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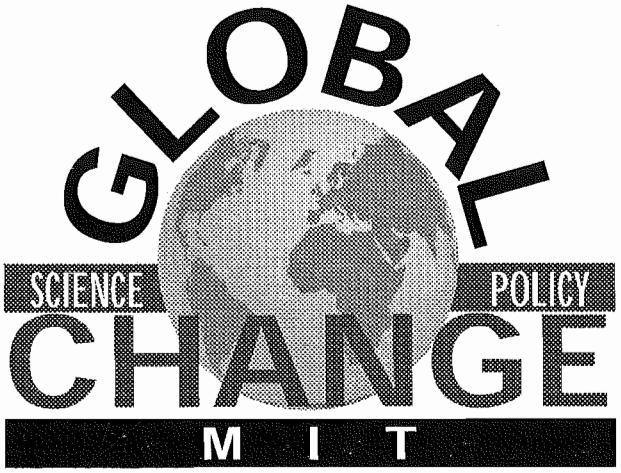

Kyoto's Unfinished Business*

H.D. Jacoby, R.G. Prinn, and R. Schmalensee

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The MIT Joint Program on the Science and Policy of Global Change is an organization for research, independent policy analysis, and public education in global environmental change. It seeks to provide leadership in understanding scientific, economic, and ecological aspects of this difficult issue, and combining them into policy assessments that serve the needs of ongoing national and international discussions. To this end, the Program brings together an interdisciplinary group from two established research centers at MIT: the Center for Global Change Science (CGCS) and the Center for Energy and Environmental Policy Research (CEEPR). These two centers bridge many key areas of the needed intellectual work, and additional essential areas are covered by other MIT departments, by collaboration with the Ecosystems Center of the Marine Biological Laboratory (MBL) at Woods Hole, and by short- and long-term visitors to the Program. The Program involves sponsorship and active participation by industry, government, and non-profit organizations.

To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives.

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TAKING THE LONG VIEW ON GLOBAL WARMING

EVEN WELL-INFORMED observers disagree about what the Kyoto Protocol on Climate Change will accomplish. Some gaze at its text and see a battle won. They cheer the fact that the generally richer nations participating in the protocol agreed to cut their collective emissions of the greenhouse gases that cause global warming to about five percent less than 1990 levels by early in the next century. These optimists also applaud features of the Kyoto accord designed to hold down the costs of achieving these reductions. In computing their emissions, nations can include changes in the six major greenhouse gases emitted because of human activity, not just carbon dioxide, the most important of the six. In addition, countries can factor in reduced carbon dioxide levels from changes in land use and new forestry techniques that take the gas out of the atmosphere. Groups of participating nations may comply jointly and reallocate commitments among themselves, as the European Union (EU) plans to do within a European "bubble," and there

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is agreement in principle to some form of emissions trading. Joint implementation, under which agents in one country can get credit for reductions they achieve in another, is to be permitted between participating nations, and a new Clean Development Mechanism will provide access to these opportunities in nonparticipating countries, mainly in the developing world. Finally, emissions targets are not rigidly tied to a single year, but to averages over a five-year "commitment period" from 2008 to 2012.

Pessimists, on the other hand, see Kyoto as a costly defeat. They note that there is no solid proof that human-induced climate change will occur or that its adverse effects would be serious were it to happen. At the same time, the expense of reducing greenhouse gas emissions to meet the Kyoto targets will be substantial, and pessimists believe that the effort will make participating countries less competitive. In the darkest interpretation, the Kyoto agreement is a pact among rich nations that will cripple their economies for decades to come, made simply because today's political leaders needed to burnish their environmental credentials.

Neither of these schools of thought is correct. Still a third group, whose views are much closer to the mark, believes that Kyoto mainly postpones much-needed work on what may prove a very serious long-term challenge. To them, Kyoto is a quick political fix for a problem created at the First Conference of Parties to the Climate Convention held in Berlin in 1995. The so-called Berlin mandate instructed negotiators to seek short-term, legally binding targets and timetables for emission control for participating countries only. In the run-up to Kyoto, many leaders publicly committed themselves to this idea. Not surprisingly, avoiding embarrassment on this score became the dominant focus of the negotiations. As a result, this group argues, the Kyoto agreement allows political leaders to declare success, but it does not address the larger climate issues at stake.

