Strategic Bargaining and Cooperation in Greenhouse Gas Mitigations

An Integrated Assessment Modeling Approach

Zili Yang

The MIT Press
Cambridge, Massachusetts
London, England

For information about special quantity discounts, please e-mail special_sales@mitpress.mit.edu

This book was set in Palatino on 3B2 by Asco Typesetters, Hong Kong.
Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Yang, Zili, 1957–
Strategic bargaining and cooperation in greenhouse gas mitigations : an integrated assessment modeling approach / Zili Yang.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-262-24054-3 (hbk. : alk. paper)
1. Greenhouse gas mitigation—Econometric models. 2. Climatic changes—Econometric models. I. Title.
HC79.A4Y36 2008
363.738′746—dc22 2008017048

10 9 8 7 6 5 4 3 2 1

1 Introduction

1.1 Integrated Assessment of Climate Change

Since the Industrial Revolution started the locomotive of economic growth worldwide, fossil fuels, along with other primary factors and technological innovations, have kept the economic engine running at a fast and steady speed. Rewinding history, it is hard to imagine civilization today without fossil fuels. While fossil fuels have brought prosperity to millions, they have also caused significant environmental pollution problems at local and regional levels. Coal miners suffer from black lung disease; farmers endure the effects of acid rain; city dwellers inhale particulates in smog. Nevertheless, carbon dioxide (CO_2) emissions produced during fossil fuel combustion seemed innocuous to most people until the past two decades when *greenhouse effect* and *global warming* became common terms.

Carbon dioxide emission is the by-product of burning fossil fuels. By absorbing infrared radiation, CO_2 concentration in the atmosphere, along with other so-called greenhouse gases (GHGs), traps heat near the earth's surface. This greenhouse effect causes a global temperature increase. Today, scientists conclude that "most of the observed increase in global average temperatures since the mid-twentieth century is *very likely* due to the observed increase in anthropogenic GHG concentration" (Intergovernmental Panel on Climate Change (IPCC), 2007). In the Summary for Policy Makers of Working Group I in the most recent Fourth Assessment Report (AR4) of the IPCC, scientists conclude that by the end of the twenty-first century, global surface temperature might increase by 1.8°C to 4.0°C, depending on different assumptions on social and economic drivers (IPCC, 2007). The consequences of such temperature increases are wide ranging: from rising sea level to extinction of certain fauna and flora species, from reductions of

agricultural outputs to increased weather-related disasters. The potential impacts of climate change are assessed in volume 3 of IPCC AR4.

Shortly after natural scientists raised the climate change issue in the academic arena, economists began to examine the issue from a socioeconomic perspective. Early literature on this issue can be traced back to the late 1970s and early 1980s (Nordhaus 1977, 1982; Nordhaus and Yohe 1983). Since the 1990s, the amount of economic literature on climate change has increased exponentially. Economics of climate change is an important research topic in environmental economics. In *Recent Developments in Environmental Economics* (Hoel 2004), which claimed to include the "47 most important papers in environmental economics from 1993 to 2003," eleven papers are on climate change directly.

Climate change is a complicated research subject of global magnitude. Economic issues associated with it cannot be separated from the natural sciences. From the very beginning, the bulk of economic studies of climate change have been interactive with other science branches, such as climatology, ecology, regional sciences, and engineering. This multidisciplinary approach has gained prominence and formed a unique research field: integrated assessment (IA) of climate change. Various models built for climate change research are labeled IA models, and most IA models are developed and employed by a group of scholars from several research fields, including economists. Famous and influential IA models have undergone continuous development and refinement over the last decade, such as the IA models maintained by MIT (2007), Carnegie-Mellon (2007), Pacific Northwest National Laboratory (2007), International Institute for Applied Systems Analysis (IIASA, Austria) (2007), Asian-Pacific Integrated Model (AIM) group (Japan) (2007), and National Institute for Public Health (RIVM, Netherlands) (2007),[1] to name just a few by seniority. These IA models are buttressed by strong multidisciplinary research groups from these institutions. Economic components are part of them. In contrast to these comprehensive IA modeling endeavors, there are IA models developed by economists that are more focused on economic aspects of climate change. An incomplete list includes the MERGE model by Manne and Richels (1992), the CETA model by Peck and Teisberg (1992), the FUND model by Tol (1997), the G-Cubed model by McKibbin and Wilcoxen (1995), and the RICE model by Nordhaus and Yang (1996).

