

Warming the World

Economic Models of
Global Warming

William D. Nordhaus and
Joseph Boyer

The MIT Press
Cambridge, Massachusetts
London, England

Contents

List of Tables	vii
List of Figures	ix
Preface	xi

I Developing the RICE and DICE Models 1

1	Introduction	3
2	The Structure and Derivation of RICE-99	9
	Overview of Approach	9
	Model Description	10
	Derivation of the Equations of RICE-99	14
	Equilibrium in the Market for Carbon-Energy	24
	Policy in RICE-99	24
3	Calibration of the Major Sectors	27
	Regional Specification	27
	Calibration of Production Function	41
	Exogenous Trend Parameters	46
	Carbon Supply	53
	The Carbon Cycle and Other Radiative Forcings	56
	The Climate Module	62
4	The Impacts of Climate Change	69
	Early Impact Studies	69
	The Present Approach	71
	Discussion of Individual Sectors	74
	Impact Indices as Functions of Temperature	89
	Calibration of the RICE-99 Damage Function	94
	Major Results and Conclusions	95

5	The DICE-99 Model	99
	Model Structure	99
	Calibration	101
6	Computational Procedures	107
	Computer Programs for RICE and DICE	107
	Solution Approach in EXCEL—RICE-99	107
	Solution Approach in GAMS—RICE-99	109
	DICE	114
	GAMS versus EXCEL	114
II Policy Applications of the RICE Model		119
7	Efficient Climate-Change Policies	121
	Alternative Approaches to Climate-Change Policy	121
	Detailed Description of Different Policies	123
	Major Results	127
8	Economic Analysis of the Kyoto Protocol	145
	Climate-Change Policy and the Kyoto Protocol	145
	Economic Analysis of the Kyoto Protocol	147
	Major Results	149
	Findings and Conclusions	166
9	Managing the Global Commons	169
	Background	169
	Summary of the Model and Analysis	170
	Major Results	174
	Analysis of the Kyoto Protocol	176
	Concluding Thoughts	178
	Appendix A: Equations of RICE-99 Model	179
	Appendix B: Equations of DICE-99 Model	181
	Appendix C: Variable List	183
	Appendix D: GAMS Code for RICE-99, Base Case and Optimal Case	189
	Appendix E: GAMS Code for DICE-99	207
	References	217
	Index	227

Tables

Table 1.1	Reference case output across model generations	5
Table 1.2	Difference in radiative forcing across models, reference case, 2100	7
Table 3.1	Regional details of the RICE-99 model	28
Table 3.2	Major regional aggregates in RICE-99 regions	39
Table 3.3	Growth rates of per capita GDP: Regional averages	40
Table 3.4	Growth rates of commercial energy/GDP ratio: Regional averages	40
Table 3.5	Growth rates of CO ₂ -GDP ratio: Regional averages	41
Table 3.6	Comparison of RICE-99 with Maddison projections	48
Table 3.7	Growth in per capita output in RICE-99 regions: Historical rates and projections	49
Table 3.8	Comparison of RICE-99 reference case with IIASA scenario B	52
Table 3.9	Non-CO ₂ radiative forcings according to IPCC-90, MAGICC/IPCC-99, and RICE-99	63
Table 4.1	Estimated impact from IPCC report, 1996	70
Table 4.2	Regions in impact analysis	72
Table 4.3	Subregional mean temperature	73
Table 4.4	Estimated damages on agriculture from CO ₂ doubling	76
Table 4.5	Coastal vulnerability	78
Table 4.6	Vulnerability of economy to climate change	79
Table 4.7	Years of life lost from climate-related diseases	81
Table 4.8	Impact of global warming on climate-related diseases	83

Table 4.9	Willingness to pay to eliminate risk of catastrophic impact	90
Table 4.10	Summary of impacts in different sectors	91
Table 4.11	Comparison of recent impact studies, United States	97
Table 5.1	Comparison of RICE-99 and DICE-99 results, reference case	103
Table 5.2	Comparison of RICE-99 and DICE-99 results, optimal case	105
Table 6.1	The Basic policies of the RICE model	110
Table 6.2	Comparison between GAMS and EXCEL solutions	113
Table 7.1	Alternative policies analyzed in RICE-99 and DICE-99 models	122
Table 7.2	Global net economic impact of policies	128
Table 7.3	Abatement cost and environmental benefits of different policies	130
Table 7.4	Regional net economic impact of policies	131
Table 7.5	Carbon taxes in alternative policies	133
Table 7.6	Emissions control rates in alternative policies	137
Table 7.7	Industrial CO ₂ emissions in alternative policies	137
Table 7.8	Temperature in alternative policies	141
Table 8.1	Runs for the analysis of Kyoto Protocol	147
Table 8.2	Industrial carbon emissions for alternative approaches to Kyoto Protocol	151
Table 8.3	Comparison of global mean temperature increase in different approaches to Kyoto Protocol	153
Table 8.4	Comparison of carbon taxes, 2015 and 2105, in different approaches to Kyoto Protocol	155
Table 8.5	Discounted abatement costs in different strategies	157
Table 8.6	Abatement costs in different regions for different policies	159
Table 8.7	Net economic impacts in different regions for different policies	160
Table 8.8	Benefits, costs, and benefit-cost ratios of different approaches	164

