

**Understanding the Design and
Performance of Emissions Trading
Systems for Greenhouse Gas Emissions:
*Proceedings of an Experts' Workshop to Identify
Research Needs and Priorities***

Michael Toman

May 2003 • Discussion Paper 03–33



RESOURCES
FOR THE FUTURE

Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202–328–5000
Fax: 202–939–3460
Internet: <http://www.rff.org>

© 2003 Resources for the Future. All rights reserved. No portion of this paper may be reproduced without permission of the authors.

Discussion papers are research materials circulated by their authors for purposes of information and discussion. They have not necessarily undergone formal peer review or editorial treatment.

Contents

Preface: Understanding the Design and Performance of Trading Systems for Greenhouse Gas (GHG) Emissions

Jason Shogren, University of Wyoming, and Michael Toman, adjunct professor Johns Hopkins University and University of California-Santa Barbara and former senior fellow, Resources for the Future

Chapter I

Modeling Challenges in Analyzing GHG Trading

Frederic Gherzi, former visiting scholar, Resources for the Future and Michael Toman, adjunct professor Johns Hopkins University and University of California-Santa Barbara and former senior fellow, Resources for the Future

Chapter II

Experimental Methods for Research into Trading of GHG Emissions

R. Andrew Muller, McMaster University

Chapter III

Exploring the Behavioral Underpinnings of Carbon Trading

Jason Shogren, University of Wyoming

Chapter IV

Greenhouse Gas Trading: Design Issues Seeking Research Answers

Tom Tietenberg, Colby College

**Understanding the Design and
Performance of Emissions Trading
Systems for Greenhouse Gas (GHG)
Emissions (Preface)**

Jason Shogren and Michael Toman



RESOURCES
FOR THE FUTURE

Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202-328-5000
Fax: 202-939-3460
Internet: <http://www.rff.org>

Understanding the Design and Performance of Emissions Trading Systems for Greenhouse Gas Emissions: Proceedings of a Workshop to Identify Research Needs and Priorities

Preface

Jason Shogren, University of Wyoming (jramses@uwyo.edu)
Michael Toman, Resources for the Future (toman@rff.org)

This “digital monograph” is based on a workshop we organized at Resources for the Future in 1999 to bring together a variety of experts to refine a list of priority research questions on greenhouse gas (GHG) emissions trading. The workshop sought to

- (1) highlight the state of knowledge regarding greenhouse gas emissions trading,
- (2) help stimulate synergy among researchers with different specialties, and
- (3) provide a resource for funders and users of research on greenhouse gas control options when setting their own priorities.

The papers in this proceedings were prepared after the workshop based on presentations made there. Rather than divide the workshop program by type of policy mechanism, we divided the program into three methodological categories that span all the flexibility mechanisms. These categories are theoretical/legal/institutional issues, modeling, and experimental approaches. The papers included in the proceedings address each of these topic areas.

Economists and policy analysts have long been interested in how to design and implement an emission trading system to reduce greenhouse gases efficiently, both domestically and internationally. In the wake of negotiations for the Kyoto Protocol, interest in the properties and implications of emissions trading has spread rapidly to governmental decisionmakers and other important stakeholders in the climate change arena. As more and more people take a hard look at emissions trading, numerous questions needing reliable answers have emerged. While no confusion exists about the basic principles behind emissions trading as an incentive-based, cost-effective policy tool, decisionmakers must address many unexplored specifics as to how GHG emissions trading would be designed and would perform in practice. For example:

- Where in the energy system can emissions trading be implemented in practice?
- What is the role of governments vis-à-vis private actors in international trading? What kinds of institutions –(i.e., clearinghouses and scorekeeping) need to be developed, and who should develop them? How do the answers differ when considering trading among “Annex B” industrialized countries and creating carbon credits through activities in non-Annex B developing countries via the Clean Development Mechanism (CDM)?

- How does one deal with the nettlesome issues of defining credible baselines and additionality for CDM transactions, given imperfect contracts and enforcement and the potential for opportunistic behavior by transaction participants?
- What liability provisions are needed for credible but workable trading, and what will the consequences of different liability regimes be?
- What will be the specific nature of the transaction costs in different GHG emissions markets? What design features will increase or decrease the efficiency of the markets?
- What would be the cost-savings from different forms of emissions trading, domestically or internationally, relative to different forms of alternative policy measures? This is particularly important when considering various departures from the theoretical ideal in policy design, such as limiting the volume of emissions permits used for compliance or implementing hybrid programs that mix emissions permits with more rigid mandates. What can be learned from different economy-wide models that lack intrasectoral detail and from richer sectoral models that lack economy-wide coverage? How can we account for transactions costs in modeling efforts?
- How does one initiate an emissions trading program? What kind of phase-in mechanisms and time periods are appropriate? What types of auctions could be used to distribute permits?
- How should emissions trading programs be designed in light of the uncertainties surrounding the long-term level of desired emissions control?
- How might cost-effective flexibility in the regulation of atmospheric concentrations of greenhouse gases be implemented as part of an emissions trading program without sacrificing program credibility?
- What kinds of sectoral and international distributional effects might arise from different program designs, and how might these "income effects" alter the overall cost of the program (e.g., by altering the size and composition of investment or innovation)?

This list of questions, while by no means exhaustive, illustrates the range of issues that require additional analysis. The list also reveals how research based on the application of existing concepts and techniques might provide a more solid foundation for any emissions trading system that might emerge in the future. As we did in the workshop, we emphasize here that our purpose is not limited to analyzing (let alone advocating) specific policy mechanisms referred to in the Kyoto Protocol. Our purpose instead is to bring to light broader questions about GHG emissions trading systems that merit research attention.

We wish to thank the authors who contributed presentations and papers and all the participants in the workshop for their helpful insights. We also wish to thank the U.S. Department of Energy's Office of Science (Grant #DE-FG02-98ER62603) and the U.S. Environmental

Protection Agency's Office of Policy (Grant #CR925715) for financial support to conduct the workshop. As always, the views expressed by the authors are theirs alone and do not reflect positions taken by Resources for the Future or the funding agencies.