Economic modeling has always been a crucial part, sometimes the central part, of IA modeling. Because climate change is a very compli-

cated matter of long-lasting impacts and global scope, economic models in the IA framework exert the dimensionality and complexity of economic modeling to its limit. The methodologies of economic modeling in the IA framework include the following approaches:

- Computable general equilibrium (CGE) models, such as MIT's EPPA model and Pacific Northwest National Laboratory's SGM model
- Intertemporal optimization (nonlinear programming) models, such as the RICE model and the MERGE model
- Scenario simulation models, such as Carnegie-Mellon's ICAM model and RIVM's IMAGE model

CGE models are set up on a database called the social accounting matrix (SAM). They allow great details of sectoral and regional disaggregations. In forecasting future GHG emissions and assessing GHG mitigation strategies, CGE models can offer much useful information. Modelers can build in ad hoc structures or "devices" in CGE models to analyze specific economic issues. One drawback of CGE modeling is that its dynamic feature is limited by data constraints. Usually, CGE models are either static or recursive dynamic. There is yet to be an operational forward-looking dynamic CGE model in the IA framework.

Intertemporal, or dynamic, optimization models are limited in sectoral breakdowns due to the dimensionality constraint, but they are much more flexible and powerful than CGE models in capturing economic agents' decisions and responses to the future events. In addition, it is easier to build in economic functionality than in CGE models because of the treatment of intertemporal economic relationships. Furthermore, the model structure of dynamic optimization is more transparent than in the other two approaches.

Scenario simulation models do not require time-consuming calculations to find optimal solutions. The model itself is a set of calibrated economic relationships that does not involve any decision making or optimization behavior of economic agents when solving the model. Simulation models are a truthful reflection of modelers' opinions and expertise in the economic relationships captured by the model. Such models can provide user-friendly interfaces and outputs.

From an economic modeling perspective, CGE and dynamic optimization models are preferred to simulation models. The CGE models capture economies' responses to market shocks, both prices and quantities. However, because climate damage will take place in the future,

it is very difficult to incorporate climate damage assessments in a recursive dynamic CGE model. In the IA framework with CGE economic models, climate impact models are separated from CGE models. On the other hand, dynamic optimization models are less "mechanical" and more "behavior bending" than CGE models. Dynamic optimization models can capture economic agents' intertemporal decision-making processes. They can also incorporate GHG mitigation strategies and climate damage in a single modeling framework. Such strengths provide a platform for modeling economic agents' behavior in an IA framework.

Functions of economic models in the IA framework include but are not restricted to the following: first, forecasting future GHG emission scenarios and serving as inputs to other components of IA modeling; second, analyzing cost-effectiveness of various GHG mitigation policies; and third, assessing a broad range of policy issues arising from climate change research. Parson and Fisher-Vanden (1997) and Kolstad (1998) provide detailed surveys and analyses of IA modeling. IA modeling has advanced since these two survey papers, but its functionality and focus in climate change research remain the same. In addition to IA modeling, economic analysis also permeates many derivative issues from climate change, from international trade to domestic taxation and from ecology to energy.

