ANL/RP--76523

DE92 041151

GLOBAL CLIMATE CHANGE: SOCIAL AND ECONOMIC RESEARCH ISSUES

Proceedings of a Conference
Held at Argonne National Laboratory
on February 11-13, 1992

Edited by
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Published May 1992

Conference Sponsored by
Midwest Consortium for International Security Studies
and
Argonne National Laboratory*

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*Participation by Argonne National Laboratory supported by the University of Chicago Board of Governors for Argonne National Laboratory and by the U.S. Department of Energy. Opinions expressed in this document are those of conference participants and do not necessarily reflect the views of sponsoring organizations.

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Preface

On February 11-13, 1992, the Midwest Consortium for International Security Studies (MCISS) and Argonne National Laboratory (ANL) sponsored a conference called *Global Climate Change: Social and Economic Research Issues*. A program and list of participants for this conference are provided in Sections VI and VII of this document.

The MCISS is an organization composed of universities that support graduate programs in international security studies. It was organized in 1986 to develop a program of interdisciplinary workshops and conferences that would encourage interactions among participants and foster networking that could lead to interinstitutional studies and projects. In carrying out its mission, the MCISS has sponsored workshops and conferences on various topics of concern to scholars studying security issues. These have included a series of workshops on various aspects of national security decision making in both the United States and the U.S.S.R., on the ethics of low-intensity conflict, on Congress and foreign policy, and on the role of women in national security. Efforts have been made to include scholars from fields whose work is related to but not traditionally seen as being concerned with security issues. These fields include history, sociology, anthropology, religious studies, and ethics. In addition, graduate students are included as full participants in each activity.

The MCISS is managed by the American Academy of Arts and Sciences. Since 1987, it has been supported by a generous grant from the John D. and Catherine T. MacArthur Foundation. With renewed support from the MacArthur Foundation in 1990, the MCISS expanded its field of concern to include security in the southeast Asia context, the impact of military expenditures and arms acquisitions on Third World security and development, the moral role of scientists with respect to the knowledge they generate, the implications of the restructuring of eastern Europe, and international security and global climate change. Additional information about MCISS activities can be obtained from Dr. Marian Rice at 5801 South Kenwood Avenue, Chicago, Illinois 60637; her telephone number is (312) 753-8162.

Argonne National Laboratory is a multipurpose U.S. Department of Energy (DOE) research laboratory engaged in basic research in the physical, life, and environmental sciences. Argonne conducts technology research in fission, fossil, conservation, and renewable energy. It is operated by the University of Chicago for DOE, which funds about 80% of the Laboratory's research and owns the sites. An important part of ANL's mission is to develop, construct, and operate facilities for use by outside scientists. Argonne actively encourages joint projects and scientist-exchange programs with universities and industry, including Cooperative Research and Development Agreements (CRADAs), to speed the transfer of Laboratory-developed technology to the public and private sectors. Argonne science and engineering education programs provide students at all levels with experience in current science and technology research.

The participation of ANL in the workshop was supported primarily by the University of Chicago Board of Governors for Argonne National Laboratory. The Board of Governors includes 21 senior executives and scientists from universities and the private sector who oversee the management of ANL under the chairmanship of the president of the University of Chicago. The contract under which the University manages the Laboratory specifies that the responsibility of the Board of Governors extends to cooperative research and educational programs between the scientific and technical community and ANL. To this end, the Board sponsors various activities that bring Laboratory and university scientists together to address problem areas that are of mutual interest and in which future cooperation may be appropriate. This conference explored such an area. Additional information about the Board of Governors may be obtained from the University of Chicago, Office of the Vice President for Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439; the telephone number is (312) 252-2500.

Section I

Introduction

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This workshop was designed to bring together a group of scholars, primarily from the social sciences, to explore research that might help in dealing with global climate change. The focus for this effort was chosen on the basis of an earlier workshop that examined the potential economic and sociopolitical consequences of climate change and the corresponding international security implications. In those discussions, it became evident that social and economic research on climate change necessarily depends on the evolving understanding of related physical and biological phenomena and can offer at present only limited insight for policy. Translating complex and only partially complete geophysical predictions into an array of policy options that might be useful for national and international decisionmaking is a daunting task that is challenging on methodological, observational, and predictive grounds. In the interim, social science research based on existing data can clarify the merits and limitations of proposed policy initiatives and provide a rough guide to their likely consequences. Such efforts will require extensive interdisciplinary dialog within the research community.

To further that dialog and illustrate the state of present understanding, it seemed useful to focus this workshop on three broad questions that are involved in coping with climate change. These are:

- How can the anticipated economic costs and benefits of climate change be identified?
- How can the impacts of climate change be adjusted to or avoided?
- What previously studied models are available for institutional management of the global environment?

The resulting discussions may (1) identify worthwhile avenues for further social science research, (2) help develop feedback for natural scientists about research information from this domain needed by social scientists, and (3) provide policymakers with the sort of relevant research information from the social science community that is currently available.

Some general background is needed to provide a context for the workshop deliberations. The possibility that significant changes in climate might inadvertently result from the introduction of trace gases into the atmosphere by human activity has been known for about 100 years. This possibility is by no means self-evident. Residues from industry, agriculture, transportation, and other activities of society may have severe local or even regional consequences, but their impact is usually small when compared with the vastness of the atmosphere or the oceans. Naturally-occurring phenomena, such as changes caused by the orbital motion of the planet or the interaction of the atmosphere and oceans, involve areas and energy flows that far exceed those affected by man. For many years, the watchwords for environmental management were to "dilute and disperse" pollutants in the planet's enormous natural reservoirs.

By 1970, systematic measurements of atmospheric carbon dioxide (CO_2) provided convincing evidence that the concentration of this gas was cumulatively increasing, roughly proportional to worldwide use of fossil energy. The increase was estimated to alter slightly the balance between the net energy coming inward from the sun and that radiated outward from the earth. Extrapolated over decades or centuries, this shift was then predicted to change the climate because of the gradual warming of the atmosphere.

This outline is simple, but the details of both theory and measurement are complicated. The apparent connection between fossil energy use and future climate change was highlighted at two scientific workshops — *Man's Impact on the Global Environment* (1970) and *Man's Impact on Climate* (1971). These workshops served as preludes to the widely attended *United Nations Conference on the Human Environment* held in Stockholm in 1972. That conference heightened worldwide awareness of global environmental problems and led to the formation of the United Nations Environment Programme (UNEP). The so-called "greenhouse effect" has been on the international environmental policy agenda ever since.

A major international scientific effort to improve man's understanding of climate change and its origins was subsequently mounted. Scientists have sought to refine the computational models that describe the effects of CO_2 and other radiatively active gases, to understand the global carbon cycle, and to expand the observational database. A major scientific conference was even devoted solely to the problem of first detection; that is, how to distinguish the greenhouse signal from the noise caused by natural climate variability. Unfortunately, nobody has a climate meter, so climate must be estimated from weather measurements. The data are still so obscure that no complete consensus exists on whether a distinguishable trend due to greenhouse gases has been observed, despite the confident assertions of some scientists, which are based on the recent series of warm years.

By the mid 1980s, a series of state-of-the-art assessments was included in the research program of the U.S. Department of Energy in an attempt to synthesize the burgeoning research literature. More recently, a massive multinational effort called the Intergovernmental Panel on Climate Change (IPCC) has been initiated. The IPCC is a joint effort of UNEP and the World Meteorological Organization (WMO) that has pulled together researchers and research results on climate change from across the globe. Participants include government officials as well as practicing scientists. Several hundred expert contributors and reviewers drawn from institutions worldwide participated in the IPCC scientific assessment. The work of the IPCC has provided input to serious discussions about limiting greenhouse gas emissions that have been held in meetings leading to the 1992 United Nations Conference on the Environment and Development (UNCED).

The continuing flow of new scientific information can affect the logic connecting greenhouse gas concentrations and climate impacts. For example, consider some of the research reported on in the first four months of 1992:

- Data from satellite measurements of cloud cover that have become available allow estimates to be made of the effect of various types of clouds at different heights on the net radiative balance.

- Data on the growth or retreat of glaciers, polar sea ice, and other ice masses have been reported on recently, sometimes with inconsistent and conflicting results.

- Speculation continues about the mechanism that removes from the atmosphere approximately half of the CO_2 introduced each year by fuel combustion. Recent arguments have attributed almost half of the missing CO_2 to uptake by the ocean.

- Changes in the salinity of the ocean are hypothesized to have cooled the northern hemisphere in recent decades, possibly masking greenhouse warming.

The IPCC scientific assessment outlines four major areas of scientific uncertainty in climate prediction: clouds, ocean processes, greenhouse gas uptake and transformation, and behavior of the polar ice sheets. It also calls for and describes an extensive program of needed research.

In view of this extensive scientific effort and the 20-year history of interest in international regimes to control greenhouse gas emissions, it is quite surprising that more effort has not been expended on a systematic analysis of the national and regional impacts of climate change and on the costs and benefits of various proposed control measures. Discussions of research that should be done by social scientists are included in recent (1991) studies published under the auspices of the International Social Science Council (*A Framework for Research on the Human Dimensions of Global*

Environmental Change) and the National Academy of Sciences (*Global Environmental Change: Understanding the Human Dimension*). Sources of significant funding for such research have not yet emerged.

The complexity of the greenhouse problem may well defy detailed rational analysis. A comprehensive model would require coupling a geophysical model of oceans and atmospheres to a socioeconomic model describing energy, other greenhouse gas sources, population, economic change, and possibly a variety of other social parameters.

As a practical matter, the geophysical models are very complex and require large amounts of computer time, and they still do not presently include all the relevant physics. Nor do the models produce results at spatial and time scales adequate to satisfy those who need a geo-based data system that can usefully distinguish positive and negative impacts. Also, geophysical predictions generally available usually provide equilibrium values of climate variables but do not describe transient phenomena. For example, moderately reduced average precipitation, considered alone, might not be very significant. If accompanied by marked seasonal asymmetry, it could lead to severe damage to the agricultural sector. Indications that increased average daily summer temperatures result primarily from higher daily night-time lows have significance for both food production and peak electricity demand. Furthermore, increases in turbulent phenomena, such as severe storms, could be of more local significance than are seasonal temperature increases.

Underlying concerns about the validity of climate models remain. For example, Dr. Paul Kenney, a participant in the 1991 workshop *Global Climate Change and International Security*, has observed:

> From 900-1000 A.D., the average global temperature was 1°C higher than now (and Iceland's colonists found it wooded, with relatively ice-free harbors). The reasons why are not well understood, but the notion that a simulation can "back-cast" the consequences of earth-orbit variations, even when the very complicated orbital dynamics are not included as model input parameters, is remarkable. The notion that the temperature rise and fall before and after 1000 A.D. was due to variations in CO_2 concentration, and that such variation might be due to human activity, would be equally remarkable.

Given the uncertain availability of data about the timing and extent of climate change, the amount of confidence that can be attributed to impact estimates is unclear. How urgent global warming should be on the agenda of international issues is also uncertain. Many believe that population growth — which drives near-term needs for food, energy, resources, and economic development — is far more central to environmental degradation than global warming. Local armed conflicts may take a far higher toll in human life.

At this point, it is reasonable to ask whether any attempt to undertake major policy initiatives to limit greenhouse gas emissions makes sense. Nevertheless, there seems to be widespread agreement on the following issues:

- On a relatively short time scale, an important geophysical parameter (i.e., the earth's radiative balance) is being altered — not by nature but by man.
- The resulting changes could have profound impacts on humans and other components of the biosphere.
- These changes could be irreversible on any time scale deemed reasonable for concerted human response.
- The likelihood of soon obtaining the capability to make truly reliable and believable predictions of the impacts and effects is small.

The need to act may simply outrun the quantitative basis for doing so.

In response to this political imperative, there may be worthwhile strategies that are relatively insensitive to detailed geophysical prediction or quantitative assessments of benefits and costs. Such an approach is implied in the recent National Academy of Sciences study, *Policy Implications of*

Greenhouse Warming, and may also serve other desirable environmental or social ends. For example, in the nearer term, growth in greenhouse emissions may be temporarily curtailed through subsidizing (or mandating) improved energy end-use efficiency and use of carbon-free fuels. Market incentives that limit tropical deforestation might be found. Substitutions for energy use, such as telecommunication for transportation, might be encouraged. Each nation might be allowed to choose its own way to meet a greenhouse gas ceiling. (Recent press reports indicate that technical experts claim that temporary caps on emissions are feasible, even in the United States). Various international bodies or tribunals that trade global warming incentives for other values might be introduced — a policy that would be equivalent, in principle, to the approach established under the Clean Air Act.

Part of the reason for the interest in the greenhouse effect is that it serves as a surrogate for a whole class of problems that involve international cooperation, including the sharing of resources, a respect for equity and integrity, and combining the efforts of many toward a just result.

Even though an elaboration of such examples is not provided here, it should be evident that research is quite urgently needed, to both develop the details and explore the designs and consequences of political approaches that are motivated, in part, by the broad implications of greenhouse warming. This workshop, in part, addressed that need.

The approach of the workshop was to present core working papers that address the themes of economics, amelioration, and institutional management. First, however, an introductory framework discussion on aspects of knowledge about climate change (not included here) was led by Dr. John Eddy, formerly of the University Corporation for Atmospheric Research and now with the Consortium for International Earth Science Information Network. Then Dr. Richard Kosobud of the University of Illinois at Chicago addressed economic issues. His application of benefit-cost arguments to the Great Lakes region provided an example of how to estimate distributed costs and benefits. Next, Dr. Peter Morrisette reviewed adaptation and mitigation strategies, paying particular attention to the different conceptual postures that these approaches entail. Then Drs. Michael McGinnis and Elinor Ostrom examined institutional issues, bringing forth a substantial body of research on ways in which other common-use resources have been managed historically, sometimes over centuries. Commentators undertook to discuss each paper as the first step in a candid and free-flowing general discussion of the concepts that were presented. Each paper was then revised by the author to reflect those criticisms deemed most cogent. Workshop participants were also invited to contribute written comments, either on a particular paper or on a more general topic that had not been otherwise addressed. The next three sections (II-IV) of this document contain the revised core papers, with appropriate written comments appended. Section V contains observations and comments of a more general nature. Drs. Marian Rice, Harold Jacobson, and I served as an informal board of editors to assemble the final text.

This workshop and these proceedings could not have been completed without the dedicated assistance of many individuals, including Drs. Harvey Drucker and Terry Surles, of Argonne National Laboratory management, and Dr. Don Hanson, whose group at Argonne served as the workshop host and who personally oversaw the production of this document. Financial support was provided to the Midwest Consortium for International Security Studies by the MacArthur Foundation and to Argonne by the University of Chicago's Board of Governors for Argonne. The final editorial and production effort was undertaken by Ms. Marita Moniger of Argonne's Information and Publishing Division, who did a superb job under often challenging circumstances.

Section II

Workshop in Economics

The Problem of Climate Change Benefit-Cost Analysis

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1 INTRODUCTION

This paper asks the question: Could benefit-cost analysis, the tool used in mainstream economics to investigate control of environmental externalities, play a larger role in the discussion of policies to deal with the greenhouse effect? For example, could economic calculations have played a larger role in the discussions that have centered around the 1992 United Nations Conference on Environment and Development (UNCED). The paper also investigates the causes of this lack of influence. Is it a result of too little research effort? Resistance by interest groups? Methodological flaws? In this paper, I probe selected forms of benefit-cost research, particularly the critical discussions raised by this type of research, in an effort to suggest where the chances of greater acceptance lie.

The paper begins by discussing the search for an appropriate policy: optimal, targeted, or incremental. It then describes the work being done in specifying and estimating climate change damage relationships. A consideration of the work being done in specifying and estimating abatement (both mitigation and adaptation) cost relationships follows. Finally, the paper ends with an examination of the search for the appropriate policy instrument. International and methodological concerns cut across these areas and are discussed in each section. The usual introductory explanation of the greenhouse effect is replaced by relevant background information at appropriate places.

This paper concludes that there seem to be a number of reasons that benefit-cost results play only a limited role in policy development. A late start and resistance to action in an uncertain problem area are among them. There is an unresolved tension between a focused, narrow, quantitative interpretation and a broad interpretation of the benefits resulting from reducing the amount of climate change damage and of the costs resulting from abating trace gas emissions. A narrow interpretation is open to the charge of neglecting many more qualitative aspects, and a broad interpretation is open to the charge of adding numerous value judgments to the analysis. The chance that more attention will be paid to economic calculations — even if there is no new scientific evidence on the significance of global warming — should not be underrated. There is some evidence that the growing interest in market-based approaches to climate change policy and to other environmental control matters is a sign of increased acceptance. Suggestions about research directions are made throughout this paper.

2 OPTIMAL, TARGETED, OR INCREMENTAL POLICY?

What matters for anthropogenic climate change is the worldwide atmospheric concentration of greenhouse gases, not the distribution of their emissions by country or region. (Qualification of this statement is required for several gases that can differ in regional concentration; tropospheric ozone and methane are examples. The former drifts far from its metropolitan-area origin, and the latter's concentration differs little by area, so the qualifications seem minor in a quantitative sense.) What matters for the associated damages is the distribution of climate change — temperature, precipitation, storm frequency, and the like — by country and region. For countries engaged in policy deliberations, it is soon apparent that no one country can wisely act alone without considering

how others will act; therefore, opportunities for coordination as well as for hard complications arise in the search for an optimal policy.

2.1 Optimal Policy

Efforts at estimating an optimal policy such as those begun by Nordhaus (1991) provide an apt illustration of the difficulties, and light, such research can provide. For a market externality, specification and estimation of the relationships between social damage and abatement cost are required; the point at which the marginal gains of damage reduction equal the marginal costs of emission abatement determines the optimal degree of emission reduction (or concentrations) and the optimal tax or emission permit value. Figure 1 is adapted from the Nordhaus study and shows the marginal damage and CO_2-equivalent cost functions for greenhouse gas (GHG) emissions.

As Figure 1 indicates, if all countries were to agree to a Pigouvian tax on trace gases of $3-$13 (1980 dollars) on the basis of their CO_2-equivalent carbon content (e.g., $0.30-$1.30 per barrel of standard crude oil), the external costs of climate change would be internalized.[1] This tax rate would reduce global CO_2-equivalent emissions by about 15% and specific CO_2 emissions by a few percentage points.

Given certain conditions (to be discussed presently) and the imposition of the optimal carbon tax, there will exist at least one set of economically meaningful non-negative prices at which producers and consumers will make consistent allocation decisions. Furthermore, at these equilibrium prices, no reallocation that all households will prefer will be possible; at least one household will object. Finally, if the reader prefers a different global Pareto-efficient allocation and can alter the distribution of goods, there is an equilibrium set of prices to give this preferred allocation. The unplanned or decentralized economy has led its participants, in theory, to the desired optimal end, where the environmental externality has been internalized.

Before one discards the results obtainable from the fundamental theorems of welfare economics, it is worth a pause to admire their depth and appreciate their value as a framework. Providing useful information for policy requires, however, a close examination of the phrase "given certain conditions."

Parry (1991) addressed the question of whether the absence of uncertainty in the neoclassical growth model used by Nordhaus made the optimal policy too conservative; that is, would not the risks of high damages, irreversible impacts of concentrations, and adjustment costs justify a more stringent

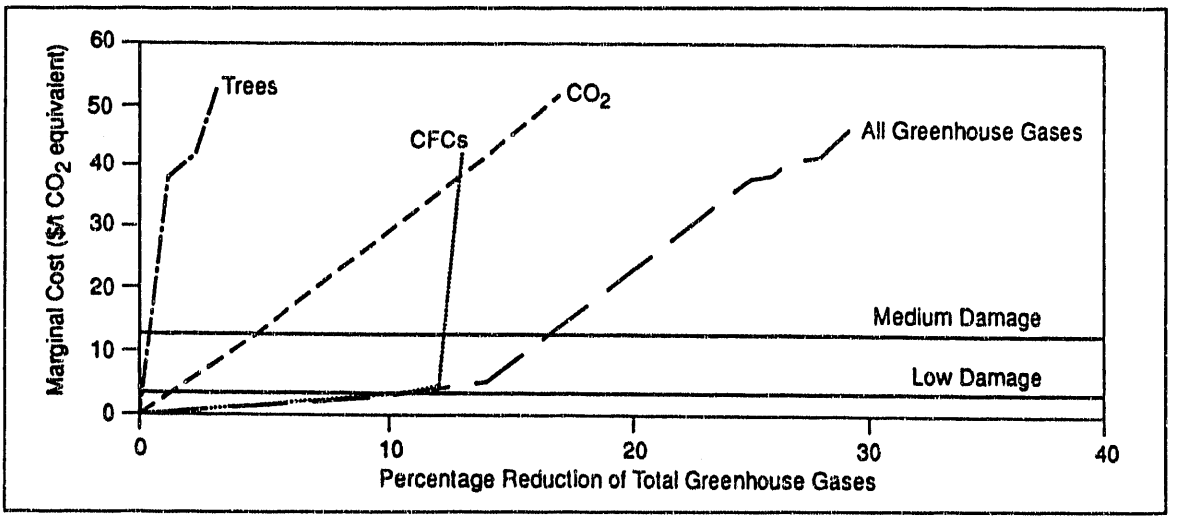

FIGURE 1 Efficient Greenhouse Gas Reduction (Source: Figure 9 in Nordhaus 1991)

policy? By introducing a subjective probability distribution over damages and by introducing growth in trace gas concentrations, Parry used Nordhaus's model so modified to reach the conclusion that society must be risk averse to warrant more action now (a higher tax rate) than in the calculations of Nordhaus.

Ayres and Walter (1991) examined another of the given conditions, the range of damage estimates used by Nordhaus. Damage had been estimated by using U.S. data on climate-sensitive industries operating under the climate change conditions induced by a doubling of current CO_2-equivalent concentrations and by then projecting the estimates onto the world stage. Ayres and Walter argued that there would be greater impacts from a rise in sea level, that land in densely settled countries should be more valuable, and that resettlement of a possible 100 million refugees would be expensive. They increased the tax rate from $3 to $30, which implies a reduction in emissions of about 23% (see Figure 1).

It seems clear that the burden of gathering information and taking measurements necessitated by relaxing only two of the given conditions or assumptions required in the search for optimal policy will be staggering. Moreover, Baumol and Oates (1988) have pointed out that nonconvexities in the production set introduced by externalities (such as the greenhouse effects by which the output of one industry can transmit, through nonprice effects, adverse impacts on other industries) can make the optimality of estimated tax rates suspect. Convexity of preferences cannot ensure that tax rates can move the economy to a preferred position in these situations.

The search for an optimal policy encounters further, and perhaps graver, difficulties when it is placed on the international agenda. For example, proposing a global carbon or CO_2-equivalent tax raises issues in international tax administration, compliance, and resource transfer that are daunting. Varying departures from competitive markets creates well-known problems, including efficiency losses. The existing tax systems of various countries also differ, a fact that creates strategic opportunities for some countries to gain advantage over others; the existing light taxation of fossil fuels in some countries could enable them to lower the gross efficiency costs of a common carbon tax. Revenues from a carbon tax, if used to reduce personal or corporate tax rates, present another similar opportunity (Goulder 1991).

The deep attraction of the optimal policy search is in its theoretical foundation: It creates incentives for decision makers on microeconomic issues to do what they do best — make cost-effective input and consumption choices with all the information at their disposal — and it allows decision makers on macroeconomic issues to decide on environmental goals. The value of benefit-cost analysis as a benchmark toward which policymakers may aim should not be underestimated. An underlying flaw could well be that economists appear to be preempting the political role with their calculations.

One alternative is to recommend that standards or targets for climate change policy be established by the political process, while the cost-effective attainment of these targets be achieved through market-based approaches, wherever feasible (Baumol and Oates 1988).

2.2 Targeted Policy

There are costs in giving up the pursuit: None of the problems are resolved by substituting targets for optimal goals, and the standards of scientific critique are weakened in appraising targets. The basis for targets becomes more or less arbitrary in an economic or scientific sense, although possibly more attainable in a political sense. Targets are the stuff of political careers, and a number of targets in terms of GHG emission reductions have been placed on the international agenda by various governments.

The International Energy Agency (IEA) publishes and updates a useful review entitled *Climate Change Policy Initiatives*, which summarizes the commitments and actions of members of the Organization for Economic Cooperation and Development (OECD). The review revealed in November 1991 that 24 countries had made a commitment to climate change policy, all commitments were in the form of emission targets. Four countries had passed new fossil fuel taxes since the start of 1990, but there were important exceptions in export industries (IEA 1991, Tables 6 and 7).

Twenty of the countries established CO_2 emission targets alone. Most called for stabilization at 1990 levels by 2000 or soon thereafter, one called for a 3-5% emission reduction, three called for a 20% reduction, and two called for a 25% reduction. Four countries, including the United States, set aggregate GHG targets that were to be either stabilized or reduced on a CO_2-equivalent basis; for the United States, this meant a reduction in the radiatively potent chlorofluorocarbons (CFCs). Many of these commitments were made conditional on other countries taking action.

A danger of seeking international approval by making targeted commitments detached from implementation proposals or abatement cost calculations has been pointed out by Schelling (1991). The danger is that the target is not taken seriously. This problem was brought out in the recent work of the Energy Modeling Forum (EMF 1991), which asked 12 builders of energy-environment-economic models to run several of these targeted emission scenarios through their models to estimate the tax rate required to achieve these reductions.

The carbon tax rate required to stabilize current CO_2 emissions by the year 2000 implied, on the average, a tax of about $50 per ton of coal and of about $15 per barrel of standard crude (all in 1990 dollars). In other words, tax rates about equal to current prices would be required for stabilization, and a doubling of these rates would be needed for a 20% reduction in emissions. Note that none of these scenarios stabilized anthropogenic climate change; they permitted a continuing, although slowed, buildup of atmospheric trace gas concentrations.

These tax rates are high, perhaps beyond the realm of political feasibility. A full appraisal of these complex models and their outputs is a vast undertaking; the expected 1992 EMF report that will compare models when comparable future scenarios are imposed on them will be a step in this direction. Among the 12 models, the optimization models, which contain the most detailed economic specifications, indicate that targets that constrain emissions in the near term will require tax rates of the magnitude just indicated or higher. This conclusion accords with one's common-sense view that imposing short-run adjustment costs on the fossil fuel and other industries will be expensive.

If damage estimates, uncertain as they are, do not seem to justify these short-term costs, is it possible to establish longer-run targets that gradually become more constraining and that call for policy actions well beyond the next election? Or to establish sequences of policy steps that escalate over time and commit future governments? Does the danger of proposing targets that secure the popular approval at the negotiating table but have little chance of fulfillment undermine effective climate change control? Do these dangers direct our attention to other forms for expressing policy control?

2.3 Incremental Policy

A more engineering type of approach to policy objectives was proposed in a National Academy of Sciences study (1991) on mitigation options. Some definitions may be in order. Mitigation options cover efforts to reduce gas emissions or enhance sinks; adaptation options cover efforts to adjust to them; and costs incurred in either could be included in abatement costs.

In this approach, an array is drawn up of new energy-efficient technologies, techniques, or practices that could replace existing ways and hence reduce trace gas emissions at little or no cost. Sometimes a negative cost is claimed. The idea, therefore, is to place this array on the international agenda to see if agreement can be reached among all countries to go some way down the list or to see if pledges can be made to undertake some of the items in the expectation that other countries will undertake their own — each effort, perhaps, requiring equal sacrifice or achieving some proportionate emission reduction.

No precise targets need be defined. Some agreement to monitor efforts and to ascertain the effect of efforts on the buildup of concentrations would appear to be important. A variety of policy instruments appropriate to each instance could be chosen and used by participating governments. Illustrative examples adapted from the NAS report are provided in Figure 2 and Table 1.

This approach makes use of the series of case studies described as "bottom-up" in the energy conservation literature. Mitigation Method 1 listed in

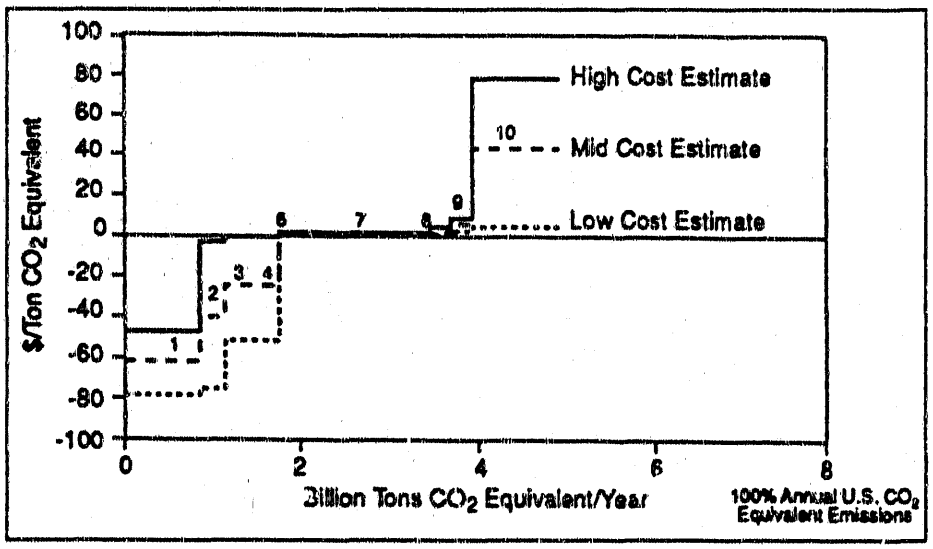

FIGURE 2 Bottom-Up Mitigation Cost Curve (Source: Based on Figure 11.1 in NAS 1991)

TABLE 1 Costs and Emission-Reduction Potentials of Various Mitigation Methods

	Mitigation Method	Net Implementation Cost ($/ton of CO_2 equivalent) Lo	Mid	Hi	Max. Potential Emission Red. (10^9 of CO_2-equiv./yr)	Percent Reduction in U.S. Emissions CO_2 (4%)	CO_2-Equiv. (%)
1	Resid. & comm. energy efficiency[a]	-78	-62	-47	0.9	18	11
2	Vehicle efficiency (no fleet change)[a]	-75	-40	-2	0.3	6	4
3	Industrial electric efficiency[a]	-51	-25	1	0.5	11	7
4	Transportation system management[b]	-50	-22	5	0.05	1	1
5	Power plant heat rate improvements[a]	-2	0	2	0.05	1	1
6	Landfill gas collection[a]	0.4	1	1	0.2	5	3
7	Halocarbons[b]	0.9	1	3	1.4	29	18
8	Agriculture[b]	1	3	5	0.2	5	3
9	Reforestation[b]	3	7	10	0.2	5	3
10	Electric supply[b]	5	45	80	1.0	21	13

[a]Category 1 includes best practice options attainable at negative or low cost.

[b]Category 2 options are attainable at additional costs.

Table 1, for example, includes data from insulation, building code, heating system, and lighting studies of residential and commercial buildings. The net implementation costs are negative, indicating that present practices in these sectors are not efficient; the market is in disequilibrium in this sector. The mitigation cost curve in Figure 2 aggregated over these methods starts below the abscissa and rises to positive costs after reductions of 2 billion tons in CO_2-equivalent emissions are achieved (25% of U.S. 1988 CO_2-equivalent emissions). This mitigation cost curve should be compared with the rising abatement cost curve of Figure 1, which is always in the first quadrant (or positive) and assumes choices are optimal before abatement occurs. Neither curve reflects the external damages of climate change.

The controversy over this approach is by no means assuaged by the issuance of a prestigious academy report. Questions have been raised about hidden costs not accounted for in the curve and about the incentives required to install those energy-conserving technologies that are not being undertaken at present.

At issue in these debates is the importance of efficiency standards, education, and informational programs when compared with economic incentives provided by taxes or emission permits. To the extent that market imperfections are barriers to energy-efficient innovations, economic incentives are less effective than command-and-control regulation. Energy conservationists argue: "Having the right price is helpful but not sufficient to achieve optimal efficiency improvements in the future" (Geller et al. 1992).

Addressing climate change policy incrementally appears to involve a long series of steps to reduce emissions by energy-efficient methods, many of which are claimed to have negative implementation costs. These steps would apparently require an extensive kit of policy tools to alter perceived market imperfections. The following questions arise. How can tests be constructed to determine the actual effectiveness of particular steps? To determine their full implementation costs? How should such efforts in the international area be negotiated and monitored? Should credit be given to a regulatory measure for an innovation or to a correlated OPEC price shock? Can ideas about market imperfections giving rise to energy inefficiencies be formulated as testable hypotheses?

2.4 Summary Comments

The search for an optimal climate change policy by means of benefit-cost analysis is only one of the flickering candles in a very dark room. To blow it out because of its recognized limitations would heighten the risks of stumbling seriously on the path to sensible policy. Yet it cannot be denied that important problems remain to be resolved.

The optimal tax rate calculated by Nordhaus and the emission stabilization or reductions called for in current proposals do not stabilize trace gas concentrations (and hence temperature change); they slow them down. Is that what policy should aim at? Given the fact that there are fossil fuels in the ground in recoverable amounts that would more than quadruple CO_2 atmospheric concentrations, should policy analysis provide guidance on a long-run goal of temperature stabilization?

The matter is complex, but the difference in consequences between short-run and long-run policy implementation was brought out recently in several experiments. Figure 3 was drawn from research carried out at Argonne and the University of Illinois at Chicago. The top panel, Panel a, shows a business-as-usual (no greenhouse policy) global projection for CO_2 that more than doubles concentrations by the year 2100. On the basis of a mathematical programming model that permits constraints to be placed on emissions and concentrations and consequently fossil fuel use, Scenario A′ was run holding concentrations constant after 2100. A different scenario, Scenario A, was run holding annual emissions constant after 2000, as so many proposals advocate. Note that both Scenarios A and A′ result in the same CO_2 concentration near 2100. In A, but not in A′, concentrations continue to build up after 2100.

The implications of these concentration scenarios for emissions, the rate of change of concentrations, is revealed in the middle panel, Panel b. Scenario A′ emissions follow the business-as-usual emissions closely up to the year 2030, which implies relatively little impact on the fossil

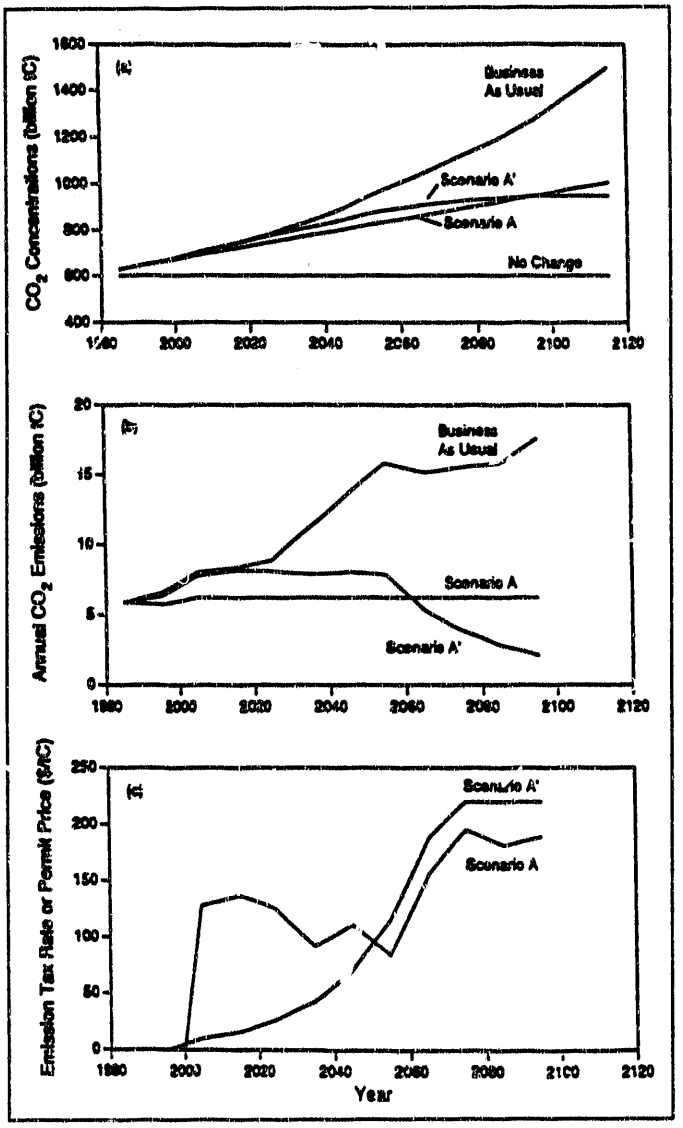

FIGURE 3 Mathematical Programming Projections of CO_2 Concentrations, Emissions, and Permit Prices (Source: Kosobud et al. 1991)

fuel industry. Scenario A' emissions remain above those of Scenario A until 2060, then they diminish to the rate that stabilizes concentrations and ultimately average global temperature.

The bottom panel, Panel c, is a preliminary exploration of the policy consequences of aiming for these two different objectives. The programming model enables the researcher to interpret the shadow prices of constraints on CO_2 emissions as either tax rates in a competitive world or, equivalently, emission permit prices in a world of certainty. To accomplish the goal of stabilizing emissions by 2000, a carbon tax that works out to be more than the current price of oil or coal (U.S. prices) is required. The rate declines a bit in the next century as the economy adjusts to the shock. To accomplish the goal of stabilizing concentrations by 2100 but permitting the economy to achieve that goal in an optimal way (by emitters equating marginal abatement costs over time), a tax rate, or permit price, that starts low and rises with the rate of interest (5% in this experiment) is required.

Scenario A' would be preferred and welfare superior, providing that long-run concentrations were the major factor in induced climate change. If the rate of change of concentrations or total damage borne were the major factors, Scenario A could be preferred. An important question for atmospheric scientists to address is the following: Which feature of trace gas buildup is most important in inducing climate change: the level of concentrations, the rate of change, or the sum of past concentrations? There is little evidence that starting with modest policy measures such as those in Scenario A' that escalate over time exacts a penalty in climate change. The follow-up question for social scientists is this: What features of climate change have the largest damage impacts?

