Climate Treaties and Models: Issues in the International Management of Climate Change

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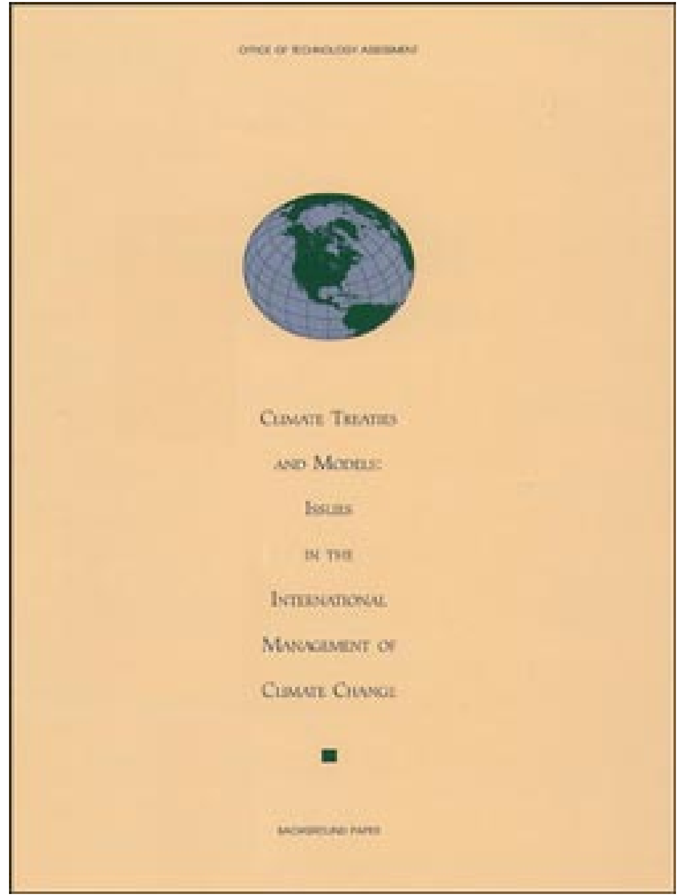

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Foreword

The Office of Technology Assessment has produced two major assessments related to climate change over the past three years. *Changing by Degrees: Steps to Reduce Greenhouse Gases,* which focused on ways to reduce U.S. emissions of greenhouse gases, was published in 1991. *Preparing for an Uncertain Climate,* which addressed the impact of climate change on natural resources, was published in 1993. OTA prepared this background paper as a technical addendum to those earlier assessments. The earlier assessments focused on national policies and concerns. This background paper seeks to place the issue of climate change within an international context. Specifically, it addresses the feasibility of forging treaty agreements among countries to achieve significant worldwide reductions in emissions of greenhouse gases.

Concerns about climate change have led over 160 countries, including the United States, to sign a United Nations-sponsored world climate treaty, agreeing to take steps toward stabilizing greenhouse gas emissions. Unfortunately, the treaty itself offers no clearly defined targets or timetables. The potential difficulties in achieving agreements on worldwide reductions in emissions of greenhouse gases are striking. These difficulties are perhaps most clearly illustrated by recent evidence of rapid increases in $C0_2$ emissions from several of the larger developing countries as they pursue the goal of economic growth. Even within industrialized countries, there continues to be concern over possible economic costs of any limit on emissions. Yet, without wide participation in a stronger climate treaty, the steps the United States has proposed to take under its Climate Action Plan could prove fruitless. Congress will face these issues as it oversees the Climate Action Plan and considers future climate treaties.

This paper was prepared for OTA by Edward Parson of the Kennedy School of Government. It summarizes discussions from an OTA workshop on climate treaties and draws upon an earlier report prepared for OTA by Jae Edmonds of the Battelle Pacific Northwest Laboratory.

ROGER C. HERDMAN
Director

Workshop Participants

Edward A. Parson
Chairman
Harvard University

Dan Bodansky
University of Washington

Tony Brenton
Harvard University

Herman Cesar
Tilburg University

Joel Darmstadter
Resources for the Future

Hadi Dowlatabadi
Carnegie Mellon University

Jae Edmonds
Battelle Pacific Northwest Laboratory

Howard Gruenspecht
Department of Energy

James K. Hammitt
Rand Corp.

William W. Hogan
Harvard University

Rick Piltz
U.S. Congress, House Committee on Science, Space, and Technology

Steve Rayner
Battelle Pacific Northwest Laboratory

John Reilly
Massachusetts Institute of Technology

Joel Scheraga
U.S. Environmcntal Protection Agency

Dennis Tirpak
U.S. Environmental Protection Agency

David Victor
Harvard University

John Weyant
Stanford Univcrsity

OTA PARTICIPANTS

John Andelin
Assistant Director

Rosina Bierbaum
Senior Associate

Michael Bowes
Senior Analyst

Joy Dunkerly
Senior Analyst

Robert Niblock
Program Director

Bill Westermeyer
Senior Analyst

Preject Staff

Clyde Behney
Assistant Director, OTA
Health, Education and Enviroment

Robert W. Niblock
Environment Program Diector

Michael Bowes
Project Director

Sherry Showell
Analyst

Edward A. Parson
Contractor

ADMINISTRATIVE AND SUPPORT STAFF

Kathleen A. Beil
Office Administrator

Nellie Hammond
Administrative Secretary

Kim Holmlund
Administrative Secretary

Sharon Knarvik
Secretary

Jene Lewis
Administrative Secretary

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Issues in the International Management of Climate Change[1]

As part of its assessment work on global climate change, the Office of Technology Assessment (OTA) cosponsored an analysis with the Battelle Pacific Northwest Laboratory to examine various hypothesized international agreements for limiting greenhouse gas emissions (5). The analysis, led by Jae Edmonds of Battelle, applied a sophisticated international energy model to generate projections of the effectiveness (in terms of reduced global emissions) and cost (in terms of losses in Gross National Product, GNP) of particular agreements, to permit assessments of how feasible and politicall y sustainable such treaties are likely to be. The goal was not to ask what level of global emission controls is justified, nor to estimate the effects of particular treaties on the United States alone. Rather, the study examined the effects of agreements on global emissions and on the economies of major world regions, so as to permit a preliminary inquiry into what kinds of agreements are desirable, and what kinds can be achieved and maintained.

On April 23, 1993, OTA sponsored a workshop entitled "Climate Treaties and Models" to bring together experts in modeling, environmental policy, and international negotiations and law to examine these questions. The workshop participants considered the implications of the Edmonds et al. analysis (5), and the prospects for other exercises of formal modeling to advance international policy debate on climate change. The Edmonds et al. paper provided the backdrop for the workshop, but workshop discussion ranged more broadly to consider a variet y of issues related to

[1]Edward A. Parson of the John F. Kennedy School of Government, Harvard University, chaired the OTA workshop and is the author of this background paper.

the feasibility and sustainability of international agreements on climate change. At the workshop, Edmonds summarized the major results of his team's study. Following his presentation, the workshop's four sessions were organized around four major issues in international agreements to manage global climate change. The first three issues concern the construction of international climate agreements—who joins, when they act. and what they do-while the final issue is institutional. The first session, "Participation," considered what will determine who participates in climate agreements, and how participation will affect the cost and effectiveness of agreements. The second session, "Timing," considered when participants are likely to act to control emissions, and how the timing of action will affect cost and effectiveness. The third session, "Formulas and Feasibility," considered what formulas participants are likely to use in allocating responsibilities under a treaty, and how the choice of a formula will affect cost and effectiveness. Finally, the fourth session considered "Uses of Models," institutional questions of how modeling exercises such as the Edmonds et al. work can inform most usefully the deliberations and negotiations involved in making international climate agreements and policy—and limits to the usefulness of models in these processes. In each session, participants discussed both the implications of the Edrnonds et al. project for the specified topic, and broader related questions. Each session opened with a brief presentation by one participant, structuring major questions to be addressed. David Victor opened the section on Participation, Jim Hammitt on Timing, Herman Cesar on Formulas and Feasibility, and Edward Parson on Uses of Models.

This paper weaves together workshop discussion of these four areas with insights provided by the Edmonds et al. project and other current 1 iterature. In effect, it is a survey of the current territory of expert opinion on climate treaties, energy economic and policy modeling bearing on international climate agreements, and relationships between the two. The paper reports in summary form the major views and arguments aired at the workshop, without attribution.

The paper is organized as follows. Section 1 introduces major issues in the design and use of economic and emissions models for studying global climate change, and provides a brief summary of the major results of the Edmonds et al. work. Sections 2 through 5 discuss in turn each of the four broad question areas that structured the day's discussion. Section 6 concludes by summarizing major points of consensus and disagreement among workshop participants. For readers who wish a more detailed and technical summary of the Edmonds et al. modeling project that animated the workshop, an appendix discusses the approach, design, assumptions, and major results of their work.

CONTEXT: POLICY MODELS FOR GLOBAL CLIMATE CHANGE

A circular chain of causal relationships define the human-climatic system. Human societies generate greenhouse gas emissions from such activities as energy use, industry, and land use. Once emitted, greenhouse gases cycle through various reservoirs and sinks, leading to changes in their atmospheric concentrations. Changed concentrations change the atmosphere's energy balance, in turn altering global, regional, and local climate. Changes in local climate bring impacts on human activities and welfare, and on managed and nonmanaged ecosystems, which may in turn lead to changes in emission patterns.

Several classes of formal models seek to represent the causal relations driving each step of this chain. Economic and energy models represent determinants of the activities that generate emissions, including the effect of policies intended to change emissions. A second class of models represent the chemical and physical cycles by which emissions change atmospheric concentrations. These range in complexity from simple "airborne fraction" models, which assume that a fixed fraction of current emissions are immediately reabsorbed while the remainder stays in the atmosphere, to complex time-dependent models of diffusion and chemistry that include multiple physical. chemical. and biological sources and sinks.