Contributions by economists to IA modeling are fruitful. The research results appear frequently in mainstream economics literature as well as in multidisciplinary climate change research venues. These economic research outcomes culminate and are summarized in the IPCC's Third Assessment Report (TAR), the series of IPCC Technical Reports, and most recently, IPCC's Fourth Assessment Report (AR4). In Volume II (Impacts, Adaptation, and Vulnerability) and Volume III (Mitigation) of the assessment reports from 1990 to 2007, one can find extensive work done by economists. All of these results are documented at the IPCC's Web site (IPCC 2007). Many economists and research groups bring their research results into the formation of IPCC reports, which are accessible to a global audience. Economists also offer their comprehensive assessments and policy suggestions on climate change (for example, Stern 2007), either commissioned by the government or sanctioned on their own.

Summarizing the achievements by economists in the IA framework would require an entire volume. I direct readers to the IPCC's Web site to gain a more comprehensive view of the literature.

1.2 Game-Theoretic Analysis of Environmental Issues

Today, climate change research is one of the major topics in environmental economics, a rich field that attracts a plethora of research methodologies. Game theory, a pillar of modern microeconomics, finds broad applications and theoretic extensions in environmental economics.

One of the central themes in environmental economics is market failure and free-riding behavior in pollution control. A famous early example of a game-theoretic application is the preference revelation mechanism in public good (bad) provision designed by Clarke (1971) and Groves (1973). Over the last two decades, game-theory models have been used to analyze various environmental problems from acid rain to preservation of commons. Two collections edited by Hanley and Folmer (1998) as well as Carraro and Fragnelli (2004) offer a spectrum of broad applications of game theory in environmental economics. A volume edited by Carraro and Siniscalco (1997) also indicates game theory's application to environmental economics. In these works, specific environmental problems are examined in light of game-theoretic angles. Games are structured to address environmental problems. Game-theoretic solutions in this line of research are indicative rather than quantitative; the models are stylistic rather than realistic.

Although it is still in early stages, game theory has been used to address several important aspects of climate change. In particular, scholars have made substantial progress on coalition formation theories with respect to international environmental agreements (IEAs). Notable publications include Chander and Tulkens 1995, 1997, on coalition theory; several contributions in Carraro 2003 on coalition formation theory with respect to global environmental issues; Barrett 1994; and Carraro and Siniscalco 1988 on self-enforcing coalitions. On the empirical side, Nordhaus and Yang (1996) first introduced an open-loop noncooperative game solution concept into the RICE model, an influential IA model. Since then, several game-theoretic applications using the modified RICE model have appeared. For example, Eyckmans and Tulkens (2003) studied the coalition problem using a revised RICE model; Carraro, Eyckmans, and Finus (2006) examined optimal transfer problems in RICE; and Yang (2003b) investigated renegotiation proofness of incentive-compatible coalitions in RICE. In addition, Tol (2001) studied coalition issues inside the FUND model.

After promulgation of the Kyoto Protocol in 1997, climate change became an important issue in international environmental politics. Negotiations, bargaining, and strategic posturing on implementing the Kyoto Protocol took place at intergovernmental and private-sector levels. The reality has prompted more active studies of climate change from a game-theoretic angle. Carraro and his research group at Fondazione Eni Enrico Mattei (FEEM 2007), Italy, along with environmental economists in other European countries, played a leading role in such research endeavors. The working paper series at FEEM offers a good view of research frontiers in the study of coalition theories applied to climate change and other environmental issues. Seminars and conferences devoted to the coalition theory applications in the environment and climate change have been held all over the world. However, game-theoretic analysis of climate change issues has yet to address the imperative policy issues directly.

1.3 Motivation and Scope of This Research

Integrated assessment of climate change is a leading research topic in environmental economics; game-theoretic modeling is a major research methodology of environmental economics. Despite the common premises, IA framework and game-theoretic modeling have limited intersection. We observe twin peaks in economic research on climate change, but no bridge connecting them. As more and more people realize the urgent need for international cooperation on GHG mitigation, both approaches expose their inadequacy in dealing with the issues. More comprehensive policy responses to climate change call for IA modeling from a game-theoretic perspective.