Another key issue concerns the cooperation or conflict that has, and will, ensue in international negotiations over a coordinated policy, if one is attainable. Developing countries have argued that the developed countries have caused the problem, at least to the present time, and ought to bear the heaviest burdens. If that argument does not carry enough weight, developing countries can threaten that in the future, with economic growth, they will be major emitters, with the upper hand in bargaining. Something like this may be in the minds of those Chinese economists of the Peoples Republic of China whom I have met and who profess a great interest in the greenhouse topic.

Yet the damage estimates that are beginning to accumulate indicate that there will be wide regional differences, resulting in winners and losers, and that some developing countries and not the developed countries will be among the potential big losers. Changes in sea level are likely to threaten

Indonesia and Bangladesh, which have long and occasionally low-lying coastlines. Agricultural impacts are likely to be more important in developing economies. In sum, the bargaining chips may alter in the future. Policy research in this area has just begun.

3 THE SEARCH FOR CLIMATE CHANGE DAMAGE RELATIONSHIPS

The benefit-cost method has its own scissors analogy: The blade of the damage reduction must fit with the blade of the abatement costs in order to cut the externality knot. The difficulty has been that in one environmental study after another, economists, with their measurement practices, have estimated damages that seem to warrant little, if any, policy action. There is a puny or no damage blade at all.[2] Many environmentalists have protested that the estimates are too narrowly focused and too small; many affected industry groups have protested that the estimates are too large. This issue is emerging, among others, in the policy analysis of the impacts of the greenhouse effect.

Specifying the relationship seems straightforward; estimating it is not so easy. In this section, I examine the top-down and bottom-up approaches to specification and the difficulties encountered in obtaining estimates with both. Several specific estimates will be presented for discussion, one being the result of an effort to estimate damages for the Great Lakes region. It is, of course, self-serving for a researcher to call for more studies, but in this area, too long underfunded, I make the call in good conscience.

3.1 An Economic View of Impacts

In principle it seems simple: All one has to do is specify the micro-production functions and consumer utility functions and include in them a vector of climate variables. Increased trace gas concentrations affect the climate vector, which then may or may not affect producer outputs and consumer welfare. To the extent that climate has an impact, one obtains the externality of a reduction in output or a reduction in the satisfaction of a producer or consumer, independent of his or her input or shopping decisions.

Admittedly the above framework does not tell us which producers or consumers are sensitive to climate variables or how exactly to go about measuring the impacts. It is, however, suggestive in pointing toward an ordering of activities, industries, and systems by their climate sensitivity. It also suggests that decision makers on micro-economic issues may be able to find adaptive strategies to lessen these impacts once they are aware of their coming. Finally, this framework plainly indicates that efforts to adapt to or mitigate climate change will have costs, so that reducing such change to zero is unlikely to be optimal.

3.2 Bottom-Up or Top-Down Specification?

This distinction is becoming a battle cry among climate change researchers, but in this application, few blows need be struck. Top-down refers to a very aggregate damage specification that some builders of energy-economic-environment models have used to study optimal tax or permit pricing under alternative scenarios. Work in this vein is underway at the Electric Power Research Institute (EPRI). Nordhaus has specified a linear relationship for the Argonne linear programming model, on which research is now underway.

These damage equations are specified as constraints in these models, so that activities giving rise to trace gas emissions (fossil fuel use giving rise to CO_2 emissions in the two models cited) are charged for the damages. These charges raise the prices of fossil fuels, for example, to a point in each time interval at which the marginal damages generated by the damage equation are equated with the marginal abatement costs of reducing, or substituting away from, fossil fuel use. The charge is a shadow price, tax rate, or permit price of an optimal policy path, providing one believes the damage relationship.

The equations are highly aggregated and meant to be suggestive; they typically make a discounted damage scalar depend over time on global or regional gross national product (GNP) per capita, the change in CO_2 concentration (or temperature),

and perhaps a separate population variable. GNP, like population, is a proxy for vulnerability, and CO_2 concentration change (or temperature change) is a proxy for the vector of climate variables impacted by the greenhouse effect.

The IPCC (1990b), adopting a wider frame of reference for climate sensitivity than the economist's usual view, prepared a list that began with agriculture and forestry, then included natural terrestrial ecosystems, hydrology and water resources, human settlements, energy, transport, human health, air quality, oceans and coastal zones, and the terrestrial cryosphere. The IPCC did not attach monetary values to damages in each area, but the panel did survey the qualitative direction of change.

For agriculture, a key sensitive sector, the findings of studies to date are complex and indicate there will be winners and losers. Higher levels of atmospheric CO_2 may enhance the growth rate of cereals such as wheat and rice but not of sorghum, millet, or maize. Use of water by crop plants may be more efficient. How much these direct effects will be felt in the farmer's field remains an open question. Negative impacts could occur at regional levels since these CO_2 impacts vary by plant type and are decidedly nonlinear. Other weather changes could bring about reduced yields, stimulate new or more virulent diseases, encourage pests, and favor weeds.

Another key area concerns impacts on the world's oceans and coastal zones: a rise in sea level of 20-30 cm (about a foot expected to occur by 2050 or so) will pose problems for low-lying island countries and coastal zones. Fresh water systems can be adversely affected by climate changes; hotter and dryer conditions in the Great Lakes area could reduce the levels of the freshwater lakes, affecting shipping, fisheries, and coast lines.[3]

3.3 Damage Estimates for the Great Lakes Region

The most courageous (foolhardy?) way to present the difficulties of estimating damages is to display some of my own. In Table 2, I provide estimates I recently drew up for the Great Lakes region by drawing on existing studies. The damage categories list the activities and sectors I judged to be the most sensitive in the five-state area (Illinois, Indiana, Michigan, Wisconsin, and Ohio).[4]

The estimation methods of Table 2 are straightforward but based on strong assumptions. The economy of the region is projected to be bigger in 2050, but grows more slowly than in the past 50 years. It has, however, the same sectoral structure, which means that agricultural and hydrological economic activities retain their relative importance in output. The climate of the region is projected to change by 2050, when global CO_2-equivalent trace gas concentrations about double (assuming no control policies are undertaken). The regional climate change is the average of the temperature and precipitation changes reported by the EPA from its survey of the projections of three general circulation models; in particular, precipitation is projected to decline.

I have attempted to be more inclusive in Table 2 than some studies and have listed a few impacts to the health and leisure sectors in addition to the traditional sectors that are considered climate sensitive. This attempt is meant to be suggestive, not exhaustive. I have drawn on other studies for monetary estimates that were then applied to the region. (These other studies are the references R1, R2, ..., Rn noted in the table; they are available from the author on request.)

Agriculture is a big item and corn is a big component in the region. Favorable effects of photosynthesis and water efficiency are more than offset by temperature and precipitation changes. The range, which may be too small, attempts to capture the possible consequences of unfavorable weather during critical growing and harvesting periods. Promising research is underway in this area, and new information should make these estimates obsolete soon, if not now.

One of the interesting sensitivities of the region is the hydrological system, including the famous jewels of the area. The reference cited, and others, project lower lake levels because thermal expansion will be more than offset by precipitation declines and evaporation. One study the author is currently working on finds that when the cool winds of fall and winter blow over the waters still warm from the summer, the evaporation volumes are enormous.

TABLE 2 Greenhouse Effect Damage Estimates for the Great Lakes Region (GLR)

Damage Category	Annual Estimate (10^9 1982$) Low	High
General		
Health		
Urban smog related (R7, Sec. E, p. 5)	-0.012	-0.030
Heat stress	NA	
Cold stress	NA	
Climate variability increase		
Storm frequency (R4, p. 33)	-0.009	-0.009
Leisure activities		
Golfing (R2, p. 3)	+0.010	+0.020
Lawn watering (R2, p. 5)	-0.010	-0.025
Biological diversity in the GLR	NA	
Sectors		
Agriculture (R3, p. 10-6)		
Corn, soybeans, wheat	-2.950	-2.950
Hydrological systems (R3, pp. 5-7, 5-23)		
Water transportation	-0.010	-0.010
Hydroelectric power	-0.002	-0.002
Shoreline maintenance	-0.012	-0.024
Recreation	NA	
Water quality maintenance	-0.018	-0.018
Energy (R3, p. 5-53)	-0.297	-0.297
Forestry (R1, Table 6-4, p. 215) (R3, p. 546)	-0.150	-0.350
Construction	NA	
Government service	NA	
Totals	3.460	10.825
GLR percent of 1982 GNP	0.6%	2%

Source: Kosobud (1990).

Declines from a few inches up to several feet have been projected by 2050 or soon thereafter, with implications for water transportation, shoreline maintenance, fisheries, fresh water supplies, and the like.

The energy sector will have opposing factors to consider — the increased demands for air conditioning offset by the decreased demands for heating. Forestry is of interest; the present furniture and value-added processing industries possible because of the quality of the trees in Wisconsin and Michigan could suffer if these trees fail to adjust and new, less valuable species replace them.

My data are intended less to persuade and more to reveal the complexities of damage estimates and the need for expanded work in this area (even at the expense of reduction in certain other areas). Conclusions are in order from this effort: a range of about $3.5 to $11 billion in damages is obtained, or 0.6% to 2% of 1982 GNP. These estimates are not all that frightening and lie between the estimates of Nordhaus for the larger U.S. economy and Ayres and Walter, who gave more emphasis to developing countries.

My estimates, however, can be attacked as too high or too low, and there is merit to both arguments. On the high side, the point can be made that I have failed to allow for adaptive behavior in agriculture and other sectors. A sensible farmer, seeing climate change coming (reading the proceedings of this conference for example), would begin to think of new seeds, new cultivation practices, and other innovations that would lessen the damages.

Also on the high side, it may be argued that the economy of the region will look a lot different in 2050 than it does today, including a larger service sector and many more activities less sensitive to climate change, like this conference.

On the low side, the point can be made that there should be more categories in the table (ecosystems, for example) and that within existing categories, there should be many more items. Furthermore, the estimates are based on average climate changes for just a few variables. What about storm frequency, wind velocities, strings of hot, dry days, etc.? Perhaps even more significant, what about the rate of change of these variables? Adjusting to a slowly changing climate (even though changes over 100 years may seem slow, they are enormously more rapid than in prior known history) is one thing. What if the rate of change of climate variables over the next 20 to 50 years turns out to be an important damage-driving factor?

3.4 Summary Comments

The search for climate change damage relationships has just begun; there is a good deal of work yet to do, especially at the regional level. Although the level of accuracy (hardly the strongest feature of the benefit-cost method) remains low, the first results do not point toward enormous damages, on the average. For some regions other than the Great Lakes, the results may differ.

A source of concern is the possibility of catastrophic damages beyond some critical amount of climate change. Added to this is a concern about damage to ecosystems and the geographical dispersion of climate-sensitive plants and animals. The limitations of traditional benefit-cost analysis are all too apparent in the face of these questions.

4 THE SEARCH FOR ABATEMENT COST RELATIONSHIPS

This section seeks to extend the understanding of efforts to estimate the costs of emission reduction or concentration stabilization. Unlike the area of damage estimates, which is noted for involving few studies with few controversies, the area of cost estimates is noted for involving many studies with many controversies.

Widespread interest in the costs of achieving environmental goals is relatively new on the political scene in the United States. The first major legislative efforts in the late 1960s and especially in the 1970 Clean Air Act Amendments (CAAA) were quite clear in indicating that improving the quality of the air for health reasons was not to involve benefit-cost analysis. Moreover, the target pollution levels — the National Ambient Air Quality Standards — were to be achieved by state and federal rulemaking that required regulators to become familiar with production processes and the

techniques that would bring them into compliance — the command-and-control approach.

Not only does this approach place enormous information burdens on the regulatory agencies, but it can also create inefficient incentives, leading some emitters to reduce more than an amount that is cost effective and others to reduce less. Recognition of these burdens was undoubtedly of some importance in the changes that led up to innovations in the 1990 CAAA that both expressed interest in cost effectiveness and permitted SO_2 emission trading.

My own guess about policy-making motivations is that the magnitude of expenditures on environmental protection (perhaps $130 billion in current dollars) began to bear on the choice of instruments. Although GHGs were not covered in the 1990 legislation, being left for later consideration, the enormity of some abatement cost estimates could have made deep marks. That market-based approaches could be more cost-effective became an argument with heightened relevance.

Another aspect of thinking about climate change may have played a role. Trace gases, especially CO_2, are not ordinary pollutants. The carbon atom is linked to other atoms in the molecules of life. Removing all CO_2 and other trace gases from the atmosphere would change the planet from greenhouse to icehouse. The problem of the greenhouse effect is trying to decide what volume of emissions or concentrations we want to live with — the kind of problem that calls for an economic calculation of costs.

Environmentalists in such units as the National Resources Defense Council and the Environmental Defense Fund relaxed their opposition to market-based approaches primarily, I believe, because of the cost effectiveness promise of these measures. The regulatory agencies themselves have become sponsors of cost studies, and the hunt for cost-effective strategies has taken interesting turns, even coming to a crossroad, as I shall argue.

4.1 Cost Concepts and Cost Measures

To attempt to correct a market externality like the greenhouse effect by regulatory restriction or by a tax rate or emission permit will affect the price the emitting producer receives; the price the consumer pays; the ratio of prices of energy-intensive products to others; the terms of trade of fuel exporters, fuel processors, and fuel consumers; and possibly the rate of technological progress. Not included in these direct and indirect effects would be damages from climate changes, or budgetary ramifications, or adaptation costs incurred because of the permitted degree of climate change.

Welfare measures of these effects suggest themselves some estimate of resource costs or deadweight loss. The fully dynamic, computable, general equilibrium model that is required to do this to the satisfaction of all is not yet in sight. Some compromises have to be made. The measures of abatement costs included in Figure 1 discussed previously have been developed from a variety of sources, including a computable general equilibrium model, partial equilibrium mathematical programming models, and various recursive projection frameworks (details from the source cited for Figure 1). These estimates are mitigation costs, in the sense that resources are required to reduce emissions, or remove gases (reforestation), or alter the radiative balance (e.g., painting things white).

Figure 1 estimates may be classified as "top-down," meaning they are derived from highly aggregated energy-economic-environment models with econometric or macroeconomic-level estimates of parameters and are based on assumptions, typically, of market clearing and long-run adjustment to price changes. They are interpretable as either deadweight losses, or approximations, such as GDP or consumption losses after policy intervention, compared with a no-policy scenario. In programming models, the losses may be calculated from the shadow prices of policy constraints.

The strengths of this approach can be discerned in Figure 1. The "all greenhouse gases" curve, conceptually a horizontal aggregation over microeconomic-level emitters and different gases, is a convex set, the exterior points of which denote efficient marginal mitigation efforts for the particular degree of emission reduction. It is nonlinear, indicating that small reductions in emissions from baseline are relatively costless as measured in dollars per ton of carbon reduced. Larger reductions will require ever-larger resource

losses. The curve could be a basic building block for cost-effective policy to the extent it is credible: Once the environmental goal, the policy target, is chosen as a percent of emissions to be reduced, the appropriate tax rate (emission permit price) can be read off the values on the ordinate.

Figure 1 implies cross-sectional efficiency in that cost-minimizing emitters everywhere are led to equate their marginal mitigation costs with the tax rate or permit price. In the next section, I examine these policy instruments more critically. The issue here is whether the top-down curve, or refinements of it, can be the basic building block we seek.

The bottom-up or engineering approach to estimating mitigation costs is exemplified in Figure 2. Termed "technological costing" by the National Academy of Sciences panel in its report on mitigation (1991), it contrasts with "energy modeling" described above. The NAS report goes on to note its "rough agreement," which, it is asserted, lends comfort to the validity of the Figure 2 curve. However, one curve lies below the abscissa and one above in the relevant policy range of reductions of emissions.[5]

Technological costing derives cost estimates on various assumptions about the technical features of particular mitigation options; that is, it involves studies at the micro-level of improvements in existing technologies, of replacement technologies, or of altered practices that may improve energy efficiencies, and for which rough appraisals of the direct costs of implementation may be made. It holds out the hope of reducing trace gas emissions by these detailed changes, often at little cost, or at cost savings.

4.2 Commentary on Cost Relationships

The debate between bottom-up and top-down (technological costing versus energy modeling) advocates may be more deep seated than appears at first glance. It may also have many implications. A closer look at the issues throws light on questions of obtaining useful estimates of the mitigation or abatement cost curve.

The debate is not only about how to estimate mitigation costs; it also "spills over" to the policy debate. I noted earlier that the bottom-up studies could be closely tied together with the incremental policy option. Instead of focusing on optimal emission reductions or eventual concentration stabilization at some future date or on a set of targeted goals, the negotiators could debate incremental policy moves, such as improving vehicle and building energy efficiencies, revising transportation systems, and others.

There are attractions to this approach: Many of the actions have attached to them negative cost estimates, which, if true, ought to generate little opposition. Countries could adopt those actions that they prefer. If each action had attached to it a trace gas emission reduction, an estimate of the aggregate reduction of emissions could be made, and each country's contribution to overall reductions could be appraised.

There are questions to be asked about this approach. How much confidence can be placed in the estimates of direct costs of implementing each action? Can a credible aggregation over vehicles, buildings, power plants, factories, farms, or the like be carried out for each new technology, or improved technology, or changed practice, so that each country's contribution can, in fact, be appraised? What set of incentives or regulatory methods are envisioned to bring about these changes in the ways things are done presently? These questions refocus our attention on the issue of how estimates of the mitigation cost function that secure wider confidence can be obtained: Through the methods of Figure 1 or Figure 2? Or through refinements of one or the other? Or through a combination of the two?

4.2.1 Technological Costing: The Cheap and No-Regrets Way?

The reasons ordinarily given for the negative costs or energy inefficiencies of Figure 2, which are by no means the most extreme of estimates available (Geller et al. 1992, p. 5), include a lack of information in the markets, high consumer discount

rates for energy investments, market barriers of various kinds, resistance to change or irrational behavior, and inadequate incentives for introduction, especially in the public utility sector. In other words, the present market solutions to energy use are not in equilibrium.

The microeconomic-level studies that underlie technological costing vary so widely in method and database that the scope of this discussion does not allow for even a sample appraisal. Several comments are in order on how confidence in the results claimed can be strengthened. High consumer discount rates are not necessarily irrational in terms of energy investments, especially ar ng the poor. Should the poor be urged to invest in energy-efficient innovations, or in education, job training, or health? A closer study of the problems confronting the poor is required, in my view.

Typically, only direct implementation costs are included for energy-efficient innovations. Secondary effects, such as those traced out in general equilibrium models, are ignored. Can estimates of these indirect costs be included? Have all additional information, adjustment, or managerial costs been considered? It would be reassuring to know that they have been. Frequently, a hidden constant cost assumption is "slipped in": If one innovation saves a certain amount, then 100 of the same innovations save 100 times that amount. What if increasing costs characterize the extension?

There is a policy bias in each of the two approaches being discussed. For the advocates of technological costing — the bottom-up approach — the bias is toward command-and-control regulation: "Having the right price is . . . not sufficient to achieve optimal efficiency improvements . . . public authorities have a responsibility for promoting energy-efficiency improvements" (Geller et al. 1992, p. 28). For the advocates of the top-down approach, the bias is toward taxes or tradeable permits or other incentive systems that get prices right. This is the crossroad now confronting policymakers.

4.2.2 Energy Modeling: Greenhouse Gas Emission Reductions Can Be Costly

Underlying the cost curve of Figure 1 are assumptions about markets being in equilibrium: There are a few appreciable energy inefficiencies to be exploited. The curve does indicate that the first few percentages of reduction are inexpensive, primarily because of the substitution away from the CFCs. But as CO_2 emissions are reduced and the fossil fuel industry is affected, marginal mitigation costs rise.

The assumption of competitive markets in equilibrium is well known to set aside imperfections such as existing subsidies, taxes, regulatory practices, and the like. Such set-asides are highly visible, it should be noted, and frequently, research is directed toward relaxing an assumption to determine the consequences for the results (e.g., see Goulder [1990] on the implications of existing taxes).

The macroeconomic-level studies or energy models that generate the top-down cost curve have other problems. They vary in specification and statistical estimation methods and are subject to specification error, aggregation bias, and other econometric difficulties. Mention should be made of inadequate data and the instability of parameters in projections over long time periods in the future. The catalog of concerns about estimates is long, but considerable research has been conducted with respect to these troubles. My impression is that the bottom-up approach cannot avoid many of them, and may have a few special problems of its own.

The energy modeling approach, in most cases, features price adjustments to changes. Autonomous energy conservation, or nonprice increases in energy efficiency, can be introduced in many such models by a parameter in the production function. This device permits the important distinction to be drawn between price-induced energy conservation and autonomous shifts, and it provides a measure of the significance of the former, frequently overlooked in bottom-up studies.

The bias in top-down models, and the bias among those who attach significance to results obtainable from them, is toward market-based approaches to greenhouse policies. The introduction of emission or concentration constraints in these models, or the introduction of tax rates or positive permit prices, are assumed to lead emitters everywhere to equate marginal mitigation costs to the tax-rate or permit-price equivalent, thus

yielding interfirm or cross-sectional cost effectiveness. The decentralized market guides consumers and producers toward energy-efficient choices. The Figure 1 cost curve traces out solutions to these cost-effective decisions as emissions are increasingly reduced.

Intertemporal cost effectiveness is also important. For this condition to hold, emitters must equate marginal mitigation costs over time, which implies that such costs must rise at the long-run interest rate. This condition has been given less attention than cross-sectional cost effectiveness, with the end result being that proposals to cut emissions sharply in the near term imply high initial marginal mitigation costs that frequently decline over time — an indication of intertemporal cost ineffectiveness.

5 THE SEARCH FOR THE APPROPRIATE INSTRUMENT

U.S. environmental history until recently was dominated by one policy instrument — regulation or command-and-control prescription as the means to obtain environmental standards. (The CAAA of 1970 prohibited benefit-cost calculations on ways to obtain environmental quality levels affecting health.) Consideration of costs has played a larger role recently; the IPCC (1990b) cited the cost effectiveness of market-based approaches (e.g., taxes or tradeable emission permits) to greenhouse policy as deserving further study, although there were reservations about these instruments expressed by spokespeople from developing countries.

In addition to cost effectiveness, other criteria need to be applied to policy tools if well-informed choices are to be made in this complex area. Implementability, flexibility, and enforcement and monitoring suggest themselves. It would seem wise to distinguish sharply between the policy and the policy tool kit. Figure 1 provides a handy illustration: A policy may be defined as choosing a point or interval emission reduction target on the abscissa, and a policy instrument(s) may be defined as the least-cost way to move vertically to the abatement cost curve, recognizing that it is possible, and easy, to be cost ineffective and move above it.

Some policy instruments may be inseparable from the policy. The advocates of energy conservation who see negative cost opportunities for reducing emissions frequently attribute some of these opportunities to badly drawn building code specifications or inappropriate utility regulations. The policy is to reform these imperfections, and the tool is the redrafting of the regulation.

Moreover, policies directed to specific trace gases (CFCs, for example) may have a link with particular instruments. The speed with which international agreement has been reached on the phasing out of these ozone-depleting chemicals is a reflection, no doubt, of the perceived risks of melanoma cancer. Attention is focused on reducing production as fast as possible and devising schemes to cut emissions from stocks of old cars and refrigerators.

While the Montreal protocol and follow-up agreements have left implementation to participating countries, provision was made for emission trading and other instruments. However, quotas and phase-out schedules — forms of regulatory controls — appear to have been the main instruments called upon to achieve the quick emission reduction called for in this global problem area. The fact that the few, large production sites and enterprises involved were ready to cooperate fully made these policy tools readily implementable and easily monitored.

While recognizing that there are difficulties in separating policy from instrument, this paper proceeds with the view that the distinction is clear in most cases and that it enables the researcher to appraise the benefits and costs of applying alternative policy instruments to a policy goal. Hence, it is envisioned that policymakers have available to them a list of various command-and-control measures, market-based approaches, and government intermediate efforts to influence behavior, such as information dissemination, research, design, and development (RD&D) stimulation, and the like. The task is to match these policy instruments to the characteristics of the atmospheric trace gases so as to reach the environmental target in the most "satisfactory" way. Such criteria of the "satisfactory" way as implementability, cost

effectiveness, flexibility, and enforcement must be interpreted in light of the greenhouse effect.

5.1 Implementability

There are two aspects of this criterion that deserve attention: the acceptance of an instrument as "fair" by those affected and the feasibility of the instrument as applied to sources and sinks of trace gases.

Tax rates (either carbon or commodity taxes) designed to reduce emissions are regressive in that they affect both poor families and poor countries more heavily than their richer counterparts, unless offsetting tax reductions or transfers are made. If carbon taxes are the agreed upon international means to deal with global warming, then acceptance of a rate by all nations has much to be said for it; duties on fossil fuel imports or fossil-fuel-intensive commodities from nontaxing countries would not be necessary. Therefore, if carbon taxes are to be implemented, the regressivity issue is on the agenda. Requiring permits results in higher energy prices, raising essentially the same issue. (If tax rates and emission permits are designed to achieve the same reduction in emissions, and if the market operates under conditions of certainty, the impact of both policy instruments on price is identical.)

Market-based approaches (either taxes or tradeable emission permits) seem more implementable for CFCs or CO_2, trace gases for which sources and sinks are better understood, than for the other major trace gases, CH_4, N_2O, and tropospheric O_3. The sources for CH_4 and N_2O are poorly understood, diverse, and, to a considerable extent, nonanthropogenic. Except for a few sources of these latter gases, such as fertilizer use and application, it seems unlikely that market-based approaches could be implemented and enforced.

For the CFCs and CO_2, questions arise as to which stage of processing implementation could best be applied. A consumption tax or emissions permit would force public officials to calculate the trace gas content of numerous end-use products. Measuring and recording the carbon content of consumer products would generate work for an army of inspectors and enumerators. The production or extraction stage would hold out more promise.

5.2 Cost Effectiveness

Market-based approaches would appear to dominate this criterion; they do not require public authorities to have the detailed microeconomic data on input and market basket options that command-and-control regulation requires. Nor do they impose rigid practices or technologies on firms and consumers. A tax rate or permit price provides the incentive for the cost-minimizing producer or consumer to utilize his or her information in making the appropriate adjustment. The public authorities can devote themselves to setting tax rates or determining the volume of permits. Both cross-sectional or interfirm and intertemporal cost effectiveness can be claimed for these decentralized, price-determined instruments.

I find the argument persuasive, but some care must be taken in particular applications. Tropospheric ozone concentrations generated by precursors appear to depend on many factors, including the number of hot, sunny days that fall together. This random variability makes it difficult to devise a market-based approach that is quickly adaptable; hence, outright bans or prohibitions may be more cost effective. If the negative cost argument of devoted energy conservationists is correct, regulation and reform of existing practices may be required, since "getting the price right" did not work in the first instance.

As multiple trace gases are at work in the greenhouse effect, the appropriate tax rate or emission permit price for each gas must reflect its warming potential; otherwise, incorrect incentives are transmitted to emitters, weakening the cost effectiveness argument. Harmonizing these rates or prices will depend on discount rates, radiative potential, and atmospheric lifetimes. To do this with a reasonable chance of success requires construction of a weighting index, a CO_2-equivalence metric, which is not without its difficulties (IPCC 1990a; Nordhaus 1990).

5.3 Flexibility

Adjusting both policy and policy instruments to new knowledge is vital in an environmental area infused with uncertainty like climate change is. One aspect of this uncertainty is the desirability of

avoiding irreversible policies or instrument settings that impose heavy costs if they turn out to be wrong. Suppose the government had invested heavily in cold fusion, or required enterprises to prepare the way for its introduction on the grounds that no trace gases were emitted from this energy source!

Among the market-based approaches, there is an argument favoring tradeable emissions on this criterion. International negotiation of tax rates, if such an instrument were to be chosen, is likely to be an arduous, time-consuming task, perhaps making GATT deals look easy. Resetting tax rates to take advantage of new information is a highly likely and desirable event, but the renegotiation may be more difficult than the original negotiation.

The volume of tradeable emission permits could be adjusted more easily. For a cumulative emission system, or undated permits, initiated in the market to accord with a targeted trace gas (CO_2) concentration volume, the number of outstanding permits could be adjusted by "open market" operations carried out by an international agency operating as a central permit bank.

Dated permits issued for a year or less would make up an even more flexible system, in the sense that next year's volume could be adjusted to next year's information. Such flexibility could carry a price: Emitters carrying out long-lived investments in abatement technologies must have some trajectory of tax rates or permit prices in mind when deciding upon the most cost-effective intertemporal allocation of expenditures. Unexpected changes in rates or prices over time could upset these plans.

5.4 Enforcement

At first glance, command-and-control measures appear to be easier to monitor and enforce than market-based measures, because they are clear-cut in prescribing standards and technologies. There is certainly more experience established with this form of regulation. However, second thoughts, always the best, cast doubt on this assertion. Checking the performance of microeconomic decision makers may entail expensive arrangements of personnel. However, market-based measures, being relatively new in the environmental field, may contain nasty surprises. The value of permits would depend in part on compliance with the rules; cheating or counterfeiting would dilute the value of authentic permits.

5.5 Matching Gas Source and Sink Control with Policy Tools

Several features of GHGs bear directly on the choice of policy tools. In the main, they are distributed after their emission throughout the global atmosphere. They have both anthropogenic and natural sources and sinks that differ in their amenability to control. A careful matching of these sources and sinks with the policy instruments is a requirement of well-advised policy.

A detailed account of the sources and sinks and of chemical transformations would be valuable at this point, but this is beyond the scope of this paper. What is important for our purpose is the anthropogenic share of total emissions: All CFC and related compound emissions are anthropogenic, as are almost all CO_2 emissions, perhaps two-thirds of CH_4 emissions, and less than a quarter of N_2O emissions. Altering natural sources and sinks as a policy device seems difficult and expensive, so policy tools will have to be applied to human activities that give rise to emissions.

The CFCs are produced at a few large sites, although emissions from old capital are scattered and diffuse. Anthropogenic sources of CO_2 arise mainly from fossil fuel use and, to a lesser extent, from deforestation; the problem here is at what level or stage of processing of fossil fuels policy control should be instigated. Anthropogenic CH_4 emissions arise from processing of fossil fuels and agricultural practices. N_2O arises primarily from the latter source.

Sink enhancement offers some promise in the case of CO_2, either through reforestation or geoengineering plans, such as seeding iron molecules in cold northern seas to facilitate growth of CO_2-absorbing organisms, or hurling particles that screen out incoming ultraviolet sunlight into the stratosphere. Sink enhancements would appear

to be activities deserving of study that would be best encouraged by government research or subsidies until they are better understood.

An overview of the matching process just described is presented in Table 3 to provide a qualitative picture of three classes of policy tools matched with the trace gas sources. The tools are grouped into regulatory, RD&D and subsidy (government partnership), and market-based approaches.

The CFCs are characterized by a few large production sites with cooperative management, so both regulation and market-based approaches have proved effective. Reducing emissions from stocks of old cars and refrigerators remains a difficult issue; creating incentives for proper disposal may involve a range of tools.

A more rapid phasing out of these gases is moving up on the international agenda. New agencies have been created in the World Bank to provide capital at subsidized rates to developing countries to aid in replacing the CFCs with more benign substitutes. Implementation of a wide variety of policy instruments seems feasible and is underway. The market-based approaches seem most promising in terms of cost effectiveness, but regulatory measures may be the most straightforward to enforce.

For CO_2 emission control, the market-based approaches, when initiated at the extraction stage of processing, hold out prospects for cost effectiveness and flexibility. Enough time seems to be available to design systems that create the proper incentives. Given the uncertainty surrounding damage estimates, emission permits may have an advantage over taxes in that they ensure policy-makers that the desired emission reduction will be obtained. Tax rates may yield widely varying emission reductions.

Monitoring and enforcement may pose problems for new market-based approaches. If CO_2 emissions are to be constrained at intermediate or end-use stages, new match options are opened up. Energy conservationists can argue that regulatory measures for buildings, appliances, etc., geared to particular inefficiencies will outperform altered price patterns; the issue is not close to reconciliation yet.

Both CH_4 and N_2O, given current knowledge, offer poor prospects for market-based approaches. The chances of success seem slim, and the costs of failure are high (casting doubt on a promising new approach). The diversity of sources suggests that experimentation with a variety of tools will be worthwhile if any action at all is to be undertaken. The same conclusions may be drawn for tropospheric ozone.

In general, Table 3 suggests that no one policy tool will fix the problem. Applying market-based approaches to those areas with the greatest chance of success — CO_2 emission reduction — seems well advised. Emission permits may be more acceptable than taxes and may offer more control in uncertain areas; they are deserving of more intensive research. Regulatory measures will continue to have their advocates and their place. Their cost effectiveness ought to be questioned in each instance. Government partnership in research and in RD&D is a good buy in this uncertain area.

6 CONCLUSIONS

The argument of this paper is that economists can contribute to the policy discussion by carrying out "plain vanilla" benefit-cost analysis, with details on its limitations clearly marked on the package. A secondary goal is one of clarifying the implications of alternative targets.

Estimation of damages remains the under-developed area; perhaps because it is messy, difficult, and lacking in glitz. The lack of reliable damage estimates in climate- sensitive areas may be due to the fact that there are not very many damages, but I remain unconvinced that the impacts of extreme climatic events, storm frequencies, soil-precipitation interactions, and the like have been sufficiently investigated.

The controversy between bottom-up and top-down cost estimation methods is one that emasculates the policy debate. The tempting promise that emission reductions are achievable at negative cost can steal center stage from more painful choices. Unfortunately, it is going to take some time to determine the degree of accuracy in bottom-up claims. More work on price-induced conservation is in the mill, and this should help.

TABLE 3 Matching Matrix: Policy Instruments and Greenhouse Gas Control Criteria[a]

Greenhouse Gas and Criteria	Policy Instruments							
	Regulatory Instruments			Government Demonstration		Market-Based Approaches		
	Technology Standards	Efficiency Standards	Bans and Quotas	Subsidies and RD&D	Information Standards	Emission Taxes	Excise Taxes	Marketable Permits
CFCs								
(a) Implementation	+	+	+	+	+	+	+	0
(b) Cost Effectiveness	-	0	0	0	0	+	+	+
(c) Flexibility	-	0	-	+	+	-	-	+
(d) Enforcement	+	0	+	0	-	0	0	0
CO_2								
(a) Implementation	+	+	-	+	+	+	+	0
(b) Cost Effectiveness	-	-	-	0	-	+	+	+
(c) Flexibility	-	-	-	+	0	-	-	+
(d) Enforcement	+	+	0	0	-	+	0	0
CH_4								
(a) Implementation	+	+	+	+	+	-	-	-
(b) Cost Effectiveness	-	-	-	0	-	0	0	0
(c) Flexibility	-	-	0	+	+	-	-	0
(d) Enforcement	0	+	0	0	-	-	-	-
N_2O								
(a) Implementation	+	+	+	+	+	-	-	-
(b) Cost Effectiveness	-	-	-	0	-	0	0	0
(c) Flexibility	0	0	0	+	+	-	-	0
(d) Enforcement	-	-	-	0	-	-	-	-
O_3 (precursors)								
(a) Implementation	+	+	+	+	+	+	+	-
(b) Cost Effectiveness	-	-	-	0	0	+	+	0
(c) Flexibility	0	0	0	+	+	0	0	0
(d) Enforcement	0	0	0	-	-	-	-	-

[a] + = good match, - = poor match, 0 = uncertain match.

The choice of policy tools is complex, given the multigas, multisource, and multisink character of the greenhouse effect. No one tool seems able to fix the problem to everyone's satisfaction, and there are good reasons for this situation. Adapting various tools to the numerous sources and sinks may prove beneficial. This policy would allow governments to choose their preferred mix. The tool-source-sink combination must be appraised by economic calculation for its cost effectiveness (e.g., cost of a reduction in CO_2-equivalent emissions per ton). Market-based approaches hold great promise on this score. Tradeable emission permits, as the "new kid on the block," have the attention of economists firmly fixed on them

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8 ENDNOTES

1. A. Pigou was the English economist who analyzed how the imposition of a tax on polluting commodities would internalize for the enterprise the external costs of the pollutant. The reason for the range in the tax given in the example is a result of the range in the estimates of damage or impacts; they ranged from low to medium.

2. The exception to this statement, which proves the rule, is the stratospheric ozone depletion problem, in which the threat of skin cancer and other damages and the feasibility of substitutes for the CFCs and other pollutants have led to remarkable international cooperation on policy. I am indebted to professor Gilbert Bassett in calling to my attention the literature on "existence value" research, which represents one way to broaden the concept of environmental damages.

3. The U.S. EPA (1988) carried out a massive survey of potential effects of climate change on the United States. The findings for the Great Lakes (Chapter 5) may be of special interest: Projections of climate change from three general circulation models under a scenario in which CO_2 concentration is doubled indicated higher temperatures (the range was from 3° to 7°C) and precipitation changes (from +0.6 mm to -0.5 mm per day). Corn yields could decline up to 60% (except for Minnesota), and lake levels could decrease from a few inches to 7 feet. The ranges hint at the difficulties of making regional climate-change projections.

4. This is the region of responsibility of the Federal Reserve Bank of Chicago. I want to thank Dave Allardice and Bill Testa of the bank for providing useful data on the region's economic and demographic characteristics. They are not responsible for the damage estimates or for errors.

5. The scales of the two abscissas are different but can be made comparable. Figure 1 is measured in CO_2-equivalent percentage reductions, and the optimal reduction point (where the marginal curves cross) is a little less than 20%. Figure 2 is measured in billions of tons of CO_2-equivalent for the United States. Where the mitigation curve crosses the axis, about 2 billion tons, represents a reduction of about 25% in U.S. emissions. Note, however, that Figure 2 data are probably average costs, not marginal costs.