A third class of models calculates the effects of changed atmospheric trace-gas concentrations on climate. These include General Circulation Models (GCMs), the large models developed for weather forecasting that are now used, among other purposes. to estimate the sensitivity y of global climate to various hypothesized increases in greenhouse gas concentrations. Some GCMs involve coupled representations of the ocean and the atmosphere. A fourth, less developed class of models seeks to characterize the impacts on ecosystems, and on human societies and economies. of specified changes in regional climatic regimes.

Each of these classes of models addresses a different set of questions. For example. the economic and energy models could ask how much emissions wil 1 grow by the year 2050, and how much will a $20 per ton carbon tax reduce this growth? The second class, the physical cycle models. could ask what wil1 the atmospheric concentration of carbon dioxide (CO_2) be in 2050 if emissions follow a specified path between now and that year? The third class, the GCM models, can ask what will be the resultant change in patterns of temperature, precipitation, soil moisture, and storms if atmospheric CO_2 concentration reaches a specified level by the year 2050 and remains there subsequent y? And the fourth class, the impacts models, could ask what effect will result on regional ecosystems. agriculture, health, and economic activity if mean July temperature in the Midwestern United States increases by 3°C and mean precipitation decreases by 15 percent?

There is a long-standing ambition among modeling communities to answer all policy questions by modeling the entire world. This ambition can be detected in the enthusiasm of the early 1970s for "global models," represented in the best-selling book *The Limits to Growth (* 18). A parallel enthusiasm is now present in the drive toward "integrated assessment" of climate change. Integrated assessment projects involve coupling two or more of the classes of models described above to permit examination of more distant causal relations and follow the impacts of particular decisions downstream through emissions to concentrations to climate to impacts—and possibly then to changes in human activities and back to emissions. The approach is in part motivated by the desire to give practical answers to practical questions, such as, "Who will suffer, how much. when, from the ultimate climatic consequences of our decision now to limit (or not to limit) emissions'?"

The utility of this approach is limited by the complexity and uncertainty that pervades each step of the causal chain. Simply propagating uncertainty through a set of cascaded models Suggests that the output of such a grand chain of models tells you nothing. On the other hand, many analysts argue that integrated assessment models can yield greater value than such a simple thought experiment suggests. Even for models addressing only one step of the causal chain, the essential value lies not in particular numerical results, but in insights into causal structure and results that are appropriate to wide ranges of input specifications. The same arguments can be applied to integrated modeling activities; they could provide great value in structuring thought, directing inquiry, identifying which uncertainties are important and unimportant, and suggesting robust conclusions, even if the precision and accuracy of their particular numerical outputs are limited. This debate persists active] y.

The modeling presented in Edrnonds et al. focuses on the first step in this causal chain. It projects global and regional fossil carbon emissions and control costs under three economic growth scenarios, and under various international agreements to control emissions. Its analysis extends in a limited way to carbon concentrations by coupling one simple carbon cycle model, but it does not seek to mode] climate, impacts, or the processes by which impacts may alter emissions. The assumed levels of emission control are exogenous rather than endogenous---specified externally to the model. rather than calculated within the model. The controls examined are not assumed to have any particular optimality characteristics, neither to represent a "correct" level of total emissions nor a fair distribution of obligations internationally. Rather, they are selected to be relevant to current policy debate, representative of proposals now discussed in international policy circles.

The following are the major results of the Edmonds et al. analysis. A detailed description of the approach and assumptions of this project, and a more detailed elaboration of its results, is presented in the appendix.

- The modeled distribution of costs among regions from any simple system for distributing emission control obligations shifts dramatically over time; consequent] y, no such simple system is likely to remain acceptable through the next century, and any system of international controls with bite must be designed flexibly enough to allow renegotiation as conditions change.
- Large savings, on the order of trillions of dollars, are available from distributing international abatement efficiently rather than using naive allocations like holding regional emissions at current levels: these savings may be particularly large for developing countries.
- Several simple, plausible schemes for allocating tradable emission permits can have paradoxical effects, and may become infeasible as time passes, For example, in the latter part of the century, China becomes a net loser under equal per capita distribution because its economy is projected to grow so much more rapidly than its population.
- Not all countries need to participate. The few nations with the largest coal resources can limit cumulative global carbon emissions themselves by controlling or taxing production. To control atmospheric carbon concentrate ion, *only coal matters;* there is not enough oil and gas in the world to make a large difference.
- Modest variation in assumed rates of change of technical end-use efficiency, and rates of dliffusion of techn ical progress among nations, make large differences in the cost and effectiveness of treaties. For example, plausible assumptions of accelerated technology development and deployment can cut total cost of stabilizing world emissions in half.
- Initial delays of 100 or 20 years in implementing emission stabilization have little effect on ultimate atmospheric carbon concentrations.

PARTICIPATION

The fundamental questions about participation in international climate agreements can be separated into two broad classes: questions of the consequences of participation, and questions of the determinants of participation. "Consequence" questions consider the implications of who participates for the cost and effectiveness of agreements, or alternatively, whose participation is necessary for an agreement to be negotiable and sustainable. "Determinants" questions ask on what each nation's (or each important actor's) decision to participate depends, and what factors are likely to persuade or dissuade each actor from joining. Each class of questions can be posecd either substantively or politically: in terms of the severity of climate change impacts and control costs, or in terms of interactions between interests and decisions of actors who favor or oppose participation.

What set of participants is necessary for an effective climate agreement? There are two answers, depending on whether the question is posed substantively or politically. On the one hand, only a dozen or two nations are big enough, rich enough, or influential enough that their participation is substantively necessary. Confining serious negotiation to these few may then offer the best hope of agreement, since the complexity and difficulty of negotiations grow with the number of participants. On the other hand, if the entire endeavor is to be seen as legitimate, it must represent a broad international consensus, possibly including most nations of the world. The Edmonds et al. work focused on the substantive implications of various groups of participants, not on questions of political legitimacy. In these terms, its results are persuasive: that limited participation can be highly effective if it includes the nations holding most of world coal resources, and that agreements in which nations not belonging to the Organization for Economic Cooperation and Development (OECD,) delay their participation by a few decades make only small increases in resultant atmospheric carbon concentrations.

The tension between the pragmatic requirement for (and sufficiency of) small negotiations and the political requirement for a broad consensus presents an apparent paradox. The paradox may be resolvable, though, through the approach of joint implementation, which allows enough flexibility that all nations can be involved in the negotiation of the overall framework, while each specific emission reduction agreement would be negotiated among the small group of nations directly affected.

What determines nations' decisions to participate'? It may be impossible to understand participation without considering impacts as well as emission controls. Impact assessment is of course necessary to do benefit-cost analysis regarding the appropriate level of emission controls. But impacts may also be central in determining participation, because some nations' participation will depend strongly on their perceiving that climate change puts them at risk. One piece of evidence of the role of impacts in determining participation is that the only new durable coalition to appear in recent cl imtite negotiations was of island and coastal states. whose shared interests are entirely impact-driven. One form of agreement likely to appeal particularly to such nations may be one based on compensation for damages associated with climate change. Such a treaty, though, would require either agreement on a basis for establishing causation of particular climatic events (an unlikely development), or willingness to compensate for broad classes of climatic events regardless of causation.

Other nations' reasons for- deciding to join an agreement will differ. Some may decide to partcipate based on an ● 'insurance*' heuristic; having decided to protect against the risk, detailed calculation of the risk's magnitude matter less than determining that the cost of protection is affordable. For these nations, participation will be control-cost driven. Indeed, public concern in OECD nations about the moderate, vague, but potentially (very low probability) catastrophic risk that climate change poses may be so large that electorates will force a level of early action that now seems excessive in view of the available (admittedly very weak) benefit-cost estimates. Recognizing these two groups of nations would suggest the possibility of agreements that combine global emissions limits with compensation, with the emission limitation component attracting the rich nations most willing to pay to protect against the catastrophic tail of the climate change distribution, and the compensation component attracting the poorer nations less able to finance adaptation measures to protect against the median projected climate change.

Nations arc not the only actors whose paticipation decisions matter, though, and the Edmonds et al. analysis may be misleading in considering only agreements based on regional or global emissions freezes, and hence in directing attention exclusively to national participation decisions. In other plausible forms of agreement, it could be participation decisions by non-national actors that are most important.

For example, an agreement could be expressed in terms of best efforts or technical forcing to limit emissions without including explicit national targets. In such an agreement, the crucial participants are not national governments. but the industrial actors that have control of, and resources to develop. the relevant technology. If these actors" incent ives can be structured proper] y, rapid gains can be realized. Alternatively, an agreement could begin with "international emission offsets" or some other informal measure to give credit for joint imple-

[2] Dav Id Victor presented the argument [hat one must consider impacts to understand the determinants of part] cipation and the delineation of different categories of potential agreements and their participation implications, in his remarks to open the "Participation" discussion.

mentation efforts, from which point the agreement could evolve into a full system of tradable emission permits. Crucial participants in this scheme would include holders of the emissions property rights that are created, who could be national governments or subnational or translational actors. Proceeding by gradual expansion of an offset system would provide two important negotiating advantages: first, it would avoid the difficult explicitly distributive negotiation over an initial distribution of permits; and second, it could be designed so as to avoid creating a constituency of permit holders who resist emission reductions out of concern for their asset values.[3]

As a third alternative, agreements could be based on a carbon tax, as is now being pursued in the European Community. The crucial participants in this case are the powerful domestic interest groups that lobby for advantages under the tax system and would seek to exempt themselves from such a tax; the agreement's effectiveness would turn on how effectively these groups can gut the proposed measures.