Even worse, these skeptics fear that by following the Berlin mandate, negotiators at Kyoto may have made it harder, not easier, to meet the long-term challenge. Now the next decade may be spent haggling over these short-term commitments, thereby diverting attention from more important century-scale issues and postponing the involvement of the developing world. The Kyoto agreement might fail to meet

even its immediate goals if the lack of domestic support in the United States prevents ratification, which in turn would rationalize inaction by other participating nations. The entire international response to climate change could be discredited, thus increasing the difficulty of collective action in the future, no matter how serious the problem turns out to be.

To some degree, these widely divergent analyses of the Kyoto achievement reflect differing interpretations of its text, key parts of which are still the subject of strong and sometimes bitter international disagreement. Some of these points will be taken up again at the Fourth Conference of the Parties in November, but others may take years to resolve. What is in dispute is not merely the Kyoto text, of course, but the underlying science and economics of global warming. Above all, for the journey from Kyoto to succeed, policymakers will need to spend more time thinking of the long term.

A GLOBAL WARMING PRIMER

To START with the basics, climate change can be driven by an imbalance between the energy the earth receives from the sun, largely as visible light, and the energy it radiates back to space as invisible infrared light. The "greenhouse effect" is caused by the presence in the air of gases and clouds that absorb some of the infrared light flowing upward and radiate it back downward. The warming influence of this re-radiated energy is opposed by substances at the surface and in the atmosphere that reflect sunlight directly back into space. These include snow and desert sand, as well as clouds and aerosols. (Aerosols are tiny, submicroscopic solid or liquid particles suspended in the air, such as smoke and fog.)

Water vapor and clouds, which typically remain in the atmosphere for a week or so, are responsible for most of the re-radiated infrared light. Central to the climate change debate, however, are less important but much longer-lasting greenhouse gases, most notably carbon dioxide. Atmospheric concentrations of carbon dioxide and other long-lived greenhouse gases have increased substantially over the past century. As this has happened, the flow of infrared energy to space has been reduced, so that, all else being equal, the earth receives slightly more

energy than it radiates to space. This imbalance tends to raise temperatures at the earth's surface. These aspects of the greenhouse effect are not controversial. It is also generally accepted that emissions of carbon dioxide from the combustion of fossil fuels (primarily coal, oil, and natural gas) are the most significant way humans can increase the greenhouse effect, and that this emitted carbon dioxide remains in the atmosphere for a long time, on the order of a century or so.

What is much more uncertain, and the cause of serious scientific debate, is the response of the complex system that determines our climate to changes in the concentrations of greenhouse gases in the atmosphere. Some poorly understood processes in the climate system tend to amplify the warming effect of greenhouse gases, while others, equally poorly understood, tend to counteract or dampen it. Any global warming will likely be delayed because it takes a lot of heat to warm the oceans, but it is not known just how rapidly heat is carried into the ocean depths.

To predict climate, scientists must use mathematical models whose complexity taxes the capabilities of even the world's largest computers. These models are based on incomplete knowledge about the key factors that influence climate, including clouds, ocean circulation, the natural cycles of greenhouse gases, natural aerosols like those produced by volcanic gases, and man-made aerosols like smog. Today's climate models cannot reproduce the succession of ice ages and warm periods over the last 250,000 years, let alone the smaller climatic fluctuations observed over the last century. In addition, climate models are driven by forecasts of greenhouse gas emissions, which in turn rest on highly uncertain long-term predictions of population trends, economic growth, and technological advances.

BURNING DOWN THE HOUSE?

To HELP quantify the uncertainty in climate prediction, we and our MIT colleagues have developed a model of global economic development, climate processes, and ecosystems. We have produced seven forecasts of climate change over the next century, each of which assumes no action to restrict future greenhouse gas emissions and can be defended as possible given current knowledge. These forecasts involve changes in global average surface temperature between 1990 and 2100 as small

as two degrees Fahrenheit or as large as nine degrees Fahrenheit (roughly one to five degrees centigrade). We cannot sort out which of these paths (or other possible ones) we are heading along, although we are less likely to be on one of the extreme ones. There may be other paths involving rapid climate changes driven by purely natural processes that are not well handled by any current climate models.

Unfortunately, we know even less about the likely impact of climate change. Warming may increase storm damage, for instance, but it may also decrease it. Very little is known about the likely impact on human health or the ability of unmanaged ecosystems to adapt to shifting conditions. Civilization and natural systems have coped with climate change in the past and can, to at least some degree, adapt. What we do know suggests that the changes summarized by the lowest of the seven forecasts would do little harm and might even benefit some countries. Most analysts would agree, however, that the highest of our seven forecasts implies significant risks to a variety of important natural processes including ocean circulation, polar glaciers, and unmanaged ecosystems, as well as agriculture and other human activities. Indeed, for policymakers, the most important finding of climate research to date may be that the range of possible outcomes is so wide. Sound policy decisions must take account of this profound uncertainty, and it is plainly vital to accelerate research aimed at reducing it.