Comment 1 on Workshop in Economics

A Note on Benefit-Cost Analysis and the Distribution of Benefits: The Greenhouse Effect

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The application of benefit-cost analysis to environmental problems in general, and to global warming as demonstrated by Kosobud in particular, is a very useful tool. Depending upon the limitations of the relevant data available (in this case, the degree to which the marginal costs and marginal benefits of a reduction in greenhouse gas emissions can be quantified), benefit-cost analysis can offer information to society about how to improve its condition. However, beyond the criticism of its estimate of the Pareto optimal point (based on theoretical considerations regarding the convexity of the social production frontier and of social preferences), benefit-cost analysis suffers from a fundamental weakness: It cannot speak to the distribution of the net benefits of implementation of an international greenhouse policy.

Within an individual country, debate on a particular policy intervention can effectively separate the issues of achieving a potential Pareto optimum and distributing the benefits necessary to actually accomplish Pareto optimality. This situation occurs because (theoretically, anyway) these decisions are made in the presence of a binding enforcement regime that can redistribute benefits as seen fit. A policy can then be introduced in the manner that achieves the best overall net benefits, and the allocation of these benefits can be treated as a stand-alone problem.

However, in the case of international policy-making such as in the greenhouse situation, it is not possible to divide these two issues. There is no enforcement regimen that can impose a binding redistribution of net benefits, at least at this time. Instead, policy analysis should focus on the determination of what is the best attainable policy, given that each actor (country) *must* be better off after the implementation of this policy, all things considered. "All things considered" would include the possibility of side payments and the nature of the additional utility that a country enjoys when a policy results in a more equitable allocation of net benefits among countries. A game theoretic approach may be more suitable to this problem because it addresses this consideration directly. Benefit-cost analysis, on the other hand, may suggest an "optimal policy" that has no chance of being successfully implemented and observed.

Comment 2 on Workshop in Economics

Issues in Benefit-Cost Analysis: Amplification Channels and Discounting Long-Term Environmental Damages

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Many environmental problems have long-term effects. Acid rain has long-term effects on soils, forests, and exposed materials. Global climate change has even longer-term effects. This difference in timing — between the near-term cost of environmental protection and the long-term environmental effects — makes it difficult to conduct a cost-benefit analysis of any program designed to abate environmental damages. The rate at which to discount long-term environmental damages becomes a key question in comparisons of benefits and costs. This comment points out an important facet of the discounting issue. The discount rate for calculating the present value of future environmental benefits may be much lower than the rate of return on investment.

Cost-benefit analysis is a framework in which to evaluate policies and decisions. Because global climate change is a complex problem, extensions of cost-benefit theory can be expected to add additional insights, particularly in the following areas:

- Distinguishing distributional effects among nations, over time, and among generations;
- Determining the rate of discount that is appropriate for long-term environmental damages and separating risk aspects from the rate of discount; and
- Assessing amplification effects when policies involve large expenditures relative to the economy or when affected sectors are significant sectors of the economy.

This comment does not add anything to the discussion of distributional effects among nations, but it should be pointed out that the target rate of economic growth is also a distributional issue. The present generation may be asked to work hard and sacrifice so that future generations can attain higher levels of consumption.

Another comment is that for highly uncertain environmental problems such as global climate change, the uncertainty component should be separated from the time rate of discounting. Some environmental effects that may not be manifested for a very long time are reasonably predictable. However, it is true that predictions can be expected to be more uncertain the farther in the future they are for.

To illustrate, consider a simple aggregate economic growth model of consumer goods and environmental goods (the last of which are a measure of environmental quality). The economy possesses the capability to transform between consumer goods and environmental goods (i.e., produce one type of good instead of another) via expenditures for environmental protection and abatement of environmental damages. Society can also transform foregone current consumption into future consumer goods via investment. The net rate of return on investment is determined within the model (endogenously) as it takes into account a valuation of the environmental damages that result from pollution associated with production. The correct formula for calculating the present value of future consumer goods is to use the net rate of return on investment as the discount factor. However, the correct method for calculating the present value of future environmental damages is to use a pure rate of time-preference --- a rate that members of society choose to discount future welfare

for themselves and future generations. The valuation of environmental damages is based on the consumer's marginal rate of substitution between environmental quality and consumer goods. The implication is that any long-term environmental damages that are foreseen may be discounted at a low rate chosen by society. Furthermore, the valuation of these damages may be high if consumer goods are relatively more abundant than environmental goods. The valuation of damages is based on the shape of the indifference curve between environmental quality and consumer goods.

What decisions or policies follow from this analysis (which does not take into account the implications of uncertainties in both environmental effects and costs of policies to abate environmental damages)? Society faces a budget constraint in that its total production (i.e., gross domestic product) must equal its production of current consumer goods, investment, and pollution-abatement expenditures. Hence, when two of these variables (e.g., investment and abatement expenditures) are chosen, the third (current consumption) is determined from the budget constraint. The decision rule (or method) to calculate investment is determined on the basis of the net rate of return. The decision rule to calculate abatement expenditures is determined through a cost-benefit analysis, in which the benefits are valued on the basis of the marginal rate of substitution and are discounted to the present through use of the pure rate of time-preference on utility. Hence, society must balance its desire for current consumption against its desire for future growth in the standard of living — a growth that depends on its investment — and its desire for environmental quality in the near term and long term. The reader seeking more information on these topics can contact the author for additional papers.

In cost-benefit analysis, total benefits should be compared with total costs — costs that include not only direct effects but also second- and third-round effects as the economy adjusts to policy changes. In this adjustment process, there are two offsetting forces: substitution and rigidities. Both substitution among consumer goods and substitution among factors of production allow the cost of an initial policy change to be mitigated in general equilibrium. However, rigidities in the macroeconomy, such as "sticky wages" (a condition in which labor resists a reduction in wages), cause total losses in the economy to be amplified relative to the original cost. (See Hanson, D.A., 1992, *The 1990 Clean Air Act: A Tougher Regulatory Challenge Facing Midwest Industry*, Economic Perspectives, Federal Reserve Bank of Chicago, May/June.)

These dimensions of cost-benefit analysis make environmental problems more complex to analyze, but they also open a door for policy improvements. Whenever possible, policies should exploit substitution possibilities and be designed to mitigate losses by allowing for smooth adjustments.

There are also interesting implications for market-based approaches that make use of emissions taxes or tradable permits. A firm will have the incentive to reduce emissions up to the point where the marginal abatement cost (MAC) equals the emissions tax (or the tradable permit price). Hence, if the overall reduction in emissions is stringent, the MAC will rise and the price of pollution (i.e., cost of the tax or permit) will be high. The resulting emissions tax revenue is in addition to total abatement costs. The emissions tax revenue and total abatement costs are either passed on to customers, taken out of wages, or taken out of profits. The emissions tax revenue, if it is large (which occurs when there is a significant carbon tax), can lead to reductions in wages and profits or increases in inflation and sectoral adjustments. Attendant *macroeconomic* losses are not fully considered in the standard Baumol-Oates theory that demonstrates the *microeconomic* efficiency of these instruments. Simulations on the size of the macroeconomic amplification effect are available from the author.

Section III

Workshop in Adaptation and Mitigation Strategies

Approaching Global Warming: A Review of the Adaptation and Mitigation Perspectives

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1 INTRODUCTION

The debate within the scientific, policy, and environmental communities on what, if anything, to do about global warming appears to be focused on whether to adapt to climate change in the future or to mitigate climate change in the present. As the issue has become increasingly politicized, the debate over these two approaches has become polarized. The two approaches, however, are not mutually exclusive; in fact, there is much common ground between them. But differences can be found in how proponents of each approach view the risks of global climate change and the values that underpin these perceptions of risk. In this paper, I will briefly outline the progression of global warming from an obscure scientific concern into a leading international political issue. I will also review some previous efforts by social scientists to assess attitudes and positions on global warming. I will then examine in detail the adaptation and mitigation perspectives and assess how they differ on the basis of different conceptions of uncertainty and risk, equity, and technology. Finally, I will examine the adaptation and mitigation approaches from the perspective of developing countries.

2 GLOBAL WARMING'S RISE TO PROMINENCE

The global warming issue is at the forefront of international science and politics. Negotiations are currently underway on an international framework convention on global warming, and some countries have even pledged to stabilize or reduce emissions of carbon dioxide. Global warming's rise to prominence on the international political agenda is remarkable. If we look back only a few years to the mid 1980s, global warming was of interest mostly to the scientific community, some environmentalists, and a handful of politicians. What makes global warming's sudden political prominence even more remarkable is that conventional political wisdom tells us that an issue like global warming, characterized by great uncertainty associated with the facts of the problem and by high potential economic costs associated with taking action, is not likely to advance very far in the policy process.

Understanding global warming's sudden prominence becomes even more intriguing when we consider that scientists have long known about the greenhouse effect. The possibility that CO_2 emissions from the burning of fossil fuels might enhance the earth's natural greenhouse effect was postulated as early as the 1890s by the Swedish chemist Svante Arrhenius (1896). Arrhenius calculated that a doubling of atmospheric CO_2 concentration could lead to a global warming of five or six degrees celsius (a predication that is not far from the current projection) and that this warming would be greater in higher latitudes. Similarly, in the 1930s, Callendar (1938) described the effect that CO_2 emissions from the burning of fossil fuels might have on global temperatures. And it was 35 years ago when Revelle and Suess (1957) made their now famous remarks describing the anthropogenic release of CO_2 as "a large-scale geophysical experiment," the effects of which could not be predicted.

It has been argued that the basic scientific principles of the global warming problem have not

changed all that much in the past 50 years. Michael Glantz (1988, p. 51) of the National Center for Atmospheric Research (NCAR), for example, writes:

> As far as the scientific aspects of the global warming issue are concerned (with regard only to the burning of fossil fuels), it appears that most of the aspects discussed today . . . were being discussed at least fifty years ago. . . . While we have acquired considerably more knowledge through modeling and paleoclimatic investigation, the scientific premise of CO_2-induced global warming remains essentially the same as it was in the 1930s.

Andrew Solow of Woods Hole (1991, p. 7) makes the same point when he writes: "In many ways the broad outline of [the global warming] debate has remained unchanged over the past fifty years. Atmospheric science and climatology have advanced quite a lot over that period, however, and the details of the debate are somewhat clearer."

If the basic scientific premise of global warming has remained essentially the same since the 1930s, what has changed, and fundamentally so, is our knowledge and understanding of what global warming might mean for the planet. For example, we now have some understanding of how the climate effects of global warming might affect agriculture, forestry, water resources, and natural ecosystems, how it might raise sea levels and flood coastal lowlands, and how it might affect economies and societies around the world. What has also changed is our perception of the problem. When Callendar was writing in the 1930s, the effects of CO_2-induced warming were seen as potentially beneficial — expanding the margins of agriculture or postponing the onset of the next ice age (Callendar 1938). Even Revelle and Suess's warning in the 1950s did not create much concern. It was not until the 1970s and the rise of political and scientific concern for the environment that the broader implications of CO_2-induced global warming began to receive serious consideration. However, outside the scientific and environmental community, global warming remained a rather obscure issue until the mid 1980s.

Several factors have been invoked as explanations of global warming's rapid rise on the international political agenda in the late 1980s. These include the North American drought of 1988 and other unusual weather events around the world in recent years that have sensitized the public and politicians in the United States and elsewhere to the variability of climate; other environmental problems such as ozone depletion, acid rain, and deforestation that have raised public and political concern for the fate of the earth's environment; an emerging consensus in the international scientific community on the climate-forcing potential of greenhouse gases; scientific advances that have improved our understanding of how the earth's various natural systems (climate, the oceans, and the biosphere) interact and of how human activities, in particular, can influence these systems; and a belief that not taking action now to limit global warming is too great a risk to take.

There is, however, a more subtle underlying explanation to global warming's prominence. The economist Lester Lave (1988) suggests that it is the symbolic nature of the global warming problem that has attracted so much attention to the issue in recent years. Global warming demonstrates not only the reality of resource constraints but also humankind's capacity to alter environmental systems on a global scale. Lave argues that we have experienced a "loss of innocence"; i.e., we can no longer ignore our environmental problems, because there are no more frontiers to exploit. In a larger sense, global warming is also symbolic of other problems that confront modern society in the late twentieth century: problems that are global in scale, highly complex, not fully understood, and not only lack an obvious solution but also fundamentally question the problem-solving capacity of existing institutions.

One interesting fact about global warming's prominence is that the public has not reacted strongly to the issue. This is evident in Willett Kempton's research on lay perspectives on global climate change (Kempton 1991). Kempton's survey of public attitudes shows that while the public has heard of the global warming problem, it has very little understanding of it. In fact, most people in Kempton's survey confused global warming with

stratospheric ozone depletion, and few understood the connection between global warming and energy consumption (Kempton 1991). Furthermore, in the public's eyes, global warming lacks the immediacy and localized concern of, for example, mismanaged hazardous waste dumps or polluted drinking water; at the global scale, the issue lacks a tangible impact, such as the Antarctic ozone hole. Thus, at this time, there appears to be no strong public mandate for action driving the global warming issue. Rather, global warming has found its most vocal and active support among scientific, political, and environmental elites.

3 PREVIOUS ASSESSMENTS OF GLOBAL WARMING

At this point, it is useful to review previous efforts at assessing attitudes toward and positions on the global warming problem. I briefly review three earlier assessments, each of which used a different approach. In the first of these assessments, Glantz (1988) described the degree to which different segments of the scientific and policy communities believe that global warming is a problem, and how this might influence international efforts to control CO_2 emissions. In the second assessment, Andrew Plantinga and I reviewed the political and economic factors that would likely influence the degree to which countries would support an international agreement to control the emissions of CO_2 (Morrisette and Plantinga 1991). In the third assessment, O'Riordan and Rayner (1991) took a more theoretical approach toward identifying the values and beliefs that underlie different "decision-making strategies" toward global warming.

Glantz (1988) has argued that within the scientific and policy-making communities, there are hawks, doves, and owls on the global warming issue. The hawks, according to Glantz (p. 41), are those who "believe that the evidence of CO_2/trace gases warming is very convincing and that the warming is already under way." The doves, on the other hand, tend to dismiss the issue and "feel that [it] is yet another doomsday scenario that will most likely fail to materialize" (p. 41). The owls, Glantz (p. 42) explains, "have yet to make up their minds on the issue." They are waiting for more information.

Glantz believes that within the scientific community, the number of hawks is increasing, while the number of doves is dwindling. The growing scientific evidence in support of the global warming theory is responsible for this shift. Yet Glantz notes that there are still "persistent scientific uncertainties," and thus there are still doves. Within the international policymaking community, Glantz believes that the owls are the largest group, perhaps reflecting the traditionally pragmatic view of the policymaker. Glantz concludes by noting that because there are still very different perceptions of the seriousness of the global warming problem, particularly relative to other problems on the international political agenda, it is not surprising that there is no firm consensus on the issue. It might even be argued that it is surprising that there is as much consensus on the issue as there appears to be.

The focus of the earlier assessment of global warming that Andrew Plantinga and I undertook was primarily on the policy positions of nations (Morrisette and Plantinga 1991). Our goal was to understand the political and economic factors that would condition the degree to which a country would be motivated to support an international agreement to control global emissions of CO_2. At the risk of being overly simplistic, we divided the nations of the world into four groups on the basis of their stated policy positions on global warming: (1) countries advocating a cautious approach, (2) countries advocating an activist approach, (3) countries unable to act, and (4) countries unable and unwilling to act.

Among the wealthy, industrial countries, the United States is the principal (if not only) member of the group advocating a cautious approach. The United States maintains that not enough scientific evidence is available to justify potentially costly measures to mitigate emissions of CO_2. The activist group is made up of those countries in the Organization for Economic Cooperation and Development (OECD) that have endorsed CO_2 stabilization and reduction targets (e.g., Germany, Canada, Sweden and Japan). These countries support the view that the scientific evidence points to a significant threat from climate change and that the benefits of averting the threat outweigh the costs of controlling CO_2 emissions. Because of more immediate political, economic, and environmental

problems, the countries of Eastern Europe and the former Soviet Union are unable to respond to the CO_2 issue with the same degree of commitment characteristic of many Western European countries. Yet these countries have professed a serious concern about the global warming problem and are willing to participate, where possible, in international efforts to respond to global warming.

Like the countries of Eastern Europe, many developing countries are also unable to commit themselves to potentially costly efforts at controlling CO_2 emissions. Furthermore, these countries have been less willing (if not unwilling) to support international efforts to control CO_2 emissions that do not at the same time directly address problems of underdevelopment. The developing countries are suspicious of the motivations behind the interest of the world's rich countries in the global warming issue and question the long-term commitments of developed countries to provide assistance to developing countries. The support of developing countries will be essential to the success of any international agreement on global climate change, yet their attitudes and positions toward the problem differ in important ways from those commonly supported by scientific and policy elites in the developed countries. I discuss the attitudes and positions of developing countries in greater detail later in this paper.

The assessment by O'Riordan and Rayner (1991) focuses on the underlying values and concepts of nature that shape different decision-making strategies toward global warming. O'Riordan and Rayner identify three decision-making strategies — prevention, adaptation, and sustainable development — and argue that each is based on a fundamentally different concept of nature. The preventivists, they argue, believe that nature is fragile and easily susceptible to catastrophic and irreversible change. The preventivist approach, O'Riordan and Rayner (1991, p. 99) write, is underpinned "by a conviction that it is morally wrong to distort natural processes by human behaviour." The adaptationist approach, on the other hand, is based on a cornucopian view of nature in which the environment is seen as flexible and easily capable of adapting to change. O'Riordan and Rayner (1991, p. 100) explain that "the ethical imperative driving this position is that it is morally wrong to curtail economic development and condemn the poor people and nations of the earth to permanent deprivation of the benefits of modern industrial society." A synthesis of these two strategies can be found in the sustainable development approach, which is underpinned by the belief that global catastrophe can be avoided through "careful stewardship of the limited opportunities that nature provides for controlled growth" (p. 100). The sustainable development view of nature sees the environment as generally forgiving of many disturbances but vulnerable to catastrophic change.

O'Riordan and Rayner believe that these different viewpoints derive not from disputes over facts and knowledge about global change but rather from different, institutionally derived ways of approaching or framing the problem. They explain that preventivists tend to be egalitarian and collectivist in their approach to problems, adaptationists are more likely to support a *laissez-faire* approach, and sustainable developmentalists tend to support hierarchical approaches to solving problems. O'Riordan and Rayner favor a "holistic" risk management strategy that could bridge these different, institutionally derived ways of framing the problem. Such a holistic strategy, they explain, "would mean reconstructing scientific and political institutions in new ways to make decisions involving global stakes at unprecedented levels of uncertainty" (O'Riordan and Rayner 1991, p. 101).

In the remainder of this paper, I present a more focused assessment of the adaptation and mitigation perspectives on global warming. In some important ways, this assessment is a synthesis of the three approaches that I have described above. Similar to the approach described by Glantz, I focus primarily on scientific, policy, and environmental elites, although I also examine the global warming problem from the perspective of the developing countries. Like Glantz's approach and that used by Morrisette and Plantinga, I focus on the practical political and economic considerations of dealing with the global warming problem. Finally, similar to the work of O'Riordan and Rayner, I assess some of the basic, underlying values that characterize different perspectives on the global warming problem.

4 TWO VIEWS: ADAPTATION AND MITIGATION

For several years, natural and social scientists, policymakers, and environmentalists have been debating over two seemingly different views about how society should respond to the global warming problem: adaptation and mitigation. Proponents of the adaptation perspective tend to stress the capacity of society to adapt to changing conditions in the environment through technological and institutional innovations. Proponents of the mitigation perspective argue that taking steps to curtail or eliminate the emission of greenhouse gases is the only reasonable, long-term approach to the global warming problem. Although there is not an inherent dichotomy between the two approaches (i.e., it is not an either/or decision; choosing one does not preclude the other), the discussion within the scientific and policy communities concerning these two approaches has become polarized.

It may be, however, that the adaptation/mitigation model is not a very useful way to conceptualize the global warming problem.* Nevertheless, for better or worse, it is the predominant conceptual model in the scientific and policy literature. The relatively modest purpose of this paper is not to argue the merits of the adaptation/mitigation model; rather, it is simply to describe these two perspectives as they have been outlined in the scientific and policy literature, assessing where they differ and how they are similar, and offering an initial explanation on why the debate seems to be polarized.

The release in 1991 of the National Academy of Sciences (NAS) report on the policy implications of global warming, in which prospects for both adaptation and mitigation were assessed, clearly illustrates how polarized the discussion has become. The adaptation panel, which was one of four panels (the others were science, mitigation, and synthesis), put forward a relatively optimistic assessment of the capacity of the United States to adapt to a moderate, greenhouse-induced climate change. But the reports of both the synthesis panel and the adaptation panel included dissenting opinions (in the form of lengthy footnotes) that questioned the reasoning employed by the adaptation panel — an unusual feature for an NAS study. Also interesting is the fact that these dissenting opinions received more attention in both the scientific and popular media than did the findings of the adaptation panel (see, for example, Roberts [1991]).

The debate over adaptation and mitigation is not new. The broad outline of the adaptation and mitigation perspectives is clearly evident in early works assessing the range of policy responses to global warming (for example, see Mann [1983] and Schelling [1983]), although in these earlier policy reviews, mitigation is commonly referred to as prevention. Just as Glantz and Solow have argued that the basic scientific foundations of the global warming theory have not changed all that much in 50 years, I would argue that the basic structure of the policy debate (i.e., the concepts of adaptation and mitigation) also has not changed fundamentally since it was first discussed seriously in the late 1970s. What has changed is our knowledge about potential impacts from global warming, although many analysts would argue that this knowledge is still inadequate for formulating specific policies. In addition, the political implications of the global warming issue have also changed. In the 1970s and early 1980s, the debate over global warming was, for the most part, confined to the scientific community. Today, it is at the top of political agendas around the world, and the stakes include not only the fate of the earth's environment but also the future of the world's economy. This debate illustrates how different values can cause scientists, policymakers, and environmentalists to interpret the same facts differently.

4.1 Adaptation Perspective

There are two themes within the adaptation perspective: first, society has a built-in capacity to adapt to changes in climate and environment;

*Discussions during the conference on Global Climate Change and International Security, in fact, reflected some misgivings among some conference participants about the usefulness of the adaptation/mitigation model.

second, the cost of preventing climate change may be so prohibitive that societies will chose adaptation over mitigation. While not mutually exclusive, these two themes often appear independent of each other in the literature. Proponents of the first theme tend to be agricultural scientists, engineers, resource economists, and geographers. Proponents of the second theme tend to be economists and policy analysts.

Adaptationists note that according to current scientific knowledge, even if the anthropogenic emissions of all greenhouse gases were eliminated today, it is likely that the earth would still experience some global warming as a result of the greenhouse gases that have already accumulated in the atmosphere (for example, see Houghton, Jenkins, and Ephraums [1990]). If this is indeed the case, then some adaptation to a greenhouse-warmed world will almost certainly occur in the coming decades, regardless of what takes place in the international political arena. Adapting to climate change, however, is something that societies are already accustomed to doing. For example, the adjustments and adaptations that farmers on the North American Great Plains have made to drought is well documented (for example, see Riebsame [1990]).

One of the principal conclusions of the NAS panel on adaptation is that there is already a well-established capacity in society for adapting both to a wide range of climate conditions and to climate change (NAS 1991a). The Academy panel emphasizes the range of climates that people already live in as evidence of humanity's capacity to cope with wide variations in climate. The panel writes that "by adjusting to extremes of the current climate, society has already made investments that would absorb some climate change" (NAS 1991a, p. 25). The panel further explains that "the capacity of humans to adapt is evident in the rapid technological, economic, and political changes of the past 90 years" (p. 2). Not all activities, however, will be able to adapt easily. The panel notes, for example, that water resources and natural ecosystems may be particularly vulnerable, and that poor countries will almost certainly have more difficulty adapting to climate change than rich countries. The panel's conclusion is, however, that for a gradual and moderate change in climate (the type of climate change on which it based its assessment), "impacts will be no more severe, and adapting to them will be no more difficult, than for the range of climates already on earth and no more difficult than for other changes humanity faces" (p. 146).

A basic premise underlying this finding is the capacity for societies to capitalize on technological and institutional innovations (NAS 1991a; Ausubel 1991). Technological innovations include advances in crop varieties or farm machinery, while institutional innovations involve changes in the underlying political, economic, and social structures. The emergence of land-grant universities in the United States would be an example of an institutional innovation. With respect to agriculture, Crosson and Rosenberg (1991, p. 19) explain how innovation in the face of climate change might take place:

> If farmers find that the alternatives available to them from among existing technologies and management practices are inadequate to compensate for the negative impacts of climate change, they may face the prospect of going out of farming, and perhaps leaving the region altogether. The prospect could stimulate agricultural research institutions and those charged with responsibility for agricultural policy to invest more research to develop a new set of technologies and practices better adapted to the changed climatic regime.

Adaptationists argue that societies will continue to adapt to climate change (either natural or anthropogenic) through technological and institutional innovation. Indeed, Ausubel (1991) notes that the trend has been toward a lessening of societal vulnerability to climate, and there is no reason to believe that this will not continue, even in the face of a greenhouse-induced climate change.

The adaptation perspective is also concerned with the potential long-term costs to society of pursuing meaningful mitigation strategies. Some economists, for example, do not see the motivation for either wealthy or poor countries to pursue costly and uncertain efforts at controlling CO_2 emissions (Lave 1988; Schelling 1991; Nordhaus 1991). With respect to the United States, Nordhaus estimates that only 3% of national income originates from sectors that are sensitive to the effects of climate

change, with perhaps another 10% of national income being modestly sensitive. Nordhaus concludes that the economic impact to the United States of climate change that was induced by doubling atmospheric CO_2 would be small — only about one-fourth of one percent of national income. Schelling (1991) agrees with this conclusion and suggests that the same is likely to be true for Japan and Western Europe as well. Schelling (p. 202) argues that "the countries that can afford to take serious measures to reduce carbon emissions may not be able to perceive any narrow national interest in doing so."

Given limited resources and competing interests, economists are also concerned with the opportunity costs associated with pursuing mitigation strategies, particularly in developing countries. This concern has been expressed by Nordhaus (1991, pp. 57-58):

> We might . . . ask whether a major commitment to slowing climate changes is a worthwhile investment for developing countries who are likely to be the regions most vulnerable to climate change. . . . To devote many billions of dollars of resources to slowing climate change at the expense of equivalent investments in education, energy conservation, or tangible capital in developing countries would probably hurt poor countries and give little return in high-income countries. . . . Faced with the dilemma of a low social discount rate and a high return on capital, the efficient policy would be to invest heavily in high-return capital now and then use the fruits of those investments to slow climate change in the future.

In essence, Nordhaus is arguing for a strategy of mitigation through adaptation.* The underlying assumption is that increased investment in development in poor countries could lead these countries, in the long run, to use energy more efficiently, produce less greenhouse gas emissions, and improve their capacity to adapt to changing climate conditions if that becomes necessary.

Adaptationists, whether they believe in the capacity of society to overcome problems or question the economic rationality of costly mitigation measures, do not dismiss the potential threat to society from climate change, although some may argue that it is being overstated. Most adaptationists acknowledge that given the existing uncertainties about the climate system, there is a risk of surprises and even catastrophic change. That risk, however, supports a policy of more research, monitoring, and alertness, not a policy of potentially costly and misguided efforts at mitigation.

4.2 Mitigation Perspective

In general terms, the mitigation perspective is based on the proposition that there are existing, cost-effective strategies available now for reducing emissions of CO_2 and other greenhouse gases. Indeed, this was the finding of the NAS synthesis panel, which indicated that "the United States could reduce its greenhouse gas emissions by between 10 and 40 percent of the 1990 level at very low cost. Some reductions may even be at a net savings if the proper policies are implemented" (NAS 1991b, p. 63). The conclusions of participants in the Second World Climate Conference were even more specific with respect to reductions in CO_2 emissions, stating that "technically feasible and cost-effective opportunities exist to reduce CO_2 emissions in all countries. Such opportunities for emissions reductions are sufficient to allow many industrialized countries to stabilize CO_2 emissions from the energy sector and to reduce these emissions by at least 20 percent by 2005" (World Meteorological Organization [WMO] 1990, p. 3).

The principal belief underpinning the mitigation perspective is that according to current scientific evidence, global warming represents a potentially serious threat and that efforts at reducing emissions

*The idea of mitigation through adaptation is suggested by Lave (1988), who argues that it will be the preferred approach by default because, given existing uncertainties and competing interests, the countries of the world will probably not agree to mitigation.

of greenhouse gases are a prudent insurance policy against this threat. Again, this was a principal conclusion of the NAS synthesis panel. "Given the considerable uncertainties in our knowledge of the relevant phenomena, greenhouse warming poses a potential threat sufficient to merit prompt responses. . . . Investment in mitigation measures acts as insurance protection against the great uncertainties and the possibility of dramatic surprises" (NAS 1991b, p. 67). Similarly, Lave (1988) also describes efforts at greenhouse gas mitigation as an insurance policy. He writes that "most people voluntarily purchase life insurance, even though the likelihood of dying in a particular year is very small. I suspect that people would be willing to pay a premium for a policy that would protect against an inhospitable Earth a century or so hence" (p. 464).

In addition, proponents of mitigation also tend to believe that many of the activities suggested as possible strategies for mitigating global climate change — improved energy efficiency, energy conservation, and fuel switching — make sense both environmentally and economically, regardless of climate change. (This is a view shared by many adaptationists as well.) Reductions in fossil fuel use and emissions could lead, for example, to a more competitive economy and less pollution. Stephen Schneider (1989) calls these activities "tie-in-strategies" and argues that even if climate change is overestimated, society will likely gain from these activities. Others have referred to such approaches as "win-win" or "no regrets" strategies, although definitions of what constitutes a win-win or no regrets approach may differ greatly.

There are three other premises that often underlie the mitigation perspective, although they are not shared by all proponents of this perspective. These include a concern that economic modeling approaches that suggest that the costs of reducing CO_2 emissions would be prohibitive are narrowly based and do not adequately account for long-term benefits; a fear that if global warming is not abated, the future of the planet is in jeopardy; and a belief that discussion of opportunities for adaptation is misplaced and even morally wrong. I will discuss each of these premises.

Miller, Mintzer, and Brown (1990, p. 70) have recently argued that "cost-benefit analyses as currently applied to the greenhouse problem do not provide sufficient or appropriate grounds for opposing immediate action to mitigate global climate change." They base their conclusion on several arguments. Most troubling in their view is that such approaches tend to emphasize short-term costs without fully assessing long-term benefits. This is because the short-term costs are much easier for economists to identify than the long-term benefits. Nevertheless, they argue that economic models cannot simply ignore "the fact that the full range of consequences of changing one of the earth's major physical systems cannot be foreseen" (p. 71). Miller, Mintzer, and Brown are also concerned that economic modeling approaches (particularly cost-benefit analysis) do not adequately address the temporal and spatial distribution of global warming's potential consequences, particularly with respect to the fact that developing countries may face a much greater burden from global warming than developed countries. Finally, they argue that because economic models tend to emphasize short-term costs, these models do not fully appreciate the capacity for technological innovation to reduce the costs of CO_2 mitigation in the long run.

Much of the support for strong efforts at mitigation is underpinned by a concern that the risks of unabated global warming are much greater than the costs associated with controlling greenhouse gas emissions. The formal statement from the 1988 Conference on the Changing Atmosphere, which called for a 20% reduction in global CO_2 emissions by 2005, concluded that global warming as well as other threats to the global atmosphere threatened international security, the world's economy, and the Earth's natural environment (WMO 1988).* Indeed, this threat was ranked second only to global nuclear war. The analogy between global warming and nuclear war has been

*The conference, held in Toronto, was sponsored by the WMO and United Nations Environment Programme and organized by the government of Canada. More than 300 scientists and policymakers from 46 countries attended.

made more emphatically by others to underscore the argument that global climate change threatens the future of modern civilization (for example, see Dotto [1988]). One need not turn to predictions of doom, however, to find expressions of real concern over the potential impacts of global climate change. For example, the Working Group II report of the Intergovernmental Panel on Climate Change (IPCC) outlined a range of damaging impacts that climate change might have on global agriculture and forestry, natural ecosystems, water resources, human settlements, and the world's oceans and coastal zones (IPCC 1990).

Finally, some advocates of the mitigation perspective have questioned the reasoning that underlies the adaptation perspective. The criticisms levied at the NAS adaptation panel are a case in point. Jessica Mathews, for example, writes in the NAS synthesis report that the adaption perspective is based on a misguided assumption "that human economic activities are largely divorced from nature and that modern technology effectively buffers us [society] from climate" (footnote to the adaption chapter in NAS [1991], p. 45). Jane Lubchenco, a member of the NAS adaptation panel, objected to the panel's conclusion that adaptation to climate change in the United States may be relatively easy, calling such a conclusion "complacent." Rather, Lubchenco argues that the findings of the adaption panel should support a policy of mitigation. Elsewhere, Mathews (1987) has argued that adaptation may be as costly and as politically difficult to achieve as mitigation, that adaptation may widen the gap between rich countries that have the capacity to adapt and poor countries that do not, and that mitigation will be necessary eventually, regardless of prospects for adaptation. O'Riordan and Rayner (1991) argue that for some proponents of mitigation (preventivists, to use their label), it is morally and ethically wrong to endorse a strategy that would allow humans to distort natural processes when it is in the power of society to prevent this from happening.

4.3 Adaptation or Mitigation: A Matter of Emphasis

It would be difficult to identify any individual, organization, or nation that precisely fits either the adaptation or mitigation approach as I have outlined them above. In reality, there are few proponents of either perspective that argue for one position at the exclusion of the other. In other words, adaptationists recognize the need for mitigation, and mitigationists accept the need for some adaptation. For example, the NAS synthesis panel recommends actions that will lead both to mitigating and to adapting to climate change (NAS 1991b); Mathews (1987) notes that even an aggressive strategy to prevent climate change will not eliminate the need for some adaptation; and Crosson and Rosenberg (1991) explain that while adaptation and mitigation strategies can be seen as substitutes, they are also complementary. The difference in these perspectives is one of emphasis, guided in part by how proponents of one perspective or the other see the uncertainties and risks associated with global warming, how they approach the question of equity in determining how to respond to the problem, and how they view the role of technology.

Both adaptationists and mitigationists recognize that there is considerable uncertainty about the eventual magnitude of the global warming problem, its potential impacts, and the costs associated with taking action to either mitigate or adapt to climate change. They differ, however, on how they approach the risks associated with this uncertainty. Adaptationists, for example, tend to believe that this uncertainty supports a pragmatic approach that does not lock society into costly and imprudent policies that, in the future, could prove misguided and uninformed. In light of the uncertainty, adaptationists place emphasis on the risks (or opportunity costs) associated with taking action to respond to climate change. They point to the potential loss in economic growth, lost opportunities for development among poor countries, and the misallocation of limited resources to prevent an uncertain event from taking place. Mitigationists, on the other hand, see the uncertainty as one of the primary factors supporting immediate action to forestall the problem. This uncertainty underscores the prospect of potentially catastrophic changes in the world's climate that could possibly be avoided by taking action today. Thus mitigationists emphasize the risks associated with not taking action to address the global warming problem: the loss of economic growth because of climate change, the loss

of natural ecosystems, and the unfair burden that the impacts of climate change would place on developing countries.

To some degree, adaptationists place more emphasis on intragenerational equity, while mitigationists place greater emphasis on intergenerational equity, although the adaptationists do not dismiss the issue of intergenerational equity. Proponents of adaptation are concerned with costs imposed on both developed and developing economies by pursuing potentially misguided efforts and controlling CO_2 emissions. Resources spent on controlling emissions in the present may be better spent on improving the capacity of both developed and developing countries to respond to climate change in the future. Thus, with respect to developing countries, the best approach to climate change may be improving their prospects for long-term economic development rather than forcing them to control emissions of CO_2. Mitigationists, while not ignoring intragenerational equity, are clearly concerned with the fate of future generations and the Earth itself. Thus, imposing costs on society in the present is justified as necessary in order to guarantee a liveable planet for future generations. Furthermore, mitigationists see many strategies for controlling greenhouse gas emissions as measures that are justified in the present for other economic and environmental reasons. They therefore question the short-term costs of these measures.

Both adaptationists and mitigationists see an important role for technology as part of the solution to the global warming problem. Adaptationists are, perhaps, more optimistic about the prospects of technological solutions than are mitigationists, but mitigationists do not discount the role that technology will play in developing mitigation strategies. Most adaptationists believe that with the exception of some catastrophic change in climate (which they see as a remote risk), the outlook for society to adapt to future climate change through technological innovation is positive. Indeed, humanity has demonstrated a remarkable capacity to adapt to all sorts of changes in the past. Mitigationists question this rather optimistic assessment. They believe that the timing and scale of the changes that society is likely to face from climate change will be unprecedented in human history. Furthermore, they question the overall success to which society has been able to buffer itself against changes in climate and the environment in the past. Nevertheless, mitigationists do tend to believe that technology will reduce the costs of mitigation activities in the long run.

O'Riordan and Rayner (1991) note that proponents of adaptation and mitigation do not disagree over the facts of global warming, rather they differ on what those facts mean. Both adaptationists and mitigationists are concerned with the implications of global warming for present and future generations and for the Earth itself. Adaptationists, however, are concerned with how responding to global warming might affect society today, while mitigationists are concerned with what failing to respond to global warming will mean for future generations. Adaptationists tend to see the global warming problem as manageable, whereas mitigationists tend to see the global warming problem as preventable. These differences demonstrate how making policy decisions about complex scientific and technical issues are influenced as much by values as they are by the facts of the problem. It is likely that during the next decade, ongoing efforts to better understand how global warming might affect climate, and thus affect economies and natural ecosystems around the world, will greatly add to the knowledge base on which to design policies for responding to global warming. It is unlikely, however, that the policy choices will somehow become self evident simply because there is more information. The choice of what, if anything, to do about global warming will ultimately rest as much on values as it will on facts.

