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The value of information for integrated assessment models of climate change ☆

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ABSTRACT

We estimate the value of information (VOI) for three key parameters of climate integrated assessment models (IAMs): marginal damages at low temperature anomalies, marginal damages at high temperature anomalies, and equilibrium climate sensitivity. Most empirical studies of climate damages have examined temperature anomalies up to 3 °C, while some recent theoretical studies emphasize the risks of "climate catastrophes," which depend on climate sensitivity and on marginal damages at higher temperature anomalies. We use a new IAM to estimate the VOI for each parameter over a range of assumed levels of study precision based on prior probability distributions calibrated using results from previous studies. We measure the VOI as the maximum fixed fraction of consumption that a social planner would be willing to pay to conduct a new study before setting a carbon tax. Our central results suggest that the VOI is greatest for marginal damages at high temperature anomalies.

Introduction

The systematic analysis of climate change policies involves combining natural science and economic models to forecast the accumulation of greenhouse gases in the atmosphere, the response of the climate to these gases, and the impacts of subsequent climate changes on the natural environment and human well-being across the globe over the course of centuries (Parson and Fisher-Vanden, 1997; Kelly and Kolstad, 2000; Sarofim and Reilly, 2010). Due to the inherent complexity of this task, the "integrated assessment models" (IAMs) typically used for these analyses are highly uncertain.[2] It is possible that some of these uncertainties can be reduced through further scientific and economic research. However, the resources available for such studies are limited, so it is important to prioritize new research efforts among the uncertain components of climate IAMs to help achieve the highest possible return on these investments.

Research priorities typically evolve through an ad hoc and unstructured process of collaboration and competition among researchers, grant funding agencies, and the editors of scholarly journals. When researchers explicitly aim to inform

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☆ The findings, conclusions, and views expressed in this paper are those of the authors and do not necessarily represent those of the U.S. EPA. No Agency endorsement should be inferred.

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[2] Integrated assessment models can be defined "broadly as any model with combined scientific and socio-economic aspects of climate change primarily for the purpose of assessing policy options for climate change control" (Kelly and Kolstad, 2000).

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research priorities in a systematic way, this is usually done through sensitivity analysis where two or more model parameters are varied and the effects of these variations on key outputs of the model are recorded. The parameters that have the strongest influence on the model outputs are then highlighted as top candidates for further research.

A number of previous studies have conducted sensitivity analyses using IAMs. For example, Stern found the Policy Analysis of the Greenhouse Effect (PAGE) model to be highly sensitive to the exponent of the damage function, the elasticity of the marginal utility of consumption, and the pure rate of time preference (Stern, 2006).[3] Hope conducted additional sensitivity analyses using PAGE and found it to be most sensitive to equilibrium climate sensitivity,[4] the pure rate of time preference, the exponent of the non-economic damage function, the elasticity of the marginal utility of consumption, and the decay rate of CO_2 in the atmosphere (Hope, 2008 p118). Nordhaus conducted a sensitivity analysis using the Dynamic Integrated Climate Economy (DICE) model (Nordhaus, 2008). Varying parameters over a range of minus to plus six standard deviations showed that the projected global temperature rise by 2100 was most sensitive to the growth rate of total factor productivity, with the equilibrium climate sensitivity parameter a close second. The temperature rise was found to be nearly invariant to the cost of the backstop technology, the damage coefficient, and the fossil fuel resource limit. Yohe and Hope (2013) used PAGE to compare the expected value of the social cost of carbon before and after simulated adjustments to some of the probability density functions representing uncertainty about economic parameters upon which the SCC depends. Yohe and Hope found only very small changes to the SCC from reasonably large reductions in the range of underlying damage function parameters.

The results of these and similar exercises help to identify those parameters that have the strongest influence on IAM outputs. However, the results of such sensitivity analyses do not necessarily translate directly into optimal priorities for future research. The value of additional research depends not only on the sensitivity of model outputs to a particular parameter, but also on how strongly the parameter influences the optimal choice of policy variables, how much is currently known about the parameter, and the cost of learning more about the parameter.

