Dealing with complex scientific and economic issues has increasingly involved developing scientific and economic models. Such models help analysts and decision makers understand likely future outcomes as well as the implications of alternative policies. In the economic literature, the DICE model (Dynamic Integrated model of Climate and the Economy) developed by the PI was the first integrated-assessment model of the economics of climate change. This model developed an approach that links together from end to end the different facets of global warming.

Under the present grant, the PI and co-workers developed a second generation integrated assessment model, the RICE-99 model. This fully revised model of the economics of global warming builds upon earlier work by the author and collaborators. The work will be published in a volume from MIT Press in the summer of 2000 entitled Warming the World: Economic Models of Global Warming, joint with Joseph Boyer.

The overall purpose of the research has been to integrate scientific knowledge of the dynamics of climate change with our understanding of the economic aspects of emissions of greenhouse gases and damages from climate change. The research provides a full description of the methodology as well as an analysis of alternative approaches to climate-change policy.
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Summary of the Model and Analysis

We provide here a short overview of the approach and major results of the study. The basic approach taken in analyzing the economics of climate change is to consider the tradeoff between consumption today and consumption in the future. By taking steps to slow emissions of greenhouse gases (GHGs) today, the economy reduces the amount of output that can be devoted to consumption and productive investment. The return for this "climate investment" is lower damages and therefore higher consumption in the future. The purpose of the study is to capture the major tradeoffs involved in climate-change policy.

In the RICE-99 model, the world is composed of sovereign countries, represented by large countries (like the U.S. or India) or large regions (like the European Union or Africa). Each region is assumed to have a well-defined set of preferences by which it chooses its path for consumption over time. The welfare of different generations is combined using a social-welfare function that applies a pure rate of time preference to different generations. Nations are then assumed to maximize the social-welfare function subject to a number of economic and geophysical constraints. The decision variables that are available to the economy are consumption, the rate of investment in tangible capital, and the climate investments, primarily emissions reductions of greenhouse gases.

The model contains both a traditional economic sector, similar to that found in many economic models, and a geophysical module designed for climate-change modeling. In the economic sectors, each country or region is assumed to produce a single commodity which can be used for either consumption or investment. In the baseline model, there is no trade in goods or capital, but countries in certain cases trade rights for carbon emissions and receive consumption goods in return.

Each region is endowed with an initial stock of capital and labor and an initial and region-specific level of technology. Population growth and technological change are exogenous in the baseline model, while capital accumulation is determined by optimizing the flow of consumption over time. The RICE-99 model defines a new input into production called "carbon-energy." Carbon energy is the carbon equivalent of energy consumption and is measured in carbon units. CO2 emissions are therefore a joint product of carbon-energy. Technological change takes two forms: economy-wide technological change and energy-saving technological change. More precisely, economy-wide technological change is Hicks neutral, while energy-saving technological change is modeled as reducing the output-carbon elasticity.

We calibrate the production function using existing data on energy use, energy prices, and energy-use price elasticities. These allow an empirically-based carbon-reduction cost function, whereas most current integrated assessment models make "reasonable" but not empirically-based specifications of the cost schedule. In the RICE-99 model, a carbon supply curve is introduced. The model contains a supply curve for carbon-energy with carbon fuels available at rising costs. Because it employs the optimal-growth framework, fossil fuels are efficiently allocated, which implies that low-cost resources have scarcity rents and that the "Hotelling rents" on
carbon-energy prices rise over time.

The environmental part of the model contains a number of geophysical relationships that link together the different forces affecting climate change. This part contains a carbon cycle, a radiative forcing equation, climate-change equations, and a climate-damage relationship. The geophysical sectors are simplified representations of more complex models. Although they have been built on first principles, the research shows that they track closely more elaborate models.

In the new models, endogenous emissions are limited to industrial CO2. Industrial emissions are treated as a joint product of carbon-energy. Other contributions to global warming are taken as exogenous. The new models contain a new structural approach to carbon-cycle modeling that uses a three-reservoir model calibrated to existing carbon-cycle models. Climate change is represented by global mean surface temperature, and the relationship uses the consensus of climate modelers and a lag suggested by coupled ocean-atmospheric models.