Figures

- Figure 3.1 Industrial CO₂-output ratios for thirteen RICE subregions, 1995 42
- Figure 3.2 Growth in per capita output 50
- Figure 3.3 Rates of growth in CO₂ emissions/GDP ratio 51
- Figure 3.4 Carbon supply function in RICE-99 model 55
- Figure 3.5 Impulse response functions for different models 61
- Figure 3.6 Comparison of projections of CO₂ concentrations from RICE-99 and Bern models for IS92a emissions projection 62
- Figure 3.7 Comparison of temperature simulation of RICE-99 model with IPCC-96 66
- Figure 4.1 Agricultural damage function 92
- Figure 4.2 Health damages from model and Murray-Lopez study 94
- Figure 4.3 Global damage function 95
- Figure 4.4 Regional damage functions 96
- Figure 5.1 Calibration error in DICE reference case 102
- Figure 5.2 Calibration error in DICE optimal case 104
- Figure 7.1 Global net economic impact 128
- Figure 7.2 Carbon taxes: Alternative policies 132
- Figure 7.3 Carbon taxes: Alternative policies 134
- Figure 7.4 Emission control rates: Alternative policies 135
- Figure 7.5 Optimal emissions control rate by region 136
- Figure 7.6 Industrial CO₂ emissions: Alternative policies 138

Figure 7.7	Regional industrial CO ₂ emissions in base case	138
Figure 7.8	CO ₂ concentrations: Alternative policies	139
Figure 7.9	Global mean temperature	140
Figure 7.10	Per capita income in base run	143
Figure 7.11	Industrial carbon intensity: Base case	144
Figure 8.1	Global industrial CO ₂ emissions	150
Figure 8.2	Atmospheric CO ₂ concentration	152
Figure 8.3	Global temperature increase	153
Figure 8.4	Carbon taxes in different policies	154
Figure 8.5	Abatement costs in different strategies	157
Figure 8.6	Impact of policy on world GDP	158
Figure 8.7	Regional impacts of alternative strategies	161
Figure 8.8	Overall impacts of alternative strategies	163
Figure 8.9	Net economic impact by region	165

Preface

Dealing with complex scientific and economic issues has increasingly involved developing scientific and economic models that help analysts and decision makers understand likely future outcomes as well as the implications of alternative policies. This book presents the details of a pair of integrated-assessment models of the economics of climate change. The models, called RICE-99 (for the Regional Dynamic Integrated model of Climate and the Economy) and DICE-99 (for the Dynamic Integrated model of Climate and the Economy), build upon earlier work by Nordhaus and collaborators, particularly the DICE and RICE models constructed in the early 1990s. The purpose of this book is to lay out the logic and details of RICE-99 and DICE-99. Like an anatomy class, this description highlights internal structure of the models and the ways different segments are connected.

The book is organized into two parts. The first part describes RICE-99 and its globally aggregated companion, DICE-99. This part contains an introduction (chapter 1) and a brief description of RICE-99 (chapter 2) that includes all the model equations. The details of the derivation of these equations and their parameterization are presented in chapters 3 and 4. Chapters 1 through 4 present RICE-99, leaving explicit discussion of DICE-99 to chapter 5. Chapter 6 explains how the models are solved. Part II presents the major results of RICE-99 and applies it to the questions surrounding climate change. The appendixes provide a summary listing of the equations, a variable list, and the programs for the RICE-99 and DICE-99 models. The models and spreadsheets are also available on the Web.

Those interested in this exciting field will recognize that this book builds on earlier work of the authors and of many others. Although it bears the names of two authors, the intellectual inspiration and contribution of many should be recognized. Among those we thank for

contributing directly or indirectly are Jesse Ausubel, Howard Gruenspecht, Henry Jacoby, Dale Jorgenson, Charles Kolstad, Alan Manne, Robert Mendelsohn, Nebojsa Nakicenovic, John Reilly, Richard Richels, Thomas Schelling, Richard Schmalensee, Stephen Schneider, Leo Schrattenholzer, Robert Stavins, Ferenc Toth, Karl Turekian, Paul Waggoner, John Weyant, Zili Yang, and Gary Yohe. Megan McCarthy and Ben Gillen provided valuable research assistance. This research was supported by the National Science Foundation and the Department of Energy. None of these is responsible for the errors, opinions, or flights of fancy in this work.