Research Frontiers in the Economics of Climate Change

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Abstract

Academic and policy debates over climate change risks and policies have stimulated economic research in a variety of fields. In this article I briefly discuss eight overlapping areas of current research in which further effort particularly is warranted. These areas include decision criteria for policy; risk assessment and adaptation; uncertainty and learning; abatement cost and the innovation and diffusion of technology; and the credibility of policies and international agreements. Further analysis in these areas not only will advance academic understanding but also will provide insights of considerable importance to policymakers.

Key Words: climate change, sustainable development, integrated assessment, environmental uncertainty, environmental policy

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RESEARCH FRONTIERS IN THE ECONOMICS OF CLIMATE CHANGE

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0. INTRODUCTION

Academic and policy debates over the risks of climate change and the appropriate policy responses have led to an enormous and continuing outpouring of literature in the past 10 years. Fields that have spurred on include computable general equilibrium analysis; theoretical and empirical dynamic optimization models with accumulative pollutants; noncooperative and cooperative game theory; econometric and simulation models of energy supply and demand; the economics of innovation; analyses of incentive-based emissions control policies; applied micro studies of numerous market and nonmarket values potentially affected by climate change; and intertemporal social welfare theory. The literature devoted to climate change issues has ranged from highly abstract to immediately relevant for policymakers.

In what follows I briefly discuss eight overlapping areas of current research in the economics of climate change in which further effort particularly is warranted. These areas include decision criteria for policy; risk assessment and adaptation; uncertainty and learning; abatement cost and the innovation and diffusion of technology; and the credibility of policies and international agreements. Because these categories blur so easily, I have not attempted to create any sort of formal taxonomy. The issues covered are both empirical and theoretical. The discussion not only is inherently idiosyncratic, but it is also broad rather than deep. I am not an expert in many of the areas identified below, but I have had to draw upon the literature addressing these subjects in formulating policy analyses both in and out of government. From that perspective, I pursue a dual concern for the state of basic knowledge and the capacity of such knowledge to shed light on actual policy decisions. The references provided are meant to be illustrative rather than to provide a definitive bibliography.

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* Senior Fellow and Director, Energy and Natural Resources Division, Resources for the Future. This paper will appear in a forthcoming special issue of *Environmental and Resource Economics*. I have benefited greatly from comments by Christian Azar, Jean-Charles Hourcade, Ian Parry, Jason Shogran, Richard Tol, and Jonathan Wiener, from conversations with Carolyn Fischer, Howard Gruenspecht, Richard Richels, and Robert Shackleton, and from the very capable research and manuscript preparation assistance of Ron Lile and Kay Murphy. Responsibility for its contents is mine alone.

1. ASSESSING CLIMATE CHANGE RISKS: PUBLIC CONCERN AND DECISION FRAMEWORKS[1]

A variety of "integrated assessment" (IA) models have been developed to assess (at varying levels of crudeness) the potential damages of climate change and costs of abatement, and to highlight emissions paths that minimize the present value sum of damage and control costs. These models essentially are dynamic benefit-cost tools. For the most part, current IA models indicate that cost-minimizing emissions paths rise through much of the next century (Manne 1996). This time pattern sharply contrasts with both the significant short-term emissions reductions for industrialized nations envisaged in the 1997 Kyoto Protocol, and the aspirations of many environmentalists to stabilize long-term atmospheric GHG concentrations at a reasonably low level compared to business as usual.

A lively debate has ensued about the extent to which the conclusions of IA models are driven by the use of a present value (discounted utilitarian) criterion for evaluating risks and responses. IA models are sensitive not just to the level of the discount rate (Azar and Sterner 1996), but also more generally to the form of the intergenerational welfare functional (Howarth 1996).

The specification of decision criteria for assessing climate change risks and response costs involves a deep and longstanding philosophical debate that may never be resolved. The debate can be seen in the discussion of decision criteria in the Second Assessment Report of the Intergovernmental Panel on Climate Change (see, in particular, Munasinghe et al. 1996). Attempts to limit consideration of tradeoffs, as with either an absolute "precautionary principle" for emissions control targets or an absolute cap on abatement costs, seem fundamentally unsatisfactory because they do not recognize the opportunity costs of actions taken or not taken.[2] Yet, a simple discounted net benefits criterion does not do justice to concerns about intergenerational equity, even if one successfully assessed all the risks and costs including option values associated with irreversible changes (Lind 1995; Toman 1994).