Understanding the economic impacts of climate change continues to be the thorniest issue in climate-change economics. The present study follows first-generation approaches by analyzing impacts on a sectoral basis. The approach is focused on estimates for all thirteen major regions rather than for the United States alone. Moreover, the new study focuses more heavily on the non-market aspects of climate change with particular importance given to the potential for catastrophic risk; this approach is taken because of finding that the impacts on market sectors are likely to be relatively limited. The major results are that impacts are likely to differ sharply by region. We estimate that Russia and other high-income countries (principally Canada) will benefit slightly from a modest global warming, while low-income regions -- particularly Africa and India -- and Europe appear to be quite vulnerable to climate change. The United States appears to be relatively less vulnerable to climate change than many countries.

Major results

Three conclusions drawn from the larger study will give a flavor of the results of the new study.

The most important set of results is to compare the relative efficiency of different approaches to climate-change policy. The RICE model is the only major integrated-assessment model that integrates regional costs and damages and is therefore able to provide guidelines about how well different policies meet a cost-benefit test. According to the new study, a path that limits CO2 concentrations to no more than doubling of pre-industrial levels is close to the "optimal" or efficient policy. By contrast, current approaches, such as the Kyoto Protocol, are highly inefficient, with abatement costs approximately ten times their benefits in reduced damages. More ambitious proposals, such as those which cut CO2 emissions sharply in the near term, are highly inefficient.

Second, earlier versions of the DICE model have investigated the role of "carbon taxes," which are a measure of the stringency of global warming policies. This measure is a useful way of calibrating different climate-change policies. According to the RICE-99 model, the optimal
carbon price in the near term is in the $5 to $10 per ton range. Policies which have near-term carbon prices in the $100 per ton range, such as those associated with the Kyoto Protocol, fail a cost-benefit test because they impose excessive near-term abatement. Moreover, all policies that are investigated that pass a cost-benefit test have near-term carbon taxes under $10 per ton.

Third, the revised RICE model paints a much less alarming picture of future climate change than the earlier climate-change models completed in the early 1990s. Whereas many studies projected baseline global temperature increases by 2100 in the 3 to 4 degrees C range, a better guess for uncontrolled warming would be close to 2 degrees C warming in 2100. It is interesting to compare the results of the new model with the earlier DICE model. The optimal carbon tax and control rate in the early periods in the two models are very close. However, the new RICE model has significantly slower growth in emissions, concentrations, and other greenhouse-gas forcings. The slower buildup of concentrations, along with the evidence of the cooling effect of other gases and the phaseout of the CFCs, implies that the baseline (no-control) global temperature increase for 2100 is 2.1 degrees C in the RICE-99 model as compared to 3.3 degrees C in the original DICE model. In addition, the new RICE model has higher controls than the original DICE model. Hence the optimized global temperature increase in 2100 is 2.0 degrees C in RICE-99 compared to 3.1 degrees C in the original DICE model.

These three conclusions are but three of many examples of how the RICE-99 model can be fruitfully employed to investigate alternative future paths of climate change and to evaluate different policy proposals. The widespread dissemination of the results through publication will contribute to the advance of knowledge in this area and to the design of sensible public policies. Earlier versions of the DICE and RICE model have been widely used in scientific and policy analyses, and we believe that the updated version will be of broad interest to the research community.

The manuscript edition is available on the Internet in an Acrobat pdf format. It is found at www.econ.yale.edu/~nordhaus/homepage/dicemodels.htm. This version will continue to be available after publication through an agreement with the publisher. The Table of Contents is as follows:

Table of Contents of Warming the World

Preface

Chapter 1. Introduction

Chapter 2. The Structure And Derivation of RICE

Chapter 3. Calibration of the Major Sectors

Chapter 4. The Impacts of Climate Change

Chapter 5. The DICE-99 Model
Chapter 6. Computational Procedures
Chapter 7. Efficient Climate-Change Policies
Chapter 8. Economic Analysis of the Kyoto Protocol
Chapter 9. Managing the Global Commons

References

Appendix A. Equations of the RICE-99 Model
Appendix B. Equations of the DICE-99 Model
Appendix C. Variable List
Appendix D. GAMS Code for RICE-99, Base Case and Optimal Case
Appendix E. GAMS Code for DICE-99