Fourth, agreements could follow the example of the General Agreement on Tariffs and Trade (GATT), linking greenhouse emission controls to other, possibly unrelated issues. Indeed, in such agreements the GATT can serve both as an analogy—an example of a long-standing forum in which a slowly evolving set of disparate issues broadly related to trade are negotiated and traded off-and as a particular instance of the kind of issues that might be linked to greenhouse emission reductions. Given the magnitude of international trade flows in energy and energy-intensive goods, to be effective, greenhouse emission agreements may have to both account for these flows and accommodate the norms of the international trading system. This would suggest negotiations that explicitly address climate and trade issues, bringing both sets of institutions and expertise together. Such broader linkages would increase the chance of meeting enough interests to obtain the near-unanimous participation required for legitimacy, but the increases in both the number of participants and the range of issues and linkages considered can vastly increase the complexity of the negotiation, risking a stalled negotiation among everyone over the entire future of the planet (21).

Among national actors, it is the developing countries (LDCs) who, because of their large growth potential, will have the greatest impact on the effectiveness of international climate agreements over a period of several decades, so assessing the determinants of their participation decisions over this period is of the utmost importance. Thus far, LDC interest in climate negotiations has been very high, higher than present understanding of risks and costs would imply. This LDC interest, likely originating partly in intellectual interest and partly in general desire to participate in important diplomatic processes, contributed to the rapid movement of early climate negotiations. This level of interest may not endure, though, nor need it indicate willingness to bear substantial emission control costs, for other policy concerns—including other environmental issues—are of much greater urgency in LDCS than climate.

What will determine LDC participation decisions over a several-decade period? Two factors are widely cited: greater sense of risk from climate impacts than has yet been evident; and agreements structured to address LDC concerns beyond emission reduction, through financial transfers or linkage to other policy priorities. There is sharp disagreement on the relative importance of these two factors. Some argue that broad issue linkages and large financial transfers are politically infeasible in industrialized countries, but that a stronger view of climate risks could motivate LDCs to participate even in narrowly drawn emission control agreements. Others contend that meaningful LDC

[3] This problem is related to the so-called "Taxi Medallion" problem, but whether permit holders would resist tightening (or relaxing) the emission limit would depend on how the change was implemented. If total emissions were changed by varying the quantity that each existing permit represented, one would normally expect owners to favor increases and oppose decreases; if emissions were changed by auctioning or buying back permits in open markets, one would normally expect the reverse.

participation will require a substantial sweetener: cash, or major initiatives on debt, trade, technology, and finance.

It is difficult to understand the contribution of perceived climate impacts to decisions to participate in international agreements, particularly because impacts of the same climatic events in developing and industrialized countries can be so starkly different. A striking example of disparities in the character of climate impacts is provided by two recent tropical storms of roughly equal force, Hurricane Andrew in Florida and a similar storm in Bangladesh. Andrew caused billions in monetary losses but took only 17 lives; the Bangladesh storm, which caused much smaller monetary losses, killed 200,000 people.

The significance and impacts of policies to restrict emissions can also be starkly different in industrialized and developing countries. In some cases these differences arise from sharply different market conditions, such as the far-from-equilibrium energy markets prevalent in many LDCs. For example, when energy systems are tightly supply-constrained, investment in new low-emission technology does not displace existing capacity but adds to it, increasing rather than decreasing emissions. Similarly, when noncommercial fuels that contribute to greenhouse emissions and other (locally more serious) pollution problems escape taxes and other policies. policies to restrict commercial fuel use have the opposite to intended effect: they drive people back to higher-emitting traditional fuels that escape the policy. An even more serious limit to our understanding of the global effect of emission control policies may lie in fundamental inter-cultural differences in what people value, and how they act and make decisions. The widespread, naive assumption of industrial country analysts that what moves them moves others is embedded in economic models that assume equilibrium markets and familiar responses to price, income, and policies across broad classes of countries. Similarly restrictive assumptions are embedded in "bottom-up" modelers' assumptions that seemingly attractive technical innovations to reduce emissions, such as high-efficiency household cookstoves, will be adopted as a matter of course. Seemingly innocuous introduced technologies can violate strong unremarked preferences for traditional ways of doing things; one culture dirty smoke from an open cooking fire may be another's valuable fumigant.

That present economic and emission models fail to capture these variations may be decisive limitations. The largest component of variance in projected global emissions in the next century comes from LDCs—their development paths, technology choices, and policies-and it is clear we do not know how to model the development process. We do not know what happened in the Asian "Tigers," nor whether and how it will happen elsewhere; nor do we know whether and how technology developed for the capital-rich, labor-constrained industrial world can be transferred to the labor-rich, capital-constrained developing world, or the impacts of doing so. These limitations of present modeling may be particularly severe in projecting effects of an international emission trading system, which requires consistent market behavior to realize its attractive cost minimization results. Indeed, there remains some question whether the required market conditions are met even for domestic emissions trading in the United States. A fundamental challenge for modeling international emissions paths is to find useful, consistent representations of noneconomic behavioral variables, including, for example, the determinants of technology adoption and acceptability.

This picture of determinants of LDC participation is mostly gloomy, relying either on major climatic events to demonstrate a serious risk, or seemingly implausible political movement in industrialized countries toward major changes in foreign aid or other policies. In contrast, optimism about LDC participation may arise from two sources. First, a recent OTA study (22) has shown there is large technical potential for improving energy system efficiency in developing countries. Many cost-effective technologies to save energy and money are now freely available (though the question of the cultural and social determinants of the acceptability of particular technologies must be addressed very careful] y). Second, the joint implementation measures of the climate convention allow advocates of global emission reductions to seek out advantageous, cost-reducing arrangements, requiring less faith in the homogeneity of markets and values than would a system of uniform emissions controls. Joint implementation can be both a precursor to an ultimate international market in emissions and a device for education or advocacy, through which those persuaded of the merits of the system can seek converts, even among those whose prior disposition is unsympathetic.

TIMING

What are the implications of acting earlier or later to control greenhouse emissions? If particular nations, or the whole world, consider varying the timing with which they undertake emission controls, several kinds of consequences can result. Some of these are captured in present modeling and some are not. If there is delay in control] ing emissions, the same decisions will be faced later in a world that is more populous, although probably wealthier. In the interim, there will have been more emissions, imposing a higher cumulative burden on the atmosphere and hence requiring stricter controls on future emissions to achieve any specified atmospheric -concentrat ion or radiative-forcing goal. Depending on whether "waiting" meant doing absolutely nothing or doing a few low-cost marginal measures, nations will either have continued to invest in the wrong capital for an emission-constrained world, or gained some cheap emission reductions by modifying the characteristics of capital turnover at the margin. They will have learned more about the climate system and the risks of climate change through continued research and monitoring. They will have experienced technological advance. And finally, they will have lived through some time path of the noisy evolution of climatic, social, and political events.

The strongest "timing" result of the Edmonds et al. work is that delays of 10 to 20 years in enacting emission controls make little difference in atmospheric concentrations at the end of the next century. A simple back-of-the-envelope calculation demonstrates the plausibility of this result. The atmosphere presently contains about 740 Gigatons of carbon, while present emissions from fossil fuels and deforestation are about 7 Gigatons annually, half of which accumulates in the atmosphere. Consequently, a delay of 20 years controlling to a specified level will increase atmospheric concentration by about 70 Gigatons, or 10 percent.[4] Beyond the Edmonds et al. work, there is broad consensus that the consequences of delaying controls by 10 or 20 years are likely to be innocuous.

Waiting also reduces the cost of controls. In the Edmonds et al. work this savings is anomalously large, because of their assumption that controlling emissions later means stabilizing at higher levels. But there is broad consensus that even given a specified control level, phasing in controls over several decades would be much cheaper than a faster program due to lower adjustment costs, technological progress, and discounting.

Omitting impacts and adaptive policies from models is particularly problematic, though, when considering timing questions. If small changes in concentration bring only small damages, then the conclusion that action can be costlessly delayed remains valid. But if impacts are a sharply nonlinear function of concentration, then a 10 percent difference in concentration can represent a large increase in damages and delay can be costly. In models that include uncertain future impacts, delaying typically means waiting for the resolution of uncertainty and then undertaking both emissions abatement and adaptation as necessary. If the information we gain by waiting tells us to act, the required action is both stronger and more sudden than we would undertake under uncertainty

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[4] Jim Hammitt Presented this calculation, and the arguments on the act-wait decision and the two forms of interaction between nations deciding whether to act, in his remarks to open the "Timing" discussion.

today. Consequently, costs of both abatement and adaptation are higher, since both increase with the speed at which they are undertaken (11). Aside from the possibility of sharply kinked damage functions, there are two other possible grounds to question the consensus that delays of 10 to 20 years make little difference. First, if developing countries are now making large capital investments whose emission and efficiency characteristics could be influenced cheaply but would later be much more costly to modify or abandon, then the benefit in acting now to influence these choices may be great. Second, if there are long political lags in negotiating and implementing a broad international agreement to limit emissions, enacting emission limits 20 years hence may require serious political activity now. It is possible, though, that these concerns could be addressed by developing broad political support now for a program to phase in controls over several decades, including early action when it is demonstrably high-leverage and cheap.

Timing questions have a political dimension. through which they interact with participation questions. If several nations are considering undertaking emission controls. are there advantages either to going first or waiting? Various plausible specifications of trade flows, market structures, and the spread of information, technology, and learning, could generate advantages either way. These two possible relationships can be modeled with two basic two-person, nonzero-sum games. In one form, parallel to the game of '-chic ken," it is terrible if both wait (neither abates), but each prefers that the other do the abatement. Under an alternative structure, which might be called "first-mover advantage," it is better to be the first to control emissions, perhaps due to learning curves or economies of scale that give the leader commercial advantages in markets for abatement-related products or technologies. Even if basic control costs and impacts are the same, the problem of negotiating an emission control agreement differs sharply between these two situations. In the first, agreements are like] y to be difficult to negotiate and require close monitoring and enforcement. In the second. those who recognize the situation would race to act first, so agreements would be easy to enforce but less significant, perhaps largely serving as a forum to instruct parties in the structure of the game. How easy it is to secure broad participation, though, will depend on other details of the parties' interests. After one has moved, does the second still have an interest in moving, and does the leader advantage depend on the second's movement? Such details in agents' interests will determine the credibility of various negotiating strategies, and whether agents will in fact undertake controls unilaterally.