If you smell smoke at home, it would be silly to do nothing until you actually see flames...

An important complement to the work on forecasts is the search for what has been called a fingerprint—evidence that would clearly reveal human influence on climate. In its 1995 report, the Intergovernmental Panel on Climate Change (IPCC) declared in its *Summary for Policymakers* that "the balance of evidence suggests a discernible human influence on climate." Several scientists, however, subsequently questioned the scientific basis of this summary and the certainty it conveyed. Hence the hunt for definitive evidence of human-induced climate change remains an important research area—mainly because the stronger the human influence on climate, the earlier it will be possible to detect its "signal" despite the "noise" of natural variability in climate over time. The larger the

proven human influence on climate, the stronger will be the case for substantial reductions in greenhouse gas emissions.

The current debate about detection does not justify inaction. As our range of forecasts indicates, we know enough to conclude that human activity may produce significant global warming, with substantial adverse impacts. It would be irresponsible to ignore such a risk, just as it would be irresponsible to do nothing when you smell smoke at home until and unless you see flames. It would also be irresponsible, of course, to call the fire department and hose down all your belongings at the slightest whiff of what might be smoke.

WHAT IT TAKES

THE ULTIMATE goal of the climate treaty to which the Kyoto protocol is attached is stabilizing atmospheric concentrations of greenhouse gases at levels that will avoid "danger" to economies and ecosystems. No one knows what the appropriate levels might be, or even if the implicit notion of a sharp line between danger and safety makes sense. The nature of the potential task can be explored, however, by studying an EU recommendation that countries stabilize the amount of carbon dioxide in the atmosphere at roughly twice preindustrial levels, in the long run. Doing this would slow climate change but, according to most climate models, not stop it. For the middle range of MIT model forecasts, following the IPCC path to stabilization at the EU target would lower projected warming between now and 2100 by only about 30 percent, although it would produce a larger percentage reduction in the following century.

Following this EU recommendation would require very sharp cuts in global carbon dioxide emissions, however, and the current signatories to the Kyoto protocol could not do the job by themselves. If the nonparticipating nations were to accept no restrictions, net emissions by participating nations would somehow have to become negative by around the middle of the next century. Even a total ban on use of fossil fuels by all industrialized countries would not reach the target.

Of course, if the nations currently participating in Kyoto reduce their emissions, other nations might also eventually agree to lower theirs. Unfortunately, income growth in the most populous nonparticipating countries—including China, India, Indonesia, and Brazil—seems

unlikely to encourage voluntary efforts until the latter part of the next century. Until then, these nations will naturally be more concerned with feeding their children than with protecting their grandchildren from potential global warming. Thus, if the relatively rich participating countries want to stabilize atmospheric concentrations of greenhouse gases, they will have to pay at least some poor countries to reduce their emissions. Achievement of substantial reduction in this way implies international transfers of wealth on a scale well beyond anything in recorded history.

...but you also should not hose down the house after one whiff of what might be smoke.

There is no effective political support for such a herculean effort, particularly in the United States. Given the uncertainties discussed above, such an effort would make little economic sense in any event. The groundwork, however, must be laid now to preserve any hope of someday mounting such a response. Future generations will find three legacies especially valuable: participation of all countries in climate-related actions, development of new technologies to lower the cost of emissions control, and the creation of institutions for cost-effective multinational action.

First, a substantial reduction in global emissions will require something close to worldwide participation, so it is essential to build a climate agreement that can encompass countries not currently participating in Kyoto—including most of the developing world. Such an accord must include a way for these countries to gradually accept the burdens of emissions control. Equally important, it must also anticipate a regime to govern climate-related transfers of resources to countries that cannot bear the cost of emissions reduction.

An exclusive emphasis on the relatively wealthy nations participating in Kyoto is a double-edged sword. If rich nations do not control their emissions, poorer ones are unlikely even to consider slowing theirs. But carbon dioxide emission controls will raise the cost in participating countries of manufacturing those goods whose production requires substantial energy. For these products, industries in developing countries will gain an advantage over industries in countries that abide by Kyoto. Once they have invested in production facilities,

nonparticipating nations will be more reluctant to take emission-control measures that threaten these activities.