One way to frame the question that retains a utilitarian but altruistic perspective is to ask how willing the present generation is to incur costs (today and in their own future) in order to provide some uncertain but identifiable set of reduced climate change risks for people in the future. In this approach, the stream of abatement costs over time is discounted as with any assessment of intertemporal opportunity cost.[3] However, one does not simply apply the

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[1] The discussion in this section and the next one overlaps (and has benefited from a reading of) the paper by Azar (1998).

[2] This same criticism applies to the "tolerable windows" approach (see, e.g., Toth et al. 1997), which seeks to identify limits on short-term and long-term GHG emissions prior to (or in some cases to the exclusion of) considering abatement costs. One could modify the approach by also including dimensions of the tolerable window that reflect abatement costs, but this is still fundamentally ad hoc. At a minimum, one would want to assess the shadow cost of each of the constraints that define a window (see, e.g., Yohe 1997) and ask if the results delivered at the margin justify the cost.

[3] This is still difficult in practice, given uncertainties about the shadow price of capital and the social rate of time preference (see, e.g., Lind 1982, 1990; Azar and Sterner 1996).

same discounting procedure to evaluate changes in expected future risks from climate change. Instead, these changes in future risk are treated as benefits reaped by the current generation, and their value reflects the marginal rate of substitution for the current generation between their own welfare and the potential welfare of future generations (Schelling 1995; Toman forthcoming). This approach seems more consistent with individual preferences (broadly defined to include equity issues) than simply setting a low social discount rate for climate change analysis to reflect intergenerational equity concerns, as described for example in the IPCC Second Assessment (Arrow et al. 1996; see also Manne 1995, and Toth 1995 for discussion of intergenerational equity).

In practice, however, implementing this approach will not be easy. The rate of substitution might be assessed through a contingent valuation referendum as described by Kopp and Portney (1997), though these authors readily acknowledge the methodological challenges of the idea. At a minimum one would seek to provide some improved characterization of the time paths of future avoided damages under different scenarios (and their associated uncertainties) as part of the political processes underlying the formulation of climate change policies. There are also questions about how best to represent uncertainty about climate change risks (see below) in the decision criteria. The standard approach of expected utility theory has been criticized, particularly when there are low-probability extreme events (see, e.g., Camerer and Kunreuther 1989), but no widely accepted alternatives yet have emerged. Further empirical (and multidisciplinary) work to understand the nature of intergenerational stewardship concerns involving climate change, vis-à-vis other current and future concerns, would be very useful.

2. UNCERTAINTY, THE TIMING OF ABATEMENT, AND INTEGRATED ASSESSMENT

Many analyses of climate change risks look at a combination of modeling and judgmental "best estimates" for the degree of climate change, the potential impacts on natural and human systems, and the associated socioeconomic consequences. This approach is exemplified in the literature on climate change damages summarized in the IPCC Second Assessment (Pearce et al. 1996). In actuality, of course, all these links in the chain are uncertain, and the presence of this uncertainty has complex implications for timing of GHG emissions reduction and the policy tools employed. These implications are beginning to be better understood, but more research is needed to bring them fully into the light.

One important element is nonlinearities in the damage function. Yohe (1993) and Tol (1995) show that nonlinearities increase estimates of social damage when one takes into account the tails of the distribution of potential impact, and thus argue for more stringent control than an analysis based on single point estimates of damages. Peck and Teisberg (1993a, 1993b) draw a similar conclusion, while showing that the value of improved information about the curvature of the damage function is substantially larger than the value of improved information about its overall scale. However, these authors find that uncertainty has very little effect on the pace of near-term emissions reductions. This result follows because in their analysis, as in most IA models, the rate of emissions control which minimizes the present value of damage and response costs is quite low for a long time. This in turn reflects both low estimates of near-term damages and the effect of discounting in reducing the present value of longer-term damages.