Modelling Challenges in Analyzing GHG Trading

Frederic Gherzi and Michael Toman



RESOURCES
FOR THE FUTURE

Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202-328-5000
Fax: 202-939-3460
Internet: <http://www.rff.org>

MODELING CHALLENGES IN ANALYZING GREENHOUSE GAS TRADING

Frederic Gherzi and Michael Toman
Resources for the Future, Washington, DC
toman@rff.org

Introduction

As interest in greenhouse gas trading policies grows in the United States and other Annex I countries, so does the need for stronger analytical tools. The paper by Tietenberg in this collection lays out some of the principal conceptual issues that analysts face in providing more accurate and relevant tools and results for decisionmakers. In this paper we build on Tietenberg's analysis to consider some of the key modeling challenges that analysts face in developing an improved capacity for quantitatively assessing real-world policies.

To date, most U.S. climate policy modeling efforts have been devoted to the consequences of a carbon tax policy to the U.S. economy. In most instances, the level of aggregation used in the analysis has permitted extension of the results to an assessment of the impacts of a comprehensive CO₂ trading system, one that operates "upstream" in the energy system to limit the supply of fossil fuels. The analytical frameworks used have included multi-sector computable general equilibrium models (CGEM),¹ detailed models of energy sector technology choice,² intermediate energy-economy simulation models,³ and macroeconomic forecasting models.⁴ Analyses have focused primarily on three dimensions:

- Revenue recycling issues: the net cost of a carbon tax or auctioned permits system varies with the use made of the income those instruments raise. Broad categories for this use are lump-sum rebates to consumers, reductions of national debt, cuts in pre-existing tax rates, and increases in public spending.
- "When flexibility": another component of research has looked at the cost implications of different *timing* in the reduction of CO₂ emissions. While this work is perhaps most easily perceived as showing the implications of different time paths for GHG control targets, it also can be interpreted as illustrating the implications of greater intertemporal flexibility through (longer-term) borrowing against future allocations in a carbon permit market.⁵

¹ Among the principal models of this types are EPPA (Yang et al. 1996), WorldScan (Bollen et al. 1999), G-Cubed (McKibbin et al. 1995), GTEM (Tulpulé et al. 1999), MS-MRT (Bernstein et al. 1999), and SGM (Edmonds et al. 1995).

² See for example the Energy Information Administration NEMS project (EIA 1998) or the Brookhaven National Laboratory MARKAL model (Fishbone et al. 1983).

³ Some examples are MERGE (Manne et al. 1995), CETA (Peck and Teisberg 1992) or GRAPE (Kurosawa et al. 1999).

⁴ See, for example, the Oxford model (Cooper et al. 1999), RICE (Nordhaus and Boyer 1999b) or FUND (Tol 1999).

⁵ See, for example, Kosobud et al. (1994), Manne and Richels (1997), and Ha-Duong et al. (1997).

- "Where flexibility": a great deal of work also has been devoted to the implications of what have come to be called the "Kyoto flexibility mechanisms" for CO₂ control costs in the United States, other Annex I countries, and the world as a whole.⁶ These mechanisms include different forms of international emissions permit or credit trading among the Annex I countries and credit-based projects in developing countries through the Clean Development Mechanism (CDM). A variety of international energy-economy models have been developed or extended for this purpose, including international general equilibrium models and energy-economy simulation models with less sectoral detail.

In each of these research fields, considerable progress has been made since the first modeling attempts at the end of the 1980s. There is now a broad consensus on the cost-efficiency of revenue recycling to decrease the marginal rate of existing distortionary taxes (income taxes in particular),⁷ and substantial potential cost-savings from using the Kyoto mechanisms.⁸ There is also broad though not universal agreement on the substantial potential cost-savings from a more gradual approach to GHG control over time. The strengths and weaknesses of allowing borrowing in a trading system has not yet been determined.⁹

Still, major uncertainties remain regarding the organization of emissions trading and its consequences. Beginning first with a closed economy, two main issues require further research effort. The equity implications of an upstream auctioned permit system with revenue recycling, or of other domestic policy designs, has received relatively little attention. The emphasis has been for the most part on economy-wide impacts (e.g., impacts on Gross Domestic Product (GDP) or the present value of lost consumption opportunities) and only secondarily on producer-, consumer-, and geographically-related distributional issues, despite their paramount importance in policy analysis. Second, given the obvious importance of technical progress in the assessment of GHG abatement costs, it is important to shift from exogenous specifications of technological possibilities (such as trends in autonomous energy-efficiency improvement or in the introduction of backstop technologies and fuels) to analysis of technical change that is induced by current and anticipated price vectors. Depending on data availability, such an endogeneization ideally would be sector-specific.

Turning to the challenges in carbon trading assessment related to open economies, there are two more major challenges. First, most available figures regarding the benefits of "where flexibility" must be considered only a measure of potential savings, because the policy scenarios implicitly or explicitly assumed in the models are quite stylized. Individual nations are assumed to implement fully cost-effective domestic policies; international emissions markets are assumed to operate costlessly with no frictions; and regulatory constraints on the international markets are

⁶ See the recent report from the Energy Modeling Forum (1999). Our use of the term "Kyoto flexibility mechanisms" as a common term of art in climate policy analysis does not imply the taking of any point of view about the desirability of the Kyoto Protocol; there is scientific interest in the issues surrounding international GHG trading with or without the Protocol.

⁷ See Bovenberg and de Mooij (1994), Goulder (1995), Parry et al. (1997), and Bovenberg (1999).

⁸ Full-fledged trading among Annex I countries—including full use of the potential excess emissions allotments in Russia and other Annex I transitional economies—could reduce costs on the order of 50% compared to a no-trading case. A further 50% costs-savings could be achieved through full use of global trading under the CDM. See also Shogren and Toman (2000) for a review of the literature.