Formulating timing as a binary choice-act now, or wait-is analytically convenient, but may be quite misleading for real pol icy choices, since it excludes both the apparently attractive option of modest action now, and the possibility of path dependence, Modest action now may change the set of later possibilities, perhaps in ways involving technical innovation that present models do not adequately capture. With continuously variable policies, the optima] time path of emissions depends strongly on the discount rate. Indeed. optimal modeled control paths ranging from essentially no control to very stringent controls can be reproduced by varying discount rates between zero and a real rate of 3 to 5 percent.

Perhaps the most serious timing questions bear on the usefulness of economic models as predictive tools over a time of a century or more, nearly as long as has elapsed since the American Civil War. In addition to the obvious unpredictability of major discrete historical events such as wars, and the difficulty of making relible population forecasts over such periods, the most fundamental limit of prediction may be the inability to project long-run technical change. The most fundamental social changes over the last century have arisen from technological change, but present ability to model the determinants and consequences of technical change are extremely limited. In particular, over a century time-horizon technical change will be substantially endogenous to policies adopted, particular] y as they affect long-run rates of capital formation. Present knowledge of these processes is extremely 1 imited.

Moreover, the utility and resilience of international agreements over periods of a half century or more is as questionable as the utility of models over the same period. The few existing international agreements that have endured so long all fall into three categories: bilateral agreements, such as the United Kingdom-China arrangement for Hong Kong, which has stood for 100 years and will soon be replaced by another 50-year agreement; agreements that create an enduring functional institution, such as the International Labor Organization (the only major extant multilateral institution that pre-dates the formation of the United Nations); and agreements that were dead letters from the day of their signing, such as the Kellogg-Briand pact, which outlaws war. The influence of international agreements is necessarily limited. While treaties do create a changed political reality, empowering constituencies within each government and nation that support the aims of the treaty, it is ultimately impossible to enforce a treaty on a major power that chooses to break it. The image of treaty enforcement drawn from enforcement of domestic laws maybe seriously misleading, as may the image of an international "contract," because the long-term resiliency of an agreement depends on the possibil ty of flexibilit y and adjustment. The principal immediate problem may be the construction of flexible resilient institutions that can serve as vehicles for making the kinds of future decisions that are required, incorporating a potentially varying set of political stakeholders over time.

FORMULAS AND FEASIBILITY

In addition to deciding who will act and when, parties to an international climate treaty must decide how to define national obligations and contributions to the shared endeavor. Negotiators of multiparty agreements always use relatively simple formulas to distribute obligations, to keep negotiations manageably simple, and to limit opportunities for cheating at the margin **(19).** The questions of what kinds of formulas are feasible to negotiate and 1ikel y to endure over time are central to the problem of crafting an initial agreement.

The Edmonds et al. work considered a small set of formulas. The first was emission stabilization in each region, though the definition of stabilization employed (in which stabilizing later means stabilizing at a higher level) makes this seemingly restrictive formula quite flexible. Other formulas include equal carbon taxes, and emission entitlements distributed according to various standards: present emissions, population, Gross Domestic Product (GDP), blends of these measures, or finally, so as to restore certain regions to their income in the absence of controls. Because of the time-dependent definition of stabilization, in all these cases the precise meaning of each distribution formula (who emits and pays how much, when) depends on nations' accession dates. The most significant results of the work concerned unexpected changes in distribution of costs over time. Most striking are four results.

- The OECD does better under regional emission freezes than under a common global tax, because a common tax requires the OECD to decrease emissions and shifts emissions from the OECD to the developing world;
- Grandfathering 1990 emissions leaves Eastern Europe and the former Soviet Union as net sellers of permits for 30 to 50 years, because of the huge drop in emissions projected to result from their present economic contraction and restructuring;
- Equal per capita distribution of permits benefits China only in the short-run, while in the long-run its projected high economic growth, low population growth, and abundant coal will leave it a net buyer of emission permits;
- Compensating the developing world for all its control costs through distribution of permits alone is not possible.

Various authors have suggested other approaches to the development of formulas derived from ethical principles. For example, a strongly egalitarian perspective, following Fujii (7), would suggest an egalitarian system that gives equal per capita entitlement not just to all presently living people, but to all people at all times. This appreach introduces the concept of the "carbon debt," the burden of cumulative past emissions borne by citizens of past and present high-emitting countries. A weighting of different ethical principles might yield formulas that blend different criteria in defining obligations or entitlements. Edmonds et al. blended status quo and GDP change; other formulas might blend either of these with population or other measures.[5]

Some simplifying formula is clearly necessary to reach agreement in broad multiparty negotiations, but developing a v i able formula for distributing obligations can be one of the most difficult aspects of negotiating an agreement. Relevant considerations in defining obligations clearly include current emissions, history, growth needs, population and economy. Finding a viable formula depends on developing a shared sense that (most) nations are bearing a fair or proportionate burden, and that none bears an unfair or disproportionate one. Because treaties cannot coerce major nations, a formula must be minimally acceptable for all. The United Kingdom blocked an acid rain agreement in the European Community (EC) for five years because the proposed formula that worked for everybody else was too costly for them.

But developing an agreed sense of what is fair or proportionate poses two major challenges. First, the many possible bases for comparison of burdens yield greatly different senses of what is fair. This difficulty is further compounded by the existence of unequal prior distortions in energy and other relevant markets. Moreover, for a problem as large and long-term as climate change, it is even difficult to develop a clear sense of what it means for a cost to be large or small. Defining "cheap" can be surprisingly difficult, because over the long times involved the apparent size of a cost can depend strongly on how it is expressed and what it is compared to. For example, a typical estimate of the cost of stabilizing world carbon emissions over the next 20 years can be expressed in three alternative ways: as a reduction in average GNP growth over the 20-year period from 2.5 to 2.45 percent per year; as a reduction of 2 or 3 percent in future-year GNP; or as a present-value loss of $300 to 400 billion. Most observers agree that, informally, the first of these numbers looks small, the second moderate, and the third large—but they are all just different ways of describing the same number. Which way of expressing the effect comes to be political] y most salient will likely determine whether it is possible to enact the corresponding measures. Whether a number looks large or small also depends on what you compare it to, and present industrial country expenditures provide ample opportunity for both kinds of comparisons. For example, the $15 billion transferred to LDCs through permit sales under the "hold harmless" scheme, described in Edmonds et al. as "smal1," can be expressed either as one-third of total present development aid from OECD countries, a seemingly large expenditure difficult to achieve politically; or as one-twentieth of present OECD agricultural subsidies, a small fraction of funds presently spent on wasteful and misguided programs, and so surely easy to realize.

In the face of these two difficulties, it can be argued that denominating agreements in terms of national emission targets or funds donated may be the wrong way to proceed. An alternative approach suggested at the workshop would turn negotiations on their head, denominating national action in terms of the taxation of environmentally harmful activities and discarding any expectation that levels of national participation on this dimension will be equal or fair.

The argument proceeds as follows. All countries must raise revenue to run their governments. Officials from many countries are liable to find persuasive the argument that it is better to tax bad things (e.g., pollution and greenhouse emissions) than good things (e.g., labor and capital), and that

[5] Herman Cesar presented the arguments about deriving formulas from fundamental ethical principles, and the argument that formulas are more (i fficult to define in the context of unequal prior market distortions, in his remarks to open the "Formulas" discussion.

there may be national advantages in shifting the total tax burden from the latter to the former. Such tax-shifting is likely to be persuasive and feasible at modest levels (e. g., $20 per ton of carbon), but infeasible at high levels (e.g., $200 per ton), because of adjustment costs and many other reasons. Some modeling studies that include impacts suggest an optimal path of carbon taxes consistent with this level, though these results are controversial. Consequently, both good domestic arguments for improving the efficiency of the tax system, and international arguments about contributing to global environmental public goods, support the proposed tax shift. And if the correct level is indeed as low as $20, this approach is less likely to be blocked by domestic opponents or large adjustment costs. Other taxes would of course still be needed, since a carbon tax this low would only raise a small fraction of government budgets.[6]

Such a scheme could be agreed in international negotiation, but the negotiations would have a completely different form and purpose than present climate negotiations. In effect, climate negotiations would become a forum for instruction and advocacy in the benefits of reforming tax systems, and a dialog on how well each is doing in achieving such reform. The taxes would not be viewed purely as national responses to an agreed common emission target, but as a way of simultaneously helping the economy and the world. Since this approach would presume that countries act for their own benefit as well as the world's, it would eliminate the requirement—and hence the difficulty of determining-that all act to equal or comparable levels. It would consequently eliminate a broad class of negotiating difficulties associated with defining fair formulas for the distribution of obligations, and may have a greater chance of actually being implemented than common emission stabilization targets. It would, though, pose a distinct set of negotiating difficulties, also associated with the problem of persuading LDC governments to participate.

First, this scheme would not involve international transfers, except those resulting from the impacts of different tax levels on trade flows. This would have obvious implications for LDC participation. If such tax shifting were to represent a pure gain for every country enacting it, then this approach would completely separate negotiations over emission control from negotiations over transfers. Modest levels of emission control—which are optimal if you believe the low damage estimates—would be realized at a small cost or none in every country, and development assistance would be a separate negotiation. There are obvious tactical reasons that LDC governments might resist such a reformulation of climate negotiations.