Another source of uncertainty is the prospect of extreme events, which can raise the costs of climate change even if there are not strong nonlinearities in the damage function. The survey of IA model results by Manne (1996) considers the possibility of both levels of warming and degrees of socioeconomic damage well above the base cases used in the models. As expected, abatement should be more aggressive in these cases, but the strengthening of near-term abatement is significant only with the compound effect of both highly adverse warming and large socioeconomic damages. Gjerde et al. (1997) present an analysis of endogenous catastrophe (on the order of a Great Depression) based on cumulative emissions growth. They too show that a more conservative emissions path and thus more aggressive abatement are indicated, but even a fairly substantial long-term catastrophe risk will not have much of an impact on the desired emissions path in the short to medium term unless the discount rate is low. Additional research on the consequences of different catastrophe representations would be useful.

Pizer (1996) shows that when one incorporates uncertainty about key parameters in an IA model, the result is more aggressive abatement leading to an emissions path that grows more slowly and turns down sooner. This result also basically reflects asymmetries in the loss function which give rise to an option value for reduced emissions, given the quasi-irreversible long-term nature of climate change. Pizer finds that uncertainty about the social discount rate is particularly important, a finding consistent with the studies cited above.

Concerns about uncertainty and irreversibility lead in turn to issues related to learning about both climate change risks and response options. A number of studies (e.g., Manne and Richels 1992; Peck and Teisberg 1993a; Chao 1995) find that the value of improved information, which would allow more precise targeting of GHG policy, is substantial.[4] Since gathering better information takes time, these analyses can be interpreted as providing a further rationale for slower emissions reduction ("learn then act" versus "act then learn").

One possible criticism of this approach is that it downplays the cost of irreversible actions. The basic theory of irreversibility (e.g., Arrow and Fisher 1974) indicates that lower levels of irreversible commitment--which in this case could be interpreted as reduced growth in the atmospheric concentration of GHGs--is desirable when it is possible to gain knowledge in the future about future risks and costs. This argument has been advanced by, among others, Chichilnisky and Heal (1993).

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[4] The gains are especially large if one hypothesizes that the political process generates policies that are very different than what is considered to be optimal in the models (for example, significant near-term emissions reductions as envisaged in the Kyoto Protocol versus much more gradual abatement). As already indicated, however, the optimality of emissions reduction paths generated by IA models and thus the gains to better information which might direct policy onto a "better" path are dependent on the nature of climate change risks and the weighting of different generations' welfare levels.

Several studies explicitly incorporate learning to address these issues. Ulph and Ulph (1997) argue that the irreversibility effect could in principle go either way, but their modeling analysis tends to indicate the desirability of less short-term emissions control. Torvanger (1997) shows that the effect depends on the nature of the risk (constant versus positively related to cumulative emissions). Kolstad's (1996) analysis includes Bayesian learning and costly commitment to capital investments (introducing an irreversibility on the response side as well as the environmental side). He finds that there is little need for short-term concern about climatic risks, since erroneously slow emissions reductions most likely can be made up later, but there is a problem of making excessively hasty fixed investments to reduce GHG emissions in the face of uncertainty about their usefulness (a conclusion in keeping with the analysis of "real options" of Dixit and Pindyck 1994). In evaluating these results, it is important to keep in mind the influence of discounting, which makes the effective time horizon for evaluating consequences shorter and reduces the importance of long-term irreversibility in the climate system.[5]

The preceding arguments connect to a larger debate over the optimal timing of GHG reduction, a debate that has often considered uncertainty only implicitly. Regardless of how one establishes long-term policy goals for GHGs--based, for example, on cost-benefit analysis in an IA model or some other basis for establishing a long-term target for GHG emissions--there are several economic reasons for favoring some delay of emissions reduction. In studies that analyze the least-cost path to achieve a fixed long-term atmospheric concentration of GHGs (as opposed to an endogenous target in the full IA models), early delay is offset by more aggressive emission reduction in the future (see, e.g., Richels and Edmonds 1995, Wigley, Edmonds, and Richels 1996, Richels et al. 1996, Manne and Richels 1997). The rationales for this "backloading" include not just the ability to postpone and thereby reduce the present value of response costs, but also the ability to turn over the capital stock more slowly and thus with less cost, and the ability to embody better new technologies and energy sources in replacement investments.