5 THE PERSPECTIVE OF DEVELOPING COUNTRIES

It is worth looking briefly at how developing countries view the global warming problem for two reasons. First, the success of any international effort to address the global warming problem will require the support of developing countries. Developing countries presently account for approximately 28% of global CO_2 emissions from the burning of fossil fuels (Ogawa 1991). If deforestation is included — and estimates of its contribution vary considerably — developing countries could account for more than 40% of total global carbon emissions (estimate derived from data

presented in Ogawa [1991] and Darmstadter [1991]). Equally important is the fact that the rate of increase in carbon emissions is much greater in the developing countries than in the developed countries. Because of the rapid rate of population growth and industrialization, developing countries will provide the bulk of new carbon emissions in the coming decades.

Second, and directly related to the theme of this paper, many developing countries are not proponents of either adaptation or mitigation. Many developing countries fear that they are trapped by the global warming issue. They have neither the capacity to mitigate CO_2 emissions nor the flexibility to adapt easily to changing climate conditions, yet they are likely to be among the most vulnerable countries to the impacts of climate change (see Jodha [1989]). Developing countries are also concerned that measures to control global CO_2 emissions will have a negative impact on their efforts to develop. Most developing countries will find it very difficult, if not impossible, to sacrifice economic development in order to curb global CO_2 emissions. It is impossible for developing countries to separate the global warming issue from other issues of economic, political, and social development. These include problems such as poverty, environmental degradation, political reform, and foreign debt.

Furthermore, there is an element of distrust and disbelief on the part of developing countries toward the developed countries. Many developing countries believe that their contribution to the global warming problem is being overstated and are suspicious of the international attention focused on deforestation and environmental degradation in the developing world. Some may even believe that the developed countries are cynically using the global warming issue to limit their development. Goldemberg and Durham (1990) explain that many developing countries "feel they are being transformed into scapegoats in a problem for which developed countries are equally, if not more, responsible." Developing countries also feel that since it is the developed countries that created the problem, the developed countries must act first to resolve it.

The world's developing countries do not see the question of responding to global climate change as a choice between adaptation and mitigation; the issue for them is rather how to foster development (with or without climate change). Developing countries do not dismiss global warming; on the contrary, many take the problem very seriously, and some are very active in current efforts at negotiating a global climate change agreement. Developing countries, however, are quick to point out that the choice between adaptation and mitigation is a luxury for developed countries.

6 CONCLUSIONS

It would be unfair to say that the generalized descriptions of adaptation and mitigation that I have provided in this paper capture the range of views on global warming. Rather they merely represent two contrasting views along what could be described as a continuum. While the adaptation and mitigation perspectives lie on different sides of this continuum, they are not polar opposites. The extremes of this continuum might best be described as the naysayers and the doomsayers. It is likely that most perspectives about global warming (many of which are a mix of adaptation and mitigation) lie somewhere along this continuum, between what I have described as the adaptation and the mitigation approaches. Furthermore, not all perspectives on global warming can be neatly placed along this continuum. Developing countries, for example, tend not to see the global warming problem as a choice between adaptation and mitigation. What differentiates perspectives along this continuum (and off it, as well) is not whether each acknowledges the facts of the global warming problem (except, perhaps, for the naysayers) but rather how each interprets those facts. Differences between the adaptation and mitigation perspectives reflect differences in the values that underpin the current policy debate over how society should respond to the global warming problem. These values will guide decision making about global warming as much as scientific and technical information will.

If perspectives toward the global warming problem lie along a continuum in which components of both adaptation and mitigation mix, then focusing on adaptation and mitigation separately may not be the ideal way to conceptualize the problem. If this is the case, the challenge is to devise a new way of conceptualizing the global

warming problem that more fully captures the range of perspectives toward global warming and how these perspectives might interact. However, simply recasting the problem is not likely to resolve the polarizations that exist between two seemingly contrasting views. This polarization is based more on values that it is on the technical or conceptual merits of various policy strategies. Nevertheless, improving our ability to conceptualize and discuss various perspectives and policy strategies could be a useful step toward addressing the issue of values.

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Comment 1 on Workshop in Adaptation and Mitigation Strategies

Why Greenhouse Warming Stays a Hot Topic

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The rapidity with which greenhouse warming burst onto the national and international political agendas is surprising. So too is the fact that it has remained of central interest despite the lack of understanding of the phenomenon exhibited by the general public. Even with lackluster public response, politicians and governments around the world are advocating costly actions designed to counter greenhouse warming.

A certain amount of attention and concern is necessary to establish and sustain the attention of government decision makers. There are several attributes of the greenhouse warming problem that generated enough attention and concern to propel it so quickly onto the international agenda and keep it in the forefront for action.

First, it is one of a new set of global problems that is intimately connected to scientific analysis. A great deal of data has been collected and analyzed since the early 1960s. Scientists have been carefully laying the groundwork for decades and have a solid foundation for addressing the problem. They were ready in 1988 to capitalize on the North American drought as a vehicle to bring the longer-term problem of greenhouse warming to more widespread attention. In short, there is a large body of knowledge about the problem and possible remediative actions.

Second, greenhouse warming is a vivid problem with considerable psychological impact. Following close on the heels of the antarctic ozone hole and more widespread depletion of stratospheric ozone, it also demonstrates human capacity to directly alter the physical planet on which we depend for survival. Greenhouse warming is symbolic of some of our deepest fears.

The third attribute is the way worldwide scientific activity makes up for periodic reductions in the importance accorded greenhouse warming in any particular country. Scientists and other experts from all parts of the world are working on the causes and consequences of greenhouse warming. For example, the Intergovernmental Panel on Climate Change involved about 600 scientists from all parts of the world. This unusually large group of geographically dispersed experts means that the level of attention in a particular country can drop and international momentum still be maintained. For example, activity may develop first in the United States, which stimulates work in Europe that continues after interest wanes in this country. Later, that European activity may rekindle attention here. The extent of international activity both smooths over lulls in any particular location and increases the number of overall actions that may be undertaken.

Professional reinforcement provides the fourth element that helps sustain attention to greenhouse warming. The problem would never have been recognized were it not for scientists. And it is scientists and other experts who provide the force underlying the present concern about greenhouse warming. Whether they work in universities, industry, or government, they derive much of their motivation from their professional colleagues. Once started, a groundswell of concern swept through professional channels and provided the basis for government attention to greenhouse warming. The political base for action on greenhouse warming is a scientific constituency rather than the general population.

The fifth element also derives from the level of scientific attention given the topic. The sheer

magnitude of research and the frequency with which new results are reported keeps attention on greenhouse warming. Hardly a week goes by without a scientific meeting somewhere on some aspect of greenhouse warming. With so much activity, there is bound to be a fairly regular flow of new ideas and findings. These, in turn, stimulate even more analysis.

Another aspect of the global appeal of greenhouse warming is the fact that the greenhouse problem involves all human activities in all parts the world. People everywhere will feel the consequences. More importantly, actions of each individual are relevant. Every human can make a contribution, however small, to slowing the onset of greenhouse warming.

The final element is the fact that many people would like to see some of the actions that would slow greenhouse warming taken for other reasons. Greenhouse warming is thus an issue with natural political coalitions. This enhances the appeal of greenhouse warming to many individuals and organizations.

All of these elements combine to make greenhouse warming a unique issue. In essence, greenhouse warming is a political issue-based on a constituency of scientists and experts. Because it crosses political boundaries, however, it has achieved a level of interest beyond other scientific and technical problems. And because of its natural base among these experts, it rapidly achieved prominence once access to the political agenda was opened. And the intrinsically global character of the problem has provided momentum to keep it there.

The strength of the influence of the scientific and expert communities on greenhouse warming policy may lead to different policy positions in various countries. For example, industrial, scientific, and other elites generally are more directly involved in determining national policy in European countries than in the United States. The fact that European countries currently advocate carbon taxes, emissions caps, and other policy responses to greenhouse warming much more strongly than the United States is consistent with a more direct policy influence of scientists in those countries who are deeply concerned about greenhouse warming.

Comment 2 on Workshop in Adaptation and Mitigation Strategies

Mitigation and Adaptation

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Discussions of greenhouse warming policy often confuse the meaning of the terms "mitigation" and "adaptation." This confusion occurs partly because these terms were developed to describe physical processes but have subsequently been used inappropriately as labels for policy strategies. It also derives in part from misunderstanding of the basic character of the two categories of intervention.

The National Academy of Sciences report *Policy Implications of Greenhouse Warming* develops quite specific definitions. The NAS report refers to mitigation as actions that alter the rate of change in the radiative balance of the planet. It describes adaptation as actions that assist human or natural systems adjust to changed climatic conditions. In other words, mitigation and adaptation each describe actions that bring into play chains of cause and effect that lead to quite different physical consequences.

An important difference between mitigation and adaptation is the time at which the benefits of these physical processes become manifest. The benefits of mitigation actions begin comparatively soon after they are taken, whereas the benefits of adaptation emerge only after climatic conditions change.

Mitigation and adaptation are sometimes confused as categories, however, because individual interventions can lead to both types of consequences. For example, planting trees would both offset emissions of carbon dioxide — qualifying as mitigation — and contribute to an overall biosphere better able to cope with increased atmospheric concentrations of greenhouse gases — also qualifying as adaptation. Similarly, actions that improve energy conservation and efficiency both reduce greenhouse gas emissions and alter long-term demand for energy.

Thus the terms "mitigation" and "adaptation" are best thought of as descriptions of specific physical phenomena that derive from given actions. It is misleading to refer to mitigation strategies or adaptation strategies because most practical action programs contribute to both types of consequences.

Section IV

Workshop in Political Institutions

Institutional Analysis and Global Climate Change: Design Principles for Robust International Regimes*

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1 THE ROAD TO RIO

Scientific evidence suggests that human activities have a significant effect on the world's climate. Political pressures are growing to establish political institutions at the global level that would help manage the social and economic consequences of climate change. Disagreements remain about the magnitude of these effects, as well as the regional distribution of the detrimental consequences of climate change. In this paper we do not wish to enter into the complexities of these technical debates. Instead, we wish to challenge a seemingly widespread consensus about the nature of the political response appropriate to this global dilemma. Specifically, we question the extent to which the "answer" can be said to reside primarily in the establishment of the new global institutions likely to emerge from the first "Earth Summit" — the United Nations (UN) Conference on Environment and Development — scheduled for June of 1992 in Rio de Janeiro.

In a single paragraph in a major report prepared for this process (MacNeill et al. 1991, p. 110), the ambitious tasks awaiting the heads of state who will attend this meeting are summarized as follows:

- "Adopt an 'Earth Charter' setting out broad directions for development and embodying new principles to govern relationships between governments, peoples, and the planet in the twenty-first century."

- "Adopt an agenda for action — 'Agenda 21' . . . [that] will set out an internationally agreed-upon work program, including targets of national and international performance for each of the critical issues . . . . The Agenda will include the estimated costs of achieving those targets, and ways and means to provide the necessary financial resources. It will also contain an operational commitment to transfer the needed technologies to developing countries. Most importantly, it will designate the national and international agencies that will bear responsibility for the first phase of implementation."

 We appreciate the comments made by David Feeny, Roy Gardner, Barry Hughes, Leo Hurwicz, Richard Kosobud, Vincent Ostrom, Karen Rasler, Vern Ruttan, Phil Schrodt, and Paul Turner on an initial draft of this paper. Financial support of the National Science Foundation (Grant SES-4843901) and the Workshop in Political Theory and Policy Analysis is gratefully acknowledged by Ostrom and McGinnis, respectively.

- "Review the negotiations underway on several conventions, in particular those to limit global warming, halt net deforestation, and preserve the planet's biodiversity."

- "Initiate significant reform of our international institutions to enable nations to manage global interdependence and to implement Agenda 21 as well as the conventions."

In MacNeill et al. (1991), the Secretary General for this "summit," Maurice Strong, strongly applauds these "far-reaching reforms of the international system" and argues that the "case made for broadening the concept of national security to include [environmental] threats is compelling" (p. xi). Strong also suggests that the current UN Trusteeship Council should be "transformed into a forum in which the nations of the world would exercise their 'trusteeship' for the integrity of the planet as a whole, including the global commons" (p. 124). MacNeill and his co-authors extol this idea of a new "Earth Council" as "another one of these innovative formulations [that] reflects the quality of imagination and the level of ambition that needs to be applied in developing new forms of governance to guide the planet through the next turbulent decades" (p. 124). The idea of an Earth Council is taking form in a proposal for a World Environment and Development Forum (WEDF) that would meet annually to coordinate the implementation of the protocols adopted as part of this process (p. 126, Figure 5.2).

It is difficult to know whether the passing days lead toward a process that will enable individuals to better understand and confront the many multi-tier, complex problems that are called environmental threats or whether the process may itself threaten future capabilities to cope effectively with these problems.[1] If most of the efforts are directed toward reaching agreement on protocols that require drastic changes in the emissions of specific chemicals and the creation of new institutional arrangements to enforce these measures, then the "cure" could be worse than the "illness."[2] The process may be one of the many useful steps if most of the efforts are directed toward (1) gaining better understandings of complex, nested problems and (2) encouraging small-, medium-, and larger-scale institutional arrangements to adopt innovative measures to cope more effectively with local, regional, and global environments.

The current emphasis on global solutions based on international conventions meant to establish global institutions to manage environmental change may be fundamentally misguided. Comprehensive negotiation sessions can too easily degenerate into public theater. The resulting treaties may amount to nothing more than words on paper. The policies of national governments, who are called upon to take the initiative to prevent deforestation and desertification, have, in many instances, been a major source of these problems. Why should officials of national governments, who have obtained a major part of their income from large-scale agro-forestry concessions, suddenly turn around and halt these lucrative opportunities? Further, even if protocols move from paper tigers to regulations with teeth, no guarantee exists that the emissions being reduced are the correct ones in a particular environment.

Global climate change is, by definition, a long-term process. Any effective political response must be based on a similarly long-range perspective. The current state of scientific knowledge strongly suggests that changes already underway will continue to affect the world's climate for many decades into the future. The political, economic, and social consequences of these climatic changes remain uncertain, but institutional innovations can be made now that will facilitate our ability to adjust to future disruptions. Any such institutional arrangement, however, must be long-lasting and robust with respect to uncertain and dramatic changes. Few political institutions satisfy these demanding conditions.

Certain forms of global management might even intensify problems. This could be expected if this process undermines existing institutions that enable individuals to govern and manage many local and regional commons or cause these groups to lose their capability for innovation and discovery. This is certainly what has happened in many developing countries where control over local resources was shifted from indigenous populations to central governments (Feeny 1988a; Arnold and Campbell 1986; Messerschmidt 1986; Gadgil and Iyer 1989; Thomson 1977). There is a lot more to learn about

complexly nested environments as well as complexly nested institutions before presuming that global regulation is the way to improve global conditions. Many proposed policy changes involve issues that could severely exacerbate conflict between the developed and developing parts of the world and even among neighbors within a region.[3] Thus, regardless of the truth or falsity of current predictions, issues that can affect future levels of international cooperation and/or conflict are actively being discussed in many substantive arenas.

We presume that major efforts will be made to alter institutions so as to respond to the perceived threat of global warming. We hope that these changes would be based on the best evolving scientific knowledge about factors that affect global climate patterns. We also hope that adopted changes would be based on the best evolving scientific knowledge about the factors that affect human behavior as this behavior in turn affects global climate. Policy changes based on an inadequate understanding of how individuals respond to institutional change can be just as damaging to our common future as changes based on an inadequate understanding of the general circulation models.

This paper should be viewed as our effort to review recent literature on international regimes, institutional analysis, and on international security and arrive at preliminary understandings of lessons that apply to designing appropriate institutional responses to the dilemmas of global climate change. We begin by briefly surveying the broad range of substantive areas studied by researchers on international regimes. After summarizing the basic principles and implications of institutional analyses of common pool resource regimes, with a particular emphasis on the "design principles" that characterize robust common-pool resource (CPR) regimes, we justify our extension of the results of research on cooperation in small-scale CPR situations to problems of global climatic change. We argue that a major difference is the diversity of actors involved in the global arena and the need to carefully "nest" institutional arrangements at the local, regional, and global levels. We offer a rough typology of the collective actors typically engaged in monitoring and sanctioning of international regimes. The diversity of possible combinations of actor types suggests some cautionary notes about the contribution formal models can make to our collective understanding of institutional responses to global climatic change. We conclude with a brief examination of the lessons for broader issues of global cooperations that can be derived from prior efforts at arms control.

2 AN OVERVIEW OF INTERNATIONAL REGIMES

Analysis of international cooperation has typically examined the "international regimes" said to exist in certain substantive areas of international interactions. In this research tradition, regimes are defined as follows:

> sets of implicit or explicit principles, norms, rules, and decision-making procedures around which actor expectations converge in a given area of international relations. Principles are beliefs of fact, causation, and rectitude. Norms are standards of behavior defined in terms of rights and obligations. Rules are specific prescriptions or proscriptions for action. Decision-making procedures are prevailing practices for making and implementing collective choice (Krasner 1982, p. 186).

Despite consensus on this definition, scholars do not always have the same thing in mind when discussing regimes. The term is used to cover broad areas such as the GATT system of international trade as well as limited areas such as international trade in crafts made from illegally obtained elephant ivory. Some authors (e.g., Porter and Brown 1991, p. 20) require that a regime be based on principles of international law established by some treaty or convention, while others focus on the regularities of patterns of relationships rather than formal agreements.

Haggard and Simmons (1987) argue that regimes differ by strength, organizational form, scope, and allocational mode, but no systematic inventory of international regimes exists. Jacobson (1984) provides a systematic list of international governmental and nongovernmental organizations, but no necessary correspondence exists between the establishment of a formal international organization and the existence of an international regime.

Classic works in the international political economy literature focus on cases selected to demonstrate the points emphasized in that analysis. For example, Keohane and Nye (1989) contrast global regimes in oceans and money, as well as bilateral U.S. relations with Canada and Australia; Keohane (1980) compares the "strength" of regimes in the areas of oil, money, and trade; Krasner (1985) examines different patterns of conflict between North and South over regimes concerning civil aviation, multinational corporations, oceans, shipping, Antarctica, and official capital transfers. Proposals for new regimes often draw on lessons from earlier regimes, as in the Sebenius (1991) evaluation of the prospects of a regime on global warming in light of the Ozone Convention and the Law of the Sea Treaty. Of course, many other studies offer detailed examinations of a single regime (see Aggarwal 1985; Benedick 1991; Sebenius 1984).

Some indication of the variety of arenas of collective action covered by the term "regime" is warranted. Textbooks on international political economy (e.g., Spero 1990; Blake and Walters 1987) typically examine regimes in the following broad areas:

- International trade (commodities, agricultural products, manufactured goods, and services),
- Money (currency exchanges and financial transactions),
- Development aid,
- Energy (especially oil), and
- Multinational corporations (including technology transfer issues).

In each of the first four areas, discussion of a specific international organization dominates analysis, namely, GATT, IMF, the World Bank, and OPEC, respectively. Many analyses focus on differing patterns within a given regime, such as contrasts between international trade in agricultural products and high technology. Also, much attention has been given to abortive efforts to establish a New International Economic Order (NIEO) that would have provided an even more comprehensive framework for the international economy.

Introductory world politics textbooks (e.g., Hughes 1991, pp. 281-290) typically discuss a variety of arrangements concerning arms control, centered around the following major arms control treaties (and associated acronyms):

- Global regimes
  - Partial Test Ban Treaty (PTB) and Threshold Test Ban Treaty
  - Nuclear Non-Proliferation Treaty (NPT)
- U.S.-Soviet treaties
  - Strategic Arms Limitation Treaty (SALT) I and II and ABM Treaty
  - Strategic Arms Reduction Treaty (START)
  - Intermediate Nuclear Forces Treaty (INF)
  - Hotline Agreement and other Confidence-Building Measures (CBM)
- Regional arrangements
  - Treaty of Tlatelolco (Latin America)
  - Conventional Forces in Europe Treaty (CFE)

Harlan Cleveland (1990/91, pp. 11-13) focuses on the following 12 examples of successful international cooperation (using his terms):

- Weather forecasting,
- Eradication of infectious diseases,
- International civil aviation,
- Allocation of the frequency spectrum,
- Globalization of information flows,
- Agricultural research and development,
- UN peacekeeping and peacemaking,
- Cooperation in outer space,
- Law of the Sea Treaty,
- UN High Commissioner for Refugees (UNHCR),

- Ozone Treaty, and
- Antarctic Treaty.

Cleveland explicitly excludes arms control arrangements. He also briefly mentions regional arrangements — like the European Community, NATO, and control of Mediterranean pollution (P. Haas 1989) — and global efforts of the World Bank and UNICEF.

Young (1989, p. 351) offers a relatively systematic listing of international interactions on natural resources and the environment, including some areas lacking any effective means of international cooperation:

- Wildlife (whales, northern fur seals, polar bears);
- Marine life;
- Wild fauna and flora (trade in endangered species);
- Deep sea-bed minerals;
- Electromagnetic spectrum (broadcast frequencies, orbital slots);
- Regional pollution;
- Radioactive fallout;
- Stratospheric ozone;
- Polar regions:
  - Antarctica,
  - The Arctic (no regime);
- Acid precipitation:
  - Europe,
  - Other areas (no regime);
- Biological diversity (no regime); and
- Global climate change (greenhouse effect) (no regime).

These lists already overlap to some extent, but a few important areas must be added, including examples of some unsavory business indeed:

- Human rights,
- International law of war,
- War crimes,
- Terrorism,
- International trade in illegal drugs,
- International arms trade (including ballistic missiles), and
- International trade in toxic waste.

Many other lists could be cited, but these examples should suffice to demonstrate the limitations of relying on classification schemes based on the substantive issues involved. We propose to use the theoretical framework of institutional analysis to help suggest ways of organizing and extending work on international regimes.

Debates on institutional responses to global change are dominated by the time-worn mind-sets of The State and The Market. On the one side, economists (and other analysts) sing the praises of market processes and advocate the definition of individual property rights as the standard solution to most problems of resource use. On the other side, advocates press for a single global standard of behavior developed in an international convention, the global stand-in for a centralized state. After expressing concern for the lack of formalized rules or institutions in a particular issue area, this second group of advocates typically calls for establishment of a new international regime, complete with a formal organization with either an I (for International), G (for Global) or W (for World) in its acronym. Both markets and states are appropriate solutions for some circumstances. However, these two types of institutions do not, by any means, exhaust the range of possibilities.

3 AN OVERVIEW OF INSTITUTIONAL ANALYSIS

Analysis and evaluation of alternatives to state and market has been the focus of the Institutional Analysis and Development (IAD) framework that

has evolved out of several decades of work by colleagues associated with the Workshop in Political Theory and Policy Analysis (Kiser and Ostrom 1982; E. Ostrom 1986; Oakerson 1986; Ostrom, Feeny, and Picht 1988; V. Ostrom 1991a,b). In particular, we will draw on research on institutional arrangements in the management of common pool resources, usually in fairly small-scale settings.[4] A major focus of this work has been on micro-level, self-organizing, and self-enforcing capabilities. More difficult to understand and essential for the question at hand is how macro-political orders enhance or detract from the capabilities of those directly involved in problem solving to create new institutions or reform prior institutions to cope more effectively with their own problems. Work on multi-level institutional problems is underway but is far more difficult than work at a single level of analysis.

This work is relevant to the analysis of global change for two fundamental reasons. First, the substantive natures of many local and global problems are similar. Second, despite the vast differences in scale involved in local and global commons, the configurations of the situations at these levels are fundamentally similar. Thus, the theoretical principles underlying successful cooperation are also similar. Third, any global regime that undermines the requisites for successful cooperation at the local level is unlikely to be sustainable in the long run.

The IAD framework helps identify the broad components and relationships among those components that are considered important for work when doing institutional analysis. To undertake analysis of a problem — such as how changes in institutions related to global warming may affect patterns of international cooperation and conflict — requires that the analyst draw on or develop theories that spell out more fully the specific variables involved in an analysis and the nature of the mechanisms that relate variables to one another. For well specified problems, the analyst may be able to develop formal models that generate quite specific predictions within the range of the model's applicability. (We evaluate the prospects for formal models of international cooperation on global climate change in a subsequent section.)

To engage in an institutional analysis, one first has to understand the structure of incentives facing actors in a situation, what choices are most likely to be made, and how these choices tend to produce particular patterns of outcomes. In other words, the first question is: What type of situation is this? To do this, one identifies a focal, conceptual unit, called an *action arena*, that is utilized to identify the structure of a problem and thus explain relevant behavior and outcomes. Action arenas include an *action situation* and the *types of actors* in that situation. An action situation is composed of participants holding diverse positions who make decisions from among the alternative choices made available to them in light of the information they possess about the structure of the situation, the way their actions link to outcomes, and the benefits and costs they will receive. To make a theoretical prediction about the type of choices that various types of actors will make in a situation, one needs to know: (1) the resources that an actor brings to a situation; (2) the valuation that actors assign to states of the world and to actions; (3) the way actors acquire, process, retain, and use knowledge contingencies and information; and (4) the processes actors use for selecting particular courses of action.

Formal, game-theoretical models can be constructed to analyze the expected behavior of participants. Many situations can be analyzed using these components, including competitive markets, principal-agent relationships, legislative and committee decisions, the harvesting of resource units from common-pool resources, and the temptation to steal resource units from a common-pool resource. For highly simplified and stylized versions of these "universal" situations, it is even possible to establish the configuration of institutional rules that yield optimal results (Hurwicz 1973). When the parameters of the models capture most of the important parameters involved in field settings, these models can be used to explain the types of outcomes obtained in the field and the likely response of individuals to changes in the incentives that the individuals face (see, for example, Plott and Meyer 1975; Shepsle 1979a,b, 1989). Applying models to field settings whose structures differ in crucial aspects from the models results in mis-specified analysis, just as it

does when a physical model is inappropriately applied.

To address whether the models used to analyze policy-relevant situations (e.g., decisions related to harvesting forests or using energy sources) are appropriate requires that analysts dig deeper than the initial givens of a model, into the underlying structure of a situation that generates these givens. Here the focus of an IAD approach is on three broad classes of underlying factors: (1) relevant aspects of the physical, biological, and technological world; (2) relevant aspects of the broad cultural understanding and valuation of that world; and (3) the nested configurations of rules that affect the strategies that actors may, must not, or must take in the situation of interest. The key problem in designing effective institutions to control adverse effects on the environment is matching the specific set of rules that are to be used with the attributes and dynamics of the physical, biological, and technological world of relevance in a particular cultural milieu. In order to simplify our analysis, we will not address the potentially important role of cultural values on behavior toward an environment for our initial analysis and will focus first on the problem of matching rule configurations to complex physical worlds.

4 MATCHING RULES TO PHYSICAL WORLDS

4.1 The World of Private Goods

When individuals engage in transactions related to private goods, matching rules to physical worlds is relatively simple. Goods are considered to be "private goods" when:

- All aspects of the goods and services that individuals produce, distribute, buy, and sell can be excluded from actors who would like to use them (or, alternatively, others can avoid having externalities of a process dumped on them) and
- Any good consumed by one individual is unavailable for consumption by others (Ostrom and Ostrom 1977).

Rule configurations that generate an open, competitive market are optimally efficient when used in relation to private goods (de Alessi 1988). Unfortunately, only a limited number of the goods and services used by individuals possess the attributes of private goods. As soon as the goods involved do not have these nice characteristics, it can be shown that various aspects of "market failure" occur, and different types of institutions other than those of an open, competitive market may be needed.

4.2 The World of Common-Pool Resources

Common-pool resources (CPRs) do not possess both of the nice characteristics of private goods. CPRs are defined to be natural or manmade resources in which (1) exclusion is nontrivial (but not necessarily impossible) and (2) yield is subtractable (Ostrom, Gardner, and Walker forthcoming). The global commons definitely share this first attribute.[5] If adverse effects to the stratospheric ozone or to the factors that could lead to severe changes in weather patterns were to be averted, it would be difficult — if not impossible — to *exclude* anyone who had not contributed to this effort. CPRs share the attribute of nonexclusion with another broad class of problems that are referred to as public goods (Ostrom and Ostrom 1977).

The second attribute of CPRs that is shared with private goods but not with public goods is the subtractability of the yield (Samuelson 1954). Another term used to describe this attribute is rivalness of consumption. Let us first illustrate this attribute with examples drawn from research on groundwater basins, irrigation systems, fisheries, forests, grazing lands, computer systems, bridges, and other natural or manmade resources that generate a yield. All of these are resources that make available a flow of resource units over time. Examples of the resource and its resource units include: (1) a groundwater basin and acre-feet of water pumped, (2) a fishing grounds and tons of fish harvested, and (3) a computer facility and processing time. The water withdrawn by a groundwater pumper is not available to anyone else. Nor are the fish caught by one boat or the central processing units used by one faculty member. The facilities or resources producing these units are, however, jointly used by multiple individuals.

When a few users first use renewable CPRs, what one person uses does not appear to subtract from what is available. Initially, the abundance of units relative to demand masks the subtractability. In some resources, such as fisheries, initial withdrawals may actually increase the amount jointly available. Fish compete for food resources, and harvesting some fish allows more fish to survive. If there are no rules in place to limit the use of a CPR, and if the resource unit that can be withdrawn is valuable, then the structure of the situation leads users to invest more and more in harvesting activities. After a threshold has been reached, each individual's investment and harvesting activities adversely affect everyone else using the same resource.

Without rules to allocate resource units, users competing with one another for ever scarcer units may engage in destructive races against one another, and their actions may destroy the very resource that is generating valuable yield for them. Garrett Hardin captured a key aspect of the problem of an open-access CPR in his now classic use of the term "tragedy of the commons."[6] Aristotle recognized a similar dilemma when he wrote: For that which is common to the greatest number has the least care bestowed upon it (*Politics,* Book II, Sec. 3). What Hardin did not capture was the capacity of the individuals involved in such tragedies to have sufficient insight into the problems that they faced to restructure their own rules and change the incentives they faced.

Where a resource produces a single, valuable resource-unit with a high level of predictability known to all participants (or where storage facilities, such as dams, enhance predictability), it is possible to devise marketable rights or other simple allocation rules that enable individuals to make efficient long-term use of the resource (Hurwicz 1973; Clark 1980). Fishery economists, for example, drawing on the important work of H. Scott Gordon (1954) and Milner Schaefer (1957), have repeatedly demonstrated how a transferable quota system can solve the "tragedy" of a fishing commons and lead to an efficient equilibrium (Scott 1979, 1982). This has led to widespread acceptance within many natural resource ministries that the transferable quota rule is the most preferred policy prescription for improving the efficient allocation of fishery resources (Matthews and Phyne 1988). In recommending transferable quotas as the favored institutional solution for most fishery problems, however, Wilson and Townsend have pointed out that the models used to generate this institutional solution are all based on a single-species fishery (Wilson 1982; Townsend 1986; Townsend and Wilson 1987). Multi-species fisheries must be characterized by different dynamic models than single-species fisheries. Complex patterns of interaction occur among species. Devising an efficient, effective, and equitable transferable quota system for a multi-species fishery is problematic (see Copes 1986; Schlager 1990).

4.3 The World of Configural Complexity

Many of the physical systems of relevance for understanding global environmental problems are not adequately modeled with the simple models of the physical world that have been used as the foundation for policy recommendations. Some models of land degradation, for example, presume that any human intervention in a watershed that increases the silt load carried downstream produces a harm. Rawlins (1991) argues quite convincingly that the movement of silt from one location to another may enhance overall agricultural productivity. Whether the movement of silt improves or degrades agricultural productivity depends on many attributes (temperature, soil density and depth, costs of transportation) that affect the potential of higher versus lower sites. Thus, whether moving silt is land degradation or land improvement depends upon many other factors that are present in a unique configuration in any particular watershed.

Similarly, it appears that the effect of some chemicals on tropospheric and stratospheric ozone depend on the amount of other chemicals present in a micro- or meso-environment. Interventions based on incomplete understandings of these complex processes can inappropriately attempt to regulate all environments as if they were similar in structure. Such interventions can be ineffective (and thus inefficient because of their cost) or even counterproductive.

A recent report released by the National Research Council, for example, criticizes the U.S. Environmental Protection Agency (EPA) for focusing

too strongly on one pollutant (Commission on Geosciences, Environment, and Resources 1991). Tropospheric ozone (smog) is generated when two classes of chemicals react in sunlight: (1) volatile organic chemicals (VOCs) and (2) either nitric oxide or nitrogen dioxide (NO_x) (see Stone [1992]). In some regions of the U.S., a high ratio of VOCs to NO_x exists. "In such regions," the report concludes, "it may be better to concentrate on the less abundant pollutant to prevent the formation of ozone."

To make the situation even more difficult, one source of VOCs has not been monitored until recently.[7] Trees and most plants produce biogenic VOCs (such as isoprene). Heavily wooded areas would thus generate a high ratio of unmeasured VOCs to NO_x, even if most manmade VOCs were eliminated. In such areas, applying a uniform rule based on a model that smog can be controlled by reducing VOCs would be an ineffective strategy. Given these recent findings, it may now be possible to understand why 20 years of heavy regulation has yielded little or no progress in the reduction of tropospheric ozone. Regulations have been based on an oversimplified, universal model of single-source smog production. While all physical processes follow universal laws, the particular processes to be controlled in any specific location involve a complex, frequently nonlinear, combination of the specific values of multiple variables.

Results from recent research on the effect of diverse anthropogenic aerosols on global warming reveal spatially and temporally nonuniform patterns. Research reported on by R.J. Charlson and colleagues from many of the major research labs related to Atmospheric Sciences in the January 24, 1992, issue of *Science* shows a surprising effect concerning the role of tropospheric aerosols in producing a cooling effect. Charlson et al. (1992, p. 429) conclude that "anthropogenic sulfate produces a mean radiative forcing of the [northern hemisphere] climate that is comparable in magnitude but opposite in sign to the anthropogenic perturbation in forcing by greenhouse gases." Further, they stress both the spatially nonuniform distribution of and large uncertainties about the magnitude of the presence of tropospheric aerosols. Trying to understand how these complex chemicals interact in different micro and meso climate systems is essential if future regulations aimed to prevent global warming are to be effective. Charlson and his coauthors strongly urge a research program that combines data collection and modelling at smaller as well as global scales.

Another new study demonstrating nonuniform temporal reactions has been conducted by Thomas R. Karl of the National Climatic Data Center in Asheville, North Carolina (and reported on in the February issue of *Scientific American*; see Beardsley 1992). Previous assessments of global warming have presumed that daytime and nighttime temperatures would increase equally as the level of greenhouse gases increases. Karl's study shows that temperatures in the Northern Hemisphere have increased primarily at night and have been recorded as daily minimum temperatures. "Daily maxima, on the other hand — generally recorded during daylight hours — have hardly increased at all in the U.S. and China and only a little in the Soviet Union" (Beardsley 1992, p. 21). The significance of Karl's and Charlson's work is currently under debate. But if sulfate aerosols do tend to counteract warming processes — even those during the day — the implications for regulations that focus on a reduction of pollution from fossil fuels might have counterproductive consequences. As Beardsley concludes (p. 24):

> If sulfate aerosol is indeed ameliorating daytime greenhouse warming, the implications for public policy could be perplexing. Nighttime warming would still be ecologically disruptive and would still melt glaciers. And the provisions of the U.S. Clean Air Act and steps by other countries to reduce pollution from fossil fuels may have an unintended effect. If the sulfate theory is right . . . the decrease in sulfate emissions might hasten global warming.

While much more needs to be learned about the factors affecting global warming, it does appear that many of the elements that enter into processes that change global weather patterns are not distributed in a spatially uniform manner. Since the effect of reducing the levels of one chemical depend upon the mixture of other chemicals present in the atmosphere, uniform rules are likely to produce some counterproductive results as well as some ameliorative results. Successful efforts to control

environmental problems may end up being those that are best matched to micro- or meso- level environments rather than trying to devise rules at a global level. That suggests that there is much that can be learned from prior studies of smaller-scale CPRs of relevance to global problems.

5 PRIOR RESEARCH ON ROBUST CPR INSTITUTIONS

Prior research has included an intensive analysis of field settings where: (1) resource users have devised, monitored, and followed their own rules to control the use of a CPR and (2) the resource systems, as well as the institutions, have survived for long periods of time. The youngest set of institutions thus analyzed was already over 100 years old. The history of the oldest institution exceeds 1,000 years. All of the institutions studied have survived droughts, floods, wars, pestilence, and major economic and political changes. The robust CPR institutions originally included grazing and forest CPR institutions in Switzerland and Japan and irrigation systems in Spain and the Philippine Islands (see E. Ostrom 1990). Since then, many more cases of robust CPR institutions have been studied, particularly related to irrigation systems (see E. Ostrom 1992; Tang 1991, 1992).

In CPR institutions that have survived for long periods of time, operational rules-in-use have not necessarily remained fixed since they were first initiated. All of these environmental settings are complex and variable over time. In such settings, it would be difficult to get "the operational rules right" on the first try, or even after several tries. These institutions are "robust" or in "institutional equilibrium" in the sense defined by Shepsle. Shepsle (1989, p. 143) regards "an institution as 'essentially' in equilibrium if changes transpired according to an *ex ante* plan (and hence part of the original institution) for institutional change." In these cases, the participants designed basic operational rules, created organizations to undertake the operational management of their CPRs, and modified the rules-in-use over time in light of past experience according to their own collective choice and constitutional rules.