Since its original release in 1996, the RICE model has been and continues to be an excellent platform for bridging IA modeling and game-theoretic solutions. RICE contains the first documentation of noncooperative Nash equilibrium solutions in IA modeling. As described in the brief survey in the previous section, simplified RICE models have been used to study coalition and transfer issues extensively. Nevertheless, all of the previous studies of game-theoretic solutions in RICE are topic driven and fragmented. Scholars use the RICE model as an illustrative tool in their own research. The IA aspects of RICE and the potentials of its game-theoretic applications are not fully integrated. In this book, I adopt a comprehensive approach that com-

bines IA modeling, noncooperative and cooperative game solutions, and policy analysis in the RICE framework.

In the research framework here, I construct a cooperative game of stock externality provision—the economic abstraction of climate change—within the framework of the RICE model. This game connects the solution of an optimal control problem of stock externality provision with the bargaining of GHG mitigation quotas among the regions in the RICE model. By analyzing the properties of this game and regions' incentives to join the grand coalition, I shed light on debates and policies of international cooperation in GHG mitigation. I hope to offer a new research angle to both IA modeling of climate change and applications of game-theoretic modeling in climate change.

This study is the first attempt at integrating the IA modeling and game-theoretic solutions comprehensively. It draws on a wide range of research results from scholars on both sides. Yet, the approach itself is accessible to both camps. The knowledge background of this research is based on well-established concepts in game theory and the abundantly documented IA modeling framework. The expositions in this research are self-contained and assume only basic knowledge of mathematical programming, the IA modeling of climate change, and cooperative game theory.

The remaining chapters of this book are organized as follows.

In chapter 2, I formulate the framework of stock externality provision as a social planner's optimal control problem. Climate change is a special application for the general formulation. Then a cooperative game of providing stock externality is constructed as a bargaining process for shares in social welfare weights. Preparatory definitions and game-theoretic solutions in the context of the optimal control setting are introduced here. Solution concepts such as the Lindahl equilibrium and the Shapley value are defined in the dynamic setting.

The RICE model is described and reintroduced in chapter 3. I implement the cooperative game and its solution concepts in chapter 2 into the RICE framework. In addition, I develop and explain the numerical algorithms for solving game-theoretic solutions in RICE in detail. In particular, I discuss the iterative procedures and incentive checking designed for searching the core allocations, the Lindahl equilibrium and the Shapley value. These numerical algorithms are building blocks on the bridge that connects game-theoretic solution concepts with IA modeling.

In chapter 4, I present, compare, and contrast the results of game-theoretic and conventional solutions of the RICE model from incentive and strategic perspectives. I examine the properties of different solutions in the context of integrated assessment. Through the numerical analysis of the simulation results, I clearly demonstrate the superiority of game-theoretic solutions over conventional solutions.

In chapter 5, I explore the properties of game-theoretic solutions in RICE through sensitivity analysis from an incentive perspective. The issues include intertemporal stability of the grand coalition under the Lindahl social welfare weights, the range of solutions with the core properties or having the Lindahl equilibrium properties, and incentive reactions to false perception of climate change by individual regions.

I apply the game-theoretic solutions of RICE to some policy-related issues in climate change in chapter 6. The difficulties confronted by unilateral actions such as the Kyoto Protocol are analyzed from an incentive angle. Sustainability of the Lindahl equilibrium solution under various unexpected shocks in economic/climate systems is examined. Redistribution and transfer issues in GHG mitigation policies are studied from game-theoretic perspectives. Furthermore, the second-best properties of subcoalitions of GHG mitigations are inspected.

In the epilogue, I point out future research directions and topics employing the research methodologies in this book. In the appendixes, the algebraic description and parametric values of RICE are provided. In addition, the core part of the model codes in GAMS language is listed here. Large portions of the algorithm and output codes are not included, but they are available from the author on request.