Second, it will be nearly impossible to slow warming appreciably without condemning much of the world to poverty unless energy sources that emit little or no carbon dioxide become competitive with conventional fossil fuels. Only a large R&D effort can have any hope of bringing this about, although it would be cheap relative to the cost of dramatic reductions in carbon dioxide emissions using current technologies. The range of technological options is wide—from using solar power to produce electricity to converting fossil fuels to hydrogen fuel and storing (underground or deep in the ocean) the carbon dioxide produced as a byproduct. Few of the alternatives currently under discussion, however, can be widely used at reasonable costs without fundamental improvements.

If rich nations do not control their emissions, poor ones will not even consider slowing theirs.

Finally, since climate change will be a high-stakes global issue for many decades, the world must begin to develop international institutions that will facilitate policies that minimize the cost of reducing greenhouse gas emissions. For starters, this requires solving the monitoring and enforcement problems necessary to implement efficient international trading of rights to emit greenhouse gases (or to implement internationally harmonized taxes on greenhouse gas emissions). It also requires an institutional structure that can exploit the cheapest abatement opportunities, wherever they may be found, and a decision-making process that can adjust policies to reflect changes in scientific knowledge and economic development.

This is a tall order. The international trade regime developed under the General Agreement on Tariffs and Trade, now the World Trade Organization, hints at the difficulties involved. This regime grew and evolved over time, adding countries and goods along the way, peacefully resolving conflicts between national economic interests, and contributing importantly to global economic growth. By the standards of international affairs, the WTO has been a stunning success, but it took 50 years of hard work—even given an intelligent, forward-looking design at the outset.

A KYOTO REPORT CARD

KYOTO'S RESULTS are mixed. The agreement failed miserably at including poorer countries. Until the last minute, the negotiating text at Kyoto contained a provision allowing a nonparticipating nation to choose, at any time and on a voluntary basis, a level of emissions control it felt was appropriate to its circumstances. This "opt-in" provision made sense as an opening to wider participation, particularly since some nonparticipating nations, like Singapore, are wealthier than some participants, like Romania. Several nonparticipating countries supported the idea, but the provision was struck from the protocol because key developing countries—especially China and India—strongly opposed adding any avenues that could lead to emissions limits for them. For their part, the developed countries were unwilling to risk deadlock on this issue and let Beijing and New Delhi have their way.

Investment in research and development on new long-term technical options was not even discussed. One phrase calling for parties to "cooperate in scientific and technical research" was tucked away in the text, but that was all; no nation was obliged to devote any resources to R&D. Politicians love to call for more research instead of more regulation, but there is little commitment to the long-term development of greenhouse-friendly technology by those countries most capable of producing it.

The news from Kyoto is more encouraging regarding provisions to facilitate flexible, cost-efficient policies for controlling emissions. Including multiple gases was a step in the right direction. In principle, schemes like the Clean Development Mechanism may encourage making emissions reductions wherever they are least expensive. But these systems give credit for specific emissions reductions, and U.S. experience with similar policies indicates that the administrative and transaction costs of the required project-by-project approval process are likely to limit their benefits substantially. Most important, the Kyoto provision that in principle allows the trading of rights to emit greenhouse gases, if implemented effectively, would yield major reductions in cost.

Other features built into Kyoto to create more flexibility give less cause for celebration. The provision for multicountry "bubbles," within which national emissions limits can be adjusted as long as the total is

kept constant, is an artifact of short-term political convenience. The creation of such a bubble for the EU is entirely consistent with other EU institutions. It provides a mechanism for differentiation within the EU while its leaders seek uniform commitments from non-Europeans. The application of the idea to other groups of nations emerged as Washington's defensive response to widespread and continuing opposition to emissions trading. If full-fledged trading were ultimately lost, at least some flexibility might be gained in the short term through government-to-government shifting of quotas. While such arrangements may reduce costs over the next few years, they will not provide flexibility in the long run, and they might make it harder to realize the benefits of full global trading by balkanizing the market.

Kyoto failed miserably at including poorer countries in the effort against climate change.

