Analyzing Climate Uncertainty and Risk with an Integrated Assessment Model

Robert Repetto and Robert Easton

Uncertainty over the consequences of unprecedented global warming is central to environmental insecurity. Global warming threatens to exacerbate all other ecological stresses and menaces human populations and economies. Despite scientific efforts, great uncertainties still pervade crucial aspects of the climate change process and its consequences. Yet integrated assessment models widely used to analyze climate policy options, such as the Nordhaus DICE model,[1] establish that model outputs are highly sensitive to plausible alternative parameter values. This paper further explores uncertainties by substituting probability distributions for pre-determined values of key parameters in the DICE model. It then draws randomly from these probability distributions to implement a Monte Carlo analysis of policy outcomes, generating hundreds of policy simulations. An important finding is that the sacrifice in world consumption entailed in keeping the rise in global temperatures below two degrees centigrade would likely be negligible if emitting countries cooperate in adopting efficient mitigation policies. In other words, the cost of insurance against dangerous climate change is close to zero. Thus, the result of this analysis suggests that science and economics agree on keeping climate change below a level threatening serious damage.

In the twenty-first century, global warming is the dominant source of environmental insecurity. The global climate is changing rapidly on a

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Robert Repetto is a senior fellow at the International Institute for Sustainable Development (IISD) and a senior fellow for the Energy and Climate programs at the United Nations Foundation. He is a leading environmental economist and is known for his writings and research on the interface between environment and economics and on policies to promote sustainable economic development.

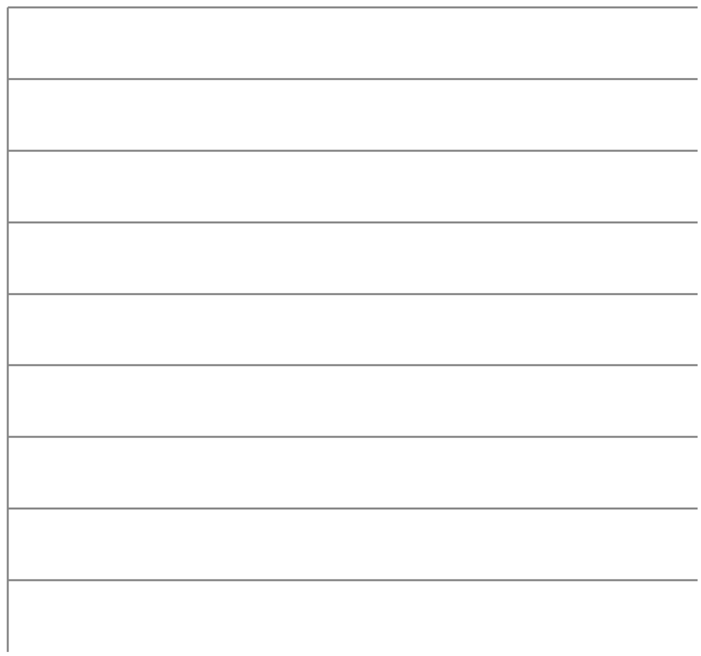
Robert Easton is a professor emeritus in the department of applied mathematics at the University of Colorado at Boulder. His research interests are in dynamical systems, Hamiltonian mechanics, statistics, macro economics, and environmental economics.

at the same assumed rate as world population grows. Growth of the capital stock depends on the randomly many times from these distributions and using those draws to solve the model repeatedly. The results in this Monte Carlo approach are then presented as frequency distributions of model outputs. This research has explored the risk implications of reaching a global warming tipping point at which a more severe relationship between damages and further warming could come into play. These studies have found that these risks should lead to higher carbon prices and more stringent emissions reductions.

Sensitivity Analysis

In the light of these previous findings, our analysis has focused primarily on other important uncertainties in the climate problem—those related to the generation and abatement of carbon emissions. Both the future rate of emissions growth in the absence of abatement and the future costs of abatement are uncertain. Future economic growth, leading to higher emissions, is partly driven by increasing world population. The DICE model accepts the current medium projection from the United Nations (UN) Population Division that world population will stabilize during this century at 10.5 billion people. This exogenous model assumption is invariable over all temperature increases, even those implying severe climate change impacts on food and water supply and human settlements. Moreover, the UN projections themselves are unrelated to socio-economic pro improvements in energy efficiency is vast. Moreover, carbon intensity is likely to improve more rapidly for several reasons: China, India, and other countries are closing inefficient coal plants and investing in alternatives because of intolerable levels of air pollution. Also, the relative costs of coal and natural gas are shifting, as coal extraction faces a rising cost curve and gas extraction costs are falling because of horizontal drilling and hydraulic fracturing, or “fracking.” Finally, as wind and solar power approach grid parity in more regions and applications, their use will increase even without explicit mitigation policies. In sensitivity analysis, emissions per unit of output are assumed to decline by 2 percent per year; a range of 1 to 2 percent is used in the Monte Carlo analysis.

