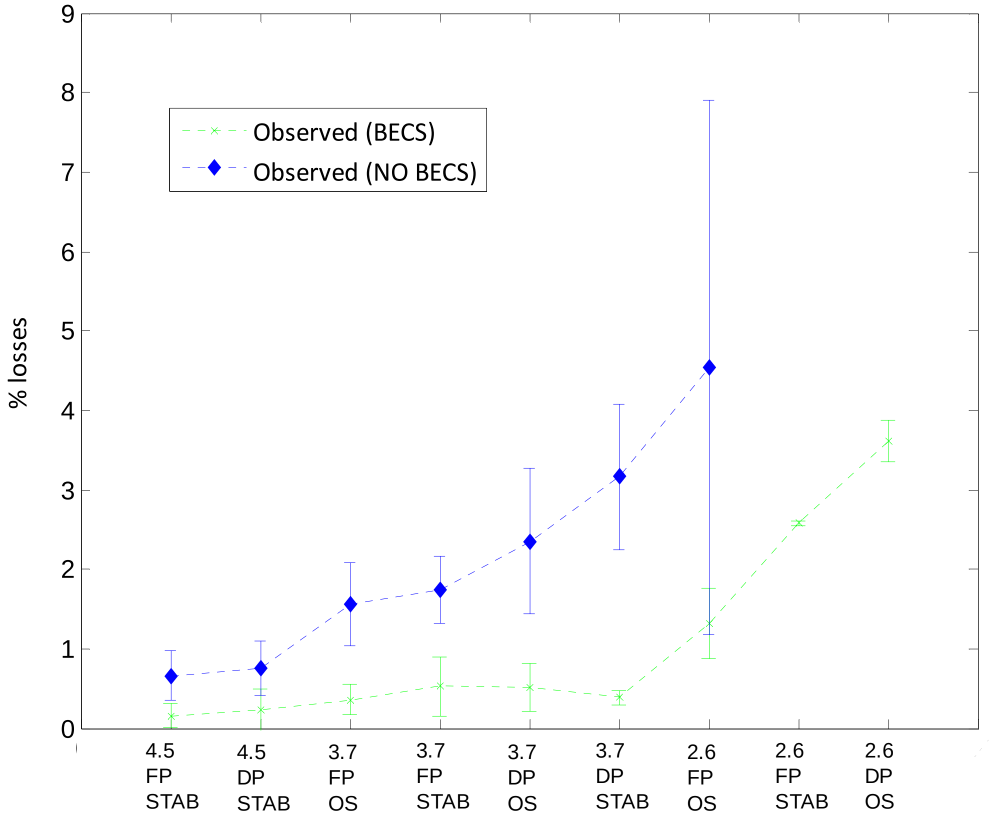

Figure 2. Mean observed policy costs for models with and without BECS. Models that feature BECS are ETSAP-TIAM, IMAGE, MESSAGE, MINICAM. Bars show 95% percentiles. Scenario legend as in Table 1.

## Summary and recommendations

In this article, we have argued against the risks of selection bias when comparing integrated assessment modeling results. Using a recent comparison exercise, we have shown that correcting the bias would lead to decisively higher estimates for the costs and the range of costs of meeting stringent stabilization scenarios in line with the objectives set forward by the European Union and the G8.

This article is meant to provide recommendations for the future analysis of integrated assessment models. We have shown that different representation of the economic activity and of decarbonization technologies have an important bearing on the costs of climate policies. Given the various ways models can differ from one another, comparison exercises are particularly important to identify robust findings across model specification, and are indeed at the heart of the reviewing work of the IPCC. The AR4 suggested that caution was needed when interpreting the results of the more stringent climate policies, as a slim number of studied had been carried out at the time. However, approaches more formal than general warnings are needed when dealing with policy relevant issues such as the costs of climate protection. This is especially important when communicating uncertainties, which are easily lost in the executive summaries. This note has provided a first attempt to resolve the issue of selection bias in meta-analysis of integrated assessment estimates of climate mitigation costs.

|  |  | **4.5 FP STAB** | **4.5 DP STAB** | **3.7 FP OS** | **3.7 FP STAB** | **3.7 DP OS** | **3.7 DP STAB** | **2.6 FP OS** | **2.6 FP STAB** | **2.6 DP OS** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number of scenarios** |  | 11 | 10 | 11 | 11 | 9 | 6 | 7 | 2 | 2 |
| **Mean of policy costs** | Observed | 0.48 | 0.55 | 1.12 | 1.30 | 1.54 | 2.24 | 2.70 | 2.58 | 3.62 |
|  | Predicted and Observed | 0.48 | 0.54 | 1.12 | 1.30 | 1.62 | 2.21 | 4.42 | 8.03 | 8.43 |
| **Standard Error of policy costs** | Observed | 0.13 | 0.14 | 0.24 | 0.23 | 0.40 | 0.65 | 0.91 | 0.01 | 0.13 |
|  | Predicted and Observed | 0.13 | 0.13 | 0.24 | 0.23 | 0.36 | 0.39 | 1.14 | 1.54 | 1.98 |
| **Coefficient of Variation of policy costs** | Observed | 0.27 | 0.25 | 0.21 | 0.18 | 0.26 | 0.29 | 0.34 | 0 | 0.04 |
|  | Predicted and Observed | 0.26 | 0.23 | 0.22 | 0.18 | 0.22 | 0.18 | 0.26 | 0.19 | 0.24 |
| **Mean of policy costs** | Observed (BECS) | 0.15 | 0.22 | 0.36 | 0.53 | 0.52 | 0.39 | 1.31 | 2.58 | 3.62 |
|  | Observed (NO BECS) | 0.66 | 0.76 | 1.56 | 1.74 | 2.35 | 3.16 | 4.54 | - | - |
| **Standard Error of policy costs** | Observed (BECS) | 0.08 | 0.13 | 0.10 | 0.19 | 0.15 | 0.05 | 0.22 | 0.02 | 0.13 |
|  | Observed (NO BECS) | 0.16 | 0.17 | 0.26 | 0.21 | 0.46 | 0.46 | 1.70 | - | - |

Table 1. Main statistics. Legend: 4.5, 3.7 and 2.6 are the radiative forcing targets in 2100. FP=full, immediate participation of DCs, DP=delayed participation of DCs. STAB.=target not to exceed, OS=target can be overshot.

| **Variable** | **Coefficient** | **Standard error** | **t-statistic** |
|---|---|---|---|
| Radiative forcing | -1.65 | 0.127 | -13.0 |
| Delayed participation | 0.423 | 0124 | 3.41 |
| Overshoot | -0.910 | 0.270 | -3.37 |
| ETSAP | -1.37 | 0.299 | -4.58 |
| FUND | 0.721 | 0.305 | 2.36 |
| GTEM | 0.606 | 0.301 | 2.02 |
| IMAGE | -1.66 | 0.297 | -5.59 |
| MERGE (opt) | 0.676 | 0.334 | 2.03 |
| MERGE (pess) | 0.138 | 0.312 | 0.44 |
| MESSAGE | -0.0791 | 0.302 | -0.26 |
| MESSAGE (NoBS) | (dropped) | | |
| MiniCAM | -0.456 | 0.286 | -1.60 |
| SGM | 0.792 | 0.315 | 2.52 |
| WITCH | -0.363 | 0.313 | -1.16 |
| Adj. $R^2$ | 0.842 | Root MSE | 0.459 |

Table 2. Regression results for the natural logarithm of the net present value of abatement costs as a percentage of the net present value of the Gross Domestic Product in the no-policy scenario.

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