The inclusion in the Kyoto protocol of credits for "carbon sinks"—increases in the removal of carbon dioxide from the atmosphere because of post-1990 changes in land use and forestry practices—is another double-edged sword. In principle, measures to encourage the use of these sinks should be covered by Kyoto because they may be cost-effective for some countries. Land vegetation is already removing carbon from the atmosphere, on balance, probably spurred by increased plant growth caused by rising atmospheric carbon dioxide. The uncertainties are great, but central estimates in the IPCC report indicate that for the world as a whole, the net removal of carbon dioxide from the atmosphere in this way amounts to about 30 percent of current emissions from the burning of fossil fuels. For countries with large forests, such as the United States, Canada, and Russia, biological sinks may play an important role in their emissions accounting. With stakes this large, and with ambiguity inherent in the protocol's definitions of the 1990 baseline and of increases in removal by sinks, fierce debates about measurement and accounting are already under way. The sinks issue could easily become a troubling diversion.

Finally, it is important to be clear-eyed about the risks involved in the core agreement of the Kyoto protocol: national targets and the 2008-12 timetable. On the positive side, the Kyoto targets are a start toward a long-term solution. If participating countries meet the 5 percent

reduction goal and stabilize their emissions at that level for the rest of the century, then—with no restrictions on nonparticipating nations—warming by 2100 will be reduced by about 16 percent. Also, these initial cuts could have important symbolic value, providing incentives for R&D and laying the groundwork for broader national participation. The risk is that these advantages will be lost, and worse, if the emissions reductions agreed to in Kyoto are not met—as they probably will not be. The longer any nation delays adopting serious controls on greenhouse gas emissions, the higher the cost of meeting its Kyoto obligations and the more difficult it will be to generate the requisite domestic political support. The current U.S. policy involves a long delay, which is likely to discourage earlier action by other participating nations fearing a loss of international competitiveness.

The current U.S. climate plan has two main provisions. First, the Clinton administration has asked Congress for $6.3 billion over five years for a technology initiative offering tax incentives and R&D expenditures "to encourage energy efficiency and the use of cleaner energy sources." Second, after a "decade of experience, a decade of data, a decade of technological innovation," the plan holds that whatever administration is in office in 2007 will cap U.S. greenhouse gas emissions and institute a domestic system of tradable rights to emit. Unfortunately, under current policy, the end of the "decade of opportunity" is likely to find U.S. emissions 20 to 25 percent above the 1990 level. The International Energy Agency estimates that by 2000 the United States' emissions will be 16 percent higher than they were in 1990, and climbing. It is simply laughable to forecast that Washington would then impose a cap on emissions stringent enough to turn the energy economy around in three to five years. Moreover, the administration has promised not to send the Kyoto protocol to the Senate for ratification until developing nations commit to "substantial participation." It is not easy to see when such a condition might be met, particularly if vigorous U.S. action is in any way needed to involve the developing world.

Thus, Kyoto is likely to yield far less than the targeted emissions reduction. That failure will most likely be papered over with creative accounting, shifting definitions of carbon sinks, and so on. If this happens, the credibility of the international process for addressing climate change will be at risk. Other outcomes are possible, of course.

Other nations may decide to move forward with emissions control despite U.S. inaction. Changes in U.S. public opinion may accelerate domestic action. Small investments in research may yield unexpectedly large near-term payoffs. Slow economic growth may hold emissions down. Still, even meeting the aggregate Kyoto target will be a hollow victory if it requires spending economic resources and political capital that would be better used to prepare for the vastly greater reductions in global emissions that may be required in the future.

NOW, THE HARD PART

EVEN THOUGH the dust has not settled from the struggle in Kyoto, preparations have begun for the Fourth Conference of the Parties (COP-4) in November. Its focus should be on the longer term.

It is most important to try again to develop a system that can include developing countries and, if necessary, transfer substantial resources to help them participate in a global effort to control emissions. Two opportunities are apparent, one recently rejected at Kyoto and the other only recently advanced there. First is an amendment to Kyoto that restores the provision that would allow nonparticipating countries to volunteer to control their emissions under flexible terms. For any nation seriously concerned with climate change, this should be a necessary condition for ratification of the Kyoto protocol. If the developing countries' opposition to even voluntary action cannot be overcome, it is probably better to scrap Kyoto and start negotiations again when opinions have changed.

Given success on this point, there may then be room for progress on negotiating the details of the Clean Development Mechanism. The protocol suggests that the "operating entities" that will decide how much credit will be given for specific emission reduction projects under the CDM might serve as intermediaries, helping to reduce transaction costs. If so, the CDM might help bring developing countries into the fold. Most studies find that emissions can be least expensively reduced in those countries, so that nonparticipating nations could, in principle, make a great deal of money selling emissions reductions to participating nations. On the other hand, the U.S. regulatory experience suggests that because it is hard to estimate precisely what emissions would have been in the absence of particular investments, the CDM could also pro-

duce red tape and plenty of administrative jobs but have scant impact on emissions. Much depends on the details to be worked out in COP-4. If those negotiations produce a heavily bureaucratic structure, perhaps burdened with taxes on trades in emissions reduction credits, it may be better to reject this proposal and begin anew.