⁹ See Toman, Morgenstern, and Anderson (1999) for a review of the literature.

assumed to be absent. A better quantitative understanding of such "transactions" costs in international carbon trading and their implications for the efficiency of carbon trading markets is needed. Second, beyond the carbon markets per se, it would appear necessary to shed some further light on the extent and impacts of "carbon leakage." This phenomenon is of interest even with a global climate agreement, given the potential modifications in terms of both trade and financial flows. It is even more of interest given a nonglobal policy, one that emphasizes constraints and actions primarily by a subset of countries (like the Annex I countries under the Kyoto Protocol.)

Closed-Economy, Domestic Policy Issues

Better understanding of distributional impacts

The need for a study of the distributional impacts of a carbon trading scheme stems from the narrowness of the "fiscal base" targeted. At first glance, it seems intuitive that the burden of a climate policy should weigh more on consumers and suppliers of energy-intensive goods. Much of the existing distributional analysis has been concerned with the impacts on income classes and sectors.

Numerous studies on different countries underscore the regressive impacts of carbon pricing (tax or auctioned permits) on households' income.¹⁰ Various ways of overcoming those impacts are assessed mainly through a modification of revenue recycling assumptions: decreases in income or payroll tax rates for lower income groups, reductions in VAT rates, increases in earned income credits, or direct financing of conservation measures for the lowest incomes. In most analyses, neutralizing the adverse distributive effect seems achievable at a negligible total welfare cost.

On the producers' side, given obviously differentiated sectoral impacts, research has focused on assessing possible exemption rules. Most analyses in this regard have been conducted in Nordic countries where CO₂ taxes are already in force. Results are strikingly divergent, ranging from optimistic in some instances—a low welfare cost of exemptions (Bergman 1996; Bye and Niborg 1999)—to more pessimistic in others (Jensen 1998; Hill 1999). Further research is needed to account for these disparities and draw clearer conclusions, notably regarding the influence of differing industrial structures (though Hill and Bergman's differing conclusions both concern Sweden).

Regarding the United States, a recent study by Bovenberg and Goulder (2000) examines various ways to provide partial offsets of profit losses borne by primary energy producers. They find that direct transfers through partial grandfathering of GHG permits to fuel suppliers would produce the offsets at a low overall efficiency cost. Other policies involving changes in tax rates are less cost-effective because they involve more distorting means of income redistribution. Bovenberg and Goulder recognize that distributional impacts downstream would be harder to address, while underlining that extending their assessment would require a further disaggregation.

Further analysis would look across or even within individual sectors to see the consequences for specific types (i.e., size and factors' intensities) or locations of firms. This analysis begins to

¹⁰ See Poterba (1991), Jorgenson et al. (1992), Schillo et al. (1993), and Bull et al. (1994) for the United States; Barker and Johnstone (1993) and Symons et al. (1994) for the United Kingdom; O'Donoghue (1997) for Ireland; and Harrison and Kriström (1999) for Sweden. Note that these references all consider general equilibrium effects.

address the key question of *where* different impacts will be felt. Similarly, existing cross-sectional information on energy demands by region can be used for households. Similar analysis was done in the debate over the Clinton Administration's BTU tax, and it can profitably be repeated to help address winners and losers from emissions trading. Concerning households specifically, two other directions might be of interest. One is an inclusion of ancillary environmental benefits into the distributional impacts, as those with lower incomes who inhabit areas relatively more polluted may capture a greater share of those. Another is analysis based not on income but household composition. Harrison and Kriström (1999) show that for Sweden, costs generally increase with household's size; it would be useful to see the extent to which this finding can be confirmed and extended in other studies.

Improved modeling of technological innovation

One would expect intuitively that the way in which carbon pricing will affect carbon consumption and the impact of a carbon mitigation effort is linked with innovation. The more available are some substitutable technologies and the lower their costs, the less expensive is any given emissions reduction target.

In most of the existing models (see the Appendix) innovation is embodied in an Autonomous Energy Efficiency Improvements (AEEI) scalar. This figure represents an exogenous trend in energy efficiency that cuts intermediate energy consumption in production functions. Some modelers also consider the exogenous introduction of one or several "backstop" (constant cost, low-cost, or non-carbon) technologies or fuels over various future periods. Both those adjustments are exogenous in the sense that they occur independently of energy prices and other economic signals.

We are certain that a change in relative prices of energy will affect the content of innovation, and possibly also its rate; there is in short an induced component to technical change that has complex consequences. To this date, most of the papers dealing with the issue of induced change have focused on the optimal timing of abatement policies and have contrasting conclusions.¹¹ A recent exception is Goulder and Schneider (1997, 1999), who modify the Goulder (1995) model by introducing an "R&D service market." These services can be used by other industries to substitute for their other production factors, including energy. Their results give several interesting insights regarding the impact of technical change endogeneization. Aggregated costs of any given abatement target are reduced; indeed, the higher the target the more the degree of reduction. Different assumptions regarding intra- and inter-sectoral knowledge-spillovers could possibly make the case for targeted R&D subsidies, even though this diverts some revenue from general efficiency-enhancing recycling. In addition, Goulder and Schneider underline the potential opportunity cost of induced GHG-reducing technical change if other R&D activity is crowded out in the economy.

¹¹ See Grubb et al. (1995), Wigley et al. (1996), Ha-Duong et al. (1997), and Nordhaus (1997). A tentative synthesis is offered by Goulder and Mathai (1998), who stress that timing implications of induced technical change depend on the assumptions regarding principal channels of innovation, either spending on research and development (R&D), or learning-by-doing: the R&D spending hypothesis speaks for delayed abatement, while the learning-by-doing hypothesis reaches the opposite conclusion.

Those first results need to be probed as well as extended, notably through a differentiation of induced technical change across industries, as underlined by Ferrante (1998). And through the crowding out effects on other R&D expenditure and the complementary potential for knowledge spillover, induced technical change is linked to the study of the distributional impacts of carbon policy.

International and Open Economy Issues

Better quantitative understanding of "second-best" costs and their implications for the efficiency of carbon trading markets

An ideal "first best" market for carbon emissions trading (from an overall efficiency perspective, abstracting from distributional concerns) would be one with complete "where" flexibility, that is a fully global market where actors can buy and sell anywhere without restrictions. This market would also have such characteristics as perfect competition and the absence of any "transactions" costs adding to the costs of the permits exchanged and the actual GHG reductions undertaken.