While substantial differences exist among the robust institutions, all share fundamental similarities. All faced uncertain and complex environments. In contrast to the uncertainty of the environment, the populations in these settings remained stable over long periods of time. Individuals shared a past and expected to share a future. It was important to individuals to maintain their reputation as a reliable member of a community. Extensive norms have evolved in all of these settings that narrowly defined "proper" behavior. Many of these norms made it feasible for individuals to live in close interdependence on many fronts without excessive conflict. Further, gaining a reputation for keeping promises, honest dealings, and reliability in one arena was a valuable asset. Prudent, long-term self-interest reinforced the acceptance of the norms of proper behavior. The most notable similarity of all, of course, is the sheer perseverance of these resource systems and institutions. The resource systems clearly meet the criteria of long-term sustainability.

The specific operational rules in each case differ markedly from one another. Thus, they cannot be the basis for an explanation across settings. While the particular rules that are used within each setting cannot be the basis of an explanation for the institutional robustness and sustainability across these CPRs, part of the explanation is based on the fact that the particular rules differ. By differing, the particular rules take into account specific attributes of the related physical systems, cultural views of the world, and the economic and political relationships that exist in the setting. Without different rules, users could not take advantage of the positive features of a local CPR or avoid potential pitfalls that could occur in one setting but not others. *Given the diversity of the settings, one should not expect to be able to discover a single formulation or set of optimal mechanisms.*

Instead of similar rules, there are similar design principles that characterize all of the robust CPR institutions. By "design principle" is meant an essential element or condition that helps to account for the success of these institutions in sustaining the CPRs and gaining the compliance of generation after generation of participants to the rules-in-use.[8] Focusing on underlying principles rather than specific mechanisms may enable us to learn lessons from a wide diversity of small field settings that have relevance to the design of robust international regimes.[9]

5.1 Design Principle 1: Clearly Defined Boundaries

Individuals or households who have rights to withdraw resource units from the CPR must be clearly defined, as must the boundaries of the CPR itself.

Defining the boundaries of the CPR and of those authorized to use it can be thought of as a "first step" in organizing for collective action. As long as the boundaries of the resource and/or the individuals who can use the resource remain uncertain, no one knows what they are managing or for whom. Without defining the boundaries of the CPR and closing it to "outsiders," local participants face the risk that any benefits they produce by their efforts will be reaped by others who do not contribute to these efforts. At the least, those who invest in the CPR may not receive as high a return as they expected. At the worst, the actions of others could destroy the resource itself. Thus, for any participants to have a minimal interest in coordinating patterns of appropriation and provision, some set of participants have to be able to exclude others from access and appropriation rights. If there are substantial numbers of potential users and if the demand for the resource units is high, the destructive potential of all users freely withdrawing from a CPR could change the perception of users regarding the likely continuance of a flow of resource-units in the future. The more that participants fear for the future sustainability of the resource, the closer the situation is to that of a one-shot dilemma, where the dominant strategy of all participants is to overuse the CPR. (This is the logic behind Aristotle's assertion quoted above.)

5.2 Design Principle 2: Congruence between Appropriation and Provision Rules and Local Conditions

Appropriation rules restricting time, place, technology, and/or quantity of resource-units are related to local conditions and to provision rules requiring labor, materials, and/or money.

Adding well-tailored appropriation and provision rules helps to account for the perseverance of the CPRs themselves. Successful, long-enduring, irrigation institutions, for example, have all developed methods to equate the costs of building and maintaining the irrigation system appropriately to the benefits that are achieved. Some examples may help the reader understand the diversity of specific rules that meet Design Principle 2.

- *The Zanjeras of Northern Philippines.* These self-organized systems obtain use-rights to previously unirrigated land from a large landowner by building a canal that irrigates the landowner's land and that of a zanjera. At the time that the land is allocated, each farmer willing to abide by the rules of the system receives a bundle of rights and duties in the form of Atars. Each Atar defines three parcels of land located in the head, middle, and tail sections of the service area where the holder grows his or her crops. Responsibilities for construction and maintenance are allocated by Atars, as are voting rights. In the rainy seasons, water is allocated freely. In a dry year, water may be allocated only to the parcels located in the head and middle portions. Thus, everyone receives water in plentiful and scarce times in rough proportion to the amount of Atars they possess. Atars may be sold to others with the permission of the irrigation association and they are heritable (see Siy 1982; Coward 1979).

- *Thulo Kulo in Nepal.* When this system was first constructed in 1928, 27 households contributed to a fund to construct the canal and received shares to the resulting system proportionate to the amount they invested. The system has been expanded several times since by selling additional shares. Measurement and diversion weirs or gates are installed at key locations so that water is automatically allocated to each farmer according to the proportion of shares owned. Routine monitoring and maintenance are allocated to workteams so that everyone participates proportionately, but emergency repairs require labor input from all shareholders regardless of the size of their share (see Martin and Yoder 1983; Martin 1986).

- *The Huerta of Valencia in Spain.* In 1435, 84 irrigators served by two interrelated canals in Valencia gathered at the monastery of St. Francis to draw up and approve formal

regulations to specify who had rights to water from these canals, how the water would be shared in good and bad years, and how responsibilities for maintenance would be shared. The modern Huerta of Valencia, composed of these plus six additional canals, now serves about 16,000 hectares and 15,000 farmers. The right to water inheres in the land itself and cannot be bought and sold independently of the land. Rights to water are approximately proportionate to the amount of land owned, as are obligations to contribute to the cost of monitoring and maintenance activities (see Maass and Anderson 1986; E. Ostrom 1990).

These three rule configurations differ markedly from one another. The zanjeras are institutional devices for landless laborers to acquire use rights to land and water and might even be called communal systems. The Thulo Kulo system comes as close to allocating private and separable property rights to water as is feasible in an irrigation system. The Valencian Huerta has maintained centuries-old land and water rights that forbid the separation of water rights from the land being served. The Valencian system differs from both "communal" and "private property" systems because water rights are firmly attached to private ownership of land.

Underlying these differences, however, is the basic design principle that the costs of constructing, operating, and maintaining these systems are roughly proportional to the benefits obtained. Slogans, such as "privatization" or "think globally, act locally" may mask important underlying principles rather than providing useful guides for institutional reform.

5.3 Design Principle 3: Collective-Choice Arrangements

Most individuals affected by operational rules can participate in modifying operational rules.

CPR institutions that use this principle are able to better tailor rules to local circumstances, since the individuals who directly interact with one another and with the physical world can modify the rules over time so as to better fit them to the specific characteristic of their setting. The presence of good rules, however, does not account for participants following them. Nor is the fact that the participants themselves designed and initially agreed to the operational rules an adequate explanation for centuries of compliance by individuals who were not originally involved in the initial agreement. It is not even an adequate explanation for the continued commitment of those who were part of the initial agreement. Agreeing to follow rules *ex ante* is an easy "commitment" to make. Actually following rules *ex post*, when strong temptations to act at variance with rules are present, is the significant accomplishment.

The problem of gaining compliance to rules — no matter what their origin — is frequently assumed away by analysts positing all knowing and all powerful *external* authorities that enforce agreements. In the cases described above, no external authority had sufficient presence to play any role in the day-to-day enforcement of the rules-in-use. Thus, external enforcement cannot be used to explain high levels of compliance. This leads us to consider the fourth and fifth design principles. Since they are so closely related, we will discuss them both together.

5.4 Design Principles 4 and 5: Monitoring and Graduated Sanctions

Monitors, who actively audit CPR conditions and participant behavior, are accountable to the participants or are the participants.

Participants who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) from other participants, by officials accountable to these participants, or by both.

It has been surprising to find that monitoring and sanctioning are undertaken not by external authorities but by the participants themselves in the robust institutions. The initial sanctions used in these systems are also surprisingly low. Even though it is frequently presumed that participants will not spend the time and effort to monitor and sanction each other's performance, substantial evidence exists from field settings as well as from the experimental lab (see Ostrom, Gardner, and Walker 1992).

To explain the investment in monitoring and sanctioning activities that occurs in these robust, self-governing, CPR institutions, the term "quasi-voluntary compliance" used by Margaret Levi (1988a, chapter 3) to describe the behavior of taxpayers in systems where most taxpayers comply is very useful. She uses the term quasi-voluntary compliance to describe taxpayer behavior in such taxing regimes. Paying taxes is *voluntary* in the sense that individuals *choose* to comply in many situations where they are not being directly coerced. On the other hand, it is "*quasi*-voluntary because the noncompliant are subject to coercion — if they are caught" (Levi 1988a, p. 52). Taxpayers, according to Levi, will adopt a strategy of quasi-voluntary compliance when they have:

> confidence that (1) rulers will keep their bargains and (2) the other constituents will keep theirs. Taxpayers are strategic actors who will cooperate only when they can expect others to cooperate as well. The compliance of each depends on the compliance of the others. No one prefers to be a "sucker" (Levi 1988a, p. 53).

Levi views coercion as an *essential condition* to achieve quasi-voluntary compliance as a form of contingent behavior. Enforcement increases the confidence of individuals that they are not suckers. As long as they are confident that others are cooperating and the ruler provides joint benefits, they comply willingly to tax laws.

The costs of monitoring are kept relatively low in many of the long-enduring CPRs as a result of the rules-in-use. Water rotation systems, for example, usually place the two actors most concerned with cheating in direct contact with one another. The irrigator who nears the end of a rotation turn would like to extend the time of his turn (and thus the amount of water obtained). The next irrigator in the rotation system waits nearby for him to finish and would even like to start early. The presence of the first irrigator deters the second from an early start, and the presence of the second irrigator deters the first from a late ending. Neither has to invest additional resources in monitoring activities. Monitoring is a by-product of their own strong motivations to use their water rotation turn to the fullest extent.

Institutional analysis that simply posits an external, zero-cost enforcer has not addressed the possibility that the rules devised by participants may themselves have a major effect on the costs, and therefore the efficiency, of monitoring by internal or external enforcers. Similarly, monitors who do a good job are rewarded, and inadequate monitors are punished.

Further, since the users tend to continue monitoring the guards as well as each other, some redundancy is built into the monitoring and sanctioning system. A failure to deter rule breaking by one mechanism does not trigger a cascading process of rule infractions, since other mechanisms are in place. Thus, the costs and benefits of monitoring a set of rules are not independent of the particular set of rules adopted. Nor are they uniform in all CPR settings. When participants design at least some of their own rules (Design Principle 3), they can learn from experience to craft enforceable rather than unenforceable rules. This means paying attention to the costs of monitoring and enforcing as well as the benefits that those who monitor and enforce the rules obtain.

5.5 Design Principle 6: Conflict Resolution Mechanisms

Participants and their officials have rapid access to low-cost, local arenas to resolve conflict among participants or between participants and officials.

In many models of rule-governed situations, the rules that structure the strategies available to participants are unambiguous as well as enforced by external, all-knowing officials. In field settings, applying rules is never unambiguous, even when the participants themselves are the monitors and sanctioners. For individuals who are seeking ways to slide past or subvert rules, there are always ways that they can "interpret" the rule so that they can argue they meet it while subverting the intent. Even individuals who intend to follow the spirit of a rule can make errors.

If individuals are going to follow rules over a long period of time, some mechanism for discussing and resolving what is or is not a rule infraction is necessary to the continuance of rule conformance itself. While the presence of conflict resolution

mechanisms does not guarantee that participants are able to maintain enduring institutions, it is difficult to imagine how any complex system of rules could be maintained over time without such mechanisms. In some cases, conflict-resolution mechanisms are quite informal, and those who are selected as leaders are also the basic resolvers of conflict. Furthermore, networks of face-to-face communication are essential to the fashioning, revision, and maintenance of mutual understandings and social accountability.

5.6 Design Principle 7: Minimal Recognition of Rights to Organize

The rights of participants to devise their own institutions are not challenged by external governmental authorities.

Participants frequently devise their own rules without having created formal, governmental jurisdictions for this purpose. As long as external governmental officials give at least minimal recognition to the legitimacy of such rules, participants may be able to enforce the rules themselves. But if external governmental officials presume that only they can make authoritative rules, then it is very difficult for local participants to sustain a rule-governed CPR over the long run. At any point when participants wish to break their rules, they can go to the external government and get local rules overturned.

5.7 Design Principle 8: Nested Enterprises

Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

All of the more complex, enduring CPRs meet this last design principle. This is probably one of the most important design principles when one begins to think about global rather than local CPRs. If different environmental zones need to be regulated in diverse manners in order to achieve the same outcomes, it is quite essential that there be governance mechanisms at all levels and ways of effectively communicating and resolving conflict between units at one level and across levels.

6 THE GLOBAL RELEVANCE OF RESEARCH ON LOCAL CPR REGIMES

There are several reasons why we think the lessons learned from past research on micro CPRs have substantial applicability to the problem of dealing with patterns of international cooperation and conflict over the potential threat of global warming. These include:

- The analytical structure of some of the problems related to global warming shares similar features with the analytical structure of many local CPRs.
- Starting with theories and models devised for the analysis of local CPRs may speed the work in developing theories and models at a global level.
- Many of the problems related to global warming (e.g., deforestation) are themselves the result of inadequate solutions at a micro level of a complementary and interactive commons problem.

To the extent that global warming shares analytical attributes with other CPRs, the theoretical and empirical lessons learned from studying micro-level phenomena may "scale-up" so that direct lessons may be learned. It is certainly the case that the attribute of nonexclusion is shared. Is the second attribute of "subtractability" shared as well? Yes, it would appear so — only in the reverse direction. The term "rivalness" may be an easier term to use in this connection. If one thinks of carbon emissions as "using up" a natural capacity to absorb carbon in the atmosphere, then the units of natural capacity used up by carbon emissions in one country are not available to be used up by any other country. Similar to fisheries, initial carbon emissions may actually generate joint benefits for everyone in terms of increased plant growth induced by higher levels of CO_2 in the atmosphere.

A second major point of similarity is the shared concern for finding means to cooperate despite the absence (or disinterest) of a higher level of political authority. Research on international regimes has emphasized the ability of governments to cooperate in an environment of "anarchy," defined as the

absence of any central authority at the global level. Political order at the international level is primarily self enforcing, in the sense that governments frequently resort to military force to achieve their goals or to restore the "peace." Despite its obvious shortcomings on normative grounds, war remains the ultimate means of conflict resolution that may never be dispensed with until a complex, multi-tiered world government is established in some remote future time.

Since many of the micro settings where individuals have jointly devised their own institutions have existed far from the purview of national, regional or local government officials, the design of these institutions and their enforcement has not always depended on the presence of a "State." Many of the self-organized institutions devised in these micro settings are not dependent upon enforcement of their rules by external officials. Further, since many of these micro institutions are neither a market nor a state, we may gain insight to alternative international institutions from studying these micro institutions.

Considerable caution has to be exercised in moving from micro to macro levels, since a change in scale frequently changes the structure of situations dramatically. On the other hand, it is not appropriate to dismiss the possibility of lessons acquired from studying micro institutions applying to macro institutions simply on the basis of a distinction between supposedly homogeneous local groups and the heterogeneous actors involved in the global system. Many successful CPR regimes are complex structures and include individuals from diverse cultural groups. Homogeneity may make it easier for groups to attain the degree of common understanding essential to the operation of robust CPR regimes, but none of the design principles listed above require actor homogeneity. Even very diverse actors can arrive at a degree of common understanding sufficient to enable them to effectively deal with their common problems.

Analyzing complex patterns of interaction in the simplest possible example of the structure (the biologist's strategy) may enable the analyst to understand the way things work in the simplest exemplar without being overwhelmed by the sheer complexity of the problem. To the extent that work at a micro level does not easily scale up, it still may be the case that key variables are identified in micro-level theories and models. Starting with the work at this level may save considerable time when contrasted with an effort to move to the global level directly. Even though it is impossible to completely decompose global problems into entirely discrete subproblems, working upward may enable solutions to be reached faster than starting from the global and working downward — at least for some subset of problems (see Ashby 1960; Polanyi 1951).

As an example of a global problem rooted in inadequate local arrangements, consider the contribution of deforestation to global climatic change (Cruz 1991). Deforestation may be the result of conversion from lower-valued to higher-valued uses. It may also be the result of either (1) ill-defined property rights where the transaction costs of gaining clear property rights (whether strictly private or communal) are very high, or (2) the creation a concession economy as the foundation for resource mobilization by national-government officials (for their government as well as for themselves). Problems like deforestation will deteriorate still further until more effective institutional arrangements can be devised at the local level. Given the varieties of physical environments that exist within even one country, no single set of rules related to the use of forests will create appropriate incentive systems for all individuals whose decisions affect the regeneration of forests over time.

As discussed above, CPRs do not have the "nice" attributes that are needed for a market to work effectively. Nor do inflexible hierarchical arrangements work effectively in relationship to spatially nonuniform problems. The inability to prescribe markets or hierarchies as solutions to CPR problems has profound implications for the study of institutions related to international cooperation and conflict over global change. First, it means that instead of seeing global change as another "issue area" where a market or an "international regime" could be created to regulate the problem, one should first attempt to understand the key linked situations that affect global weather patterns. Some of these situations create incentives leading actors to use various combinations of energy sources in different parts of the world. Others relate to the structure of incentives leading actors to clear previously forested areas. Still others have to

do with the structure of incentives leading actors to increase or decrease the number of animals grazing in different parts of the world (for their effect on surrounding terrain and their production of methane gas). While all of these situations jointly affect the level of CO_2 in the world's atmosphere, the logic behind these situations differs substantially.

Second, it means recognizing that proposed changes in rules (or in technology) will have different effects around the world. The attempt, for example, to create a worldwide carbon emission permit system is likely to have drastically different effects in (1) open political economies that have already established competitive markets and political-legal systems that are relatively predictable, responsive, and accountable than it would in (2) closed political economies with mercantilist market systems and unchecked and rampant rent-seeking among public officials. Ignoring for the moment the extraordinarily difficult task of achieving the agreement of most national governments to a particular permit system, the implementation and monitoring of a permit system in the United States is an entirely different problem than the implementation and monitoring of that same permit system in almost any country of the developing world.

Third, recognizing that the outcomes of individual choices that affect global change occur in many differently structured situations that are embedded in a wide diversity of institutional and cultural settings leads to a further recognition that no uniform set of rules imposed at the international level is going to "solve" the problem of global warming. Whether the wide diversity of variables that affect global weather patterns are changed so as to reduce the risk of global warming (or, alternatively, reduce the adverse consequences that global warming would have in some locations) will not depend alone (or perhaps even strongly) on sweeping changes written in treaties made at large-scale, international meetings and ratified by national governments. Such meetings may indeed be crucially important if they provide an opportunity for open discussion of truly difficult and complex problems that need multiple solutions at multiple scales. But the change in human understanding of the nature of the problems involved may be far more important in the first instance for a change in behavior than a new international convention whose pronouncements are nothing much more than words on paper.

On the other hand, we are cautious about casual analogies. We fully recognize that there are substantial differences in the range of actors involved in many global problems. In many of the micro studies, the actors involved are individuals whose own livelihood depends strongly on solutions to use a resource system more efficiently over time. In many local commons around the world, individuals do devise for themselves rather ingenious institutional arrangements that have enabled them to make productive use of fragile resource systems over long periods of time. Even then, there are many "tragedies of the commons" in these situations where individuals as principals interact directly with one another. Once we move to the problem of the global commons, in addition to the millions of individuals who make choices, we add many corporate actors who are designated as the agents for complex publics, and their behavior is far more complex. Yet many corporations and national governments can reasonably be expected to exist for long periods of time, providing their agents with incentives to establish predictable rules of behavior that reduce future levels of uncertainty (Keohane 1984). One issue that we emphasize below is the extent to which the nature of these collective action organizations affects the patterns of monitoring and sanctioning that can realistically be expected to occur in any global regime.

7 A PRELIMINARY TYPOLOGY OF INTERNATIONAL ACTORS

Many of the prior applications of the IAD framework have been to situations where the actors are individual persons or firms. One of the challenges of our current assignment is to apply this framework to situations where the actors involved are far more diverse and where the corporate nature of the actors is particularly relevant to predictions about activities and outcomes. A diverse array of organizational actors participate in the global arena, including national and subnational governments, international governmental organizations (IGOs), domestic economic corporations and multinational corporations (MNCs), domestic nongovernmental organizations (NGOs), and international

nongovernmental organizations (INGOs). We propose a typology of actor types based on the three-fold characterization of political, economic, and epistemic contingencies that constitute patterns of order in human societies (V. Ostrom 1991b). The point of this typology is not to locate any particular organization in some pigeonhole but rather to identify the combinations of interests and capabilities that most commonly impinge on international cooperation.

Groups of individuals form different types of collective action organizations to pursue diverse goals. Individual agents in different organizations are then authorized to undertake specific actions. In addition to their personal goals, agents of economic corporations are driven by pursuit of profit; political agents are driven by a desire to remain in office and to achieve certain policy goals; and agents of NGOs strive to attain the purposes that inspired formation of that type of organization. Some INGOs, such as Amnesty International, are widely regarded as impartial sources of information relevant to various areas of international relations. Others, such as Greenpeace, become direct action groups that play a distinctive, confrontational role in political processes.

Even though any particular association may be simultaneously engaged in economic production as well as rule-making and knowledge-generating activities, different types of associations tend to emphasize one or the other type of activity. In Table 1, we use these characteristic goals and/or arenas of activity to differentiate among the type of actors most relevant to analyses of international cooperation. (We differentiate among governments grounded in fundamentally different forms of political order below.)

It is important to treat actors in the epistemic category as having distinctive interests and capabilities rather than relegating them to a residual "other" category left after political and economic actors have been identified. For example, Peter Haas (1989) emphasizes the role played by technical experts in establishing the political preconditions for effective control of pollution in the Mediterranean Sea. He argues that regimes are most effective when based on consensus among a technically informed "epistemic community" about the nature of the problem to be solved and the merits of alternative solutions. In other words, technical experts share a "common understanding" that can provide a basis for political cooperation. The phrase "epistemic community" frequently appears in analyses of the prospects for increased international cooperation on environmental issues (P. Haas 1992). Technical experts may play a large role in monitoring governmental or corporate behavior, by providing an impartial source of information upon which sanctions could be based. Even if the information provided by "public interest" groups is seen as biased, competing information provided by more blatantly self-interested corporate groups can also be taken into account. It is important to realize that no one group, nor any type of collective actor, has a monopoly on legitimate participation in these inherently political processes.

TABLE 1 Classification of Actor Types

Primary Arena of Activity	Scope of Activities	
	Domestic	International
Political	National governments; other bureaucratic agents	IGOs
Economic	Domestic corporations	MNCs
Epistemic	NGOs; technical experts	INGOs; epistemic communities

For our purposes, a particularly important distinction is the scale of the activities of collective action organizations. We have in mind especially the standard distinction between "domestic" and "international" organizations (see Table 1). The prominence given "sovereign states" in the international relations literature and in practice requires this distinction be used for some analytical purposes, even though many important actors and networks transcend national boundaries. In general, agents of collective action organizations formed by members of the same political community may tend to pursue different goals than agents of organizations drawn from multiple communities. For example, agents of national governments pursue different goals and fulfill different roles than do the

"international civil servants" that carry out the activities of IGOs. Similarly, domestic corporations may have interests that are systematically different from multinational corporations, especially regarding such matters as restrictions on foreign trade or currency exchanges. Although domestic and international NGOs tend to resemble each other more closely, in some circumstances the distinction between NGOs and INGOs may be important.

Some organizations are difficult to locate in any one of these categories. Should cartels of drug dealers be treated as multinational corporations? Or should drug cartels and terrorist groups be included in the same NGO (or INGO) category as religious and scientific organizations? Do some national governments engaged in the international arms trade tend to take on the interests and characteristics of purely economic agents? Despite some remaining ambiguities, these basic distinctions among governments, IGOs, domestic corporations, MNCs, and domestic and international NGOs remain valid for many analytical purposes.

8 NEGOTIATIONS AND THE DESIGN OF NESTED REGIMES

Collective-action organizations with a wide variety of interests will contend in upcoming negotiations to establish a global convention on limiting emissions of greenhouse gases. The governments of advanced industrial democracies must respond to pressures from domestic environmental groups as well as the economic corporations that produce the vast array of consumer goods deemed essential to our modern society. Governments of developing countries must strike a balance between external inducements to minimize environmental degradation (especially deforestation and desertification) and domestic pressures for economic growth and development. Multinational and domestic corporations seek stable and predictable laws and regulations that will facilitate their continuing pursuit of profits. Private voluntary organizations will press the claims of scientists and environmentalists, no doubt too vigorously for the comfort of the leaders of established governments and corporations. Finally, international civil servants will press for establishing additional levels of bureaucracy at the international level as well as insuring access to more regularized sources of income. The task of reconciling such a wide diversity of interests is truly formidable.

Although we cannot provide a comprehensive survey of the interests of the organizations that will be involved in establishment of a global climate regime, we can discuss some general design principles that may facilitate establishment of a stable and robust regime. The "design principles" discussed above are relevant to the development of any regimes intended to be robust and long lasting. We realize that difficulties exist in scaling up principles of local commons regimes to the global scale, but it is not necessary to apply these principles to global institutional arrangement as a single regime. It may indeed be counterproductive to visualize establishment of a single, integrated, global management scheme covering all issues of global warming, deforestation, desertification, and other forms of environmental degradation.

A more appropriate conceptualization is based on the idea that sustainable global regimes must make sense at all levels of aggregation — local, regional, national, transnational, and global. Institutional arrangements at these multiple levels must be nested in such a way that the institutions at each level are robust with respect to the type of challenges that are likely to arise at that level. For if the local manifestations of a global regime fail to satisfy the design principles identified above, then that regime is subject to fragility and eventual dissolution.

This nesting cannot be expected to happen automatically. Quite the contrary is the case, since successful management of resources by some local group often imposes negative externalities on other groups. In such circumstances, some means must be found by which representatives of affected groups can come together to establish mutually beneficial institutional arrangements. Despite the current emphasis on state-to-state negotiations, this type of interaction should be expected to take place at all levels of aggregation.

This process itself raises the standard problems of principal-agent relations, that is, the difficulty of insuring that an agent selected to act in the name of a principal will indeed pursue the interests of the principal rather than acting solely out of self interest. Ideally, arrangements at local and

intermediate levels are incentive compatible, in the sense that the interests of agents are somehow made to coincide with the interests of the principal. The design principles identified above, when applied to institutional arrangements at the local level, may be said to constitute necessary but not sufficient conditions for establishment of a robust global regime. In order to establish a robust, multilevel regime, additional design principles can be used to guide efforts to make institutional arrangements at the local, regional, and global levels mutually reinforcing.

One important design principle relevant to all levels of aggregation is that institutional arrangements must remain tied to the physical realities of the environmental situation. Thus, if the boundaries of a river basin do not correspond to the official boundaries among sovereign states, groups within all affected states must be included (whether or not all national governments are directly represented). An example of relatively successful cooperation among a large group of heterogenous governments is the control of pollution in the Mediterranean Sea (P. Haas 1989, 1990). Intergovernmental negotiations should not be considered the only, nor even the best, forum for the cooperation needed to address the consequences of environmental change. Sometimes international agreements play an important role, but they rarely (if ever) tell the whole story. Although it might seem obvious that a global problem like greenhouse warming necessarily requires a solution that is similarly global in scope, no global regime can remain robust if it neglects to take account of local circumstances or the conflicting interests of smaller-scale collective action organizations.

Perhaps the most important nesting principle is that the interests of all relevant groups must be incorporated in the ultimate agreement, or else the regimes's sustainability will be undermined by those groups whose interests are excluded. It is not enough to impose an arrangement by majority vote (of, for example, the UN General Assembly), for those groups whose interests are not represented will dismiss the result as unfair or illegitimate. Instead, we should expect complex linkages between different issues, as occurred in negotiations over the Law of the Sea Treaty (Sebenius 1984). Negotiators should also be attentive to possibilities for side payments of various sorts, in order to complete a mutually advantageous package deal.

In addition to the standard problems of collective action, negotiations over global climate change are complicated by an unusual degree of inherent uncertainty. Although some regions may benefit from global warming while others suffer, the identity of potential winners and losers remains very uncertain. Also, regions that benefit from early aspects of climatic change might later suffer dire consequences as changes accumulate or accelerate. In effect, all governments and other organizations may consider themselves to be potential losers, simply because even successful adjustments to changing environments are likely to prove costly. But these costs remain in the future, whereas the policy changes being proposed may impose very real short-term costs on certain governments or corporations.

This is an example of a classic dilemma of collective action: a large group of potential beneficiaries facing diffuse and uncertain gains is much harder to organize for collective action than clearly defined groups who are being asked to suffer easily understandable costs. To overcome the resistence of "blocking coalitions" most adversely affected by any agreement (Sebenius 1991), one of two types of leadership is crucial. First, small privileged groups may find it in their interests to directly provide the public good (Olson 1965). Second, some political (or other) entrepreneurs may take the lead in educating members of the relevant groups as to the nature of the common problem they face. The record of robust CPR regimes reviewed above clearly demonstrates the ability of individuals to solve difficult dilemmas of collective action even in the absence of a dominant leader.

In the international political economy literature, the role of the United States in establishing the post-World War II economic order is emphasized, as are the difficulties of achieving policy coordination in the absence of a hegemon (Keohane 1984). Advocates of a more active environmental policy are often disappointed about the lack of U.S. leadership in the second sense, but recent work has emphasized the leadership role played by "epistemic communities" of technical experts in the establishment of a wide range of regional or international

regimes, including the Montreal Protocol on ozone depletion (P. Haas 1992). Indeed, scientific groups have played a major role in bringing the issues of global climate change to the attention of policy-makers and the mass public. But the crucial step will still require joint action on the part of a large number of diverse groups. Our basic point is that these discussions should be informed by the lessons drawn from analyses of the principles underlying successful patterns of cooperation at the local level.

Reliance on hegemonic leadership to establish cooperation is short sighted, because that hegemonic position is unstable in the long run (since free-riders gain relative to a hegemon paying for public goods production). Although technical experts can help educate the public about the nature of the problem of climate change, an even more effective technique is available to those seeking to design a sustainable climate regime. As long as individuals and groups pursue their own self interest, a regime is most likely to be sustainable if it so configures individual and group interests as to support the achievement of collective goals.

Designers of a global regime to deal with climatic change can draw important lessons from the designers of the U.S. Constitution, who concentrated on finding ways to balance power against power, to use contestation among individuals to provide a firmer foundation for achieving public order (see V. Ostrom 1987). Rather than seeing the diversity of actors and interests as an impediment to agreement, it is important to put this diversity to use in order to increase the robustness of any resulting regime. In particular, the diverse interests of groups can be used to monitor various aspects of the agreement. If the monitoring activities of different groups overlap to some extent, then each can serve as a check on the other, providing increased confidence that sufficient compliance will be forthcoming.

Statistics provided by official government sources can play some role in helping to monitor greenhouse emissions, but they cannot remain the sole source of information. If so, then government officials might have strong incentives to misreport levels in order to protect their own government from punishments, and they might also be subject to bribery by corporate officials eager to cover up their own excessive use of carbon fuels. Insuring regular alternative sources of information is essential. Scientists can play an essential role in this process, for the same sort of activities needed to improve basic scientific understanding of global climate change will also contribute to any potential ability to monitor any future agreement.

Where should sanctioning of violations of greenhouse gas restrictions be focused? Typical proposals require that exports from states whose aggregate carbon use exceeds the allotted permits be subject to tariffs or other trade restrictions. But this would seem to be the wrong target, since it is the behavior of corporations that must be changed if these emissions are to be reduced. Governments might try to identify the guilty parties through regular police procedures, but this assumes a level of consistency between international treaties and domestic law that may be rather difficult to maintain in all circumstances. Thus, some non-governmental monitoring of individual violators would seem to be required as a supplement and check on official governmental activities.

In addition to assigning responsibility for violations of existing agreements, other types of legal claims may also become part of the ongoing application of a global climate regime. It is generally assumed that the detrimental consequences of climate change will be intense, at least for some regions and some time periods. To what extent can these "victims" of global climate change be said to have a valid legal claim for compensation from those groups less severely affected by, or perhaps even benefitting from, climatic changes? Settlement of such claims would be greatly facilitated by establishment of clear principles of legal liability, but it is difficult to imagine how the validity of such claims could be ascertained.

Implicit normative principles have already been involved in negotiations over global warming, in particular, the widespread perception that some exceptions should be provided for developing countries in order to not unduly hamper their efforts to achieve better standards of living through economic growth. Some advocates propose providing a disproportionate amount of marketable emissions permits to developing countries, as a means of indirect income transfer. But do we really want to institutionalize a process by which any group disadvantaged by climate changes can press

claims for compensation in national and international courts?

Environmental change may sow the seeds for new issues of conflict over access to resources, but a poorly designed global regime may itself exacerbate conflict by merely providing governments something new to fight over. For example, richer oil-exporting states (especially Saudi Arabia) allowed other OPEC members to produce disproportionate levels in order to provide a more equitable distribution of the gains this cartel provided. However, this arrangement itself exacerbated distributional issues, including contributing to tensions that led to Iraq's invasion of Kuwait and the subsequent Gulf War. It is important to insure that global institutions, once established, do not themselves become catalysts for future wars.

The distributional consequences of global climate change may well be significant, but they are also likely to become clear only slowly. Thus, sufficient time may exist to develop some shared sense of fairness. Even though conflict over climatic change cannot be prevented, institutional arrangements can be established that facilitate the resolution and management of conflict that does arise.

Any political bargain on the scale of the proposed global regime limiting emissions of greenhouse gases should be grounded on some clear fundamental principles, both normative and practical (see Dorfman 1991). The principles cannot be imposed but must instead emerge from a process of contestation in which a wide range of feasible alternatives are given careful consideration. In the next section, we return to the literature on international regimes to propose some alternative forms of institutional arrangements that are generally overlooked because of the tendency of most analysts of international relations to focus exclusively on the behavior of national governments.

9 MONITORING AND SANCTIONING IN INTERNATIONAL REGIMES

Having earlier proposed a classification scheme based on the dominant objectives of organizations and their scope of activities, we would now like to focus on two of the dimensions that are closely related to Design Principles 4 and 5 described above. That is, in this section, we examine how the types of actors involved in monitoring and sanctioning may affect the types of incentives and likely outcomes produced. We realize that the types of actors involved in constitutional decisions affect who participates in a regime and which type of authority and scope rules are used, and we also are concerned about the types of dispute resolution that can be adopted depending on the types of actors. But a preliminary focus on monitoring and sanctioning activities is warranted by their fundamental importance in any effort to achieve meaningful and sustainable changes in the level of cooperation over global change issues.

We distinguish categories of regimes according to (1) what type of actor is primarily responsible for monitoring compliance with the rules of that regime and (2) what type of actor is sanctioned for rule violation. This latter type of actor is generally the same as the type of actor whose behavior is restricted, although this relationship is not necessarily the only option. For example, national governments could be sanctioned for the activities of domestic corporations that violate rules laid down in a given regime.

Since the extent to which an IGO can be considered to be a separate actor remains in doubt, we do not consider the possible existence of regimes in which IGOs are sanctioned. (Efforts by the Reagan administration to withhold payment of U.S. dues to some UN organizations can be interpreted as sanctions against some of their previous activities.) However, IGOs can fulfill important information-gathering functions, including monitoring the behavior of governments, corporations, and other organizations (Jacobson 1984). Also, for these purposes, there seems to be little reason to distinguish between domestic corporations and MNCs, or between NGOs and INGOs. This leaves us with four types of actors engaged in monitoring activities (IGOs, governments, corporations, private groups) and three actor types subject to sanctions (governments, corporations, private groups or individuals).

Not all of the resulting 12 categories are relevant to the existing set of international regimes. Illustrative examples of relevant categories are given in Table 2. These categories are rough, and

TABLE 2 An Actor-Based Classification of International Regimes

Entity that Monitors	Entity that Gets Sanctioned: Government	Corporation	Private Group or Individual
Government	1 Arms control laws of war	4 LDC-MNC relations	8 War crimes NIIO
IGO	2 Nuclear nonproliferation	5 Sea-bed mining (Law of the Sea)	
Corporation	3 Trade restrictions frequency spectrum	9 Cartels	
Private group or individual	6 Human rights environmental	7 Future environmental?	

many real world cases will fail to fall clearly within a single category, especially since many different types of groups may be engaged in monitoring activities. Nonetheless, we believe this categorization has some utility in preparing the way for a more precise analysis of international regimes. In Table 2, numbers are assigned to each of the categories discussed below.

9.1 Category 1: Government Monitored-Government Sanctioned

Realist theorists of international politics focus almost exclusively on situations in which governments play both roles, that is, regimes that fall within Category 1. In his classic study of international order, Bull (1977, chapter 3) argues that "sovereign states" (which he interprets as individual members of "international society") are primarily responsible for performing all functions of rule making, monitoring, interpreting, legitimizing, and enforcement at the international level. For example, compliance with U.S.-Soviet arms control treaties has been monitored by each government's intelligence agencies.

The international law of war also fits into this category. Many observers are reluctant to describe war as an orderly activity, yet war has long served as a prominent institution of "international society" (Bull 1977), and certain restraints on the use of force are widely (but not universally) observed. The application of regime analysis to war or security rivalries remains controversial, but we take the position that any regime will include some mixture of cooperation and conflict, and thus that some regimes will be rather more conflictual than others.

Even relatively clear examples of the imposition of sanctions on national governments illustrate the extent to which international law falls short of the standards of domestic legal systems. Since Iraqi intervention in Kuwait was widely seen as a violation of international agreements against aggression, it was relatively easy to arrange global agreement on the imposition of economic sanctions on Iraq. Yet, this example reinforces concerns about the fairness of applying sanctions to collectivities rather than to individual actors raised in *The Federalist* (see V. Ostrom 1987). After all, the individual policymakers responsible for Iraqi actions were able to circumvent the deleterious effects of economic sanctions, which fell hardest on the poor and powerless elements of Iraq's population. Although economic sanctions have been used several times in recent decades, the use of physical force to enforce UN resolutions remains very unusual. Despite President Bush's claims that these events signal the birth of a new world order, it is more

widely believed that the ability of the U.S. government to garner such widespread support for military enforcement must attributed to special circumstances that are unlikely to be repeated.