Second, the disparity of existing institutional arrangements among countries may well call into question the ease with which this reframing could take place. Since many developing countries levy most of their taxes not on labor and capital income, but on imports and property, a separate argument for the superiority of taxing emissions must be made, and a separate set of difficult internal political-economy issues addressed (1). Moreover, some existing energy market distortions in LDCS serve important welfare functions, such as distribution of subsidized kerosene. For regions

6 The basis for this tax-shifting argument is as follows. It is well known that taxes impose costs, or excess burden, on the economy by distorting agents' decisions between labor and leisure, between savings-investment and current-period consumption, and among commodities. A particular tax "s burden depends on how much it distorts each of these margins, and on what other taxes are present. There is reason to be] ieve that taxes related to energy (such as carbon, Btu, or gasoline taxes), principally because of their narrower base, impose larger burdens than income or profits taxes. But greenhouse gases and other energy-related emissions represent an initially unpriced negative externality, which is mitigated by taxing them. If the environmental welfare gain of shifting taxes from profits to emissions exceeds the accompanying increase in conventionreally defined excess burden, then the shift benefits the economy. Whether this is the case for a particular tax shift of course depends on the details, and much analytic work in this area remains to be done. These issues are discussed in detail in Goulder (9). In economic emissions models, whether a gain from such tax shifting can be detected depends on how carbon tax revenues are recycled (among other things). Many models, including Edmonds et al., use lump sum recycling and so do not represent this effect.

where people's alternative to subsidized kerosene is traditional biomass, reducing the subsidy may be environmentally harmful.

Third, the viability of this alternative approach depends on $20 per ton being a roughly correct estimate of the marginal environmental damage of carbon emissions. Since the proposal achieves its domestic political attractiveness by recycling revenues, it raises no funds to compensate for residual environmental damages. Compensation and residual damages are likely small problems if the $20 per ton figure is roughly correct. If climate change damages are much larger, though, this approach neither realizes the required reduction in emissions nor solves the major problems of impacts and compensation.[7]

One should not be naive about the ease of negotiating such a scheme. While it is not yet clear whether the EC proposal for a shared carbon and energy tax will include the parallel reduction of capital taxation necessary to support the argument of domestic economic gains, the difficulties this proposal has encountered illustrate how hard it can be to negotiate such a scheme. Originally the EC's developing countries. led by Spain, argued that they need energy to grow and refused to tax it; more recent proposals that exempt these countries have been blocked by the United Kingdom.[8] Moreover, tax policy is a field in which domestic interests are expert at shading measures to their own advantage. Even in the context of tax shifting, domestic political actors may load a carbon tax with so many loopholes that it becomes utterly ineffective, the equivalent of "an energy tax for those who don't use energy."

Still. the argument is not that such a tax-shifting scheme would be easy to negotiate and implement, but only that it may be easier than an agreement based on emissions stabilization. While many argue that the OECD will soon agree to stabilize carbon or greenhouse emissions, this tax-based scheme addresses the contrary argument: that pursuing emission stabilization is overreaching, and that such a commitment, even if nominally adopted, would be rapidly eroded by slippage in implementation and redefinition of goals. The tax scheme is more likely, because it is modest and defensible on solid environmental and economic grounds. It may also be easier to implement in a wide variety of political environments. Tracking fuel accounts for quantity-based controls requires good national statistics and monitoring of economic activity and transborder flows, which many countries lack; in contrast, prices remain observable even in chaotic economies in transition such as the former Soviet Union.

USES OF MODELS

Decisions about participation. timing. and formulas will be made by a long, progressively revised process of negotiations among national representatives, influenced and informed both by their domestic constituencies and by transnational networks and organizations of industrial, environmental, and other nongovernmental interests. Because the questions to be resolved in such negotiations are so complex and difficult, it is reasonable to expect that formal modeling of the cost and effectiveness of proposed agreements can help to inform the deliberations.

But how can they do so most usefully? How can formal energy, economic, and climate models most constructively support the international processes of negotiation and renegotiation. institution building, and implementation that are involved in management of the global climate change issue? While there is little directly applica-

[7] These difficulties include recognizing climate change damages (or agreeing not to care); raising funds for compensation; maintaining appropriate incentives for averting behavior while compensating for damages, and defining a compensation system based on differences in impact among groups, since under the more serious scenarios of climate change there may be net global losses, rendering it infeasible to compensate all losses.

[8] *International Environment **Reporter*** 1613, June 30, 1993, p. 470, 474. The Commission's proposal of a tax of $10 per barrel of oil is equivalent to about $80 per ton of carbon.

ble experience, three kinds of evidence are plausibly relevant: the kinds of uses of models that are possible in general policy discussions such as this workshop; and prior experience with formal modeling, and with similarly complex technical advice from experts, in processes of domestic and international policymaking.

In this workshop, the group used the Edmonds et al. model principally in three ways. First, they tested particular results of the modeling against their intuitions, looking particularly at those instances where the model result was not obvious ex ante; in some of these cases, the result was plausible ex post, so the model served to point attention to unanticipated but persuasive results. Second, they used highly schematic summaries of particular results to draw out unmodeled political implications of particular agreements. Third, they talked around the model, using the model results to identify important analytic omissions. These are three instances of ways models can help one think through policy problems, independent of the political setting in which they are used.

In many ways, the potential uses of models in domestic and international policymaking are quite parallel. In both settings, there are some things models cannot do. They cannot provide answers with certainty; they cannot resolve political and value choices; and they cannot be demonstrated secure against error or bias. They can explore and demonstrate causal relationships, characterize and identify key uncertainties; show what pieces of information matter and what ones do not; and provide instruction in the behavior of complex systems and decisionmaking under uncertain y.

Polic ymakers ask models for robust answers to policy-relevant questions (if they ask them for anything). What are the costs of waiting? How much more costly is it for nations to control emissions separately? Can a subset of nations control emissions effectively, and at what cost? If we 1 im it emissions, what happens in the regions that are not limiting emissions? Are there economic advantages or disadvantages in undertaking emission controls before others do? Sometimes models can provide reasonably plausible, well-supported answers to such questions. When such answers are not available, or are not robust, then a useful stopgap would be information about what uncertain parameters matter, and how much. For example, modeling work by Edmonds and by Nordhaus and Yohe has argued that for projecting emission control costs, neither fossil fuel resource constraints nor backstop technology prices matter. Rather, the most important uncertain values include income elasticities, growth rates of labor productivity in the LDCs, ease of substitution away from fossil energy in national economies, and the autonomous rate of energy efficiency improvement.

In a policymaking setting, the most constructive role models can play is to reduce the set of things that policy makers argue about, removing from the table those factual matters that are either well-known or insignificant for the decision to be made, and leaving those things that are either truly political, or important and uncertain.

The difficulty of communicating model results and insights effectively to decisionmakers is an old and sad story. An ideal description of communication between modelers and decisionrnakers might follow the rule that "if you need the model to explain the result, you're in trouble"; modelers would plumb their models not for mere numerical results but for insights that make sense even when examined apart from the model, and would seek to convey those insights, or whatever subset of them is policy-relevant.

Effective communication of model insights, though, can be exceedingly difficult. Even those significant, novel insights that arise from a modeling investigation are liable to be complex and subtle, perhaps even be most effectively expressible in technical language. Such facts can easily be lost in the noise of a political environment. Frequently the most significant insights from a model will concern the sensitivity of policy-relevant outcomes to particular parameters values, and the uncertainty in those parameters. These two concepts are often confused (by analysts as well as by policymakers), and communicating them effectively is difficult. Communicating information from some models is harder than from others; some models may be intrinsically enigmatic, with the structure of their formulation making communication of their results difficult. On some occasions the most important insights may concern how results vary across models, which can be particularly challenging to communicate clearly.

The difficulty of fully communicating models and their results leads some to advocate expansive roles for the policy advisors who lie between analysts and decisionmakers, distilling complex uncertain bodies of analysis into statements such as, “Minister, if we impose a $20 per ton carbon tax, we will meet our carbon emission target,” or even answers to the question, “HOW should I vote?*’ —and willing to take the accompanying risk. The role for such expansive intuitive expert judgment may be further increased by considering foreseeable ways that a particular piece of technical information will be used in political settings. For example, the result that waiting 10 years to curb emissions costs little may promote a political complacency leading to ignoring the issue completely. Under these conditions, the technical message may be “it’s fine to wait,” while the appropriate political message is “act speedily.”

It may be inevitable that intuitive expert judgment plays an important role in supplementing formal modeling results. Relationships are often “known” by expert judgment before they acquire solid enough verification to be put into models, perhaps including recent revisions of the indirect radiative forcing of chloroflurocarbons (CFCs) and of the effect of sulfate aerosols. Sophisticated modelers may have to make subjective revisions in interpreting model output to reflect these insights, thus providing better representations of, for example, endogenous technical change or cross-country differences in economic structural parameters than the literal running of the model. Such adjustments carry their own risks, though, including both difficult y of validation and the possibility that modelers may fail to document and forget their ad hoc adjustments.

In international policymaking, parties have diverse levels of technical expertise to use in pursuit of their desired outcomes. Models could come into the process in two ways. First, interested participants (national delegations or others) could introduce models or modeling results to advance the case for their preferred decisions. Alternatively, models could be introduced under neutral auspices: through a Secretariat, or by some other clearly impartial vehicle.

There are a few striking instances of effective and constructive uses of modeling, or of other sources of technical expert advice, in international policymaking processes. In particular, there are at least two instances of multilateral negotiations in which models played highly constructive roles in advancing decisionmaking. In the financial negotiations related to seabed mining provisions in the Third United Nations (UN) Conference on the Law of the Sea, a financial model of the seabed mining industry developed at the Massachusetts Institute of Technology (MIT) and made available to conference patirticipants offsite under the auspices of religious groups proved highly effective in focusing debate, reducing disagreement to specific uncertainties, and eliciting a constructive negotiating atmosphere (20). The transport and chemistry models developed at IIASA seem to have played a similarly constructive role in European negotiations over acid rain (14). The constructive role of these models seems to have been associated with their accessibility—nonmodels could play with the models to test the implications of altemative input assumptions they may wish to specify—and the clear objectivity of the source. The presentation of comparative results from scientific climate models (GCMS) to the recent climate negotiations by Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC) appears to have played a similarly constructive, though limited, role.