In practice, real international GHG markets cannot match this idealistic description. The operation of the markets may be constrained by political concerns. For example, the volume of individual Annex I country participation in trading might be restricted, following the "supplementarity" constraint advocated by the European Union (EU). The possibility that countries will associate in a redistribution of their negotiated commitment (forming so-called "bubbles", an option stemming from the willingness of the EU to enter the negotiations as a single entity) could amount to another form of restriction on trading. In addition, real GHG markets will have to bear the costs of organizing and consummating exchanges, the establishing the credibility of joint implementation (JI) or CDM credits through defining baselines, and monitoring performance after the fact to ensure that credits are legitimated by actual emission reductions. For example, the "additionality" condition, requiring that any reduction credits earned through trade with non-Annex I countries should be reflected in real aggregated abatement relative to a business-as-usual scenario, will induce monitoring expenses that might amount to 20% of the gross abatement cost considered (Chomitz 2000). Finally, distortions from market power, such as monopoly or monopsony positions, might arise and could have a strong impact on equilibrium prices and market efficiency.

The shift from a first-best to a second-best setting in modeling has begun only quite recently, and not all the dimensions outlined above have been explored. With respect to "where" flexibility, in a recent special issue of *Energy Journal* research teams from the Energy Modeling Forum (EMF) have modeled the implications of different restrictions on the volume and scope of individual Annex I country participation in trading (Weyant and Hill 1999). As might be expected, these constraints substantially distort the international emissions market and reduce its cost-effectiveness. Some of these same studies underscore the potential problem of a cartelization of dominant suppliers like Russia (and, perhaps later, China and India) or large buyers (see the Appendix).

On the other hand, with very few exceptions, existing analyses do not distinguish between emissions trading involving Annex I and non-Annex I countries. Typically, the models simply assume a business-as-usual "growth baseline" for non-Annex I emissions to determine the "additionality" of emissions control in these countries. This assumption provides some insights

regarding the potential gains from global GHG trade, but it does not permit the disentangling of complex issues such as the impact of carbon leakage from nonglobal emission caps, technological spillovers from CDM projects, or transactions costs.¹²

The WorldScan model (Bollen et al., 1999) is an exception in its treatment of CDM opportunities. These opportunities are limited to retrofit investments (a convenient way to minimize carbon leakage). They follow an explicit profit-maximizing rule that balances the retrofit costs and the permits consecutively gained (priced at the shadow price of carbon in the investor country) under the additionality constraint that those investments come on top of any amount economically rational under the host country's perspective.¹³ However, this approach does not address transactions costs. Unfortunately there is no straightforward way to address the issue, in part since the existing literature generally is sector-specific and not very empirical. Some insights could be gained by ad hoc modeling of cost markups to reflect transactions costs; however, transactions costs will depend on the number of transactions rather than on the scale per transaction. This issue requires further study to develop a credible approach. One possibility is the experimental method discussed in the paper by Muller in this volume, in which transactions costs might be designed right into the trading experiments in some fashion.

Better understanding of the implications for international carbon trading of international commodity trade and financial flows

As indicated in the Appendix, a number of the commonly used models either apply only to the United States, or they incorporate international economic relationships only to a limited extent (e.g., trade in carbon permits and energy goods). Ten out of the 15 models summarized in the Appendix include trade in energy goods. Foreign-produced energy is either a perfect or imperfect substitute to the domestic energy, with transportation costs added or not. In these models, a drop in global energy prices outside Annex I countries follows the reduction of demand in Annex I countries. Net energy exporters will be affected in an adverse manner, with major consequences in countries in the Organization of the Petroleum Exporting Countries (OPEC), where revenues from oil amount to huge shares of national income.¹⁴ On the other hand, net importers benefit (all else equal) from the new state of the market, since lower energy prices help stimulate their growth.

The extension of trade possibilities to nonenergy goods and the inclusion of capital flows considerably enriches these analyses, as revealed by studies using particularly the G-Cubed and MS-MRT models (see especially Bernstein et al. 1998 and McKibbin et al. 1999). These studies highlight the various international impacts of a carbon emissions reduction effort in Annex I countries, which are

¹² Both Bernstein et al. (1999) and Kurosawa et al. (1999) constrain non-Annex I emissions in the CDM case to be under the level those emissions would reach if Annex I Kyoto commitments are observed without any trading within Annex I. In these cases an additionality constraint involves emissions beyond an exogenously specified amount resulting from terms-of-trade related leakages. Moreover, in the GRAPE model (Kurosawa et al. 1999) an exogenous (1990) \$10 per ton of carbon is added to the price of imported carbon credits to reflect transactions costs.

¹³ Note that this constraint is particularly strong, provided the ongoing shortage in capital often experienced by developing countries.

¹⁴ Only half of these models provide a specific region encompassing oil-exporting countries, and G-Cubed is the only one from the (EMF) study that produces specific estimates for the losses of those countries under different trading assumptions.

- An increase in non-Annex I export competitiveness, as a consequence of higher energy costs in Annex I.
- A decrease in overall Annex I demand, as a consequence of a decrease in real income.
- A decrease especially in Annex I demand for energy; this has dire consequences for non-Annex I countries highly dependent on oil export earnings, but it is a benefit for other non-Annex I countries who see their energy import costs decrease.
- A decrease in the rates of return to capital in Annex I, provoking capital outflows that would further encourage non-Annex I non-oil exporters to expand their production of energy-intensive goods.

Thus, a carbon emissions reduction effort in Annex I would amplify the shift from agricultural to industrial economies outside Annex I and OPEC, with a potentially large impact on growth for the developing countries but with uncertain consequences for the size of the decline in aggregate global emissions. However, McKibbin et al. underline though that the United States, as the industrialized country with the lowest abatement costs, would not see its rate of return to capital fall as much as other countries in the Organization for Economic Cooperation and Development (OECD). Benefiting from the size of its economy and its readiness to absorb potentially high quantities of investment, the United States could hence capture much of the capital outflows from other OECD countries. This would in turn render the carbon “leakage” lower than feared.