In practice, issues of intertemporal credibility arise in implementing such a backloading approach, as discussed below. Here I focus on other counterarguments (see, e.g., Grubb et al. 1995, Hourcade and Robinson 1996, Grubb 1997, and Ha-Duong et al. 1997). Critics of this approach note that it may increase, not decrease, the expected long-term cost of GHG abatement. This would occur if delay allows more "lock-in" of long-lived capital based on GHG-intensive technologies; retard the development of new technologies that would be

[5] These analyses all consider risk-neutral decisionmakers. The impact of risk aversion will depend on the nature of the risk, for example the distinction between a risk that grows over time (and thus could act like a higher discount rate in increasing current emissions), and the risk of catastrophe that is increased by higher rapid emissions. Parry (1993) finds that even if decisionmakers are modeled as being risk-averse, an "insurance motive" for stronger short-term GHG reductions is quite weak unless the discount rate is very low. Eismont and Welsch (1996) introduce a concept of "ambiguity" related to the modification of existing judgments about climate change risks, and show that ambiguity aversion (broadly comparable to risk aversion with fixed probabilities) leads to more stringent emissions control.

spurred by near-term abatement policies (at least those that are incentive-based); and expose the economy to the risk of having to make costly rapid future decreases in GHGs in the face of investment and technological inertia if future scientific analyses revise upwards the risks of climate change. Advocates of backloading in turn reply that taking gradual steps on a long-term road toward significant GHG limits will provide early incentives for investments that help deter lock-in; that support for R&D (see below) can help offset a shortfall in induced innovation; and that the cost savings from a more gradual approach are so large that some risk of rapid future action is justified. These points of dispute highlight the points of clarification needed from future research.

Last but not least, bringing uncertainty more fully into climate change analysis also is useful in considering policy design. For example, Pizer (1997) extends the classic Weitzman (1974) prices versus quantities analysis to a dynamic assessment of climate change policies. He finds that given uncertainty about abatement cost and a relatively flatter marginal damage cost schedule compared to abatement cost, emissions taxes are likely to yield higher expected social welfare than quantity controls (implemented with tradable emission permits).[6] This finding has important implications especially in the United States, where environmentalists' concerns for firm emissions control goals have combined with a broad political aversion to energy taxes to make an emissions trading program the leading method for implementing the Kyoto Protocol. One useful extension of the analysis would be to bring in the risk of catastrophe discussed above, which is absent in Pizer's current model but would likely swing the balance somewhat back toward a quantity-based approach.

3. ADAPTATION TO CLIMATE CHANGE AND THE IMPORTANCE OF INFRASTRUCTURE

It goes almost without saying that improved understanding of the risks posed by climate change is crucial for formulating well-designed long-term strategies. A great deal of interdisciplinary work is addressing these issues (see, e.g., IPCC 1998 for a recent contribution). In evaluating efforts to improve our understanding of risks, I would underscore the importance of incorporating a socioeconomic perspective.

This point is especially important in considering potential adaptation to the risks of climate change. Most observers acknowledge that some degree of adaptation to a changed climate will be inevitable. Yet, adaptation potential and adaptation policy to some extent have been orphan stepchildren in the debate over climate change. This is due in part to the nature of the Framework Convention on Climate Change, which effectively relegates adaptation to a national versus international issue, as well as to the ongoing political struggles over abatement targets. It is also due to the fact that analysis of adaptation requires analysis

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[6] Pizer (1997) considers only regulation of the rate of GHG emissions, but very preliminary extensions of that framework suggest that the findings extend (with some limits) to a situation in which one is regulating GHG concentrations (personal communication). One interesting unanswered question in this context is the extent to which the results would be affected by the introduction of declining near-term marginal benefits from reductions in conventional pollutants as a byproduct of effort to cut GHG emissions.

of specific kinds of assets used for specific purposes in specific places, as opposed to the use of stylized aggregate models for abatement cost analysis.