International policymaking thus far on climate change, and the related negotiations leading up to the UN Conference on Environment and Development (UNCED), has made little use of economic modeling. Essential] y no economic modeling was done under IPCC,[9] and the only substantial use of economic modeling in the negotiations was the U.S. delegation's use of early results of the Global 2100 model, which showed extremely high emission control costs, to support their position that no emission controls were wamanted.

In an international setting, several institutional questions related to the use of modeling maybe of decisive importance. For example, it may be crucial that the scientific and technical advice received by various delegations matches; if so, this suggests the great potential value of some legitimate external forum for international groups of experts to determine the degree of their technical consensus. Both the assessment panels under the Montreal Protocol and the IPCC served this function. A related but distinct question is developing indigenous technical expertise for use by representatives of LDCS. Dissemination of modeling expertise from international bodies could help bring this about by training advisors to LDC governments. Of course, the recipients of this expertise may legitimately and correctly decide that they have higher priorities for its use than participating in international negotiations. A recent foundation-funded program trained upper-middle LDC officials in environmental science and economics to develop their capacity to participate in international negotiations, but most of the officials have used their training to work on other environmental issues of greater local concern such as air and water pollution.

It is not easy to obtain an objective, neutral forum for modeling and disseminating results. First, opportunist use of models is easy. Changing five parameters each by 20 percent, each change lying within the uncertainty, may change a policy target from trivially easy to impossible. Models may also be biased by the need to match other unrelated political goals. For example, U.S. modeling of greenhouse emissions had to use the same extremely optimistic projections of economic growth as had been used for budget projections, which was partly responsible for high base-case emissions and costs of control.

The extent to which issues of uncertainty in modeling can be kept distinct from political disagreements in part depends on the character of uncertainty in the modeling. A fundamental distinction in model uncertainty is that between parameter uncertainty and model uncertainty. The ability of modeling to serve as a constructive aid to decisionmaking may crucially depend on which (or both) of these kinds of uncertainty are present. There are conflicts in which parties disagree on the parameters, but accept the same model. When this is the case, i.e., when uncertainty or dissent over model structure is limited, the modeler can act as an impartial "friend of the court." For example, in a political conflict within the United Kingdom over construction of the Sizewell B Pressurized Water Reactor (PWR), an analytical team developed an economic model of the technology that both the proponents and opponents accepted. When extensive work with the model persuaded the opponents that they could not challenge the technology on economic grounds, they decided instead to challenge it on safety grounds, which were outside the scope of the model. The modelers deemed this outcome a success, since advocates had come to a common view of that part of the world that was modeled (6).[10]

In contrast, in economic, energy, and policy modeling relevant to climate there is disagreement over both parameter values and model structure. Among participants in this workshop there was disagreement over the representation of technological change, and the appropriate representation of economies in developing countries. Given

[9] IPCC Working Group 3 (Response Strategies) developed three alternative scenarios for baseline growth of greenhouse emissions, but made no attempt to model the cost or effectiveness of emissions control policies (14).

[10] Ironically, that common view of the world turned out to be wrong. Neither proponents, opponents, nor modelers imagined that the (Teal unions would be broken and coal prices would fall so low, rendering the PWR economically unviable.

a particular model structure there may be some set of results that remain sound despite changes in the model parameter, but the set of results that are robust to changes in model structure will inevitably be smaller. In the opinion of most workshop participants. the only candidate for a result robust to variation in modeling structure is that modest delays in realizing emission controls are innocuous. Not even on this did all agree. Still, one result of the recent comparison of greenhouse emission models conducted by the Energy Modeling Forum of Stanford University suggests that structural model uncertainty may not be a decisive obstacle to estimating economic effects of emission limits. When common boundary conditions were imposed on the 14 structurally diverse models participfating,, the project found that most variation was explained by about five parameters, and that under common input-parameter streams the models generated consistent results (8,23).

CONCLUSIONS

The OTA workshop provided a review of the current distribution of expert opinion on economic, political, and negotiation issues relating to international climate change agreements. This may in fact have served a more valuable function than an articulation of a definitive consensus would have. While discussion ranged over a broad set of modeling, economic. and political questions, there was consensus on a few results, mild disagreement on many, and sharp disagreement on a few, This concluding section seeks explicitly to summarize the extent of convergence and divergence of opinion in major areas covered by the workshop.

A few results achieved broad consensus. On these points the bulk of workshop participants agree with the results in the Edmonds et al. paper.

- Significant reductions in atmospheric concentrations of greenhouse gases will require large reductions in emissions.
- Large emission reductions are likely to be costly, but phasing emission controls in over a long period can reduce the cost substantially.
- Presently articulated emission targets have been stated with little regard for analysis of impacts.
- Delaying the implementation of emission controls for 10 to 20 years will have little effect on atmospheric concentrations.
- The small group of nations that controls most of the world's coal resources could, by controlling production, effectively control world emissions.
- Costs of controlling emissions are highly dependent on assumed rates and determinants of technological innovation, and this process is not adequately understood or modeled at present.

On many other policy-important questions, there is no consensus in this workshop group, or among existing models. There are differences on the character and rate of technical change, on the homogeneity of rationality assumptions across nations, on the likelihood and impact of an early industrial country agreement to stabilize carbon emissions or agree on a common carbon tax; on the relative advantages of tax, target, and permit instruments; and on the relevance of a formal international agreement to control emissions.

While some participants argued that most present uncertainty comes from parameter uncertainty, agreement on this point is not unanimous. All acknowledged that parameter uncertainty is easier to deal with, but participants differed on how serious structural model uncertainty is likely to be in understanding the economic effects of emission limits. In this workshop, a great deal of discussion focused on factors omitted from all present models, that most agreed could have dominant effects on future emission trends: political and strategic linkages; time dependencies in international negotiations; details of the process of domestic politics and implementation; and hypothesized differences in behavior and motivation among countries.

Focusing on one line of the day's discussion, a slightly cynical summary of the workshop 'climate treaties and models" could be that treaties are irrelevant and models useless. Treaties are irrelevant because measures adopted in particular countries for their own domestic reasons, plus informal bilateral and multilateral arrangements, including those animated by nongovernmental actors, will drive essentially all of the emission controls that are achieved. Models are useless because of the important long-term driving forces that they omit, and because they do not address the correct level of analysis for examining looser agreements of this sort.

While a few disagreed, most participants found the most promise in smaller-scale agreements negotiated under the umbrella of the framework convention, with much involvement of nongovernmental actors and (in recognition of the inevitably voluntary character of national emission controls) less emphasis on international monitoring and enforcement. This approach allows much room for institution building, and presents the umbrella treaty as a kind of "storefront": explicit negotiations occur not for their own sake, but to provide a forum for the crafting and legitimation of many constructive deals under the rubric of "'joint implementation," meanwhile engaging people in thinking and talking about the problem and persuading them it is serious.

Under such an approach, participants in agreements may all undertake different implementation measures, for their own culturally or politically distinct reasons. Those who like markets can use them; while those who like command-and-control measures can use them. Modeling can also be useful in analyzing international action under such an umbrella, though the actors modeled would have to be a broader set than nation states.

Perhaps the strongest conclusion of the workshop concerned the long time horizon of the problem, and the weakness of our present analytic and institutional tools in the face of an issue so enduring. Participants returned repeatedly to the difficulty of understanding an issue evolving over centuries, for predicting parameter values, designing sufficiently enduring institutions and commitments, and understanding what projections mean for how people will live. Participants recognized that they understand little about what long-term differences between emissions of 1 and 3 tons per capita actually mean for people's lives, or about how citizens of a societies with median incomes of $100,000 would live and use energy. While current income variation within the United **States** could provide insight into the latter question through cross-sectional analysis, using today's richest decile as a proxy for future society, these studies are at very early stages and one must be cautious about generalizing their results. Moreover, understanding technical change over such a period is a fundamental and daunting challenge. Technology represents the dominant change in people's lives over the past century, but we have limited ability to project how it will change over the next.

Appendix: Summary of Edmonds et al. Paper

THE MODEL: ORIGIN AND STRUCTURE

The Edmonds et al. study used version 4.01 of the Edmonds-Reilly -Barns model (ERB), which projects global energy, and related greenhouse gas emissions, through the end of the next century, [11] The model explicity represents (he energy resource base, plus supply and demand in nine world regions,[12] and includes international trade in fossil fuels, and fuel-specific greenhouse gas emission coefficients.

The model consists of four separate modules representing energy demand, energy supply, energy balance, and greenhouse gas emissions. The energy demand module begins with external assumptions of population and labor productivity growth in each world region, and calculates total final-energy demand in each sector from energy prices (world prices augmented by local energy taxes and tariffs) and incomes. The demand module also maintains a set of energy flow accounts for each region, determining the mix of energy sources used to meet final-energy demands by a S-shaped (logit) function of relative prices.

The supply module represents the fossil fuel resource base of each region in detail, including several grades of resources with increasing extraction costs, and limits on the rate at which production capacity can be expanded. Separate costs and capacity

11 A brief description of the Version of the model employed for this project is provided in Edmonds, Barns, Wise and Ton (5). The original model is described in Edmonds and Reilly (2), and major early revisions arc documented in Edmonds et al. (3).

12 The regions modeled are the United States, OECD West (Western Europe and Canada); OECD East (Japan, Australia, and New Zealand): Eastern Europe and the former Soviet Union; China and other centrally planned Asian economies; the Middle East; Africa; Latin American; and South and Southeast Asia.

constraints are presented for nuclear fission in each region, and a nonfossil energy supply (solar electric or nuclear fusion) is assumed available as a "backstop technology "-a technology that can provide essentially any quantity of energy at a constant, high marginal cost, which in this model is also assumed to decline overtime due to technical advance.

The energy balance module represents international trade in liquid, solid, and gaseous fuels, generating world energy prices that yield approximate equilibrium in each global fuel market, Electricity is not traded. The greenhouse-gas emissions module calculates regional and global emissions of greenhouse gases from specific emissions coefficients for each category of fuel.