This analysis applies if abatement occurs in Annex I exclusively. If emission reductions also occur outside Annex I, there are contrary effects for the two groups of non-Annex I countries distinguished. On the one hand, the inclusion of massive quantities of coal consumption within the energy baseline subject to abatement activity lifts some of the downward pressure on oil consumption inside Annex I, thereby benefiting countries heavily dependent on oil incomes. On the other hand, the relatively higher world prices for oil, together with lower general abatement costs in Annex I, would diminish some of the aforementioned benefits accruing to other developing countries.

Both Bernstein et al. and McKibbin et al. recognize the importance of how various Armington and energy-substitution elasticities are specified, providing sensitivity analyses around values are commonly used. Further empirical work on their estimates, with refined geographical detail, would be useful. Furthermore, coupling more accurate depictions of CDM mechanisms with the elaborate characterization of international economic activity in G-Cubed and MS-MRT would be illuminating.

Concluding Remarks

We have already noted that most analyses of domestic carbon policies have focused on carbon taxes and their dual, upstream auctioned permits. One can certainly imagine more complex portfolios of policies. In fact, some countries have already started to implement different approaches. The Japanese have enacted a new law on energy efficiency that is intended to set stricter product energy efficiency standards. Rather than relying on a carbon tax, the Japanese intend to use these standards, along with pledges of improved energy efficiency in industrial sectors and other measures (including international emissions credits, which is discussed below) to meet their Kyoto Protocol emissions target.

In Europe there is growing interest in emissions trading and increased carbon taxes. However, many trading programs (for example, in the United Kingdom) focus on energy-intensive "downstream" sectors (e.g., power plants and heavy industry), leaving open the mix of policies that might be pursued economy-wide to meet Kyoto targets. Similarly, in France there is great interest in increased carbon-based revenues, but the form of revenue recycling that would be pursued would emphasize funding for social measures as opposed to other tax reductions. It would be useful to be able to assess in an integrated way the impacts of various domestic policies on technology choice and the social cost of compliance.

Existing general equilibrium and aggregate energy-economy models are inherently limited in what they can do with respect to this kind of analysis. This is because of the high degree of aggregation and the stylized representation of production possibilities in these models. As shown in the Appendix, even the more detailed models have limited breakdowns of sectors. It would be possible, for example, to look at the implications of emissions trading between electricity and steel producers by imposing a carbon tax on these two sectors. Different sectoral energy-efficiency standards could be modeled indirectly by sector-specific carbon taxes that generate the target standards. But these models do not allow analysts to explore the implications of intra-sectoral or inter-regional trading; nor do they allow analysts to look at specific technology efficiency standards since the representation of technology is through a sectorally aggregated production function.

Analysts could instead use more detailed energy optimization models (see Appendix for examples). But because these models are engineering-based, they do not fully represent the range of economic tradeoffs that individual actors make, nor do they allow analysts to calculate full economic costs in a theoretically consistent fashion. Yet another option is to look at more detailed sector models. For example, some models of the electricity sector can provide a good representation of investment, plant use, and economic cost impacts. However, such modeling capacity is sparse (especially outside of electricity), and reliance on sectoral models begs the question of what policies could have important economy-wide effects.

To be able to look in more detail at more varied policy menus, including distributional as well as efficiency impacts, some synthesis and extension of existing modeling approaches is needed. The steps needed likely will require further basic modeling progress to meet emerging analytical needs. Given the importance that carbon trading is assuming in international and domestic policy debates, a stronger capacity to provide clear and relevant analysis of how different trading schemes might work seems useful.

References

- Barker T., and N. Johnstone. 1993. Equity and efficiency in policies to reduce carbon emissions in the domestic sector. *Energy and Environment* 4(4): 335-361.
- Bergman, L. 1996. Sectoral Differentiation as a Substitute for International Coordination of Carbon Taxes: A Case Study of Sweden. In *Environmental Policy with Political and Economic Integration: the European Union and the United States*, edited by J.B. Braden, H. Folmer, and T.S. Ulen. Cheltenham, United Kingdom: Edward Elgar.
- Bernstein, P.M., W.D. Montgomery, T.F. Rutherford. 1999. Global Impacts of the Kyoto Agreement: Results from the MS-MRT Model. *Resource and Energy Economics* 21(3-4): 375-413.
- Bernstein, P.M., W.D. Montgomery, T.F. Rutherford, and G.F. Yang. 1999. Effects of Restrictions on International Permit Trading: The MS-MRT Model. *Energy Journal*, Special Issue: 221-256.
- Bollen, J.C., A. Gielen, and H. Timmer. 1999. Clubs, Ceilings, and CDM. *Energy Journal*, Special Issue: 177-206.
- Bovenberg, A.L. 1999. Green Tax Reforms and the Double Dividend: An Updated Reader's Guide. *International Tax and Public Finance* 6(3): 421-443.
- Bovenberg, A.L., and R.A. de Mooij. 1994. Environmental Levies and Distortionary Taxation. *American Economic Review* 84(4): 1085-1089.
- Bovenberg, A.L., and L.H. Goulder. 2000. Neutralizing the Adverse Industry Impacts of CO₂ Abatement Policies: What Does It Cost? In *Behavioral and Distributional Effects of Environmental Policies: Evidence and Controversies*, edited by C. Carraro & G.E. Metcalf. Chicago: University of Chicago Press, forthcoming
- Bull, N., K.A. Hassett, and G.E. Metcalf. 1994. Who pays broad-based energy taxes? *Energy Journal* 15(3): 145-164.
- Chomitz, K.M. 2000. *Evaluating carbon offsets from forestry and energy projects: How do they compare?* Washington, D.C.: World Bank, Development Research Group.
- Cooper, A., S. Livermore, V. Rossi, J. Walker, and A. Wilson. 1999. Economic Implications of Reducing Carbon Emissions: the Oxford Model. *Energy Journal*, Special Issue: 335-365.
- Edmonds, J.A., H.M. Pitcher, D. Barns, R. Baron, and M.A. Wise. 1995. Modelling Future Greenhouse Gas Emissions: The Second Generation Model Description. In *Modeling Climate Change*, edited by L.R. Klein and F.C. Lo. Tokyo: United Nations University Press.
- EIA (Energy Information Administration). 1998. The National Energy Modeling System: An Overview 1998. DOE/EIA Report No. 0581 (98). Washington, D.C.: Department of Energy, February.
- Ferrante, F. 1998, Induced Technical Change, Adjustment Costs and Environmental Policy Modeling. *Applied Economics* 30: 649-665.