9.2 Category 2: IGO Monitored-Government Sanctioned

In Category 2, an IGO is established to monitor governments' compliance with an international agreement. For example, the Nuclear Non-Proliferation Treaty established an international agency (the IAEA) intended to monitor possible violations. (We discuss some lessons of arms control regimes below.) As for any other bureaucracy, care must be taken to somehow make it in the self interest of individual bureaucrats to report accurately and reliably, and the data reported by IGOs cannot be honestly evaluated without some consideration of the purposes that willful misrepresentation might serve. However, the actions of most IGOs are generally seen as relatively impartial, perhaps because IGOs have too small a resource base to sustain extravagant graft or corruption, at least in comparison to many national governments.

9.3 Category 3: Corporation Monitored-Government Sanctioned

Category 3 encompasses the standard set of international economic regimes. Although typically established by negotiations among national governments, economic corporations are the actors most directly involved in monitoring compliance, with rules against imposing trade barriers or unfair trade practices. Corporations keep careful track of any advantage gained by their international competitors. Once violations are detected, corporations and economic interest groups typically press their own governments to seek redress of the violations through negotiations with the other government. For example, accusations of Japanese dumping of automobiles on the American market were resolved by a bilateral agreement on voluntary import restraints. Other types of policy changes include imposing penalties on corporations engaged in unfair trade practices (see Jackson 1990). Thus, the policies of national governments lie at the center of economic regimes, even though the monitoring is usually handled by those corporations most directly affected by rule violations. This central location of governments opens up several opportunities for rent-seeking and other predatory activities, especially by governments relying on concessions from MNCs as their primary source of revenue. (We discuss this problem below.)

9.4 Category 4: Government Monitored-Corporation Sanctioned

Category 4 includes examples of agreements between a multinational corporation (MNC) and a less developed country (LDC) that serves as "host country," in the sense that some of the economic activities of that MNC occur within that country's territory. LDC governments can use sanctioning mechanisms ranging from increased taxation to outright expropriation (or "nationalization") of MNC property. MNCs have access to national courts, but these are unlikely to impose real punishment on their own governments. MNCs, on the other hand, can frequently threaten moving their business activities elsewhere. Indeed, it is often asserted that, in most circumstances, MNCs have unfair bargaining advantages over their LDC hosts. A major unachieved goal of negotiations concerning establishment of a New International Economic Order was to establish some international regulation of the activities of MNCs.

9.5 Category 5: IGO Monitored-Corporation Sanctioned

Instances of Category 5 regimes, in which IGOs monitor compliance of economic corporations to international agreements, point the way toward establishment of a fundamentally new international legal framework. A potential example is the Law of the Sea Treaty, which calls for establishment of an international agency that would regulate mining activities on the deep sea-bed outside the 200-mile offshore exclusive economic zones also established in that treaty. The purpose of this International Seabed Authority is to insure that profits from these mining activities are distributed to all peoples of the world. Concern with the precedent set by this example of international control of a still-emerging area of economic activity led the Reagan administration to refuse to sign the LOS (Law of the Sea)

treaty. The extent to which similar international agencies will be established to redistribute profits made in other areas considered to be the "common heritage of mankind" remains to be seen.

9.6 Category 6: Private Monitored-Government Sanctioned

In Category 6 regimes, NGOs monitor government activities that may be subject to sanctioning under emerging regimes, as in the area of the protection of individual human rights. Governments have long monitored the ways in which other governments treat ethnic or religious minorities of concern to them. More recently, private groups, such as Amnesty International and the various groups established in Eastern Europe after the signing of the Helsinki Accords, have achieved credibility as relatively impartial monitors of human rights violations. In this case, application of sanctions to a government is clearly appropriate, since it is the oppressive activities by the government itself, or by some of its agents, that is of concern. Thus, the link between the identity of the rule violator and the target of sanctioning is more direct than in economic regimes.

Scientists and environmental action groups are likely to emerge as the most credible monitors of future international environmental regimes. In many proposed schemes, governments would bear the brunt of punishment for allowing domestic corporations to violate internationally established restrictions. For example, in the Ozone Convention, national governments agreed to establish guidelines for certain emissions for all industrial activities within their borders. Each government is delegated to incorporate these into its own legal system. Then it remains up to the governments involved to decide how to allocate these limits to domestic corporations.[10]

9.7 Category 7: Private Monitored-Corporation Sanctioned

Innovative proposals to establish a market in pollution permits (e.g., Victor 1991) might retain a major governmental influence in setting limits on these permits, but the underlying logic is fundamentally different. Since these permits would be purchased by corporations, the onus for exceeding limits would fall on individual corporations. That is, the overall emissions within a given territory might exceed the limit that would have been set under some international convention, but as long as the corporations polluting that territory had obtained sufficient permits, there would be no violations of that regime. A regime of that type would fall under a new category of private monitoring and sanctioning of corporations, marked by Category 7 in Table 2.

9.8 Category 8: Government Monitored-Private Sanctioned

In Category 8 regimes, private groups or individuals are subject to sanctions imposed by other governments. Proposals for establishment of a New International Information Order (NIIO), in which international news media would have been subject to explicit regulation by governmental authorities, would point toward such a regime, since disgruntled governments would supposedly have been able to punish news organizations for unflattering news reports, but this regime was not established. Examples of Category 8 regimes are extremely rare, with perhaps the best example being the war crimes trials after World War II, in which the victorious powers established tribunals to establish individual guilt for crimes considered unacceptable within the standard tenets of the laws of war. More recent examples include abduction of reputed terrorists to stand trial in the country in which their victims lived, or the practice of using U.S. courts to try deposed dictators for corruption (e.g., Marcos and Noriega). Complete realization of this type of regime awaits establishment of a new constitutional order at the global level.

9.9 Other Combinations

The remaining categories are less directly relevant to international regimes, at least as they are normally conceptualized. An example of the type of issue that would arise in a regime in which corporations monitor and sanction each other would be typical cartel arrangements, which are often technically illegal. In other situations, corporations may monitor each other but receive sanctions from some external source, as in cases where one

corporation sues another for patent infringement. Our understanding is that such disputes can usually be handled under the confines of existing "private international law," which differs from "public international law" in that it deals with the activities of groups and individuals rather than the activities of public authorities (usually in terms of national governments). Further development of the international legal system toward an increased similarity to domestic legal systems might well prove a key step in transforming our current state-centered system into an entirely new form of world order, but for now, the remaining cells in Table 2 are left blank.

10 ADDITIONAL CONSIDERATIONS

In order to expand this monitoring and sanctioning analysis to include the remaining design principles discussed above, a systematic survey of international regimes could be organized around the following additional questions:

- How many actors are involved? Two, a few, or many?
- Do actors have common or complementary interests? Are the actors relatively symmetric in resources and perceptions? Or do gross inequities exist in these areas? Do actors share a common understanding of the issues?
- Was the regime established by a single hegemonic power? Or by a small group of leaders in that field of endeavor, after they had attained their position of leadership? Or was it established before oligopolistic position (or its equivalent) could be attained?
- What are the procedures for change in membership? Do new members qualify by attaining recognition as a sovereign state? Or must they engage in some qualifying activities? Must current members vote on admission of new members?
- How are rules established and altered? Can rules be changed during regular meetings of representatives of participating parties? Or must special global conventions be held?
- What arenas exist for the resolution of disputes? How are decisions enforced on the parties? How likely is it that disputing parties will resort to military force?

In lieu of a comprehensive survey, discussion of a few examples may be useful. Bilateral regimes include relations between adversaries (U.S.-Soviet arms control) and allies (demilitarization of the U.S.-Canadian border). Antarctica is a classic example of a regime established by a relatively symmetric group of leading states that took control before the rest of the world could get involved; only those governments actively engaged in Antarctic research can quality for participation in Antarctic governance. The Law of the Sea involves all countries of the world, and it is a rare example of efforts to impose regulations on an emerging technology (deep sea-bed mining) before it can establish its own practices. The Law of the Sea emerged from some 15 years of complex global negotiations, but the Ozone Convention required considerably less time to complete and to revise towards stricter standards.

In summary, the basic ideas underlying the analytical framework presented here are that those international regimes that are most effective are likely to have been established by interested parties with common or complementary interests, shared cognitive understandings, and relatively symmetrical capabilities. But probably the most important point is that a successful regime must inspire those actors most directly affected by that regime to engage in regular monitoring activities. Actors should also have access to a graduated scale of sanctions, flexible procedures for revising rules, and a well-established arena for resolution of the disputes that will inevitably arise. In the international arena, the diversity of actors greatly complicates analysis, and considerable research must be completed before the utility of this theoretical framework can be adequately assessed.

11 FURTHER REFLECTION ON THE NATURE OF GOVERNMENT ACTORS

Another important consideration is the nature of the political order within which any "national government" or "state" acts (V. Ostrom 1991a).[11] Open political orders in which contestation is the

norm can have dramatically different consequences for possible forms of international cooperation than political orders more closely resembling the unaccountable sovereign portrayed in Hobbes's *Leviathan*. In open political systems, for example, groups of individuals are allowed to form various types of associations that would be deemed illegitimate or unlawful in a closed political system. Thus, it would be difficult to rely on NGOs or economic corporations as monitors in any international regimes among Hobbesian sovereigns. Such associations would be encouraged in regimes formed by governments of open political orders. Furthermore, the state-centered monitoring activities characteristic of a Hobbesian system may remain insufficient to sustain global cooperation on climate change, since there is no reason to expect that sovereign states would always provide accurate information on their own activities. (We address the limitations of state-centered monitoring in our discussion of arms control regimes below.)

Any international regime that includes governments of very different political orders suffers from additional complications. This difficulty is most apparent in regimes covering North-South relations. Many governments in the Third World are based on nontax sources of revenues (national revenues obtained largely from rents, concessions, and/or donors), hidden taxes, and/or brute force. Government officials, who do not need to rely on the *consent* of taxpayers and obtain substantial revenue from mineral sales and from selling agricultural produce at world market prices (while buying at lower controlled prices), face fewer incentives to invest resources efficiently to generate real economic growth than do governments that are answerable to citizen-taxpayers. When large quantities of donor funds are added to the fiscal resources of a central government, centralized opportunities to seek rents increase still further (Bates 1983). Amos Sawyer, reflecting on the emergence of autocracy in Liberia, stresses the perverse effect of overreliance on obtaining revenues from forest concessions:

> The impact of these arrangements on the society was profound. First, they increased the capability of the government in a manner that further strengthened institutional capacities at the center. The proprietary role of the government — the president, in other words — was enormously increased. Reliance on rents, royalties, and profits gave the presidency an independent existence, with the capability to operate without any of the pretensions of accountability that would have been required had the president been dependent on income or other taxes raised directly from the people (Sawyer 1992, p. 261).

There are two problems at the international level when some of the national participants rely heavily on rents for revenue — particularly when these rents are based on forest products. It is not just that these national governments have a delicate political issue to face in limiting the extraction of forest resources. Such an action might eliminate the major source of revenue to the government itself. Furthermore, if a government has not yet established accountability to its own citizens, it is hard to know how to develop trust and accountability at an international level.

12 THE LIMITATIONS OF COMPUTER AND GAME MODELS

We now discuss some implications of this multilevel theoretical perspective for the development of formal models of international environmental regimes, specifically simple game theoretic models and large-scale computer models. Much of the concern with global warming is based on the conclusions of large-scale computer models of atmospheric circulation patterns and related physical processes. These models provide a firmer scientific basis for similar concerns about the sustainability of current trends popularized in a series of modeling exercises initiated by the influential book *Limits to Growth* (Meadows et al. 1972). (For extensive reviews of computer models of dynamic feedback relationships among various demographic, technological, resource, economic, and political factors, see Hughes 1985; Onuf 1983.)

The political economic micro foundations of both types of global models tend to be overly restrictive or poorly articulated. Such models typically presume the existence of readily manipulable policy "levers" that can immediately change the behavior of all relevant actors. In order to evaluate the consequences of alternative policy proposals, modelers must presume that the underlying

patterns of behavior will remain the same, whether that behavior occurs by habit or as the aggregate result of market processes. But we have emphasized the importance of devising institutional arrangements that enhance capabilities for artisanship in which individuals creatively design new responses to emerging problems. In addition, the vast array of private actors affecting global environmental change will adapt to any policy change implemented by an international convention. A considerable tension exists in relying on models of constant processes while trying to change the underlying processes themselves.

One adaptation that can be expected is technological innovation. Substantial evidence exists that when relative factor prices have changed substantially, technological changes have occurred with a distinct factor-saving bias (Binswanger 1974, 1977; Binswanger and Ruttan 1985). When regulations specify technology rather than changing those incentives that help to induce technological innovation, less positive adaptations are stimulated. No model that fails to consider these responses can adequately represent the implications of any globally mandated policy change. Previous critiques along these lines have focused on the potentially beneficial consequences of technological innovation inspired by increasing resource costs, but it is also important to consider the implications of induced innovation in political and economic institutions (see, for example, North and Thomas 1973; Davis and North 1971; North 1981, 1990, 1991).

Simple 2x2 game models stand in stark contrast to massive computer models of global dynamics. By eschewing any pretensions to completeness, simple game models, especially of Prisoner's Dilemma, Chicken, and various coordination games, have proven to be very useful devices for highlighting some fundamental dilemmas of collective action. One can draw on many of the recent developments in game theory, public choice theory, and microeconomic theory to go beneath the surface of an "issue area" in an attempt to isolate structures of situations that occur in many different guises and forms across different issue areas.

A particularly influential body of research focuses on lessons drawn from simple game models in which self-interested or egoistic actors cooperate in the absence of any centralized authority. Influential works by Axelrod (1984) and Oye (1986) emphasize that cooperation (in repeated Prisoner's Dilemma games) is facilitated in situations involving a small number of actors with common or complementary interests and who perceive a long shadow of the future (or low discount rate). Cooperation can also be facilitated by increasing the transparency of a regime (meaning the extent to which individual behavior can be monitored and sanctions focused on rule violators). Other modelers examine the implications of various factors on the range of equilibria solutions for these simple models. For example, a wider range of cooperative behavior becomes feasible if players are allowed to link their behavior in different issue areas (E. Haas 1980; McGinnis 1986) or have access to some means of informally correlating their behavior (McGinnis and Williams 1991).

Although the basic insights of these models remain relevant to global cooperation on environmental change, these lessons should be applied with care. Nearly all game models suppose that the 2 (or n) players are fundamentally symmetric in the sense that they play similar roles (see Gardner and Ostrom 1991). Although game players differ in their exact preferences and in their relative resource endowments, they typically have the same or similar set of possible actions. More generally, regimes may include a diverse set of actors, with very different interests and capabilities.

While the n-person, iterated Prisoner's Dilemma game has frequently been equated to the commons problem (as if there were only one commons problem), a much richer array of specific n-person games are found in situations that have the two initial attributes of CPRs. Depending upon the specific rules-in-use, CPR problems can be represented as rent dissipation problems, assignment problems, or technological externality problems. Some of these "typical" structures found in CPR situations lend themselves both to mathematical modeling (see, for example, Gardner and Ostrom 1991; Weissing and Ostrom 1991a,b) and to empirical research conducted in an experimental laboratory (see Ostrom, Gardner, and Walker 1992, forthcoming; Walker, Gardner, and Ostrom 1991; Walker and Gardner forthcoming; Ostrom and Walker 1991).

More elaborate, extensive form game models have recently been used to model the variety of monitoring activities that can be used to maintain stable common pool resources regimes in situations in which rule violations cannot be entirely eliminated (Weissing and Ostrom 1991a,b). These latter models demonstrate that it is often effective to combine different types of monitoring activities, with individuals playing specialized monitoring roles being supplemented by self monitoring by the individuals most directly involved. Since there is no way to eliminate all temptation for shirking on the part of monitoring officials, it is useful for the individuals involved to also monitor the level of effort exerted by officials selected to do the monitoring. Even then, rule violations are not totally eliminated, but their effects are sufficiently constrained to allow the overall regime to remain in operation. In short, equilibrium solutions do not require perfect cooperation.

The monitoring models of Ostrom and Weissing suggest important lessons for the regime literature, much of which is based on much simpler models containing only a single type of actor. Even when national governments establish some intergovernmental organization intended to monitor compliance with some specific agreement, they also engage in a substantial amount of self monitoring. (We discuss this issue in the context of arms control regimes below.) But in practice, the most effective monitors of compliance with international trade agreements, for example, are not national governments themselves but rather those economic corporations seeking to prevent their competitors from gaining an unfair advantage by circumventing domestic laws or international treaties.

Our purpose in presenting this preliminary typology of international regimes is to suggest that a much wider range of possibilities exists than has generally been realized in the existing literature on international regimes. Although the activities of corporations and interest groups receive considerable attention in case studies, formal models of international cooperation continue to focus on a single, undifferentiated set of actors. Richly detailed case studies of specific regimes that incorporate the actions of a wide range of actors generally lack a coherent, well-articulated theoretical framework that makes sense of systematic differences in the interests and capabilities of different actor types.

But it is the modeling literature that is most guilty of ignoring the diversity of actor types. Far too sweeping conclusions about the limited possibilities of cooperation have been based on models including only a single undifferentiated set of actors. In our opinion, to fairly model the variety of configurations available for use in designing international regimes, the goals and behavior possibilities characteristic of each of the following actor types would have to be specified:

- Governments: Open political orders, coercive political orders, and concession economy-based;
- Corporations: Domestic and MNCs;
- NGOs and INGOs; and
- IGOs.

Unfortunately, we cannot point to any examples of multiple-actor-type models of international regimes, but we strongly encourage their development. Consider, for example, the problem of monitoring compliance with emissions standards that might be established as part of a global climate regime. If corporations find that compliance with some of these controls would lower their profits, they are likely to seek some way of circumventing them. Yet other aspects of the regulations might have relatively little effect on profit margins and yet a more direct impact on environmental degradation. A corporation's competitors would be particularly concerned about violations that would unfairly lower costs of production, whereas nongovernmental environmental groups would be particularly concerned with violations that adversely affect the environment, whether or not they affect prices.

A model of a game with multiple monitors could be set up, in which corporate competitors would receive benefits from uncovering the first type of violations, and NGOs could receive benefits (through increased exposure to potential contributors or providing satisfaction to their current members) by detecting the second type of violations. An additional step might be added to represent the

ability of conflict resolution mechanisms to correctly determine whether or not violations had actually occurred. Officials of the conflict resolution arenas (whether representatives of governments, IGOs, or other institutions) would have an incentive to keep the proportion of correct judgements sufficiently high to insure a continued perception of the entire scheme as fair and equitable, but they may also be subject to the temptations of bribes to overlook certain violations. A formal model of this monitoring scheme might help clarify the extent to which multiple types of monitoring activities can be combined to achieve lower equilibrium rates of cheating or other properties.

This informal sketch suggests that considerable insights might be derived from very simple models of international regimes in which these different actor types interact on a regular basis, even if only a few types are included in any given model. Such models might help specify circumstances under which different arrangements most effectively enhance the prospects for stable patterns of cooperation. Empirical analyses can suggest the range of possibilities that have already been realized in various circumstances, but formal models complement empirically based studies by giving them a broader and more rigorous foundation.

In summary, we advise that computer models of the consequences on global environment of alternative policy changes be used with great caution. Simple game models can play an important role in helping clarify the underlying dilemmas of collective action, and computer models can help strengthen our intuition about the implications of feedback processes in complex systems. Response to global change is a massive, ongoing process of evaluation and re-evaluation. Yet if the modeling effort is attempted too early in this process, one may develop a perfectly good model, but a model of a different situation than the one of interest. Our focus should instead lie on enhancing the ability of individuals and collective groups to design institutional arrangements that facilitate creative, locally based adaptation to changing circumstances.

13 LESSONS FROM ARMS CONTROL REGIMES

One important means to understand the range of possible solutions to collective action problems at the international level is to examine some examples in some detail. In this section we attempt to draw some lessons from examples of arms control regimes. (For an excellent survey of the lessons that can be drawn from the Law of the Sea Treaty and the Ozone Convention, see Sebenius 1991.)

Some scholars are concerned that global environmental change will be a new source of conflict, since unaccustomed deprivations will exacerbate contention over access to various resources (Homer-Dixon 1991; Jodha 1988). However, the novelty of environmental conflict can easily be exaggerated, since resource issues have long been a source of international conflict. Since efforts to eliminate international conflict are unrealistic, the basic problem has always been managing conflict and preventing disputes from escalating into war. Similarly, some global climate change will occur no matter what. A robust global regime must find some means of dealing with the conflict that arises from these changes. Thus, a brief examination of earlier efforts to manage conflict would seem to be in order.

It is also the case that security regimes are much simpler to examine, since analysis of security regimes can reasonably focus on the behavior of national governments. Although any analysis of economic and environmental regimes must also include the behavior of other types of actors, many of the same principles that have proven successful in dealing with security problems may prove equally useful in more complex configurations of actors.

The historical record of arms control efforts provides several lessons for the types of monitoring activities and sanctioning options needed to establish and maintain international cooperation. In evaluating these examples, it is important to keep in mind that the connection between those actors engaged in monitoring and those being

sanctioned is more direct and clear than in other areas of international relations. Regimes in other areas require more complicated relationships among a wider range of actors. Since national security is one of the primary concerns of all national governments, these governments are exactly the right actors to monitor activities related to their own security, but other types of actors more directly affected by economic or environmental regimes are likely to prove more effective monitors in these issue areas.

Analysis of international cooperation on security issues has long been plagued by high-blown rhetoric and unrealistic expectations (neither of which is in short supply in the literature on global environmental change). In classic "idealist" accounts of the interwar period, emphasis is typically placed on the establishment of formal institutional structures meant to supersede existing national governments or new legal systems intended to restrain governments from undertaking certain activities. Yet the record of the League of Nations (which supposedly established a global collective security system), the Kellogg-Briand Pact (which supposedly outlawed war as an instrument of national policy), or the Washington Naval Conference (which set limits on naval forces) is bleak. Most efforts undertaken since World War II have had less grandiose goals, and some of these efforts have proven remarkably successful.

Bilateral arms control treaties between the United States and the Soviet Union have been self monitored, with both governments relying on what are euphemistically called "national technical means" (spy satellites and other forms of espionage) to observe the other superpower's force deployments and weapons tests. Indeed, meaningful arms control treaties became feasible only after reconnaissance satellites were developed that enabled each superpower to monitor the other state's military activities with a relatively high degree of confidence (Gaddis 1987). Scientific advances have played a similarly crucial role in identifying the problem of global climate change as well as providing means for monitoring its development.

In the SALT treaties, accusations of violations were raised in a bilateral, ad hoc institution of the Standing Consultative Committee, which served primarily as a means of conveying concerns to the other side. Each government had other means to let the other know of its ability to detect violations, although neither would tell the other all that it knew for fear of revealing the limits of their own intelligence-gathering capability. Throughout the period of these treaties, there was considerable controversy about the extent of Soviet cheating, which occasionally became an important issue in U.S. domestic politics. In retrospect, it is clear that the Soviets repeatedly pushed at the edges of the agreement. It is hard to determine, however, whether this means they were (1) trying to get away with whatever they could, (2) probing to find the limits of U.S. detection capabilities, or (3) simply taking advantage of the latitude provided by ambiguities of the treaties. In any event, this uncertainty greatly complicated later negotiations, since critics could continue to insist that better detection capabilities were needed.

These controversies necessitated more elaborate inspection schemes in INF and START treaties, including relatively permanent inspection stations to be established outside certain production facilities and provisions for a limited number of surprise inspections elsewhere in each country. These provisions can be seen as a successful achievement of terms long advocated by the United States, even though these same provisions led some U.S. military experts to express concern that the Soviets would gain too much information from these activities! It now appears that many of these remarkable procedures may never actually be implemented, given the recent dissolution of the Soviet Union and ongoing massive cuts in strategic arsenals.

One disturbing lesson of U.S.-Soviet strategic arms control is how politicized monitoring efforts can be, even when undertaken by supposedly objective experts. Even in areas in which technical consensus is available, expert advise may have little impact on policy. One of the most important multilateral arms control agreements is the 1963 Partial Test Ban Treaty, which prohibited nuclear weapons tests in outer space, the oceans, or the atmosphere. This treaty was to some extent a response to a massive public outcry against world-wide radioactive fallout from atmospheric tests, specifically the detection of radioactive isotopes in milk products. In retrospect, limitations of the

treaty were relatively easy to obtain, since any tests in these areas could be easily detected from remote locations (i.e., from satellites) and since underground tests were allowed to continue.

Progress toward a comprehensive test ban has been virtually nil, despite a widespread consensus among seismologists that any meaningful levels of underground tests could be distinguished from naturally occurring earthquakes by a relatively minor expansion of the worldwide system of earthquake monitors, many of which could be remotely controlled. Despite this clear realization of the technical feasibility of a comprehensive test ban, both sides insisted on being able to continue to test in order to develop new weapons systems (such as components of SDI) as well as to ensure the potency of existing warheads. This example demonstrates that developing a consensus among technical "epistemic communities" is not generally sufficient to insure international cooperation, even though such a consensus may often be a necessary precondition for establishing a sustainable regime (see P. Haas 1992). But technical agreement is useful only up to a point. Eventually some political compromises must be made. Since compromises are likely to attract continuing controversy, the need for information dissemination and political bargaining never goes away.

Some types of global regimes for control of CO_2 emissions would involve extensive inspection procedures that corporations are likely to find very troublesome, given their natural reluctance to reveal industrial secrets to their competitors. Indeed, exactly these concerns have slowed progress on verifying international treaties supposedly controlling the spread of chemical and bacteriological weapons. In this area, the basic problem is that the same factories can produce chemical weapons or commercially valuable products. Intrusive inspection schemes would be required to determine whether chemical weapons are being produced.

The nuclear nonproliferation regime demonstrates the problems entailed in comprehensive agreements among actors with diverse interests. The basic logic of this agreement was the following deal: states capable of building nuclear weapons pledged to help nonweapons states build nuclear power plants in exchange for their agreement not to try to obtain nuclear weapons for themselves. The problem is that civilian and military uses of nuclear technology cannot be neatly demarcated, since many of the same procedures useful for power supply are also relevant to the development of nuclear weapons.

An international agency (the IAEA) was established to monitor the nonproliferation regime, and it was staffed by technical experts in the field. However, the inadequacy of its monitoring efforts was dramatized by inspections of Iraqi facilities after the Gulf War, which revealed a very extensive program in nuclear weapons development (see Pilat 1992). This example suggests a deeper problem with the IAEA. Many of its clues concerning where to look for evidence of nuclear weapons facilities came from U.S. intelligence sources, and this reliance on the CIA exposed the IAEA to charges of being an American "lackey." On the other hand, is not clear how independent sources of intelligence could be arranged for use by an international agency. Nor is it obvious that an international intelligence service should be welcomed.

In environmental regimes, some way must be found to monitor compliance without forcing corporations to forfeit trade secrets to their competitors. This suggests the importance of remotely positioned sensors, especially on satellites. Limits on emissions of greenhouse gases may prove much easier to monitor than weapons production, since it has been suggested that so-called "carbon taxes" could be levied on energy inputs. If this were feasible, direct monitoring of the output of individual factories might not be required. However, this procedure would require that monitors have access to a large amount of information concerning economic transactions, which might easily be falsified. Also, under many proposed schemes, sanctions would be applied to all exports of an offending country, even if only a few corporations were responsible for violations of emissions limits. In the long run, more intrusive technical monitoring stations would need to be established in order to attribute responsibility to individual corporations. After all, it is the behavior of individuals and corporations that must be changed if the problems of global climate change are to be addressed — simply changing governmental policies solves nothing unless these policies successfully elicit the desired response by other actors.

To return to the simpler confines of the U.S.-Soviet case, strategic arms control negotiations were complicated by their differing (and changing) views toward the goal they should be pursuing. In the early stages of the SALT talks, the United States (under the Nixon administration) emphasized the desirability of maintaining a situation of mutual assured destruction (MAD) that the Soviets countered was less ethical than relying on defense. Later, during the Reagan's administration's pursuit of a space-based strategic defense system, the United States emphasized the ethical merits of defence over deterrence, and Soviet leaders and Reagan's domestic critics sang the praises of the MAD doctrine. Also, throughout these negotiations, the United States stressed its concern about the destabilizing nature of the land-based multiple-warhead intercontinental ballistic missiles (ICBMs) that play such a dominant role in the Soviet force structure. U.S. concern with Soviet ICBMs led to insistence on complicated limitations on various categories of weapons systems in hopes of indirectly shaping the Soviet force structure in ways the Soviets were unwilling to accept. In resisting these efforts, the Soviets forced U.S. negotiators to accept occasionally ambiguous terms. Later innovations in Soviet weapons (which they may well have been planning at the time the treaties were signed) could be interpreted as violating these ambiguous terms. This perception of Soviet cheating in turn increased pressures for obtaining even more specific restrictions on Soviet forces, which the Soviets resisted even more forcefully. In short, a lack of common understanding of the nature of the problem continued to complicate strategic arms negotiations.

On the other hand, leaders of both superpowers shared a clear and common understanding of the dangers of losing control of their own forces during a crisis. Perhaps the most successful area of arms control does not concern weapons per se, but rather the establishment of direct communication links between U.S. and Soviet leaders that were painfully lacking during the most serious confrontation of the Cold War era, namely, the 1962 Cuban Missile Crisis. Establishment of a teletype "Hot Line" and its subsequent upgrades in technology, along with other confidence-building measures (Hughes 1991, p. 286), are included under the rubric of "quiet arms control" (Carnesale and Haass 1987). These communication links definitely served their purpose. The record of quiet arms control suggests important lessons for advocates of comprehensive conventions on greenhouse warming and other aspects of global climatic change. Crucially important small steps toward a better future were most easily taken when leaders eschewed trying to solve all the world's problems at once.

In this brief examination of arms control regimes, we have drawn a series of lessons for environmental issues. The most fundamental lesson is that, despite the highly technical nature of both nuclear and environmental issues, the heart of the matter remains contention among collective action organizations (whether they be states, corporations, or private interest groups). International cooperation is an inherently political matter that cannot be reduced to simple technical formulas.

14 CONCLUSIONS

In this paper, we have drawn lessons from a wide range of research traditions. This survey of institutional research on local commons and on international security regimes should lead one to be cautious about insisting on global steps toward global solutions. The most important institutional changes for coping more effectively with the conflict likely to grow out of global change issues may be the development of open information and communication regimes to enhance the capabilities of actors at many levels to come to a better common understanding of both the physical as well as the economic and social aspects of global climate patterns. Global steps may well be accomplished most effectively if many small steps are taken first, providing these steps can be sustained and complement wider efforts.

We conclude with a brief recapitulation of the major conclusions of our analysis.

- Analyses of responses to common-pool resource dilemmas have demonstrated that a wide variety of monitoring and sanctioning schemes can be established and maintained by the individuals and groups directly involved in collective action dilemmas. Continued reliance on choosing between the standard policy options of market-based privatization or state-based management is far too constraining.

- The current emphasis on global solutions based on international conventions on managing environmental change reflects an incomplete understanding of the inherently multi-level nature of this problem. A global regime is more likely to be robust with respect to significant changes if it implies institutional arrangements at the local level that satisfy the design principles identified in analyses of common-pool resource regimes.

- The existing literature on international regimes exhibits excessive concentration on the behavior of national governments and intergovernmental organizations. Much more attention should be paid to the incentives and activities of economic and other types of collective actors. Policy proposals emerging from these analyses should consider ways in which these diverse interests can be combined to establish robust regimes.

- Emphasis should be placed on understanding the ways in which actors and outcomes at one level of interaction (local, national, regional, global) affect other levels. Institutional arrangements at different levels should be "nested" in order to insure that their effects reinforce each other rather than acting at cross purposes.

- Scientific groups have important contributions to make in furthering our collective understanding of global processes and in monitoring compliance with any future agreement. However, if comprehensive models of physical processes are to be used to evaluate the implications of alternative policy regimes, some way must be found to incorporate the implications of the technological and institutional innovations that are likely to be induced by global climate change.

- Examples from "quiet arms control" and regional pollution control suggest that early concentration on smaller and more manageable portions of inordinately complex problems can establish a sound foundation for future cooperation.

- Changes in the global environment will have differential effects. New forms of conflict can be expected to arise. However, we are unlikely to be able to predict the forms such conflict will take. Emphasis should be placed on developing effective means of managing conflict whenever it occurs.

- Contestation should be encouraged at all levels. Information should be solicited from individuals and collective groups with varying interests and perspectives. Arenas for conflict resolution at the local, national, regional, and global levels should be established to help contesting groups arrive at common solutions.

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16 END NOTES

1. It is somewhat paradoxical that environmental regulations also substantially increase the cost of monitoring environmental conditions. A current example is the strict measures adopted by the signatories to the Antarctic Treaty that make conducting research more difficult. "Not only are there environmental impact statements to file, but there are also rules on treatment of indigenous wildlife, prohibitions on the importation of alien species to the continent (no more sled dogs, for example), and rules on waste disposal" (Palco 1992, p. 277).

2. See Manne and Richels (1991, forthcoming) and Nordhaus (1991) for estimates of the costs involved in meeting proposals to limit total carbon emissions to their 1990 level. See also Grubb (1989) and Morgenstern (1991).

3. See papers by Gleick (1991), Okidi (1991), and Suhrke (1991) presented at the Conference on Environmental Change and Acute Conflict in Toronto in the fall of 1991 and also those by Jodha (1989), Latin American and Caribbean Commission on Development and Environment

(1990), Task Force on International Development and Environmental Security (1991), and World Resources Institute (1991).

4. See E. Ostrom (1990); Gardner, Ostrom, and Walker (1991); Gardner and Ostrom (1991); Tang (1992); Blomquist (1992); National Research Council (1986); McCay and Acheson (1987); Berkes (1989); Pinkerton (1989); Ostrom, Feeny, and Picht (1988).

5. See Robinson (1991) for an imaginative application of the results of our micro-CPR environments to problems of the global commons.

6. Hardin also contributed to the contemporary presumption that there were only two solutions to this kind of problem. The "only" alternatives that he saw to the commons was what he called "a private enterprise system," on the one hand, or "socialism" on the other (Hardin 1978, p. 310). He proposed that change would need to be instituted with whatever force was needed. In other words, "If ruin is to be avoided in a crowded world, people must be responsive to a coercive force outside their individual psyches, a 'Leviathan' to use Hobbes's term" (p. 314). Contrary to many casual, contemporary descriptions, the English commons was not an open-access CPR (see Dahlman 1980).

7. Monitoring problems plague many efforts to understand patterns of global warming. The hypothesis that global warming was responsible for the "bleaching" of coral reefs in the Caribbean cannot be established due to the lack of adequate data. Researchers are calling for a major monitoring effort but point out that the number of different variables required and the number of sites required would lead to a monitoring effort that would cost millions of dollars a year (see Roberts 1991).

8. We do not think it is possible to elucidate necessary *and* sufficient principles for enduring institutions, because it takes a fundamental willingness of the individuals involved to make any institution work. No set of logical conditions are sufficient to insure that all sets of individuals are willing and able to make an institution characterized by such conditions work.

9. These principles are drawn from E. Ostrom (1990) and are explained in more detail therein.

10. This logic is similar to procedures used in allocation of the electromagnetic frequency spectrum: The ITU allocates frequency ranges to national governments, which then allocate specific frequencies to local broadcasters, according to their own rules and procedures. In the United States, this allocation is carried out by the FCC, and broadcasters closely monitor each other's behavior.

11. See Neitschmann (1991), which examines the historical struggle of the Miskito Indians to retain control over what they consider to be their own territory and resource base by a "foreign" state, even though it is this "state" that is recognized in the international realm.

Comment 1 on Workshop in Political Institutions

Meso-Level Regimes and Robust Plans

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The paper by McGinnis and Ostrom is important for at least three reasons. First, it provides a number of useful guidelines for the construction of political regimes that can control commons problems (global warming being one example) for generations yet that do not require an external enforcing authority. Second, the paper introduces some important concepts and theoretical tools from political science, history, and economics that can be used to further study such regimes. Finally, and I believe most importantly, the paper is an excellent example of the type of study that needs to be done if the social control of global warming is to be taken seriously. McGinnis and Ostrom remind us that it is not enough to impose rules; these rules must be backed by stable self-monitoring and self-correcting institutions.

Since I am in agreement with most of the points of the paper, my remarks are largely suggested extensions rather than criticisms. I focus on three issues: (1) I extend their discussion of local systems and international systems to the national and regional level; (2) I discuss a typology for how systems might fail, and (3) following John Eddy's opening comments at the conference, I make some observations on communication between the natural and social sciences.

1 LEVELS OF ANALYSIS AND SELF ORGANIZATION

The empirical studies in the McGinnis and Ostrom paper, which are based on Ostrom's book, *Governing the Commons*, are generally local. In a terms of the basic levels of analysis shown in Table 1, most of their analysis is either at the micro level (CPR problems) or the macro level (international regimes).

As McGinnis and Ostrom point out, when dealing with the international systems as a whole, there is a good empirical reason for focusing on relatively autonomous local systems. Since these systems have been stable in the absence of meso-level (i.e., state) intervention, they are applicable to the quasi-anarchic macro level. Ironically, stable regulatory regimes at the international level may have more in common with those at the local level than they do with those at intermediate levels, since the intermediate levels usually presuppose the existence of political institutions with monitoring and enforcement capabilities. One should note, however, that the concept of "the state" is very much an illusion derived from long experience; in fact, national governments are nothing more than unusually stable and long-lived regimes that solve an assortment of collective goods problems.