Given specified input assumptions, the model presents snapshots of the world energy system every 15 years from 1990 to 2095. In each of these years, the model projects each type of energy demand and supply in each region, the price of each energy type, and resultant greenhouse gas emissions. The model investigates the effect of measures to limit greenhouse gas emissions by imposing various forms of regional emissions constraints or taxes, and comparing the resultant projections of energy use and prices to those in a base-case model run. In earlier versions of the model, regional costs of emissions constraints were calculated by a simple, region-specific energy-GNP feedback elasticity; a specified percentage change in world energy prices was assumed to cause a related percentage GNP decrease (for net energy importing regions) or increase (for net energy exporting regions). The authors drew their estimated feedback elasticities from a literature review of estimated energy-GNP interactions. While this mechanism sought to capture macroeconomic effects of changes in energy markets, critics suggested the assumed constant-elasticity relationship was likely invalid for the large energy price changes that would accompany serious emissions constraints. Consequently, in the model version presented to the OTA workshop, the authors modeled regional costs of emission constraints by a partial-equilibrium approach, summing changes in consumer's and producer's surplus in energy markets as the regional economy shifts from the unconstrained to the emissions-constrained equilibrium.

SCENARIOS AND ASSUMPTIONS

The study used three scenarios to specify different plausible rates of emissions growth in the absence of controls. All are based on the same regional population projections, estimated by the World Bank (25) and used in the first report of the Intergovernmental Panel on Climate Change (13). Projected world population reaches 9.5 billion by 2050, and 10.4 billion by 2095.

The three scenarios represent variation in potential economic growth rates by different assumed rates of labor productivity growth. In the first scenario, productivity growth in industrialized nations declines from 1 .5-1.6 percent per year to about 0.9- 1.0 percent over the next century, while China's productivity growth remains around 2.6-2.8 percent, and the rest of the developing world increases from 1.6 to 2.2 percent. The two other scenarios, representing high- and low-growth futures, double and halve all these assumed productivity growth rates.

Other assumptions and parameters are maintained constant across the three scenarios. These include the size of fossil fuel resources, the size and cost of biomass energy resources, and the economic parameters that define market responses to changes in incomes and energy prices. The income elasticity of energy demand in OECD nations is assumed to be 1.0 through the next century.[13] Income elasticities in other world regions start higher (1.25 in Eastern Europe and the former Soviet Union, and 1.4 in the developing countries), and decline to 1.0 through the next century. The price elasticity of demand for aggregate final energy is assumed to be 0.7 in all regions.

[13] That is a 1 percent increase in income is assumed to generate a 1 percent increase in energy demand, other things remaining equal.

Consequently, all variation between scenarios in factors contributing to greenhouse gas emissions is subsumed into different labor productivity growth rates. The authors argue that this simplification is reasonable, because prior sensitivity analysis with this model has demonstrated the following to be true. While the cost of reducing emissions from any particular baseline level depends on that baseline level (holding emissions to 100 costs more if the unconstrained level was 150 than if it was 120): the cost depends very little on the particular combination of assumptions that generated the baseline level (reducing emissions from a baseline of 120 to 100 costs about the same, regardless of what combination of population and productivity growth, resource availability, and sensitivity to price and income change generated the original baseline of 120) (4).

OTHER IMPORTANT DESIGN ISSUES

In addition to the price and income sensitivity of energy demand, the analysis assumes a non-price-driven, or "autonomous,'' improvement in end-use energy efficiency of 1 percent per year in all regions. The authors argue that this value represents the long-term trend in energy intensity over the past 70 years. This value is controversial, though, with some analysts advocating values both higher and lower than 1 percent, and others arguing that the quantity is misspecified and should, if employed at all, be negative (12, 17,24). After a test of the ability of different values to replicate observed 1987 fuel consumption from historical data, Edmonds et al. reaffirm that within the specification of this model, a value of 1 percent is appropriate.

To represent variation in technological progress, the authors include two mode] runs with widely differing technological assumptions. The first includes optimistic assumptions for improvement in fossil electrical generating efficiency (reaching 55 percent by the year 2020), and solar electric cost (dropping to 5 cents per Kilowatt hour (KwH) by the turn of the century). The second focuses on technology transfer. assuming that some fraction of the price-induced energy efficiency gains realized in regions that control their emissions is transferred to noncontrolling regions without requiring the higher price to elicit it. In effect, some fraction of price-induced efficiency gains are assumed to take the form of innovations that, once discovered, are cost-effective even at lower energy prices. Originally implicitly zero, this fraction is varied from 10 to 100 percent.

Other than the variation represented in the three scenarios for labor productivity growth, the mode1 does not represent uncertainty. Each run of the model generates a single future history. Other input parameters are not varied systematically, and distributions of relevant output variables are not generated.

The model uses a simple carbon-cycle model to show the consequences of different emission paths for atmospheric concentrations, the same model as used in the 1990 IPCC report to calculate global warming potentials (GWPs). This carbon-cycle model makes the common, but controversial, assumption of a "neutral biosphere"-assuming that the unknown total carbon uptake by terrestrial biota is equal to the atinthropogenic source from land-use change, as was roughly true between 1940 and 1980. Computationally, the model splits current-year carbon emissions into three shares, each of which decays in atmospheric concentration with a different time-constant. About 30 percent of emissions decay with a time constant of about 7 years, 34 percent with a constant of71 years, and 36 percent with a constant of 815 years.

POLICIES AND PROTOCOLS STUDIED

The assumptions described thus far define how the mode] represents the basic world energy system and its evolution in the absence of emission controls. The bulk of the work presented to the workshop, though, consisted of imposing various international emission controls and examining how they affect emissions, energy markets, and economies in both participating and nonparticipating regions.

The paper examined five different emission control protocols. All five protocols are expressed as stabilizing carbon emissions, but stabilization is defined as a region's holding its emission constant at then-current levels when the region enters the protocol. That is, a nation joining in 1990 stabilizes emissions at 1990 levels, while a nation joining in 2005 holds them at 2005 levels. While this may be a reasonably accurate prediction of how baseline emission levels would likely be defined politically, the approach differs from recent national emission control pledges, most of which pledge to hold emissions at 1990 levels beginning in 2000 or 2005. Under the paper's definition of stabilization, a nation that delays its accession to a stabilization agreement stabilizes its emissions at a higher level.

Given this definition of stabilization, the paper's five protocols differ only in the years that emissions are stabilized in different world regions. In the first protocol, all nations stabilize at 1990 levels in 1990 (the first year represented in the model); a second protocol delays worldwide participation to 2005. Variants of these two protocols have staggered participation. in which the OECD stabilizes emissions in the specified year, while Eastern Europe and the former Soviet Union (EEFSU), China, and the rest of the developing world delay their stabilization by 15, 30, and 45 years respectively.[14] A final protocol variant delays OECD stabilization to 2020, with other regions staggered at the same intervals.

In a separate examination, the paper considers the effect of protocols that only ever achieve limited participation. A "Big Three" protocol includes only the three largest coal-bearing regions —OECD, EEFSU, and China—all stabilizing emissions from 1990. Separate analyses were also conducted of the same protocol with only "Big Two" (OECD and EEFSU), and OECD-only participation.

Each protocol is examined under three forms of implementation: a uniform carbon tax; regional emission targets; and tradable permits. Under a carbon tax, all participating regions tax carbon emissions at the same level, so as to stabilize their total emissions joint] y.[15] Taxes are in fact the only policy that the model can represent directly; other measures are represented by surrogate taxes, whose effects are equivalent to the specified measure under the assumption of competitive en–ergy markets in equilibrium. For example, under separate regional emission targets, each region imposes a tax high enough that it meets its own target. Under this system, taxes—and hence marginal abatement costs-are unequal between regions, so total compliance costs are higher than under a uniform tax. Since the model only represents multination regions, though (except the United States), this system does assume joint reduction among the nations in each region, so is less restrictive and more efficient than separate national targets.

A tradable permit system is also modeled indirectly by imposing a uniform tax on participating regions, and assuming regions will trade permits to reach the efficient distribution of emissions from whatever starting point the initial distribution is defined. All trades are assumed to be at the competitive price, equal to the marginal cost of emission reduction and the uniform tax rate, equivalent to assuming no market power in the market for emission permits. Under these assumptions, the paper examined the consequences of six different rules for distributing permits. Whatever rule applies, permits are redistributed according the rule in each 15-year modeling period. The six distribution rules are as follows:

[14] For example, in the variant of the first protocol, OECD controls begin in 1990, EEFSU in 2005, China in 2020, and the rest of the world in 2035.

[15] The revenues from carbon taxes are assumed to be retained within the tax ing region, and recycled in some manner that does not affect the rate of capital formation. Consequently, the potential gains available from shifting the total tax burden away from investment-deterring taxes on capital toward carbon taxes are not represented in the model.

- "Grandfathered emissions:" permits are distributed to continue emitting at 1990 levels.
- Equal per capita: permits are distributed in proportion to adult population each year (10).
- Equal per GDP: permits are distributed in proportion to regional GDP in each period.
- "GDP-adjusted grandfathered emissions:" an original distribution by 1990 emissions is adjusted over time based on regional differences in GDP growth.
- "No harm (o developing nations:" developing nations receive enough permits that their revenue from permit sales restores their GDP to that of the noncontrol case. The allocation between OECD and EEFSU is in proportion to grandfathered emissions.
- "NO harm to non-OECD:" as above, except that EEFSU is also given enough permits to restore its unconstrained GDP.