- Fishbone, L.G., G. Giesen, G. Goldstein, H.A. Hymmen, K.J. Stocks, H. Vos, D. Wilde, R. Zolcher, C. Balzer, and H. Abilock. 1983. User's Guide for MARKAL (BNL/KFA Version 2.0). Upton, NY: Brookhaven National Laboratory 51701.
- Goulder, L.H. 1995. Environmental Taxation and the Double Dividend: A Reader's Guide. *International Tax and Public Finance* 2(2): 157-183.
- Goulder, L.H., and K. Mathai. 1998. Optimal CO₂ Abatement in the Presence of Induced Technological Change. Working Paper W6494, National Bureau of Economic Research, Cambridge, Massachusetts, April.¹⁵
- Goulder, L.H., and S.H. Schneider. 1999. Induced Technical Change and the Attractiveness of CO₂ Abatement Policies. *Resource and Energy Economics* 21(2-3):211-253.
- Grubb, M.J., T. Chapuis, and M. Ha-Duong. 1995. The Economics of Changing Course: Implications of Adaptability and Inertia for Optimal Climate Policy. *Energy Policy* 23(4-5):417-432.
- Ha-Duong, M., M.J. Grubb, and J.C. Hourcade. 1997. Influence of socioeconomic inertia and uncertainty on optimal CO₂-emission abatement. *Nature* 390:270-274.
- Hamilton, L.D., G.A. Goldstein, J. Lee, A.S. Manne, W. Marcuse, S.C. Morris, and C.O. Wene. 1992. *MARKAL-MACRO: An Overview*. Upton, NY: Brookhaven National Laboratory, November.
- Harrison, G.W., and B. Kriström. 1999. General equilibrium effects of increasing carbon taxes in Sweden. In *Green Taxes—Economic Theory and Empirical Evidence from Scandinavia*, edited by R. Brännlund and I.M. Gren. Cheltenham, UK: Edward Elgar.
- Hill, M. 1999. Green Tax Reform in Sweden: the Second Dividend and the Cost of Tax Exemptions. Discussion Paper No. 119. Stockholm, Sweden: Beijer Institute of Ecological Economics, The Royal Swedish Academy of Sciences.¹⁶
- Jacoby, H.D., and I.S. Wing. 1999. Adjustment Time, Capital Malleability and Policy Cost. *Energy Journal*, Special Issue: 73-92.
- Jensen, J. 1998. Carbon Abatement Policies with Assistance to Energy Intensive Industry. Working paper No. 2/98, MobiDK Project, Ministry of Business and Industry, Copenhagen, Denmark.¹⁷
- Jorgenson, D.W., D.T. Slesnick, and P.J. Wilcoxon. 1992. Carbon Taxes and Economic Welfare. In *Brookings Papers in Economic Activity: Microeconomics 1992*. Washington, D.C.: Brookings Institution, 393-431.
- Kainuma, M., Y. Matsuoka, and T. Morita. 1999. Analysis of Post-Kyoto Scenarios: AIM Model. *Energy Journal*, Special Issue: 207-220.
- Kosobud, R., T. Daly, D. South, and K. Quinn. 1994. Tradable Cumulative CO₂ Permits and Global Warming Control. *Energy Journal* 15(2): 213–32.

¹⁵ Available in PDF format from <http://papers.nber.org/papers/W6494>.

¹⁶ Available in PDF format from http://www.beijer.kva.se/publications/discussion/discussion_papers.html.

¹⁷ Available in PDF format from http://www.gams.com/projects/dk/mobi_p.htm.

- Kurosawa, A., H. Yagita, Z. Weisheng, K. Tokimatsu, Y. Yanagisawa. 1999. Analysis of Carbon Emissions Stabilization Targets and Adaptation by Integrated Assessment Model. *Energy Journal*, Special Issue: 157-175.
- MacCracken, C.N., J.A. Edmonds, S.H. Kim, and R.D. Sands. 1999. Economics of the Kyoto Protocol. *Energy Journal*, Special Issue: 25-71.
- Manne, A.S., R. Mendelsohn, and R. Richels. 1995. A Model for Evaluating Regional and Global Effects of GHG Reduction Policies. *Energy Policy* 23(1): 17-34.
- Manne, A.S., and R. Richels. 1992. *Buying Greenhouse Insurance: The Economic Costs of Carbon Dioxide Emissions Limits*. Cambridge, MA: MIT Press.
- . 1997. On Stabilizing CO₂ Concentrations-Cost-Effective Emission Reduction Strategies. *Environmental Modeling & Assessment* 2(4):251-265.
- . 1999. The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives? *Energy Journal*, Special Issue: 1-23.
- McKibbin, W.J., M. Ross, R. Shackelton, and P.J. Wilcoxon. 1999. Emissions Trading, Capital Flows and the Kyoto Protocol. *Energy Journal*, Special Issue: 257-333.
- Nordhaus, W.D. 1997. Modeling Induced Innovation in Climate Change Policy. Paper presented at the Workshop on Induced Technological Change, June 1997, IIASA, Austria; and at NBER Summer Institute on Public Economics, August 1997, Cambridge, Massachusetts.
- Nordhaus, W.D., and J.G. Boyer. 1999a. Requiem for Kyoto: An Economic Analysis. *Energy Journal*, Special Issue: 93-130.
- . 1999b. Roll the DICE Again: Economic Models of Global Warming. <http://www.econ.yale.edu/~nordhaus/homepage/dicemodels.htm>
- O'Donoghue, C. 1997 Carbon dioxide, energy taxes and household income. Working paper 90, The Economic and Social Research Institute, Dublin, Ireland.
- Parry, I.W.H., R.C. Williams III, and L.H. Goulder. 1999. When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets. *Journal of Environmental Economics and Management* 37: 52-84.
- Peck, S.C., and T. Teisberg. 1992. CETA: A model for carbon emissions trajectory assessment. *Energy Journal* 13(1):55-77.
- . 1999. CO₂ Emissions Control Agreements: Incentives for Regional Participation. *Energy Journal*, Special Issue: 367-390.
- Poterba, J.M. 1991. Tax Policy to Combat Global Warming: On Designing a Carbon Tax. In *Global Warming: Economic Policy Responses*, edited by R. Dornbush and J.M. Poterba. Cambridge, MA: M.I.T. Press.
- Schillo, B., L. Giannarelli, D. Kelly, S. Swanson, and P.J. Wilcoxon. 1993. The Distributional Impacts of a Carbon Tax. Working Paper 12.9, *Energy Modeling Forum*, Stanford University, Palo Alto, CA: January.
- Schneider, S.H., and L.H. Goulder. 1997. Achieving Low-Cost Emissions Targets. *Nature* 389: 13-14.