Analyses of the risks and costs of climate change that do not adequately allow for potential adaptation of informed and motivated economic actors necessarily will come to biased conclusions. This seems to be the case, for example, with the estimates of economic damages summarized in the IPCC Second Assessment (Pearce et al. 1996). Several studies that largely postdate the literature underlying the IPCC assessment illustrate the potential for adaptation (including reduction of other stresses on resource systems) to lower the cost of climate change in connection with agriculture, forestry, and water resources (Crosson 1989, Mendelsohn et al. 1994, Reilly 1995, Frederick et al. 1997, Sohngen et al. 1997).[7]

This argument does not mean that adaptation can obviate the need for abatement, especially since adaptation is more difficult for less managed ecological resources, but only that an accurate assessment of risks and damage costs requires an accurate assessment of potential adaptation by self-interested parties (Smith et al. 1995, Toman and Bierbaum 1996). Another critical element that needs to be highlighted in empirical work on adaptation potential is the role of different kinds of infrastructure--a knowledge base about the risks, general technical facility, the extent of human capacity to exploit scientific and technical knowledge, and the functioning of institutions for resource management and public health. Studies of adaptation potential explicitly or implicitly rely upon these social assets. However, the lack of adequate infrastructure is already recognized as an impediment to adaptation, especially in poorer countries which are arguably more vulnerable to climate change. A sharper empirical understanding of the roles of different infrastructure components will increase the potential to enhance adaptive capacity through economic and other policies that nurture the necessary infrastructure, including institutional changes that will lower adaptation costs.[8]

4. ASSESSING GHG ABATEMENT COSTS: THE "ENERGY EFFICIENCY GAP"

Debate has raged for years about the extent to which there are low-cost options for reducing fossil energy use because market failures. This debate is highlighted in the IPCC Second Assessment, which states that energy efficiency improvements on the order of 10-30% might be possible at little cost or even with net benefits, even while most "top-down" economic models indicate a significant cost for stabilizing or cutting OECD emissions below 1990 levels (see Hourcade et al. 1996b). More recently, several National Laboratories in the United States have released a "bottom-up" report indicating that US domestic emissions reductions on the order needed to meet the Kyoto Protocol could be achieved at very modest

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[7] For example, the last of these studies shows how adaptive forest management (such as salvage cutting of stressed trees, reseeding with better-adapted species, and plantation cultivation) and international trade both are likely to buffer the negative impacts of climate change on forest yields.

[8] World Bank (1992, 1994) provides useful summaries of interrelationships among environmental problems, patterns of economic development, and investments in infrastructure. For other discussions of adaptation potential and challenges see OTA (1993), Smith et al. (1996), and Jepma et al. (1996).

total cost through the deployment of various existing technologies and aggressive R&D (Interlaboratory Working Group 1997). In this study, the marginal cost of carbon reduction may be significant (on the order of $50/tonne), but the total cost is small because of a substantial well of low-cost or even negative-cost options. A similarly optimistic conclusion is reached by Krause (1996).

The basic theoretical dimensions of this debate as it applies to the United States and other advanced market economies are well established (see, for example, Sutherland 1991, Grubb et al. 1993, Sanstad and Howarth 1994, Jaffe and Stavins 1994, 1995, Hourcade et al. 1996a).[9] Market failures in the choice of energy efficiency could arise because of liquidity constraints, moral hazard problems (landlords rather than tenants pay utility bills, managerial reward structures may be suboptimal), shortages and asymmetries of information, existing regulatory distortions, and other factors. If these market failures can be reduced, then low-cost emissions reductions can be achieved. On the other hand, comparisons of an engineering ideal for a particular energy use to average practice for existing technology are inherently misleading because of "hidden costs" that reflect not only buyer reactions to product attributes but also the real-world costs of improving institutional performance and reward structures.

At this point there is an urgent need for further and more detailed empirical work that can help clarify influences on technology choices, including those potentially associated with market failures. The micro-level work by Newell et al. (1998) on the relative influences of prices, information campaigns, and direct regulation on specific choices of energy-using equipment, and the attempts by DeCanio (1994) to analyze micro-level firm decisionmaking, are recent examples.[10] Another important question pertains to the persistence of low-cost energy reduction opportunities over time. Even if one did accept the view reported in the Second Assessment that cheap 10-30% reductions were possible, would these opportunities persist? Or is it more likely that if they do exist, they are more like a one-shot windfall that cannot be repeated as GHG reductions continue to be enforced? The latter seems more plausible if one argues that any existing "low fruit" results from low market and regulatory incentives to promote energy efficiency. If this is the case, it would imply that the higher long-term abatement costs indicated by top-down models may not be so wide of the mark.