RESULTS

The model's three uncontrolled scenarios generate time paths of world energy and carbon emissions that roughly span the range of estimates in the literature. World primary energy consumption grows from 350 Exajoules (EJ) in 1990 to 750, 1300, and 1980 EJ in the year 2095 under the low, medium, and high-growth scenarios, while global fossil carbon emissions grow from about 6 Petagrams (Pg) in 1990 to 11, 20, and 32 Pg, respectively. Under all scenarios, primary energy is increasingly dominated by coal, with oil and gas contributions peaking in the first half of the next century, then declining. Nonfossil primary en–ergy provides shares up to about 30 percent. Regionally, the developing countries, especially China, account for an increasing share of both primary energy and carbon emissions under all three scenarios, with total carbon emissions from the industrialized countries flat or declining through the century under both the low and medium-growth scenarios.

Applying the carbon-cycle model to these emission scenarios gives the range of atmospheric carbon concentrations that result. Atmospheric CO^2 concentration passes 550 parts per million, roughly double the pre-industrial value. in approximately the years 2095,2070, and 2060 under the high, medium, and low-growth scenarios. In all three cases, concentration is increasing at the end of the modeling period.

Under the first protocol, emissions are stabilized immediately at 1990 levels and held there through the century. Achieving this stabilization through a common global carbon tax requires a tax level that is initially modest, about $40 per ton in 2005, and grows to $400 to $500 by the end of the century. (These figures are for the medium-growth scenario. Required taxes in the high- and low-growth scenarios are roughly double and half these values.) Through the century, this common tax Progressively redistributes emissions from the industrialized to the developing countries. While the bulk of the early cost burden is borne by OECD nations, later in the century costs are increasingly borne by the LDCs, especially China: the tax redistributes emissions toward China, but not enough to keep its costs down. In terms of GDP, costs of emission control remain below 1 percent in all regions except EEFSU (where they reach 2 percent by 2095) and China (where they reach 3 percent). Under the high-growth scenario, costs of stabilizing emissions are higher in absolute terms, but are not in all cases higher as a fraction of GDP (since GDP is also higher). Under this protocol, per capita emissions converge to the range of 0.5 to 1.0 tons in all regions except the United States, whose emissions decline from about 5.5 to about 3.0 tons per person over the century.

Broadly speaking, the high and increasing tax rates required to stabilize emissions are predictable consequences of a few model assumptions. Energy demand is exponentially increasing, with no technological miracle available to provide large quantities of low-cost, low-emission energy. Because the carbon tax is recycled in a way that does not stimulate investment, it provides no offsetting macroeconomic benefit. Under these conditions, holding emissions constant becomes increasingly costly over time, and requires increasingly high marginal tax rates.

The same global stabilization goal yields substantially different consequences when implemented by separate stabilization targets in each region rather than by a common global tax. Because marginal abatement costs are no longer equalized across regions, world abatement cost is higher—in fact, more than double the cost under a common tax. Cost differences vary sharply across regions, though, with some regions paying less under uniform targets than under a common tax. EEFSU costs are zero under uniform targets through the first part of the century; because unconstrained emissions do not surpass 1990 levels, a regional stabilization constraint is not binding. OECD costs start higher under uniform targets, then become lower, because the uniform tax eventually requires OECD nations to reduce their emissions below 1990 levels.

When stabilization is realized by tradable carbon emission permits, total world costs and the distribution of emissions are the same as under a uniform tax (by assumption), but the various rules for distributing emission permits yield wide variations in the distribution of costs. Since regions are assumed to buy and sell permits at marginal cost to move from the initial endowment to the efficient inter-regional distribution of emissions, a distribution of permits uniquely determines a distribution of costs.

Under ● *grandfathered emission s," the distribution of permits remains at 1990 emission levels through the next century. Under this system there is little trading in the early years, but as LDC growth outstrips the OECD, LDCs buy permits in increasing quantities. Since the OECD and EEFSU earn money by selling permits, their total cost burden is very small (in fact, negative in EEFSU), while transfers from the LDCs to the industrial countries due to trading reach $1.2 trillion annually by the end of the century. These transfers clearly render this scheme infeasible.

Equal per capita distribution of permits mostly reverses the direction of trading and transfers. LDCS receive the most permits, and their share increases further over time due to their higher rates of population growth. Most LDCS sell excess permits while OECD and EEFSU buy them, but China provides a surprising anomaly. China's share of perm its does not grow fast enough to meet the demand driven by its rapid economic growth, so it turns from selling to buying permits in mid-century. In effect, China's projected rapid economic growth and abundant coal resources cause its demand for emissions to exceed its entitlement, which grows only with its modest population growth. By the end of the century, China buys $500 billion of permits annually and the industrial countries buy another $500 billion.

Two other allocation systems are based on regional GDP. In the first, permits are distributed according to current GDP. Under this system trades are initially small, while late in the century China's more coal-intensive resource base leads them to buy permits from the OECD. The second scheme begins with grandfathered emissions, but modifies future shares in proportion to relative GDP growth. Under this scheme, distributions closely track the determinants of furture emissios, so inter-regional trade is small. Total transfers from trading remain at a few tens of billions through the first half of the century, growing to $200 billion by 2095. Most trade is from EEFSU to OECD.

Two final allocation schemes investigate a "hold-harmless" rule. These schemes give enough permits to specified regions that their revenue from selling excess permits precisely offsets the costs of reducing emissions, leaving them as well off as under an unconstrained growth path. In the first of these schemes, only the developing countries are held harmless; in the second, the EEFSU countries are added, in effect making the OECD nations bear the entire world's emission abatement cost.

The consequences of these schemes change sharply over time, as the LDC economies grow. Initially, it requires only small transfers to LDCS to make them whole, so the allocation of permits is close to the "grandfathered" scheme and transfers are only about $15 billion in 2005. But the LDC losses that must be compensated grow rapidly through the century, so that by 2080 even giving LDCS all the permits in the world fails to yield transfers large enough. Consequently, this scheme eventually requires that the industrial countries be allotted “negative emission permits” and be required to buy their way out of the hole before they begin purchasing emission permits. Total transfers to LDCs reach $1 trillion annually by 2080, and $1.7 trillion by 2095. When EEFSU countries are also “held-harmless,” the negative allocation to OECD appears sooner (in 2065) and grows larger; associated transfers reach $2 trillion in 2095.

A separate series of model runs examined the effect of protocols in which only a limited set of nations participate. In particular, a “Big Three” protocol examined the effect of controls by only OECD, EEFSU, and China, which together hold 96 percent of world coal resources. These regions stabilize their emissions by a tax levied half at the point of combustion and half at the point of extraction. This case exhibited a number of remarkable results. Global emissions grew modestly through the first half of the century through increases in nonparticipating regions, but declined abruptly near the end of the century as nonpm-ticipants exhausted their coal. Through the century, progressive exhaustion first of conventional oil and gas, and later of nonparticipants’ coal, drive up world energy prices, eventually bringing involuntary price-driven emission reductions even in countries that did not intend to do so.

The ‘Big Three” is the only scenario modeled in which world emissions drop below 1990 levels, and the only one in which atmospheric carbon stabilizes by the end of the next century, reaching about 500 parts per million (ppm). Two subsequent runs tested the same form of controls in the “Big Two” (OECD and EEFSU) and the “Big One” (OECD only). These agreements were much less effective at reducing global emissions, indicating that the strong results of this scenario depend on participation by nations holding the great bulk of the world’s coal. The OECD-only protocol, for example, yielded global emissions that differed by only a few percent from the reference case.

The involuntary reductions in nonparticipating nations that the “Big Three” protocol brings represent an interesting reversal of the well-known “offshore effect,” by which controls in some countries induce adjustment in nonparticipating countries. The standard offshore effect dilutes the effect of emission control measures that a subset of countries enact through taxes or controls on *consumption.* When such consumption measures reduce world energy demand and hence prices, participating countries’ emissions reductions are partly offset by price-induced emission increases elsewhere. The “Big Three” scenario illustrates that when participants tax fossil fuel *production,* hence reducing their energy exports or turning themselves from exporters to importers, world energy prices can increase and so cause price-induced emission reductions in nonparticipating nations.

A final set of model runs explored the effect of technology development and diffusion. One run used optimistic assumptions of improved fossil generation efficiency and solar-electric cost. With these assumptions, unconstrained global emissions were 25 percent lower than in the reference case (due to a 20 percent reduction in primary energy demand and a doubling of primary solar energy), while the cost of stabilizing world emissions at 1990 levels was cut by half. A further series of runs examined technology diffusion. varying the fraction of price-induced technical efficiency gains in participating regions that become available to nonparticipating regions for free. The benefit from such diffusion is necessarily temporary, lasting only as long as some regions participate in a protocol while others do not. Under the most extreme assumptions, in which all price-induced efficiency gains are transferred, world emissions in some years can be 25 percent below the reference case. These temporary reductions yield atmospheric concentrations in year 2100 at most 2 or 3 percent below the reference case, a significant reduction, though smaller than that generated by the optimistic technological] development scenario.

The following are the major results of the Edmonds et al. project, as presented in the text of the paper and summarized by Edmonds for workshop participants.

- No simple system for distributing emission control obligations and resultant costs is likely to remain acceptable through the next century, so any system of international controls that bites must be designed flexibly enough to allow renegotiation as conditions change.
- The savings available from mechanisms that distribute in ternational abatement efficiently are large, of the order of trillions of dollars, and these savings may be particularly large for developing countries.
- Several simple, plausible schemes for allocating tradable emission permits can have paradoxical effects, and may become infeasible as time passes. For example, in the latter part of the century, China becomes a net loser under equal per capita distribution.
- Not all countries need to participate. The few nations with the largest coal resources can limit cumulative global carbon emissions themselves by controlling or taxing production. To control atmospheric carbon concentration, *only coal matters;* there is not enough oil and gas in the world to make a large difference.
- Modest variation in assumed rates of change of technical end-use efficiency, and rates of diffusion of technical progress among nations, make large differences in the cost and effectiveness of treaties. For example, plausible assumptions of accelerated technology development and deployment can cut total cost of stabilizing world emissions in half.
- Initial delays of 10 or 20 years in implementing emission stabilization have little effect on ultimate atmospheric carbon concentrations.

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