- Symons, E., J. Proops, and P. Gay. 1994. Carbon taxes, consumer demand and carbon dioxide emissions: A simulation analysis for the UK. *Fiscal Studies* 15(2):19-43.
- Tol, R.S.J. 1999, Kyoto, Efficiency, and Cost-Effectiveness: Applications of FUND. *Energy Journal*, Special Issue: 131-156.
- Toman, M.A., R.D. Morgenstern, and J. Anderson. 1999. The Economics of 'When' Flexibility in the Design of Greenhouse Gas Abatement Policies. *Annual Review of Energy and the Environment* 24: 431-60.
- Tulpulé V., S. Brown, J. Lim, C. Polidano, H. Pant, B.S. Fisher. 1999. The Kyoto Protocol: An Economic Analysis Using GTEM. *Energy Journal*, Special Issue: 257-285.
- Weyant, J.P., and J. Hill. 1999. Introduction and Overview. *Energy Journal*, Special Issue: vii-xiiv.
- Wigley, T.M.L., R. Richels, and J.A. Edmonds. 1996. Economics of environmental choices in the stabilization of atmospheric CO₂ concentrations. *Nature* 379(6562): 240-243.
- Yang, Z., R.S. Eckaus, A.D. Ellerman, and H.D. Jacoby. 1996. The MIT Emissions Predictions and Policy Analysis (EPPA) Model. Report 6. Cambridge, Massachusetts: MIT Joint Program on the Science of Global Change, May.

Appendix: Summary of Various Models

	EPPA (version 1.6)		MARKAL-MACRO
	Goulder	Yang et al. (1996) Jacoby et al. (1999)	Hamilton et al. (1992)
Equity issues			
regions	1 (U.S.)	12 (global)	1 (U.S.)
sectors	13 (6 energy-related)	10 (7 energy-related)	infinitely-lived single agent economy
households	1 infinitely-lived representative household	1 myopic representative household	
other	n.a.	n.a.	bottom-up energy module
Technical change			
in energy	carbon liquid backstop, available 2010	<ul style="list-style-type: none"> carbon liquid backstop, available 2000 carbon-free electric backstop, av. 2000 global constant AEEI in all non-energy sectors global constant efficiency improvement for oil and gas supplies 	AEEI differing in energy demands
other	n.a.	n.a.	n.a.
Carbon trade			
modeling	as a carbon tax (Bovenberg et al., 2000)	n.a.	as a carbon tax
market powers	n.a.	n.a.	n.a.
supplementarity	n.a.	n.a.	n.a.
geographic restrictions	n.a.	no trading, Annex 1	n.a.
CDM	n.a.	n.a.	n.a.
International linkage			
Trade	<ul style="list-style-type: none"> Armington specification for all goods except oil and gas Heckscher-Ohlin zero balance constraint every period 	<ul style="list-style-type: none"> Armington specification for all goods except oil and gas Heckscher-Ohlin zero balance constraint after 4 periods 	n.a.
Finance	n.a.	n.a.	n.a.

	MERGE	SGM	G-CUBED
	Manne et al. (1995, 1999), http://www.stanford.edu/group/MERGE/	MacCracken et al. (1999) Edmonds (1995)	McKibbin et al. (1995, 1999)
Equity issues	5 (global), 9 (global) in MERGE 3.0	12 (global)	8 (global)
regions		13 (11 energy-related)	12 (5 energy-related)
sectors	infinitely-lived single agent economy	1 myopic (?) representative household	1 hybrid representative household
households		n.a.	n.a.
other?	9 electric, 9 non-electric energy supplies in energy module		
Technical change	<ul style="list-style-type: none"> • 2 carbon-free electric backstops, av. 2010 (low cost) and 2020 (high cost) • carbon liquid backstop (high price) • global constant AEEI in the aggregated sector 	<ul style="list-style-type: none"> • sector-specific exogenous growth in total productivity rate for energy sectors 	<ul style="list-style-type: none"> • global constant AEEI • region-specific exogenous growth in total productivity rate for energy sectors
in energy		sector-specific exogenous growth in total productivity rate	region-specific exogenous growth in total productivity rate
other	n.a.	sector-specific exogenous growth in total productivity rate	region-specific exogenous growth in total productivity rate
Carbon trade	regional endowments are traded on an interregional market	as a carbon tax harmonized within trading limits	regional endowments are auctioned then traded on an interregional market
market powers	buyer's and seller's market	seller's market	n.a.
supplementarity	cap on trade (33% of targeted reductions for net buyers)	cap on trade (10% of targeted reductions for net buyers, exact compensation in actual domestic efforts for net sellers)	n.a.
geographic restrictions	no trading, Annex 1, global trading	no trading, double bubble, Annex 1, global trading	no trading, double bubble, Annex 1, global trading
CDM	supplies an exogenous 15% of observed global trading transactions	global trading is provided as a limit of its benefits	n.a.
International linkage	<ul style="list-style-type: none"> • oil, gas, coal, and the single output, plus energy-intensive goods (EIG) in MERGE 3.0 are perfectly substitutable • carbon permits are perfectly substitutable • zero balance constraint every period • international transport priced • S/D ratio of domestic EIG provide assessment of trade impacts 	<ul style="list-style-type: none"> • all goods perfectly substitutable except distributed gas nontradable • possibility of fixed quantities or prices • zero balance constraint after a few periods 	Armington specification for all goods, with sensitivity analysis on the elasticities
trade			
finance	n.a.	n.a.	global investment market, perfect in OECD, constrained elsewhere