As the IPCC Second Assessment notes, in the economies in transition and in many developing countries, there may be greater potential for low-cost improvements in energy efficiency because of a legacy of economic distortions (see also Chandler and Evans 1996, and Halnaes 1996). Large subsidies to energy production and use are often singled out, along with legacies of over-industrialization in centrally planned economies (and failure to

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[9] A number of more specific studies also have been published, particularly in *Energy Policy* and the *Energy Journal*.

[10] One of the ways the Interlaboratory Working Group study attempted to describe greater attentiveness to available technological opportunities is by lowering the "hurdle rate" for energy-saving investments by more than half when carbon controls were assumed to be employed. This is an ad hoc approach that largely assumes the answer and highlights the need for deeper analysis.

adequately address conventional environmental externalities). While these points no doubt are true, their importance may shrink over time as formerly planned economies restructure and energy subsidies continue to be squeezed out. At the same time, regulatory and other institutional barriers to the diffusion of improved technology into developing and transitional economies have received relatively less attention in economic analyses and warrant deeper consideration (Blackman and Wu 1997 illustrates this kind of analysis).

5. INCENTIVES FOR TECHNICAL PROGRESS AND THE COSTS OF GHG ABATEMENT

Whereas the energy efficiency gap is concerned primarily with the use of existing technology, it is widely agreed that technical innovation is the ultimate key to successful (meaning affordable as well as quantitatively adequate) global measures to stabilize the concentration of GHGs in the atmosphere. Economists' general understanding of the forces that drive the discovery and development of new technologies remains limited. This is demonstrated by the use of ad hoc "autonomous energy efficiency improvement" rates in many top-down economic models. These rates represent exogenous trends in energy efficiency improvement that occur independently of energy price and other economic signals.

Beyond this general point, a second important dimension is that induced innovation directed toward reduced GHG emissions may have indirect opportunity costs: if the supply of innovative effort is less than infinitely elastic, which seems reasonable to assume, then increased innovation in GHG reduction necessarily will make other innovation more expensive and thus crowd it out to some extent. This in turn will reduce long-term economic growth prospects, and raise the long-term cost of GHG abatement (Goulder and Schneider 1998).[11]

In addition to better understanding these basic issues in the economics of innovation, there is a need for additional work on how different abatement policies may affect incentives for innovation.[12] For example, a fixed emissions tax rate can have a more powerful effect on innovation incentives than a tradable permits system with allocated initial endowments, since innovation reduces the equilibrium permit price and erodes the value of permit holdings. But if permits are auctioned the incentives for innovation can be enhanced, since the drop in the equilibrium permit price lowers total payments in the auction. The degree of appropriability of economic rent from an abatement innovation also affects incentives.

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[11] To avoid confusion, it is important to note that if existing rates of investment in GHG-reducing technologies are too low, for example because of the usual concerns about appropriability, then GHG abatement policies that stimulate technical change will help to reduce this R&D market failure as well as addressing the environmental challenge of GHGs. The general equilibrium argument put forward by Goulder and Schneider points out that these combined gains must be compared to the consequences of any reduced R&D investment elsewhere in the economy (where rates may also be below the social optimum before the imposition of GHG policies) as well as to the direct costs of climate-related R&D.

[12] More recent work in this area that builds on Milliman and Prince (1989) includes Jaffe and Stavins (1995), Parry (1995b, 1997), and Jung et al. (1996).

6. OTHER CONTINUING CHALLENGES IN GHG ABATEMENT COST ANALYSIS

There is a large published and "gray" literature on the economic costs of meeting various targets and timetables for greenhouse gas (GHG) control, especially for the United states.[13] A wide variety of top-down modeling platforms have been used, from macro forecasting systems to computable general equilibrium models. This literature increasingly underscores the importance of both general equilibrium and multinational analysis. The importance of general equilibrium analysis at a national level is in the ability to better capture the many direct and indirect impacts of GHG abatement policies, which elevate the social cost of control compared to partial equilibrium calculations of direct expenditures (Hazilla and Kopp 1990).