Dealing seriously with climate change requires a substantial R&D program to produce new technologies that could bring about deep global emissions reductions and still allow robust economic growth. Such an effort should involve several wealthy participating nations. Candidate technologies include nuclear, solar, hydroelectric, geothermal, and hydrogen from fossil fuel. Methods for safe and economical long-term storage of carbon in subterranean reservoirs, the deep ocean, and forests are also important research areas, as are technologies that enhance energy efficiency. In contrast, the U.S. "technology initiative" concentrates on subsidizing the adoption of existing technologies but would spend little in the search for long-term breakthroughs. Efforts elsewhere are similarly dwarfed by the challenge.

Finally, a well-designed, durable institutional structure can significantly reduce the cost of limits on global emissions. Here, the key piece of unfinished business from Kyoto is implementing a system for trading the rights to emit greenhouse gases among participating nations. In negotiating the details of this system, now scheduled for COP-4, a focus on clear definitions, vigilant monitoring, and strict enforcement is essential. Otherwise, the market should be left unfettered. Many nations oppose trading in any form; others want to restrict its use in meeting emissions commitments. If they make it impossible to implement a plausible framework for international trading of emission rights, the Kyoto protocol is headed for a dead end, obviating the point of ratifying it.

The challenge will be developing a framework for international decision-making that can work for several decades. Building these three legacies—inclusion of the developing world, R&D, and flexible provisions for emissions reductions—will be a huge undertaking. But since no serious response to climate change is possible without them, the task merits the same sense of urgency that motivated Kyoto. When it comes to climate change, the world's work has just begun.

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JP 97-002. What does stabilizing greenhouse gas concentrations mean?, H.D. Jacoby, R. Schmalensee, and D.M. Reiner, Critical Issues in the Economics of Climate Change, B. Flannery, K. Kolhase, and D. LeVine (eds.), International Petroleum Industry Environmental Conservation Association, London, 1997. (Also JP Report No. 14)

JP 97-003. Linking a global terrestrial biogeochemical model with a 2-dimensional climate model: implications for global carbon budget, X. Xiao, D.W. Kicklighter, J.M. Melillo, A.D. McGuire, P.H. Stone, and A.P. Sokolov, *Tellus*, 49B:18-37, 1997.

JP 98-001. Parameterization of urban sub-grid scale processes in global atmospheric chemistry models, J. Calbo, W. Pan, M. Webster, R. Prinn, and G. McRae, *Journal of Geophysical Research*, 103(D3):3437-3467, 1998. (Also JP Report No. 20)

JP 98-002. Kyoto's unfinished business, H.D. Jacoby, R.G. Prinn, and R. Schmalensee, *Foreign Affairs*, 77(4):54-66, 1998. (Also JP Report No. 32)

JP 98-003. World carbon dioxide emissions: 1950-2050, R. Schmalensee, T.M. Stoker, and R.A. Judson, *Review of Economics and Statistics*, 80:15-27, 1998. (Also JP Report No. 5)

JP 98-004. A flexible climate model for use in integrated assessments, A.P. Sokolov, and P.H. Stone, *Climate Dynamics*, 14:291-303, 1998. (Also JP Report No. 17)

JP 98-005. A global interactive chemistry and climate model: formulation and testing, C. Wang, R.G. Prinn, and A. P. Sokolov, *Journal of Geophysical Research*, 103(D3):3399-3417, February 1998. (Also JP Report No. 24)

JP 98-006. Transient climate change and net ecosystem production of the terrestrial biosphere, X. Xiao, J. Melillo, D. Kicklighter, A. McGuire, R. Prinn, C. Wang, P.H. Stone, and A. Sokolov, *Global Biogeochemical Cycles*, 12(2):345-360, 1998. (Also JP Report Report No. 28)

JP 98-007. Uncertainty in the oceanic heat and carbon uptake and its impact on climate projections, A. Sokolov, C. Wang, G. Holian, P. Stone, and R. Prinn, *Geophysical Research Letters*, 25(19):3603-3606, October 1998. (Also JP Report No. 23)

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