This recognition by Ostrom and McGinnis — that the study of CPR regimes must commonly begin with an understanding that there is nothing special about the state — is the political science equivalent of Isaac Newton's recognition that the moon was falling. To the common wisdom, it is clear that the moon is not falling; to the common

TABLE 1 Levels of Analysis

Micro	Local and individual
Meso	National and regional
Macro	International system

wisdom, it is clear that systems with sovereign enforcement are very different than those that do not have this characteristic (i.e., the international system or local CPR systems). Only by recognizing that the common wisdom is wrong can one begin to develop the theoretical tools to understand the fundamental workings of the system.

McGinnis and Ostrom characterize the robust CPR systems as "self organizing." This characterization is correct in the sense that the design and implementation of these systems is not imposed in the short term by a sovereign; contrast, for example, the design of an aircraft or a computer. However, the utility of the concept of short-term "self organization" in its pure form is somewhat limited, for the simple reason that humans *plan*, and even the most simple human organizations are the product, to some extent, of foresight and design. In this respect, the CPR regimes are quite different than physical self-organizing systems such as the convection cell in a thunderstorm or primordial FNA.

Rather than self organization, I find the following two characteristics most important for robust CPR regimes. First, they are *self monitoring*: These systems solve the problem of *quis custodiet ipsos custodes* (i.e., who guards the guards, or who monitors the monitors). As McGinnis and Ostrom point out, solutions other than a sovereign exist for this problem, and some of them are surprisingly simple. Second, they are *self correcting*: They can transmit a working set of rules across generations; they can correct deviations from those rules; and they can adapt the rules to fit new circumstances in a fashion that preserves the system.

In the long term, the self-correcting and adaptive character of robust systems does provide a form of self organization. For example, the Constitution of the United States was originally designed to handle the collective goods problem of a small, isolated, agrarian set of newly independent colonies; 200 years later that same document governed an industrial superpower with territory spanning a continent and global political commitments. While the original document was not self organized in the short term (i.e., its authors had very explicit and carefully argued reasons for constructing it in the fashion they did), it has become more of a self-organized system as it has adapted to systems vastly different than those for which it was originally conceived.

2 STABLE REGIMES AT THE MESO LEVEL

Since the examples provided by McGinnis and Ostrom are either at the micro or macro level, I will suggest some at the meso level, since much of the work on solving the global warming commons problem is likely to involve regimes at either the national or regional level, even though the problem itself is global. (This is not to imply that those authors are unaware of these examples; I am simply using this opportunity to elaborate on them.) In general, I think many of the characteristics of these systems will reinforce the lessons from the McGinnis and Ostrom studies of local systems. In choosing these examples, I looked for cases that had lifetimes in excess of two centuries and survived considerable turmoil in their external environment.

2.1 National Systems: Federal

The U.S. Constitution (1789 to the present) and the Swiss confederational system (15th century to the present) are examples of two federal systems that have the characteristics of self correction and self monitoring. Both survived the Industrial Revolution; in the process, both the United States and Switzerland became among the wealthiest nations on earth and survived a variety of changes in their external environment.

The success of these two systems has led many political scientists to see federal systems as the obvious answer to stable meso-level systems. The past 50 years have indicated otherwise; the federal scheme has failed or at least appears to be failing in countries such as Pakistan, Nigeria, Canada, Yugoslavia, and Belgium. Federalism alone is not the answer. Additional research is needed to determine what rules, implicit or explicit, operate to stabilize federal structures that, on their surface, appear potentially very tenuous.

2.2 National Systems: Hierarchical

The two long-lived hierarchical systems of note are the Tokagawa Shogunate (1600-1868) and the

British system of a parliamentary monarchy (1688 to the present). (My thanks to Barry Hughes for pointing out this example.) These systems are in many ways quite different (e.g., the Tokagawa system was considerably more static than the British), but they are both characterized by decentralized control under the guidance of very general guidelines, a relatively rigid class structure, the constant accountability of the nobility to the central system (through the *sankin kotai* system in Japan* and the Parliament in Britain), and the advantage of the physical isolation of island nations. Interestingly, both systems provided a "soft landing" into the industrial age, absorbing revolutionaries from the hinterlands (industrialists from Kyushu and Scotland respectively) rather than breaking under revolutionary movements. Both systems also evolved highly autonomous bureaucratic services that insulate much of policy from democratic influences.

2.3 Regional Systems: The Westphalian State System

The Westphalian nation-state system (1648 to the present), which evolved in Europe following the century and a half of chaos occasioned by the end of feudalism and the Protestant Reformation, can be usefully considered a stable regional system, even though it is typically considered a macro-level "international" system. The regional system, composed of a relatively small number of territorially contiguous, legally equal, sovereign states, was unprecedented in European history and yet survived democratization, industrialization, and the major wars of the first half of the 20th century.

The Westphalian system underwent a number of self modifications. The system adapted to a transition from aristocratic to democratic rule. It easily expanded to encompass non-European industrialized states such as the United States and Japan in the late 19th century, then went on to be adopted throughout the rest of the planet. The system developed, and in a sense co-opted, a variety of international organizations. It has changed many of its own norms. For example, the "state monopoly on violence," now considered fundamental to the system, did not operate fully until the 19th century with the control of dueling, mercenaries, and state-sanctioned piracy.

2.4 Religion

The empirical — as opposed to theological — phenomenon of organized religion provides a final example of an extraordinarily stable system at the meso level; in this case, the institutions are typically transnational rather than strictly regional.

Religious belief provides psychological benefits; moreover, virtually all religious communities also provide an unusually stable environment that provides some insurance against random misfortune (illness, bereavement, etc.) through the pooling of resources. The collective goods problem is solved because there is a very strong norm, which, if believed, provides a long-term rationale against defecting from the coalition. In the Judeo-Christian-Islamic tradition, this is usually a very explicit promise of a pleasant and eternal afterlife (i.e., by engaging in short-term "irrational" altruistic behavior, one maximizes long-term benefits). Buddhism and Hinduism provide much the same norm, albeit through a diametrically opposite mechanism: an escape from eternal life rather than the promise of it.

These promises are social constructs, not empirical facts, and they are self perpetuating only to the extent that they succeed. When they do, the myth is reinforced in economic terms: Individuals trading within religious groups in which the social norms are enforced by the community obviously have much lower information costs than do individuals trading in groups in which members must be constantly alert to the possibility of defection. All of the following — Quakers and other dissenting industrialists in 18th century England and Scotland; the diamond trade among orthodox Jews in Amsterdam, New York, and Tel Aviv; the agrarian communities of the Amish in Pennsylvania, Indiana,

*This was the system of "alternate attendance" established by Iemitsu Tokugawa in 1635, which required most of the nobility (*daimyo*) to spend every other year in the shogun's court in Edo.

and Iowa; and the Mormons in 19th century Illinois and Utah — provide conspicuous examples of the economic advantages of self-enforcing communities with strict norms, which, in many instances, survive despite the efforts of sovereign authorities. Virtually any reasonably stable religious group provides at least a modest example of the practical benefits of membership in a community with strongly held norms. By doing good, one can do very well. This prosperity, in turn, appears to provide empirical evidence of the validity of the group's beliefs, which reinforces the believability of the unobservable system of sanctions and rewards.

This mechanism provides the potential for an exceedingly stable social unit. This is precisely what we observe empirically: Religious institutions are unquestionably the most long-lived and stable of all large-scale human institutions, surviving and often thriving in chaotic times that destroy all other forms of organization. Empires and ideologies are fragile and passing wisps of fashion compared to the two-and-a-half millennia record of Judaism, Confucianism, and Buddhism. The Christian monastic orders preserved Roman law through the disorder and social upheavals of the Dark Ages; Islam spread a creed from Morocco to Malaysia in an age when goods and people moved by oar and ox-cart. The assessment of modern revolutionaries such as Jefferson, Paine, Robespierre, Lenin, and Mao — that a civil religion of political ideology (be it democratic liberalism or communism) should be created to replace the function of deistic religion — was correct with respect to the social function of religion and, quite curiously, consistently and completely incorrect with respect to the ability of those secular formulations to actually provide a substitute for religion.

These meso-level systems are suggested as points of departure for the further study of robust regimes. They seem to share four of the characteristics of local systems discussed by McGinnis and Ostrom; for example, they are all relatively decentralized;* all of the systems except religion are relatively isolated; and the British, Tokagawa, and Westphalian systems all provided outwardly rigid structures in response to periods of considerable civil war and instability. Beyond this, however, there is probably ample room for studying the successes and failures of robust meso-level systems.

3 HOW SYSTEMS FAIL

McGinnis and Ostrom discuss a number of characteristics of successful systems. To extend this, I think it is also useful to consider how they might fail. On the basis of their studies and other work, I would suggest the following typology:

3.1 Design

A system may fail because it never worked in the first place (i.e., the design was flawed). For example, most people would now concede that the centrally planned economic systems devised in the early 20th century (most notably the model of the Soviet Union that was either copied or imposed in a variety of places) didn't work for some fairly straightforward reasons involving information and incentives.

Lest this seem unduly obvious, it should be noted that such systems persisted for the better part of a century despite their problems. This situation occurred because political systems, particularly those that have substantial coercive power and are relatively isolated, can be very slow to respond to feedback, when compared with market systems. Sovereign states are, by definition, monopolies, and the cost of competitive entry is very high. Once a political coalition is established that is sustainable (a criterion quite different from efficiency), it is likely to be maintained through the lifetimes of those who established it, as occurred with the Soviet system. This phenomenon is not unique to leftist regimes; the fascist regimes in Spain and Portugal showed a similar behavior.

*The day-to-day decision making is decentralized, although the imposition of the rules of the system may be centralized. For example, this distinguishes the social rigidity of Tokagawa Japan from the administrative rigidity of the France of Louis XIV, the Spain of Philip II and Franco, or the Soviet Union of Brezhnev. The British system could survive 60 years of George III; the French could not survive 20 years of Louis XIV.

Political systems generally have slow feedback, and it is difficult, in the short term, to distinguish between those that are truly robust and those that are merely surviving in a relatively static environment.

3.2 Rent Seeking

Hugh Nixon, in the March 15, 1991, issue of *Science*, observed "All successful systems accumulate parasites." Rent-seeking behavior — a phenomenon well-studied by development economists but oddly ignored by political scientists — is a second reason systems may fail. Corruption, to use the less polite word, is a failure of the self-monitoring function of the system.

The experience of the United States with Prohibition provides an excellent example of failure due to rent seeking. (The prohibition on the consumption or manufacture of alcoholic beverages began with the ratification of the 18th Amendment to the Constitution in 1919; the 21st Amendment reversed this in 1933. The 18th Amendment has been the only change to the U.S. Constitution that has been subsequently repealed.) Contrary to a popularly held belief in the United States, Prohibition was quite successful; the rate of alcoholism and health problems associated with alcohol dropped dramatically during the 1920s compared with rate of the previous half-century. The system was abandoned, however, with the rise of gangsters such as Chicago's Al Capone and the corruption of the judiciary and law enforcement agencies. Prohibition of alcohol provided too many opportunities for rent seeking by law enforcement officials and undermined a legal system that had previously functioned with a relatively low level of corruption. In the end, the public health benefits from Prohibition were judged less important than the costs of corruption in the legal system. In solving one problem, rent seeking may create another. The United States started with an alcoholism problem and ended with a judicial corruption problem.

3.3 Information Cost

A system can fail because the information costs are too high. "Information" here is meant broadly to include all of the costs of monitoring and administering a program, including the cost of allocation penalties rather than simply of monitoring. As McGinnis and Ostrom point out, robust CPR systems tend to have low information costs.

If the information load of a system is high, one of two things can happen. First, the system can bog down into spending most of its finite resources in handling information rather than in actually changing the environment. For example, this criticism has been leveled at the U.S. Superfund program for the cleanup of toxic waste sites, which spends the bulk of its efforts on litigation rather than cleanup.

Alternatively, if the system attempts to bypass the information costs of fairly administering a system, enforcement becomes essentially random, and probabilities of getting away with cheating or being unjustly punished become roughly equal. Since we are dealing with a collective goods situations here (i.e., in the absence of punishment, an individual has more to gain from cheating than obeying the law), when the likelihood of being punished is roughly identical whether one is cooperating or defecting, it becomes rational to defect, and the CPR system fails.

Recognition of this fact may account, in part, for McGinnis's and Ostrom's observation that successful systems tend to use graduated rather than severe sanctions. In a system where mistakes of judgement are possible (i.e., all systems), individuals are likely to demand more information (proof) for severe sanctions than for modest sanctions. The information load increases as the severity of the punishment increases, and eventually the system becomes unenforceable in a self-monitoring system. This is counterintuitive if one looks only at the simple benefit-cost calculations (i.e., for a fixed probability of detection, the likelihood of compliance should increase with the severity of punishment), but it becomes clear when one does the appropriate calculations, taking into account the collective characteristics of the situation.

3.4 Transmission Failure

The final source of system failure occurs when a system is changed in the process of being

transmitted from generation to generation; it can also occur if the organization fails to adapt appropriately to new circumstances.

In the biological self-organization literature, Eigen and Schuster (1978, p. 555) consider the problem they term the "error catastrophe":

> Genetic reproduction is a continuously self-repeating process, and as such differs from a simple transfer of a message through a noisy channel [i.e., the classical problem of information theory]. For each single transfer it requires more than just recovery of the meaning of the message, which, given some redundancy, would always allow a fraction of the symbols to be reproduced incorrectly. It is also necessary to prevent any further accumulation of mistakes in successive reproduction rounds. In other words, a fraction of precisely correct [optimized] copies must be able to compete favorably with the total of their error copies. Only in this way can the [optimal copy] be maintained in a stable distribution.
>
> [These results] can be summarized as follows: Any mechanism of selective accumulation of information involves an upper limit for the amount of digits to be assembled in a particular order. If this limit is surpassed, the [information] will fade away during successive reproductions.

This problem is particularly strong when an organization attempts to maintain rules and behaviors that are effective during crisis situations but costly and inconvenient in noncrisis situations. Any "mutations" (i.e., modifications of the procedure) that are easier in the noncrisis environment will be selected for and compete against the "correct" rules that were originally developed to cope with the crisis.

Wohlstetter's classic study of the U.S. intelligence failures prior to the attack on Pearl Harbor (Wohlstetter 1962; also see Janis 1982) provides an excellent example of this phenomenon in action. The military knew what it *should* have been doing in a state of heightened tensions with Japan. Rules more effective than those actually employed in Hawaii were amply available in the *formal* institutional memory of the military; the means of improving performance were no mystery. However, two decades of peace had allowed a great deal of "genetic drift" to occur in the *actual* organizational heuristics. For example, commanders recognized the necessity of maintaining anti-aircraft gun crews on alert, but they mutated this rule to provide an exception for Sundays. The accumulated errors provided opportunities that the Japanese were able to exploit through careful planning.

Ironically, erroneous transmission of information, normally considered a liability, can also provide a source of inadvertent innovation. An organization that is totally efficient and accurate in information transmission will give up some advantage in innovation. Total transmission efficiency is most useful when it occurs in a very stable environment; the Confucian bureaucracy of imperial China, which spent an inordinate amount of time in ensuring transmission fidelity, comes to mind. Flexible organizations with transmission errors, in contrast, should be better able to generate the innovations required in a rapidly changing situation. The U.S. response to Pearl Harbor, which was basically to junk the existing military structure and build a completely new one, was completely appropriate in this regard. This conclusion is also consistent with the observations about the importance of experimentation and failure — as opposed to rational planning — found in bureaucratic maxims about innovation, such as "It's easier to apologize than to ask permission."

4 CRITERIA FOR DEVELOPING ROBUST SYSTEMS

McGinnis and Ostrom provide a number of suggestions on how robust systems might be developed and, in particular, caution against trying to do this with overly simple modeling techniques. I would add two additional points to their list.

First, efficiency may be less important than sustainability in a robust system. The motto of Tom West, the computer development manager in Tracy Kidder's novel, *Soul of a New Machine*, is, "Not everything worth doing is worth doing well."

Biological systems, which evolved rather than were designed, tend to be grossly inefficient in many regards but are all very robust.

A legal system that is only partially successful may be more robust than one that attempts to be completely successful. For example, by most accounts, the complex U.S. income tax system fails in the sense that most people under-report income. However, the system is successful in the sense that it is largely self enforcing and generates substantial amounts of income by using relatively small amounts of coercion. Consistent with McGinnis and Ostrom's observations, that system's use of carefully graduated sanctions reduces the rent-seeking behavior that is characteristic of many internal revenue systems.

A system for the control of global warming must be sufficiently thorough to solve, or at least control, the basic physical problems of global warming. Interest-group politics being what they are, the temptation will probably exist to solve additional social and environmental problems at the same time, to make the effort at global cooperation more efficient. Experience would indicate that such efforts are likely to be counterproductive.

The other point to note is that complex systems (for example, the transportation or telecommunication systems of industrialized countries or any mature legal system, in addition to biological organisms or ecosystems) are not designed, they are grown; they arise as a response to prior selective pressures. The more frequently an organization is confronted with a particular problem, the more efficient is its response. However, the first time the organization is so confronted, its response will probably be inefficient and possibly unpredictable, since the interaction effects of all of the rules of a system are unknown. One can rarely take the formal organization chart and rule books of a human system and deduce from those the outcome of a specific change. Nor are such systems necessarily logically consistent; were that the case, there would be no need for lawyers. These observations argue against trying to overdesign a global warming regime, particularly in view of the uncertainty concerning even the physics of the problem.

5 CONCLUSION

As I indicated at the beginning of these comments, robust CPR regimes are an important topic that are very relevant to the global warming problem. The McGinnis and Ostrom paper, and more generally Ostrom's work in *Governing the Commons*, provide examples of how to proceed with systematic studies of these problems.

In his remarks opening this conference, John Eddy suggested the need for greater cooperation between the natural and social sciences. Let me extend this suggestion with two comments, the first a reminder as to why there has been so little funded cooperation in recent years, the second to indicate that communication may be easier than it would first appear.

Until the onset of the Reagan administration in 1981, cooperation between the social and natural sciences had been encouraged in policy research. Under David Stockman's aegis, however, it was noticed that social scientists had an awful tendency to say things the Reagan ideologues did not want to hear. Economists said that tax cuts would lead to a massive expansion of the federal deficit and that deregulation of the savings and loan industry would lead to corruption and bankruptcy; political scientists pointed out that the Soviet Union was economically stagnant and riven with ethnic divisions; and sociologists pointed out that cutbacks in social programs might lead to increases in homelessness, drug abuse, and poverty. Uncomfortable with the message, the Reagan administration did everything possible to cut funding for the messengers. While funding was restored in some areas, such as the National Science Foundation, it is still absent from others. Without being too much of a disciplinary chauvinist, I would suggest that the absence of social scientists from the policy process has been due at least as much to the accuracy, rather than the failures, of their predictions.

The other important point is that the social sciences and the natural sciences have much more in common now in terms of their methodologies than they had 50 years ago. Robert Pool, reporting in the August 18, 1989, issue of *Science* on the

Santa Fe Institute, a collaborative effort of physicists and economists to share ideas, observes:

> The physical scientists were flabbergasted to discover how mathematically rigorous theoretical economists are. Physics is generally considered to be the most mathematical of all the sciences, but modern economics has it beat. . . . The flip side of the physicists' surprise at the rigor of the economists was the economists' astonishment at the physicists' lack thereof.

Social scientists are now quite conversant in mathematical modeling, statistical methodologies, experimental design, and computer simulation. C.P. Snow's gap between the "two cultures" may still apply to the humanities and the natural sciences, but there has been a great deal of convergence between the methodologies of the social and natural sciences. Some of the concepts most relevant to the problem of understanding global warming (for example, general systems, feedback, and adaptation) have been part of the study of social behavior for decades. General systems theory was at the forefront of the "behavioral revolution" in political science in the 1950s, through individuals such as David Easton in American politics, Karl Deutsch in comparative politics, and Morton Kaplan in international relations; economics was put into a rigorous mathematical form in the late 19th century by conscious emulation of the mathematical models of physics.

This being said, the problem of understanding the social and political implications associated with the control of global warming is not going to be easy to solve. The social system is at least as complex as the physical; both have long lag periods and poorly understood feedbacks. In the social as well as the physical and biological realms, intuition may not always be a good guide, and purely deductive models, divorced from the study of the operation of actual systems, are unlikely to be very useful. The McGinnis and Ostrom paper shows that these social and political issues can be studied and provides a worthwhile agenda for future research.

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Comment 2 on Workshop in Political Institutions

Principal-Agent Relationships

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In recent decades, economic analysis has been extended to situations in which there are important asymmetries of information between actors. One important class of these situations are principal-agent relationships, in which one party, the agent, acts on behalf of the other, the principal. In such situations of incomplete and asymmetric information (in which the agent may be better informed than the principal), is it possible to devise mechanisms to ensure that the agent acts in the best interests of the principal? How can we construct relationships so that physicians act in the best interests of patients, lawyer in the best interests of their clients, or public officials in the best interests of their constituents?

When complex, multilayered problems such as those associated with global warming are being considered, the concept of principal-agent relationships has two important applications. First the concept of the ideal principal-agent relationships can be used as a normative standard. Under ideal circumstances, leaders (agents) of groups (such as nation states) will negotiate to maximize net social benefits on behalf of their constituents (the principals). Thus one could examine the set of feasible agreements that could occur if there was perfect agency (i.e., situation in which agent acts in the best interests of the principal) among all of those who took part in a given round of international (or national or subnational) negotiations.

Second, recognizing that perfect agency does not accurately characterize most regimes, one could examine the likely set of feasible agreements in actual practice. Even in democratic systems, imperfectly competitive political arenas mean that narrow, well-organized special interests are often disproportionately represented relative to the general social interest. In less accountable regimes, the scope for the agents to pursue their own interests at the expense of the principals is often quite substantial.

Principal-agent relationships are also relevant in a situation of decomposable, nested hierarchies. Such hierarchies may be a mechanism through which coordination on a global scale may be achieved in a relatively decentralized fashion. In such hierarchies, the leader of a small-scale group would act as agent on behalf of the members when negotiating with higher levels in the hierarchy. Such systems of nested hierarchies would appear to be of great relevance in the context of issues of the global commons.

Comment 3 on Workshop in Political Institutions

Problems of Institutional Analysis

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The following is mostly an elaboration of the comments I made during the discussion stimulated by the McGinnis-Ostrom paper (McG-O hereinafter). It will be seen that I have added references to other papers by these two authors, kindly made available to me after the conference. I had been ignorant of this literature, and I am grateful both to the authors and to the organizers of the conference for so broadening my horizons.

MacNeil et al. (1991, p. 220, as cited on p. 1 of McG-O) states that the design of appropriate institutions is on the Rio "Earth Summit" agenda: "the heads of state . . . will be asked to . . . (4) initiate major reforms of 'international institutions to enable nations to manage global interdependence and to implement Agenda 21 as well as the conventions.'"

The use of the term "institutions" in the above quotation illustrates the multiplicity of meanings given to this term and the frequently resulting confusions.[1] The relevant dichotomy in the present context is between (1) using "institution" as referring to an organization, agency, or other mission-oriented entity on the one hand and (2) interpreting "institution" as referring (in one of several possible senses) to rules governing behavior. The above quotation seems to use the term in its first (1) meaning. But the focus of the McGinnis-Ostrom analysis concerning problems due to the prospect of global warming, and in particular problems being faced by the Rio conference, is — and I believe should be — on the issue of existing or needed international regimes relevant to the ecology of the globe. The concept of such regimes is broader than but includes institutions in the second (2) sense. From now, unless stated to the contrary, the second (2) meaning is intended. This is not to minimize the possible need for (1)-sense institutions when it comes to the implementation of rules inherent in (2)-sense institutions.

McG-O raises a host of important issues, both substantive and methodological, but it also takes strong positions on what institutional solutions are desirable and are likely to be successful. I am rather sympathetic with many of these positions, especially insofar as they favor decentralization. However, the extent to which one can hope to avoid external (third-party) enforcement and the extent to which external enforcement can be made effective are complex and do not lend themselves, in my opinion, to simple generalizations. To analyze this problem, I find it convenient to formulate somewhat more precisely the meaning I attribute to (2) institutions.

In McG-O, and even more so in the two authors' other writings, game-theoretic models are used at times to formalize various institutional arrangements. But there is, I believe, a distinction to be made between their formulation and the one I am about to state. The difference between the two formulations is, in turn, related to the distinction between what is technically called a *game* and a *game form* (or *mechanism*). What the latter two concepts have in common is the specification of the players' permissible *strategy domains* (i.e., permissible sequences of moves that are, in general, conditioned on the preceding moves of the various players).[2] Where they differ is in functions defining the consequences of strategic choices made. In a game, associated with each player is his/her *payoff function*, specifying the utility level (a number) that the player would derive from each permissible configuration of strategy choices.[3] It is this payoff that the player seeks to maximize. But

the payoff functions can be viewed as being composed of two elements: the physical[4] consequences of the strategic choices made (more or less global warming, degree of destruction of forests, state of health of different groups, etc.) and the preferences or values that different players attach to these consequences. The physical consequences of strategic choices are specified by what we call an outcome function. Here, as for the payoff function, the independent variable (what the mathematician calls the domain) is the configuration of strategies chosen. But while for each payoff function, the dependent variable is a (utility) number, the dependent variable for the outcome function is a physical[5] event. Thus a player's value of the payoff function for a given configuration of strategies is given by his/her utility of the outcome associated (by the outcome function) with that configuration.[6] Thus a game form is defined by the strategy domains and the outcome function, while a game is defined by the strategy domains and the payoff functions.[7]

The rules of a game, as ordinarily conceived, are contained in the game form, because the rules specify which strategies are permitted or possible and the consequences of strategy choices.[8] Note that if the players' preferences changed while the rules of the game remained the same, the payoff functions would change, but the outcome function would not and hence the game form would not.

Given that game rules are specified by the game form and that institutions (2 sense) are often interpreted as rules, it is tempting to think of an institution (again, in 2 sense) as *the component of the game form that is subject to change by human action.*[9] But when we examine specific examples, we see that typically it is a whole *class or category of game forms,*[10] rather than a single game form, that is thought of as *a specific institution.*[11] One might say that an institution is an *attribute* of game rules, or even that it is a *rule about rules."*[12]

Following this digression about the basic concepts, let us return to the problem of enforcement of rules, or — more broadly — what one might call effective implementation, such a crucial issue in institutional design for problems of global warming.

Superficial reading of certain comments in the literature of game theory might make one believe that there is no problem of enforcement, since it is often stated that Nash equilibrium solutions (in noncooperative games) are self enforcing. But this claim is only valid when it is assumed that the players will not go outside their strategy domains (i.e., will not use "illegal" strategies) and that the postulated outcome function can be made effective. But why should these assumptions be satisfied?

Consider first the problem of "legal" versus "illegal" strategies. Typically, it is physically possible for players to use strategies outside the permissible domain. Unless players have internalized the prohibitions, the relevant (to be called *natural*) game form contains all strategies, legal and illegal; that is the *natural domain.* As for the consequences, the corresponding *natural game form* contains the actual consequences, whether they are determined by the laws of physics, the reactions of others, an enforcement system, or other factors. If these various factors act so as to discourage the use of illegal strategies, the original ("desired") game form will prevail. Otherwise, some or all players will use illegal strategies, and the results will be different from what would have happened at a Nash equilibrium of the "desired" game form.

Typically, when new institutions are designed, the game is augmented in still another way: players are added. These additional players may be real persons ("third parties") or they may be "artificial persons" (organizations, agencies, committees, etc.). For example, when a democratic system is introduced, a parliament (an artificial person) may be brought into existence. On the other hand, an enforcement system may use third parties such as police, judges, etc., whose (collective) mission is to discourage the use of illegal strategies. The game form that takes into account the natural domains, the natural outcome function, and the extra players is called the *augmented game form.*

But, assuming that only legal strategies will be used, a mechanism (game form) cannot be made effective unless its outcome function operates as prescribed. That may, in particular, involve taxes, subsidies, fines, and hence transfers of goods and

money. A machinery is needed to specify various procedural details and also to see that transfers are actually made (e.g., to collect taxes or make social security payments to those who are entitled). If all of this is successfully done, I speak of *effective implementation*.[13]

To effectively implement a goal function means that the augmented game form yields equilibrium outcomes consonant with that function. Since typically there is cost in operating the system (whether for information processing or enforcement), the ideal "first best" solution is usually not attainable. But even the "second best" solutions are not always effectively implementable. The recommendations contained in the McG-O paper suggest procedural prescriptions (meta-rules) designed to result in communities adopting rules that are enforceable.

McGinnis and Ostrom point to situations in which, given a transgression on the part of individual A, there is an individual B who has both the motivation and the ability to note that a transgression has occurred and who can either discourage (or even stop) the transgression or report it to someone who can do so. Individual B is what I have called an *intervenor*: a player who has the motivation and ability (power, assets, even powers of persuasion or charisma) to intervene in such a manner as to minimize the probability or even totally prevent illegal behavior and to make the desired outcome function operational. But an intervenor (in the sense of this definition) may not be a person directly affected by the transgression. Consider a policeman stopping a speeder, or a prosecutor determined to root out corruption. Effective implementation may be a result of the fact that there are participants (individuals or groups) who believe in the system as designed, and who, without having direct (i.e., "material") interest,[14] are determined to see it work, and who, again, are somehow endowed with the powers to accomplish this. They qualify as intervenors. On the other hand, there may be a chain consisting of individual A (the object of enforcement activities) and the enforcers E^1, ..., E^{n-1}, and E^n. Individual E^n is special in that it is in his/her ("material") interest that A obey the rules. The behavior of person A is monitored by enforcer E^1, who in turn is monitored by E^2, etc. It is further assumed that each E^i among the enforcers E^2, ..., E^n has the power to enforce proper (supervisory or enforcement) behavior on the part of the underling E^{i-1}, whose behavior E^i monitors. This configuration may be called "closing the circle." Here E^n is an intervenor, having both the ("material") interest in seeing that A behaves and the powers (indirectly) to bring this about.[15]

Without studying the nature of the goal to be implemented and the nature of the facts bearing on probable ("natural") behavior, it is difficult for one to generalize as to the need for external (third-party) enforcement. Perhaps the GATT experience, the Montreal Agreement, or disarmament negotiations provide clues as to what can be achieved without third-party intervenors on a global scale.

Similarly, one cannot be too dogmatic about gradual versus "wholesale" reforms. When many components are interdependent, the gradual approach may not be feasible. On the other hand, such radical changes across the board also have their dangers and difficulties. The experiences of Central and Eastern European countries emerging from communism and command economies illustrate this point.

A few additional comments are in order. First I will mention a technical point concerning what McGinnis[16] calls two-level games in which, for instance, elected representatives of organizations (lower-level bodies) are engaged in bargaining. The traditional approach of treating these representatives as being motivated by a utility function[17] — when in fact the representatives are under instruction generated by (for example) majority votes in the lower bodies — is clearly inappropriate. But there are ways of dealing with such situations without postulating a utility-maximizing behavior. For example, in a paper[18] dealing with the implementability (in Maskin's sense) of goal functions,[19] I replaced Maskin's assumption that each player[20] is maximizing his or her utility or preference by the assumption that each player has a choice function. This choice function could reflect the majority votes of the lower body that the player represents. The important point is that such a choice function need not be rationalizable in terms of a transitive, complete, ordering relation. Nevertheless, one still obtains counterparts of Maskin's implementability

theorems, both for necessary and sufficient conditions. It is true that when the lower bodies' choice functions are "irrational," the meaning of implementability is weakened, but this seems unavoidable. In any case, models of this type are more representative of international negotiations and deserve further study.

The second issue is about design versus spontaneous development or self-organizing behavior. If the world were satisfied with spontaneous development of institutions dealing with global ecological issues, we would not (I think) be witnessing Montreal or Rio. History provides what to me are clear cases of conscious design, the U.S. Constitution being perhaps a prime example. But looking at the matter from the point of view of what we have called the natural game form, one encounters a philosophical question. One can argue that the natural game form cannot be altered by the designers. But then, what is the role of design? Perhaps it is only a matter of discovering that the natural game form contains more advantageous solutions than those previously arrived at and of persuading others that this is so. In that case, the role of design is purely at the level of cognition. But having a new design adopted may involve playing a game based on the natural game form. The two-stage Reiter-Hughes model points in that direction.

It should be noted that the outcome of such a game need not result in a resource allocation that is Pareto-superior to the previous one. In other words, as is often the case when decisions are made by majority vote, there may be losers as well as winners. It is in this context that the (theoretical) role of benefit-cost analysis can be understood. Subject to a technical point concerning the customary underlying assumptions (to be discussed below), if the benefit-cost analysis shows that a certain change would yield positive social (i.e., consumer plus producer) surplus, we conclude that it is, in principle, possible to find a compensation scheme so that there would be no losers while some or all would be gaining. But, as has often been pointed out in the literature, it does not follow that the proposed is desirable even if such compensations are not made.

Further, there is the technical problem mentioned above: Customarily, the calculations underlying benefit-cost analysis are made as if preferences were quasi-linear (i.e., characterized by constant marginal utility of money). In that case, one can separate the issue of efficiency from that of distribution. But there is usually no justification for that assumption, and then distributional issues affect conclusions as to efficiency. This fact does not, in my opinion, invalidate the benefit-cost approach as such, but it does call for estimation procedures that are more sophisticated. Furthermore, there is then no longer a unique, efficient, social-resource allocation but rather a whole spectrum of different efficient arrangements corresponding to different distributive policies. Together with the problem of compensations, this issue, far from being an abstruse point of theory, is, I believe, at the heart of the conflicts between the more developed "North" and the less developed "South." Similarly, the debates concerning appropriate discount rates may, to some extent, be interpreted as distributional conflicts between the present and future generations.

Finally, I will mention the suggestion, discussed in some detail in Kosobud's paper, concerning the use of market-type methods (in particular, tradeable pollution permits) in dealing with pollution and other environmental hazards. The basic and rather natural idea is to make the pollution activity into a negative commodity (i.e., commanding a negative price) and then take advantage of the known "invisible hand" advantages of competitive markets. However, it has been shown by D. Starrett[21] that when such negative commodities are adjoined to the conventional ones, the phenomena of detrimental externalities such as pollution result in nonconvex production possibility sets. Consequently, it is likely that no fixed price vector will balance supply and demand. This does not mean that a market equilibrium is impossible, but it will not be a "perfectly competitive equilibrium." For a market process to yield efficient resource allocation — which is the objective — it becomes necessary to use "nonlinear prices" (i.e., prices that vary as functions of the volume traded). But to find the appropriate nonlinear formulas for these prices, some informational centralization may be unavoidable, and so some of the customary advantage of the market process may be lost.

END NOTES

1. See E. Ostrom, 1986, *An Agenda for the Study of Institutions*, Public Choice, *48*:3-25. As will be seen, I tend to side with Ostrom's interpretation of the term "institution" (in the sense related to rules and labeled as 2 in what follows) rather than the equilibrium behavior sense given to it by A. Schotter, 1981, *The Economic Theory of Social Institutions*, Cambridge University Press. However, because of my somewhat broader interpretation of what is meant by rules, the contrast is not as strong as might appear. See L. Hurwicz, forthcoming, *Towards a Framework for Analyzing Institutions and Institutional Change*, in Democracy and Markets: Participation, Accountability and Efficiency, S. Bowles, H. Gintis, and B. Gustafsson (editors), Cambridge University Press, and L. Hurwicz, forthcoming, *Implementation and Enforcement in Institutional Modeling*, in Political Economy: Institutions, Information, Competition, and Representation, W. Barmnett, M. Hinich, and N. Schofield (editors), Cambridge University Press.

2. The concept of a player's strategy domain covers the three categories in Ostrom (1986): permitted, required, and prohibited. Everything outside the strategy domain is prohibited; everything within it is permitted. If a move is required, it constitutes an element of every strategy in the domain.

3. There are, of course, as many payoff functions as there are players.

4. The term "physical" should be interpreted quite broadly, possibly to include even emotional states and behaviors. In economic models, the outcome is usually the resulting resource allocation. In voting models, it may be the candidate elected or the issue prevailing in a referendum.

5. Typically multidimensional (see the preceding footnote).

6. Some notation may help avoid ambiguity. Let there be n players, and let s_i be the strategy chosen by the i-th player. If h represents the outcome function, and the given strategy configuration (n-tuple) is $S = (S_1, ..., S_n)$, then the outcome produced by that configuration is h(s). Now let the i-th utility function be denoted by u^i, and the i-th payoff function be denoted by p^i. We then have the relation $p^i(s) = u^i(h(s))$; that is, the i-th payoff function is the composition of the i-th utility function with the outcome function.

7. Using the notation of the preceding footnote, and denoting the strategy domain (i.e., the set of permissible strategies) of the i-th player by S_i, we defined a game form by the n+1 entities $(S_1, ..., S_n, h)$, while a game is defined by the 2n entities $(S_1, ..., S_n, p^1, ..., p^n)$.

8. However, strategy domains are limited by laws of physics, and the outcome function is also, at least in part, determined by these laws as well as other factors. That is why we say that game rules are contained in (but are not coextensive with) the game form.

9. As distinct from components due to physical laws, etc. The distinction made here is close to, if not identical with, that between physical and "deontic" statements in R. Gardner and E. Ostrom, 1991, *Rules and Games*, Public Choice, *70*:121-149.

10. More precisely, with a class of those components of game forms that are influenceable by humans. We may note here that since the rules, in addition to governing behavior, are generated by human actions, they may in particular be viewed as solutions to a prior game. See S. Reiter and J. Hughes, 1981, *A Preface on Modeling the Regulated U.S. Economy*, Hofstra Law Review, *9*(5):1381-1421. This aspect of the situation bears a relationship to Schotter's view of institutions as behavior patterns that are equilibrium solutions of games.

11. Consider, for instance, the institution of marriage. We may think of a particular type of marriage (say monogamous) as being defined by one game form, while another (say polygamous) is defined by another game form. But it is the common features of these two game forms (and other game forms defining other types of marriage) that correspond, in my interpretation, to the notion of the institution of marriage as such.