Another important uncertainty is the future cost of abating emissions through energy efficiency, use of non-carbon fuels, and carbon capture and storage. The DICE model assumes that technological improvements reduce abatement costs by 0.5 percent per year, regardless of the abatement policy adopted. This assumption denies the likelihood of induced technological change and “learning-by-doing” improvements achieved with greater deployment of non-carbon technologies. In recent decades, the costs of renewable energy have declined at a much faster rate than



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Turning to the temperature implications of these emissions trajectories, the graphic in figure 2 shows that, under the alternative assumptions regarding emissions generation and abatement, the lower trajectory of emissions is sufficient to keep the temperature increase below two degrees Celsius over the twenty-first century. Adding the damage sensitivity component implies that temperature should be kept well below the two degree limit. In other words, the sensitivity analysis shows that under reasonable alternative assumptions, economic analysis supports the international consensus that global warming should be contained within “safe” limits.[21] Thus, there is no conflict between science and economics.

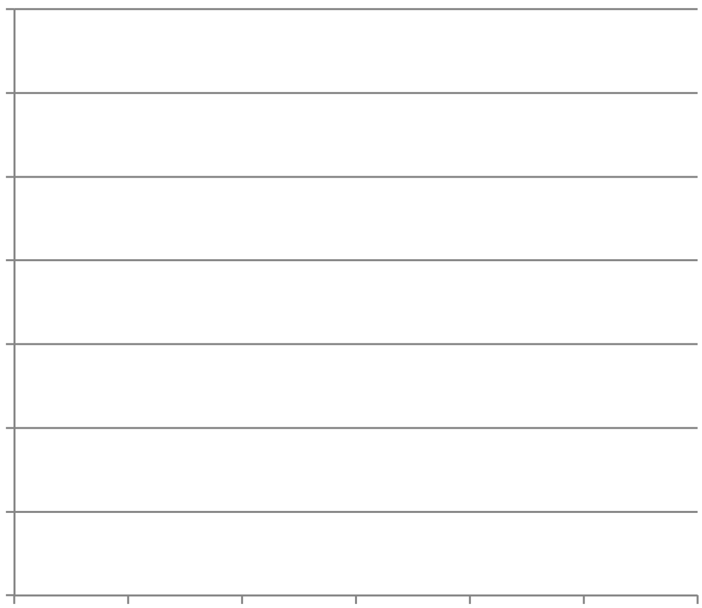

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Figure 3 depicts the impact on more ambitious abatement policies on future consumption. What is remarkable is how insensitive future consumption is to changes in emissions. Contrary to political claims, future consumption continues to grow at an almost unchanged rate under all scenarios. The reason for this result is easily understood: higher abatement costs imply reduced emissions and lower climate change damages. These costs largely cancel, leaving little net effect on consumption. It is worth noting that these results of the sensitivity analysis have not invoked any greater degree of risk aversion or valuation of future consumption than assumed in the original DICE model.

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Monte Carlo Analysis

With this sensitivity analysis as background, probability distributions have been specified for these parameter values spanning DICE model assumptions and our alternatives. The following table (table 1) lays out these distributions. The Monte Carlo analysis drew randomly from each of these distributions five hundred times and solved the model with each set of parameters. This procedure led to probability distributions for variables of interest, including the emissions at all points in time, the cumulative emissions over the century, the temperature increase at all points in time, the levels of output, and the levels of aggregate consumption.

Table 1. Monte Carlo Probability Distributions

Parameter	Distribution	Range

A key finding is that there is no conflict between a policy based on keeping global warming to a safe limit and a policy based solely on economic criteria. This finding differs from the position implied by the original DICE model and discussed in the recent book by Professor Nordhaus, *The Climate Casino,* which concludes that an economically optimum temperature increase, even with all countries participating

[1] For background information on the DICE model, see William Nordhaus,

[21] Further results, not shown here, show that if climate sensitivity is estimated to be greater, even more abatement of emissions would be called for.

[22] A uniform distribution ranging from 1.5 to 2.5 percent of output has been assumed for the extent of damage at two degrees of warming. A uniform distribution ranging from 20 to 50 percent of output has been assumed for a warming of five degrees, in view of the wide range of uncertainties regarding impacts, irreversible factors, and discontinuities under extreme warming.

[23] William Nordhaus, “Climate Policy by Balancing Costs and Benefits,” in *The Climate Casino: Risk, Uncertainty and Economics for a Warming World* (New Haven: Yale University Press, 2013).!