In this paper we use a value of information (VOI) framework to formally examine the optimal allocation of effort across areas of research related to climate change damage assessments.[5] Specifically, we examine the relative value of additional research on three crucial components of any IAM: marginal damages at low temperature anomalies, marginal damages at high temperature anomalies, and equilibrium climate sensitivity. Most empirical research on climate change impacts has estimated the economic damages at relatively low temperature anomalies, up to 2.5 or 3 °C. In contrast to this traditional research focus, some recent studies have emphasized the risks of “climate catastrophes,” or “fat-tailed” climate risks, which depend on potential damages at higher temperature anomalies and scientific uncertainty about the sensitivity of the climate to green house gas (GHG) emissions (Weitzman, 2009, 2010). The growing appreciation for these low-probability high-impact outcomes and uncertainty about the slope of the damage function at high temperature anomalies (Kopp et al., 2012) raises an important question for future research: Should we continue “searching under the lamp post” by studying impacts at low temperature anomalies where data are relatively plentiful and existing models can be reasonably well calibrated, or should we begin searching in dimmer territory by shifting some of our research effort toward studying impacts at higher temperature anomalies farther outside of the range of historical experience? This question has been highlighted as one of the pathways for improving official U.S. Government estimates of the social cost of carbon (Kopp and Mignone, 2012) and is the main motivation for this paper.[6,7]

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[3] In the climate economics literature the term “damage function” is used to describe a mapping between the climate impacts of anthropogenic activity (e.g., temperature increases, precipitation changes, and sea level rise) and consumption-equivalent monetized loses.

[4] “Equilibrium climate sensitivity” represents the long-run steady state temperature anomaly (increase above pre-industrial level) that would be reached with global radiative forcing equivalent to a sustained doubling of the atmospheric carbon concentration above pre-industrial levels. As such, the equilibrium climate sensitivity provides a summary measure to the responsiveness of the climate to anthropogenic activity.

[5] The value of information is closely related to option value (Conrad, 1980; Hanemann, 1989; Pindyck, 2002, 2007). In most studies of option value the information is obtained passively through observations over time. In this paper we focus on the value of active information collection through the funding of new research. For a general overview of VOI studies in the area of environmental health risk management see Yakota and Thompson (Yokota and Thompson, 2004), for an application to medical decision-making and research design see Willan et al. (2012), and for an application to climate thresholds see Keller et al. (2007).

[6] Some researchers have suggested that impacts at high temperature anomalies are not only unknown but may be “unknowable” (Pindyck, 2013). This claim could be interpreted in at least two ways. A “strong” interpretation is that it is not possible to conduct a study that will provide any additional information on climate damages at high temperature anomalies, i.e., no research we can undertake will allow us to update our prior over this parameter. A “weak” interpretation is that new studies can provide some information on potential climate damages at high temperature anomalies, but repeated studies will not cause the prior to converge to a degenerate probability density function over the true value; i.e., there may be a limit to how narrow we can collapse the probability density function representing our priors no matter how much effort we devote to studying these effects. The strong interpretation would obviate the usefulness of our study with respect to damages at high temperature anomalies, since it implies the marginal cost of additional information about these outcomes is infinite. The weak interpretation, on the other hand, does not materially diminish the relevance of this aspect of our study. Our main results are principally based on the marginal value of information about each parameter and so are not compromised by the weak interpretation of “unknowable.” That is, our main results rely on the assumption that some updating of the prior over each uncertain parameter is possible, not that perfect knowledge is ultimately attainable.

[7] Improving our estimates of damages at low temperatures should be possible with additional data collected within the contemporary ranges of spatial and temporal variability in temperatures. There are far fewer opportunities to collect data on damages at very high temperatures, so learning about high temperature damages may require expanded applications of mechanistic models that can produce realistic representations of spatial and temporal climate variability as well as the physiological and behavioral responses of humans and other species to those changes. For example, Sherwood and Huber examined the direct impact of climate change on humans and other mammals in the form of heat stress using an approach based on first-principles of thermodynamics that is “relatively well-constrained by physical laws” (Sherwood and Huber, 2010 p 1). Additional learning about potential climate damages at high temperatures presumably will require more research using the same basic approach combining detailed integrated simulation models to forecast climate and economic response variables of interest, where the constituent models are parameterized using a blend of scientific and economic first