The importance of multinational analysis is that national policies to restrict GHG emissions necessarily will alter terms of trade among different countries. These terms of trade effects will have a variety of real and monetary consequences, including changes in capital flows and exchange rates, that will have further economic ramifications and ramifications for the scale and location of GHG emissions (the "leakage" issue). While a number of models incorporate trade in energy goods, and many incorporate trade in other goods as well, the next challenge is to more fully integrate capital flows.[14]

Another important opportunity for advancement of policy-relevant knowledge concerns the "double dividend" resulting from interaction between climate policies and existing taxes (Bovenberg and de Mooij 1994, Bovenberg and Goulder 1996, Goulder 1995, Parry 1995a, Parry et al. 1997, Welsch 1996). Most empirical analysis of these interactions focus mainly on full-employment economies like the US. Less is understood empirically about double dividends in underemployment economies, or about tax interaction effects associated with command-and-control policies. There is also a need for further assessment of the distributional implications of double dividend policies and their political economy.[15]

Finally, a concern arises in addressing the cost of abating multiple GHGs. In principle the greater flexibility available with a more comprehensive approach should reduce cost. However, there is considerable ongoing dispute about the appropriate *economic* weights for trading off abatement of gases with different lifetimes and warming potentials (Stewart and Wiener 1992, Reilly and Richards 1993, Hammitt et al. 1996).

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[13] See Hourcade et al. (1996b) and Repetto and Austin (1997) for surveys; for recent analyses see, e.g., IAT (1997), Edmonds et al. (1997), Bernstein et al. (1997), Jacoby et al. (1997), Manne and Richels (1996), McKibbon and Wilcoxen (1995), and Jorgenson and Wilcoxen (1995).

[14] To illustrate, the "G-Cubed" model being developed for USEPA by Peter Wilcoxen and Warren McKibbon indicates that when developing countries do not participate in GHG reductions, they may indeed benefit at the expense of industrialized countries that do; but the benefit may result from capital inflows triggered by changes in exchange rates and real interest rates, not by the "leakage" of more energy-intensive industry out of Annex 1 countries.

[15] Yet another dividend needing further study is the value of reduced conventional pollutants resulting from curbs on GHGs; Burtraw and Toman (1997) provide a recent survey and assessment of these potential benefits.

7. FLEXIBILITY VERSUS STRINGENCY--CREATION OF CREDIBLE AND COST-EFFECTIVE ABATEMENT POLICIES OVER SPACE AND TIME

There is an inherent tradeoff between the stringency of a policy target and the flexibility with which this target is pursued: the more flexible and cost-effective are the means pursued, the more affordable are the ends. This observation motivates the search for ways to enhance the flexibility and cost-effectiveness of policy options, while preserving credibility of the policies in achieving whatever targets are determined. Flexibility can be enhanced in the timing of emissions reductions, as already noted, and in where emissions reductions are carried out and by whom.

An important challenge to the use of intertemporal flexibility in abatement is that in a world in which binding intertemporal contracts across governments are impossible to write, and binding long-term regulatory contracts with private agents are difficult to enforce, there is a challenge in avoiding perpetual delay in emissions reduction that thwarts the long-term environmental goal. Put another way, if backloading is thought of as borrowing GHG emissions from the future, how does one ensure that the carbon debt is not defaulted on? The first step in attacking this problem is formulating a model of dynamically consistent public and private decisions without intertemporal forcing contracts. The second step is devising ways in which commitments to future carbon reductions might be made more intertemporally credible, for example through investments that seek to induce cost-reducing technical innovation which makes it easier for future decisionmakers to accept more stringent emissions targets.[16]

Substantial potential cost savings also are possible with various forms of international emissions trading (see, e.g., Manne and Richels 1996 and Edmonds et al. 1997).[17] One challenge in achieving such benefits in practice is that emissions trading makes explicit an international allocation of emissions opportunities or rights (though *any* meaningful agreement also involves such an allocation). Implementation of international emissions trading also may require at least some harmonization of both domestic GHG policies and fiscal policies. For example, countries seeking to auction their permits (to obtain additional revenues or to exploit a double dividend) may fear a loss of competitiveness if other countries allocate their allowances gratis, though the seriousness of this issue in practice is unclear. Differences in the domestic tax treatment of corporate income also will have implications for where international businesses participating in an international carbon market locate or expand their activities. Similar issues arise in developing coordinated international GHG taxation.

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[16] It might also be possible to maintain a revenue-raising policy over time by increasing the cost of eliminating it--for example, by dedicating the revenue to funding social insurance programs.