12. Thus, I interpret Ostrom's rules as being such "rules about rules." Typically, we are subject to many institutions, or what Ostrom (1986) calls a *configuration* of rules. Therefore, a configuration of rules in Ostrom's sense is the intersection of sets of game forms, with each set defining one of the institutions of the configuration. Clearly, as pointed out by Ostrom, the class of game forms admissible under the configuration is narrower than the individual institutions would permit.

13. This goes beyond the concept of implementation as defined by Maskin, 1977, *Nash Equilibrium and Welfare Optimality*, M.I.T. mimeo, where enforcement and the proper workings of the outcome function are taken for granted. Hence the adjective "effective" used here.

14. There may be an indirect interest in, for example, maintaining a reputation for impartiality and incorruptibility, which may be professionally valuable. But one should not exclude the possibility of idealism, or ethics, or ideology.

15. This is different from the McG-O irrigation rotation example, where everyone has a direct interest in his/her predecessor observing the rules and where everyone is an intervenor with both motivation and power.

16. From a paper done jointly with John T. Williams, which the authors were kind enough to make available to me but which is not yet in final form available for quotation.

17. Or, more generally, by a preference relation, whether or not it can be represented by a utility function. An example of a preference relation that cannot be so represented is the so-called lexicographic ordering, in which, for example, one good (such as one's child's probability of survival) holds absolute priority over another good (such as one's chance to save $10). It may be noted parenthetically that certain criticisms of the benefit-cost analysis (voiced in connection with the Kosobud paper) can be interpreted as saying that when such lexicographic ordering is present, no finite rate of substitution is appropriate, and the conventional calculus techniques do not apply.

18. See L. Hurwicz, 1986, *On the Implementation of Social Choice Rules in Irrational Societies*, in Social Choice and Public Decision Making, Essays in Honor of K.J. Arrow, W.P. Heller, R.M. Starr, and D.A. Starrett (editors), Volume 1, Chapter 4, pp. 75-96.

19. Here we permit functions to be multivalued (i.e., the term function covers correspondences as well as single-valued relations).

20. In the above example, each representative of a lower body is a player.

21. In D. Starrett, 1972, *Fundamental Non-Convexities in the Theory of Externalities*, Journal of Economic Theory, 4:180-199.

Section V

General Technical Comments on Climate Change

Comment 1:
Answers to Five Questions Posed at the Conference

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1. *What are the projections of global average temperature increase?*

The Intergovernmental Panel on Climate Change (IPCC), assuming a "business as usual" scenario of emissions, projected a 0.3°C temperature increase per decade, with an uncertainty range of 0.2°C to 0.5°C per decade. The authors of the recent update of the IPCC study looked at the many papers that have been published since the original report and decided that there was no scientific need to adjust this earlier projection.

Climatologists have long recognized that the natural variability of the climate system is sufficiently large that the warming generated by human-induced emissions will not be clearly visible in the global data until the end of this century or later. Even so, the impatience of everyone to see progress in specifying the global rate of change has led groups to make comparisons of model calculations with the heating deduced from global data sets.

A number of groups have attempted such comparisons. They conclude that the global average surface temperature has increased approximately a half degree in the last 100 years, whereas climate models retrospectively forecast an increase over the same period of between a half degree and one degree. Taken at face value, these comparisons favor those models that project the smallest future heating, but when they are viewed in the context of the large natural variability, the comparisons merely remind us that it will be some years or decades before the question of the rate of heating can be answered observationally. It should also be remembered that the same natural variability will prevent the 0.3°C-per-decade warming from being a steady increase.

Sea level is projected to rise 6 cm per decade, with an uncertainty range of 3 to 10 cm per decade.

2. *What are the prospects for projecting regional climate change?*

The regional effects projected by IPCC are as follows: Land surfaces will warm more rapidly than the ocean. In winter, high northern latitudes will warm more than the global mean. Temperature increases in southern Europe and central North America will be larger than the global mean and be

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accompanied by reduced summer precipitation and soil moisture. There will be apparent regional variations in the rise in sea level because of the rising or subsiding motions of islands and continental margins.

These projections are both coarse and uncertain and of little help to planners interested in preparing for climate change at a specific locality. Therefore, there is a vigorous effort underway in various laboratories to improve the ability of climate models to simulate the sensitivity of regional climate to increases in infrared-trapping gases in the atmosphere.

Much of the difficulty in foreseeing regional changes arises from the fact that global climate models are themselves coarse grained (i.e., a single point used for calculation in the model represents a large area on the surface of the earth, and important features on the surface such as mountains can be represented only crudely). Limitations in computer speed and memory prevent modelers from quickly increasing the spatial resolution of global climate simulations.

The approach that may be most effective for promptly producing improvements consists of imbedding a fine-mesh regional model of an area of particular interest into a global climate model. To the extent that features in the local regions (such as mountains, shorelines, and areas of vegetation) can be thought of as processing large-scale flows of the atmosphere to produce the detailed local climates, this approach can be expected to produce progress in our ability to project regional climate changes.

3. *Do the climate models produce outlooks for a group of climate variables closely related to societal impacts?*

Many variables are involved in general circulation model (GCM) calculations and could, in principle, be retained and displayed as time series. Those directly produced at each level above each model grid point include pressure, density, temperature, wind, humidity, downflowing and upwelling radiation (both solar and long wave), and any cloud at that point. At the surface, both precipitation and evaporation are computed and soil moisture is derived. For the ocean portion of the model, variables such as salinity and the area of sea ice are also calculated. Additional variables could be derived (e.g., amount of cloud cover or ocean-wave height). Newer models are beginning to include the concentrations of a few chemicals as variables.

Some of these variables — in particular soil moisture — are now routinely computed because of requests from scientists interested in responses of agriculture to climate changes. Variables not now retained in the data sets produced by model calculations could, if needed, be stored for later use, and new variables derivable from the ones already calculated could be added to the calculation, but always at a sacrifice of the length of time that can be simulated with a fixed computer resource.

4. *What is the feasibility and what are the costs of proposed geoengineering options for responding to climate change?*

For the most part, proposed geoengineering plans have not been studied in any detail and no answer to the question is possible. The reason for the lack of study arises from the fact that most such proposals involve complex systems, so a great deal of work needs to be done to convert the idea into one that can be quantified in a climate or related model.

For example, the notion suggested by a laboratory experiment — that iron fertilization of certain ocean areas might enhance biological activity and, through this activity, the ocean storage of atmospheric carbon — will require extensive work on ocean biology and integration of this biological knowledge into calculations of carbon fluxes to and from the ocean and transfers within the oceans. The ocean biological system is sufficiently complicated that a single ocean experiment now would not provide final answers. If changes in carbon fluxes were observed in such an experiment, one would not necessarily know the chain of events that produced the changes; thus, the experiment could not readily be scaled up. Further, without additional knowledge of the oceanic carbon cycle, one would not know whether the carbon taken up would stay stored for the centuries required or whether unacceptable shifts in the ocean food-chain might be an accidental result of the plan. Thus,

decades of work, large teams of scientists, and a large amount of funding for field observations and model experiments would be required to begin to assess the feasibility of the proposal.

Some of these steps are underway. Scientists familiar with ocean biology in the suggested regions have studied the proposal and presented arguments that the net long-term carbon storage would be small, thus beginning the usual scientific process of testing a new idea. Other groups have also begun to apply what they already know to the question. If work over several years by many groups shows a favorable possibility for carbon storage and a lack of troublesome side effects, we should then expect plans to be formulated for some sort of field test of the proposal.

The iron fertilization suggestion envisions a method of removing one of the causes of human-induced climate change from the atmosphere. In that respect, it is similar to the proposal that we plant trees to remove carbon from the air. Most other geoengineering proposals, however, are designed to counteract one feature of the resulting climate change and, as such, have a defect that slows their consideration. A major climate-change event, such as the one that we are now inducing, is complex, involving all aspects of weather and climate — cloudiness, wind, temperature, and precipitation. The defect of most geoengineering proposals is they attempt to slow one kind of climate change (temperature increase) by the creation of another kind of climate change (e.g., change in cloudiness or atmospheric transparency). So far, none of the proposals has included a careful study of the effects of the different kinds of climate change that would be produced by the proposed action.

Finally, all geoengineering proposals share the problem that their true impacts are as difficult to project as the impact of additional carbon dioxide in the atmosphere. We see evidence in the preparations for the meeting to be held in Rio that a rough estimate of the global average rate of climate change may be sufficient to trigger actions to slow that rate of change. But a much more precise calculation would likely be required before people would intentionally set about to modify the climate.

5. *What climate variables co-vary with global average temperature?*

Both average absolute humidity and global rainfall should increase as temperature increases. However, the rainfall would not be distributed evenly or even proportionally to current rainfall. The estimate from IPCC is that precipitation will increase in winter in mid latitudes and at all seasons in high latitudes and in the tropics.

Scientists have speculated about whether atmospheric variability will change as temperature increases, or whether the strength of hurricanes will increase with higher surface temperatures, but no conclusions are yet possible.

It is, of course, very likely that the frequency of hot spells will increase and the frequency of cold spells will decrease in a hotter climate, but, again, giving details of such a change will require improved regional calculations.

Comment 2: Nurturing Multidisciplinary Research on the Global Commons

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Both an improved understanding of the causes and consequences of global warming as well as the exploration of responses to global warming require the integration of knowledge from a wide variety of disciplines in the natural sciences, social sciences, and humanities. The need for high-quality research drawing on a number of disciplines has a number of implications.

There are a variety of examples of successful multidisciplinary enterprises that have conducted useful research over an extended period of time. It is possible, however, that the challenges involved in the creation and maintenance of multidisciplinary research teams and institutes to date have been less formidable than the challenges facing the creation of appropriate institutional arrangements for research on global warming. Global warming appears to require both greater integration among a number of disciplines in the natural sciences and greater integration with social science disciplines. Multidisciplinary success in the health sciences and agricultural sciences has probably been less demanding.

Successful multidisciplinary settings would appear to share several characteristics. First, it is important that there be a critical mass of investigators from each key discipline to provide ongoing personal development and intellectual support within each discipline. It is also important that each member of such a research enterprise be committed to the conduct of multidisciplinary team research, at least over the medium term. In such a situation, there is an incentive to bear the heavy initial costs of learning how to communicate among the disciplines. It is also important to nurture a culture of mutual respect for the contributions of each member of the team. The involvement of senior, well-respected investigators from a number of disciplines is important to legitimize the intellectual enterprise and provide useful role models for more junior investigators.

Standard academic programs in graduate schools are often not well suited for the training of investigators for such settings. It remains important, however, that such investigators obtain solid training in their own discipline. Such training, when combined with practical experience working in teams (perhaps as a research associate of a faculty supervisor or in a postdoctoral position), might provide a viable training path for disciplinary scholars capable of working effectively in multidisciplinary teams.

The traditional departmental/disciplinary-based structure of academic settings is also often not well suited to the conduct of multidisciplinary research. The reality is that publications in journals in one's discipline are weighted more heavily than publications elsewhere. Successful ongoing multidisciplinary programs of research will require that the incentive structure be altered to recognize achievements in other fields. Disciplinary-based departmental committees and chairs will have to engage in communication with departments on the relative merits of various outlets. Explicit *ex ante* agreements on the relative weights to be accorded to accomplishments in various activities might be useful (e.g., 25% for teaching, 35% for research within one's discipline, 25% for multidisciplinary research, and 15% for service).

Institutional mechanisms to support the training of investigators capable of contributing to multidisciplinary research and to support the conduct of such research will need to be further elaborated to enhance the capacity to provide rigorous and timely basic and applied research on global warming. Medium-term commitments will be required to provide the incentives to overcome the

initial fixed costs of establishing interdisciplinary communication and collaborative working styles. Accomplishments in creating such arrangements for global warming research will have important spillover benefits in other areas.

Comment 3: The Research Agenda: Social Science Research on Global Warming

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The institutional analysis group discussed a number of topics and methodological approaches that would constitute important components of the social science contribution. I have elaborated upon those discussions to record a somewhat personally idiosyncratic set of items for the social science research agenda.

A number of social science and historical disciplines contribute relevant case studies and comparative case studies. Economic and technological history studies that address the factors that affect the speed and direction of bias in technological change are of obvious relevance and will be useful in informing presumptions about the degree of substitutability within and among natural and man-made inputs to production. Case studies of existing and historical nested hierarchies are also very important.

Norman Rosenberg reviewed the Resources for the Future MINK study (Missouri, Iowa, Nebraska, and Kansas) for the group. The study included a careful descriptive analysis of the economic activities of sectors in the region that are sensitive to changes in climate (agriculture, forestry, water resource management, energy). Carefully calibrated models describing inputs and outputs were developed. Simulations were then conducted to assess the independent effects of autonomous economic change, autonomous climate change, and their interaction. The results represent one meaningful and attractive approach for assessing economic-change/climate-change interactions. Additional studies such as the MINK study and alternative approaches for the assessment of economic-change/climate-change interactions appear to be warranted.

A number of disciplines in the social sciences have developed measures that reflect nonpecuniary objectives and aspects of human quality of life other than the material standard of living. The social indicators approach provides a broad measure of quality of life. Within health-services research, there are a variety of broadly and narrowly focused measures of health-related quality of life. Preference measurement approaches developed to evaluate the health-related, quality-of-life value of changes in health status may be an especially useful model for developing methods for eliciting preferences over nonpecuniary environmental outcomes.

In recent decades, the social sciences have exploited small-scale laboratory experiments to sharpen the ability to test theory or the efficacy of proposed new institutional mechanisms. There have been a number of informative studies on small-group collective-action problems, committee behavior, voting rules, and other topics relevant to managing the global commons.

The social sciences have also conducted large-scale field experiments to inform assessments of major social policy issues. Examples include negative-income tax, alternative pricing policies for public utilities, and health-care expenditure insurance experiments. Although field experiments are difficult and expensive and although such experiments involve ethical issues, the conduct of such research has much to contribute to the formulation of well-informed, effective policy interventions.

Studies on the design of incentive-compatible mechanisms are crucial for improved policy formulation for global climate change problems. Under existing arrangements, private actors take into account private costs and benefits that poorly reflect the underling social costs and benefits of their actions. New institutional arrangements that

would more closely align private and social costs and benefits would help to ameliorate global change problems. Our understanding of the design, creation, and maintenance of such incentive-compatible mechanisms needs to be further developed. Better understanding is needed at the level of theoretical/analytical knowledge. It is also needed at the level of practical implementation and the transition path from one set of institutional arrangements to another. A variety of analytical approaches, including noncooperative and cooperative game theory, are of relevance. These analytical techniques need to be complemented by experimental methods and case studies.

Comment 4: Policy for Sustainable Development: Some Unresolved Issues

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1 INTRODUCTION

We are now in the midst of the third wave of social concern since World War II about the implications of natural resource availability and environmental change for the sustainability of improvements in human well-being.

The *first* wave of concern in the late 1940s and early 1950s focused primarily on the quantitative relationship between resource availability and economic growth. The response to this first wave of concern was technical change in raw material production. The *second* wave of concern, in the late 1960s and early 1970s, focused on the rising demand for assimilation by the environment of residuals derived from growth in commodity production and consumption — primarily at the local and regional level. Since the mid 1980s, these two early concerns have been supplemented by a *third*. This more recent concern centers around the implications for environmental quality, food production, and human health of a series of environmental changes such as global warming, ozone depletion, acid rain, and others that are occurring on a transnational scale. Before actions to resolve these more recent challenges to sustainable economic growth are taken, a number of unresolved issues must be confronted to allow a commitment to this resolution to be translated into an internally coherent reform agenda. In this note, I discuss three of these issues.

2 ISSUE OF SUBSTITUTABILITY

One area where our knowledge is inadequate is with respect to the role of technology in widening the substitutability among natural resources and between natural resources and reproducible capital. Economists and technologists have traditionally viewed technical change as widening the possibility of substitution among resources (of fertilizer for land, for example) (Solow 1974; Goeller and Weinberg 1976). The sustainability community rejects the "age of substitutability" argument. The loss of plant genetic resources is viewed as a permanent loss of capacity. The elasticity of substitution among natural factors and between natural and man-made factors is viewed as exceedingly low (James, Nijkamp, and Opschoor 1989; Daly 1991). This is an argument, in economists' language, over the form of the production function. If a combination of capital investment and technical change widens the opportunity for substitution, imposing constraints on present resource use could leave subsequent generations less well off. On the other hand, if real output per unit of natural resource input is narrowly bounded (i.e., cannot exceed some upper limit that is not too far from where we are now), catastrophe is unavoidable. While the argument between adherents to these two views is often cast in philosophical terms, empirical research should lead toward a convergence. But since the data needed to resolve the issue will never be adequate, continued disagreement can be expected.

3 ISSUE OF OBLIGATIONS TOWARD THE FUTURE

The second issue is one that has divided traditional resource economists and the sustainability community. That is the issue of how to deal analytically with the obligations of the present generation toward future generations. The issues of intergenerational equity is at the center of the sustainability debate (Pearce, Barbier, and Makrandaya 1990; Solow 1991). Environmentalists have been particularly critical of the approach used by resource and other economists in valuing future

benefit and cost streams. The conventional approach involves the calculation of the "present value" of a resource development or protection project by discounting the cost and benefit stream by some "real" rate of interest (i.e., an interest rate adjusted to reflect the costs of inflation).

The critics insist that this approach results in a "dictatorship of the present" over the future. At conventional rates of interest, the present value of a dollar of benefits 50 years into the future approaches zero. "Discounting can make molehills out of even the biggest mountain" (Batie 1989, p. 1092). Solow has made the same point in more formal terms. He notes that if the marginal profit (marginal revenue less marginal cost) to resource owners rises more slowly than the rate of interest, production is pushed nearer in time, and the resource would be exhausted quickly (Solow 1974, p. 3; Lipton 1991).

A question that has not been adequately answered is this: As a result of the adoption of a widely held sustainability "ethic," would the market-determined discount rates decline toward the rate preferred by those advancing the sustainability agenda?[1] Or would it be necessary to impose sumptuary regulations in an effort to induce society to shift the income distribution more strongly toward future generations? It is clear, at least to me, that in most countries, efforts to achieve sustainable growth must involve some combination of (1) higher contemporary rates of saving (i.e., deferring present consumption in favor of future consumption) and (2) more rapid technical change, particularly technical changes that will enhance resource productivity and widen the range of substitutability among resources.

4 ISSUE OF INCENTIVE-COMPATIBLE INSTITUTIONAL DESIGN

A third area in which knowledge needs to be advanced is the design and implementation of institutions that are capable of internalizing (within individual households, private firms, and public organizations) the costs of actions that generate the negative spillover effects (i.e., the residuals) that are the source of environmental stress. Under present institutional arrangements, important elements of the physical and social environment continue to be undervalued for purposes of both market and nonmarket transactions. Traditional production theory implies that if the price to a user of an important resource is undervalued, it will be overused. If the price of a factor (the capacity of the atmosphere to absorb greenhouse gases, for example) is zero, it will be used until the value of its marginal product to the user approaches zero. This condition will be true, even though it may be imposing large social costs on society.

The dynamic consequences of failure to internalize these costs are even more severe. In an environment characterized by rapid economic growth and changing relative factor prices, failure to internalize resource costs will bias the direction of technical change (Ruttan 1971). The demand for a resource that is priced below its social cost will grow more rapidly in this environment than in a situation where substitution possibilities are constrained by existing technology. As a result, "open access" resources will undergo stress or depletion more rapidly than they would in a world characterized by a static technology or even by neutral (unbiased) technical change.

The design and implementation of incentive-compatible institutions (institutions capable of achieving compatibility between individual, organizational, and social objectives) remain, at this stage, an art rather than a science. The incentive compatibility problem has not been solved even at the most abstract theoretical level.[2] This deficiency in institutional design and implementation capacity is evident in our failure to institute policies capable of achieving contemporary distributional equity, either within countries or among rich and poor countries. It impinges with even greater force on our capacity to design institutions capable of achieving intergenerational equity.

5 AN UNCERTAIN FUTURE

In closing, I would like to emphasize how far we are from being able to design either an adequate technological or an adequate institutional response to the issue of how to achieve sustainable growth. At present, there is no package of technology that can ensure the sustainability of growth in production at a rate to meet the demands that are being placed on either developed or developing

countries. Sustainability is appropriately viewed as a research agenda rather than as a guide to practice (Ruttan 1988; Graham-Tomasi 1991).

At present, the sustainability community has not been able to advance a program of institutional innovation or reform that can provide a credible guide to the organization of sustainable societies. We have yet to design the institutions that can ensure intergenerational equity. Few would challenge the assertion that future generations have rights to levels of sustenance and amenities that are at least equal to those enjoyed (or suffered) by the present generation. They also should expect to inherit improvements In institutional capital (including scientific and cultural knowledge) needed to design more productive and healthy environments.

My conclusion with respect to institutional design is similar to that which I have advanced in the case of technology. Economists and other social scientists have made a good deal of progress in contributing the analysis needed for "course correction." But capacity to contribute to institutional design and implementation remains limited. The fact that the problem of designing and implementing incentive-compatible institutions (institutions capable of achieving compatibility between individual, organizational, and social objectives) has not been solved at even the most abstract theoretical level means that institutional design proceeds in an *ad hoc* trial-and-error basis and that the errors continue to be expensive. Institutional innovation and reform should represent a high-priority research agenda.

6 END NOTES

1. The question of the impact of the use of a positive discount (or interest) rate on resource exploitation decisions is somewhat more complex than often implied in the sustainability literature. Simply lowering the discount rate to favor the natural resource sector will not ensure slower exploitation of natural resources if the market rate of interest remains high. Recipients of the lower interest rates may transfer the revenue from resource exploitation to investments that have higher rates of return rather than reinvesting to sustain the flow of resource benefits. Furthermore, high rates of resource exploitation can be consistent with either high or low interest rates. In the case of forest exploitation, for example, a low discount rate favors letting trees grow longer and planting trees that take longer to grow. On the other hand, a low discount rate will make it profitable to invest in mineral exploitation, land and water development, or other investment projects that might otherwise be unprofitable. That is why, in the past, resource economists and environmentalists have argued in favor of higher interest rates on public water resource projects (Norgaard 1991; Price 1991; Graham-Tomasi 1991). As an alternative to lower discount rates, Mikesell (1991) suggests taking resource depletion into account in project benefit-cost analysis.

2. The concept of incentive compatibility was introduced in a 1972 paper by Hurwicz (1972). In that paper, he showed that it was not possible to specify an informationally decentralized mechanism for resource allocation that simultaneously generates efficient resource allocation and incentives for consumers to honestly reveal their true preferences. For the current state of knowledge in this area, see Groves, Radner, and Reiter (1987).

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Comment 5: Agricultural Response to Climate Change

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1 DISCUSSION

The complex interrelationship between global climate change and agricultural production will become one of the most significant policy issues, in both developed and developing countries, in the first decades of the 21st century. Global and regional climate change will modify both agricultural production capacity and its location. And the intensity of agricultural production will contribute to environmental change at both the regional and global levels.

The best single source currently available for evaluating the impact of climate change on agriculture is the recent book by Martin L. Parry, *Climate Change and World Agriculture.*[1] Parry notes that two major types of adjustments may be anticipated at the farm and the regional level. These are changes in land use and changes in farm management.[2] But there is almost no discussion by Parry, or in the climate change literature more generally, of the capacity of the agricultural research system to "invent around" the new temperature and rainfall regimes associated with global warming. Yet the historical record suggests that modest investments in agricultural research have enabled societies characterized by vastly different resource endowments to achieve relatively rapid growth in agricultural production. In our book *Agricultural Development* and in other writings, Yujiro Hayami and I have developed and tested, against the experience of both developed and developing countries, an "induced technical change" model, in which the direction of technical change is induced by changes in relative resource endowments.[3] Countries with comparable levels of land per worker have been able to achieve widely different levels of output per hectare and per worker (Figure 1). It is clear that changes in relative resource endowments have, in the past, had a pervasive impact on the adoption of technical innovations by farmers, on the supply of the industrial inputs in which technology is embodied, and on the direction of research efforts by agricultural scientists and technologists in both public- and private-sector institutions. This induced behavior must be more explicitly built into the interactive models if we are to build more credible models to estimate the impacts of climate change.

The fact that the agricultural research system has in the past been reasonably successful, at least in the presently developed countries, in responding to growth in demand and to changes in resource endowments cannot, of course, be taken as assurance that it will be able to do so in the future.[4] Its capacity to do so will depend both on the rate of climate change and on the level of investment in agricultural research. We now have in place an effective system of international agricultural research centers (IARCs) funded by a donors consortium, the Consultative Group for International Agricultural Research (CGIAR). In spite of the high rates of return generated by the CGIAR institute, there were, beginning in the mid 1980s, growing signs of "aid-weariness" on the part of the donor countries. A more serious concern, however, is the limited national agricultural research capacity in the poorest developing countries.[5] Even Brazil, which was remarkably successful in strengthening its national agricultural research capacity in the 1970s, has experienced substantial erosion of that capacity since the mid 1980s. And biological technology, needed to make the location- specific technical changes needed to adapt to climate change, will not be available.

The capacity of agricultural research systems, even in the most highly developed countries, to respond to the effects of global warming will depend on the rate at which climate change occurs. We are

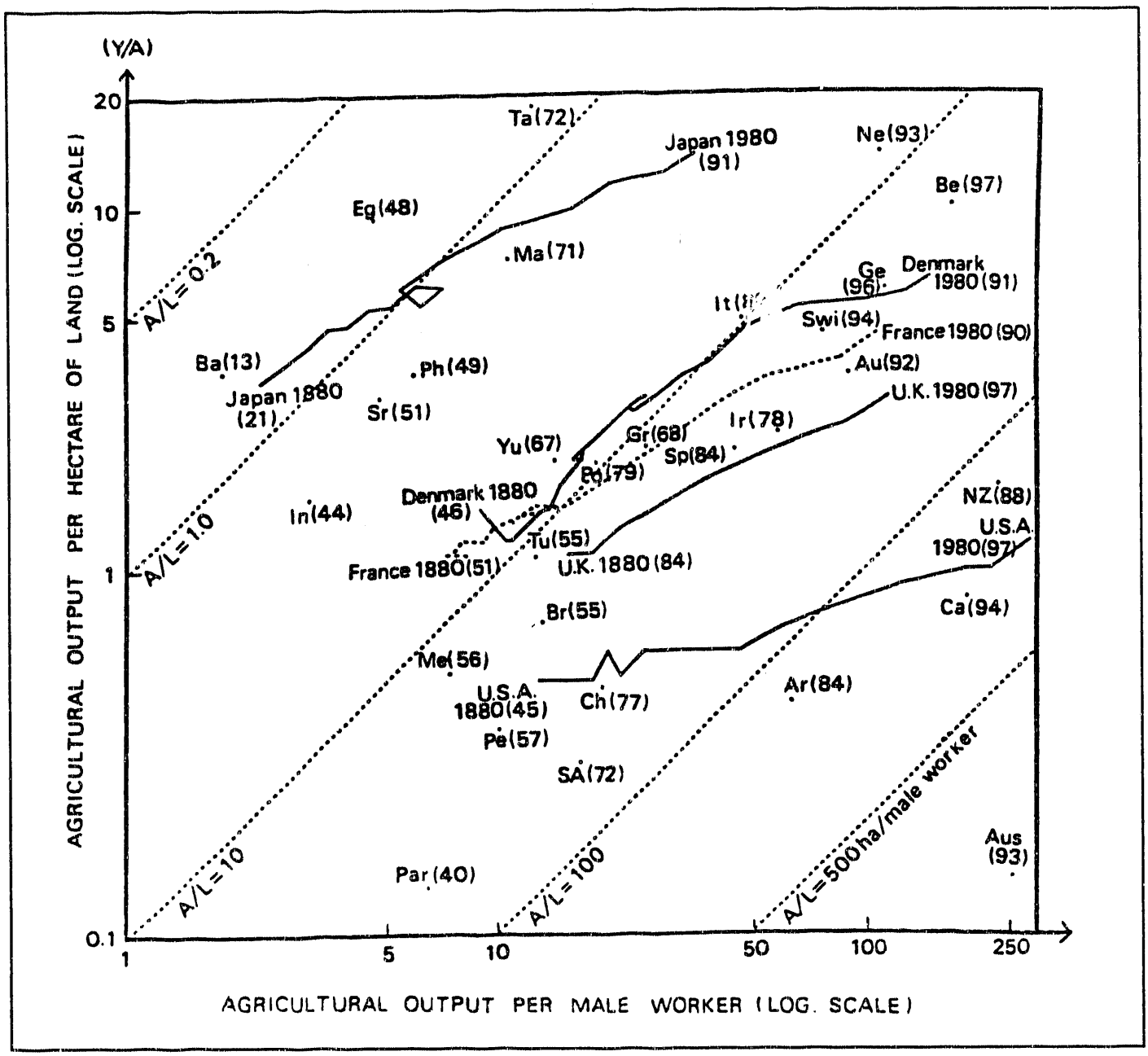

FIGURE 1 Agricultural Output

on the edge of a transition from an older Mendelian-based biological technology to a new molecular-based biological technology. At a conference held at the University of Minnesota in July of 1989, a group of leading agricultural scientists attempted to assess relative contributions of the "old" and "new" biotechnology to agricultural production over the next several decades.

Several conclusions are particularly relevant to the issue of global warming.[6]

- *Advances in conventional technology will remain the primary source of growth in crop and animal production over the next quarter century.* Almost all increases in agricultural production in the future must come from

further intensification of agricultural production on land that is presently devoted to crop and livestock production. Until well into the second decade of the next century, the necessary gains in crop and animal productivity will continue to be generated by improvements resulting from conventional plant and animal breeding and from more intensive and efficient use of technical inputs including chemical fertilizers, pest control chemicals, and higher-quality animal feeds.

- *Advances in conventional technology will, however, be inadequate to sustain the demands that will be placed on agriculture as we move into the second decade of the next century and beyond.* Advances in crop yields, particularly in wheat and rice, have largely accrued as a result of efforts by plant breeders to (1) change plant architecture to facilitate increases in plant populations per hectare and (2) increase the ratio of grain to straw rather than to increase total dry matter production. Advances in animal feed efficiency have come about through decreasing the proportion of feed consumed that is devoted to animal maintenance and increasing the proportion used to produce usable animal products. There are severe physiological constraints to continued improvement along these conventional paths. These constraints are most severe in those areas that have already achieved the highest levels of productivity — areas in western Europe, North America, and parts of eastern Asia.

- *Advances in basic science, particularly in molecular biology and biochemistry, are opening new possibilities for supplementing traditional sources of plant and animal productivity growth.* The possibilities range from the transfer of growth hormones into fish to conversion of lignocellulose into edible plant and animal products. The realization of these possibilities will require a reorganization in the performance of agricultural research. An increasing share of the new knowledge generated by research will reach producers in the form of proprietary products or services. This means that the incentives exist to draw substantially more private-sector resources into agricultural research. Within the public sector, research organizations will have to move increasingly from a "little science" to a "big science" mode of organization. The capacity of national and international agricultural research systems to successfully negotiate the transition from the old to the new biological technology will be of critical importance in determining the impact of climate change on agricultural production as we move beyond the first quarter of the next century.

2 END NOTES

1. Parry, M.L., 1991, *Climate Change and World Agriculture*, Earthscan Publications, London, United Kingdom, in association with the International Institute for Applied Systems Analysis and the United Nations Environmental Program, 1990. See also the review by V.W. Ruttan in Environment, *33*:25-29, July/Aug., 1991.

2. Parry, M.L., *Climate Change*, p. 119.

3. Yujiro Hayami and V.W. Ruttan, *Agricultural Development: An International Perspective*, The Johns Hopkins University Press, Baltimore, Md., 1st ed. 1971, 2nd ed. 1985; also V.W. Ruttan, 1971, *Technology and the Environment*, American Journal of Agricultural Economics, *53*:707-717, Dec.

4. There is now a large body of research documenting the underinvestment in agricultural research in both developed and developing countries. The high annual rates of return that are documented in these studies, which typically range from 30% upward to 100%, are an indication of underinvestment. See V.W. Ruttan, 1982, *Agricultural Research Policy*, University of Minnesota Press, Minneapolis, Minn., pp. 242-248. For a more recent compilation, see Ruben G. Echeverria, 1990, *Assessing the Impact of Agricultural Research*, Vol. II in Methods for Diagnosing Research System Constraints and Assessing the Impact of Agricultural Research, R.G. Echeverria (editor), International Service for National Agricultural Research (ISNAR), the Hague, the Netherlands.

5. See Philip G. Pardey and Johannes Roseboom, 1989, *ISNAR Agricultural Research Indicator Series: A Global Data Base on National Agricultural Research Systems*, Cambridge University Press; Philip G. Pardey, Johannes Roseboom, and Jock R. Anderson (editors), 1991, *Agricultural Research Policy: International Quantitative Perspectives*, Cambridge University Press, London, United Kingdom, forthcoming; Johannes Roseboom and Philip G. Pardey, 1990, *Measuring the Development of National Agricultural Research Systems*, Staff Notes 9095, International Service for National Agricultural Research (ISNAR), the Hague, the Netherlands, Nov.

6. V.W. Ruttan (editor), 1989, *Biological and Technical Constraints on Crop and Animal Productivity: Report on a Dialogue*, Staff Paper P89-45, University of Minnesota, Department of Agricultural and Applied Economics, St. Paul, Minn, Nov.

Section VI

Conference Program

FEBRUARY 11, 1992

6:00 - 8:00 Reception and Dinner

8:00 - 10:30 **Welcome**

Joel Snow, Associate Vice President for Argonne National Laboratory, University of Chicago
Harvey Drucker, Associate Laboratory Director, Argonne National Laboratory

Keynote Address and Discussion

Where Are We Now? Where Are We Going?
John Eddy, University of Michigan

FEBRUARY 12, 1992

9:00 - 12:15 **PLENARY SESSION I: DISCUSSION OF BACKGROUND PAPERS**

9:00 - 9:10 **Opening Remarks**

Harold Jacobson, University of Michigan (Chair)

9:10 - 10:05 **Workshop in Economics**

The Problem of Climate Change Benefit-Cost Analysis
Richard Kosobud, University of Illinois at Chicago
Discussant: Khairy Tourk, Illinois Institute of Technology

10:05 - 10:15 Break

10:15 - 11:10 **Workshop in Adaptation and Mitigation Strategies**

Approaching Global Warming: A Review of the Adaptation and Mitigation Perspectives
Peter Morrisette, Resources for the Future
Discussant: Rob Coppock, National Academy of Sciences

11:10 - 11:20 Break

11:20 - 12:15 **Workshop in Political Institutions**

Institutional Analysis and Global Climate Change: Design Principles for Robust International Regimes
Michael McGinnis and Elinor Ostrom, Indiana University
Discussant: Philip Schrodt, University of Kansas

12:30 - 2:00 Lunch

2:00 - 5:15 **Small Workshop Groups**

5:30 - 7:30 Dinner

FEBRUARY 13, 1992

9:00 - 10:20 **PLENARY SESSION II: REVIEW OF WORKSHOP DISCUSSIONS, WITH EMPHASIS ON CROSS-CUTTING ISSUES**
Joel Snow, Associate Vice President for Argonne National Laboratory, University of Chicago

10:20 - 10:40 Coffee Break

10:40 - 12:00 **Plenary Session II (continued)**

12:15 - 1:45 Lunch

1:45 - 3:15 **Small Workshop Groups**

3:15 - 3:30 Coffee Break

3:30 - 3:45 **Closing Remarks and Adjournment**
Harold Jacobson, University of Michigan (Chair)

Section VII

Conference Participants

Mr. David Admiraal
Department of Political Science
University of Illinois

Dr. Gilbert W. Bassett, Jr.
Department of Economics
University of Illinois at Chicago

Dr. Gale Boyd
Environmental Assessment and Information Sciences Division
Argonne National Laboratory

Dr. Rob Coppock, Staff Director
Panel on Policy Implications of Greenhouse Warming
National Academy of Sciences

Ms. Kirsten Dow
Center for Technology, Environment and Development
Clark University

Dr. John Eddy
Consortium for International Earth Science Information Network

Professor David Feeny
Department of Economics
McMaster University

Dr. John W. Firor, Director
Advanced Study Programs
National Center for Atmospheric Research

Professor Roy Gardner
Department of Economics
Indiana University

Dr. David Goetz
Department of Political Science
Utah State University

Dr. Donald Hanson
Environmental Assessment and Information Sciences Division
Argonne National Laboratory

Dr. Madeleine Hosli
Institute for Social Research
University of Michigan

Professor Barry B. Hughes
Graduate School of International Studies
University of Denver

Professor Leonid Hurwicz
Department of Economics
University of Minnesota

Professor Harold Jacobson, Director
Center for Political Studies
University of Michigan

Professor Roger Kasperson
Department of Government and Geography
Clark University

Dr. David Kee
Regional Air & Radiation Division
U.S. Environmental Protection Agency

Dr. Elizabeth Kirk
Senior Program Officer
American Association for the Advancement of Science

Professor Richard Kosobud
Department of Economics
University of Illinois at Chicago

Professor Douglas MacLean
Department of Philosophy
University of Maryland,
Baltimore County

Professor Howard Margolis
Graduate School of Public Policy
Studies
University of Chicago

Ms. Annette Matheny
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University of Illinois

Professor Michael McGinnis
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Climate Resources Program
Resources for the Future

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The Woods Hole Research Center

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Resources for the Future

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Department of Political Science
University of Kansas

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Dr. David Streets
Environmental Assessment and
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Stuart School of Business
Illinois Institute of Technology

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Mr. J. Michael Walsh
Economic Analysis and Planning
Department
Chicago Board of Trade

Ms. Judith L. Weddle
Department of Political Science
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Dr. Dee Wernette
Environmental Assessment and
Information Sciences Division
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Dr. Richard Winter
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Information Sciences Division
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END

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11/2/92