[17] There is also an active area of research concerned with how a domestic cap-and-trade system for GHG emissions would be constructed. For example, would it be "upstream" or "downstream?" How would an auction for GHG permits be designed; how would gratis allocations be pursued? This is a hugely important issue in the United States, with a rapidly growing literature, but in the interest of conserving some space I do not develop these ideas further here. Stavins (1997) provides an overview of some of these issues from both domestic and international perspectives; see also Toman and Shogren (forthcoming).

Credibility issues also arise in connection with participation in GHG trading by parties in countries whose total emissions are not capped.[18] In the absence of national emissions caps in the host country, it is unclear whether net emissions are reduced or emissions are just displaced (another form of emissions "leakage"). Complex procedures have been proposed for calculating the "additionality" of emission reductions in such projects (see, e.g., Carter 1997), but the incentive effects of these procedures are not yet well understood. Moreover, even if there was no uncertainty about the net emissions reductions conditional on project completion, asymmetric information and the potential for contract breach or opportunistic behavior create potentially significant uncertainties about the outcomes of such projects. Problems of these types all fall under the general heading of optimal contracting and agency relationships. However, this powerful set of theoretical tools is just beginning to be brought to bear on JI issues (Hagem 1996, Nannerup and Steiner 1997). These analyses need to be expanded and joined with institutional and legal analyses of GHG trading issues (see, e.g., Tietenberg and Victor 1994 and Stewart et al. 1996).

8. INTERNATIONAL CLIMATE AGREEMENT IN THEORY AND PRACTICE

Because climate change is a canonical example of a collective action problem--actions within each country affect welfare in all countries, and effective responses require a large degree of international participation--climate change also is a canonical example of the difficulties of achieving effective collective action noted by Olson and Zeckhauser (1966). Since that classic paper, and especially in the past 10 years, a large literature using concepts from noncooperative and cooperative game theory to analyze the negotiation of coalitions for GHG abatement has developed (see, e.g., Carraro and Siniscalco 1993, Barrett 1994, Hoel and Schneider 1997). These studies have highlighted the conflicting incentives in the formation of effective coalitions. For example, when the benefits from forming a large coalition are substantial, the incentives to stay with the coalition also may be weak; the presence of side payments can help ameliorate this problem.[19]

Simple models abstract from the fact that international relations are affected by actions on a number of issues at once, leading to linkage between climate and other environmental and economic issues. The treatment of countries as unitary actors in simple models also sidesteps the complex hierarchy of relationships between government representatives and

[18] These programs used to be referred to as "joint implementation," but the Kyoto Protocol created a new label, the "Clean Development Mechanism."

[19] Burtraw and Toman (1992) use a heuristic bargaining framework to suggest that simple rules of thumb for sharing the benefits and costs of GHG reduction measures are unlikely a priori to command adequate support to form a basis for international agreement. Rose and Stevens (1993) analyze different equity principles in the context of an international trading system; Rose and Tietenberg (1993) consider the consequences for economic development of international trading.

interest groups, both domestically and internationally. Current research in this area is loosening these strictures, but there is substantial room for further progress.[20]

Another important and promising research area looks at different possibilities for "graduation" of developing countries into the coalition of countries that have accepted some form of national emissions constraint. One way to do this is to simply offer enough wealth transfer through an initial allocation of tradable emission credits that the developing countries are induced to join. However, this is quite likely to be unacceptable in practice to the industrialized countries. This leads in turn to consideration of various second-best approaches, where developing countries gradually assume greater responsibility as their per capita incomes rise. Various proposals include staggered participation in emissions stabilization and reduction targets, with the possibility of eventually converging to equal per-capita emissions levels (for illustrative analyses see Edmonds et al. 1995 and Manne and Richels 1997)

9. CONCLUDING REMARKS

The research agenda implied by my priority list emphasizes expanding empirical understanding as well as utilizing contemporary theoretical advances such as the economics of agency and contracts and the analysis of dynamic consistency issues. It also is an agenda which emphasizes both short-term and longer-term studies. Continuation and enhancement of current research activities, if adequately supported by the appropriate national and international authorities, could yield new and useful insights for decisionmakers in the relatively short term. In other cases, though, basic factual uncertainties--in particular, about climate change risks and possibilities for adaptation--also need to be reduced.

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[20] Ulph and Maddison (1997) illustrate another interesting extension by showing that in some cases, the value of improved information about climate change risks with multiple national decisionmakers could be negative.

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