	RICE-99	FUND (version 1.6)	GRAPE
	Nordhaus et al. (1999a, b)	Tol (1999)	Kurosawa et al. (1999)
Equity issues	13 (global)	9 (global)	10 (global)
regions	infinitely-lived single agent economy	non-overlapping generations single agent economy	infinitely-lived single agent economy
sectors			
households			
other	n.a.	n.a.	bottom-up energy module
Technical change			
in energy	<ul style="list-style-type: none"> carbon-free energy backstop (high price) region-specific A Carbon EI in the aggregated sectors 	<ul style="list-style-type: none"> global AEEI in the aggregated sector global A Carbon EI in the aggregated sector 	<ul style="list-style-type: none"> AEEI in the aggregated sector oil substitutes in transports av. 2010 nuclear substitute available 2050
other	region-specific exogenous growth in total factor productivity in the aggregated sector	n.a.	n.a.
modeling	as a carbon tax harmonized within trading limits	as cooperation in a game-theoretic sense: sum of the welfares of the trading regions is maximized with actual regional reductions as control variables	as a carbon tax harmonized within trading limits, with a constant unit transaction cost of 1990\$10 a ton
market powers	n.a.	n.a.	n.a.
supplementarity	n.a.	cap on trade (10% of targeted reductions for net buyers, for net sellers, and for both jointly)	n.a.
geographic restrictions	no trading, OECD, Annex 1, global trading	no trading, double bubble, Annex 1, Annex I and Asia, global trading	no trading, Annex 1, global trading
CDM	n.a.	n.a.	global trading has emissions outside Annex I constrained to their no-trading level; CDM is not explicitly mentioned
International linkage			
trade	n.a. except single output in compensation of permits	n.a.	<ul style="list-style-type: none"> in single output in energy products in the bottom-up energy module
finance	n.a.	n.a.	n.a.

WORLDSCAN

AIM

MS-MRT

Bollen et al. (1999),

Kainuma et al. (1999)

Bernstein et al. (1999)

http://www.opb.nl/nl/pub/pub/bijzondere_20/

<http://www-cger.nies.go.jp/ipcc/aim/>

Equity issues

regions	13 (global)	21 (global)	10 (global)
sectors	11 (4 energy-related)	11 (7 energy-related)	6 (4 energy-related)

households	overlapping generations	1 myopic representative household	1 infinitely-lived representative household
other?	<ul style="list-style-type: none">high and low-skilled labourregion-specific informal (low-productivity) sectors	n.a.	n.a.

Technical change

in energy	n.a.	<ul style="list-style-type: none">global constant AEEIglobal constant A Carbon EI	<ul style="list-style-type: none">carbon-free backstop (high price)AEEI
-----------	------	--	--

other	region- and sector-specific exogenous growth in factors productivity rate	n.a.	region- and sector-specific growth in total factor productivity, endogenous but to equate returns on capital
-------	---	------	--

Carbon trade

modeling	as a carbon tax harmonized within trading limits	regional endowments are traded on an interregional market	regional endowments are traded on an interregional market
----------	--	---	---

market powers	n.a.	n.a.	seller's market
---------------	------	------	-----------------

supplementarity	cap on trade (10, 15 and 25% of targeted reductions for net buyers, and for net sellers)	n.a.	<ul style="list-style-type: none">cap on trade (10, 30 and 50% of targeted reductions for net buyers, 30% of unrestricted Annex I sales for net sellers)ban on "hot air"
-----------------	--	------	---

geographic restrictions	no trading, double bubble, Annex 1, global trading	no trading, double bubble, Annex 1, global trading	no trading, Annex 1, global trading
-------------------------	--	--	-------------------------------------

CDM	<ul style="list-style-type: none">financing of retrofit projects following a cost-benefit analysis with additionality constraint (cf. text)exogenous 5% of targeted reductions	as global trading with emissions outside Annex 1 constrained to their BAU level	supplies an exogenous 15% of observed global trading transactions
-----	---	---	---

International linkage

trade	Armington specification for all goods turning to Heckscher-Ohlin in the long-run	<ul style="list-style-type: none">all foreign goods perfectly substitutableArmington specification for domestic and aggregated foreign goods	<ul style="list-style-type: none">Armington specification for all goods except oil Heckscher-Ohlin and electricity nontradabletrade balanced over total time horizonstudy of terms-of-trade variationsevolution of output in energy-intensive sector provide assessment of trade impacts
-------	--	---	---

finance	imperfect global investment market	perfect global investment market	<ul style="list-style-type: none">zeroed on the balanced growth pathperfect mobility of capital
---------	------------------------------------	----------------------------------	--

GTEM**OXFORD****CETA**

Tulpulé et al. (1999)

Cooper et al. (1999)

Peck and Teisberg (1992, 1999)

<http://www.abare.gov.au/pdf/gtem.doc>

Equity issues	regions	18 (global)	22 (mostly OECD), key macro variables for 50 more	2 (global)
	sectors	16 (5 energy-related)	infinitely-lived single agent economy	infinitely-lived single agent economy
	households	1 myopic representative households		
	other	saving decisions (forward-looking) are disaggregated in age groups	6 energy supplies, 4 energy demands in energy module for 8 regions	7 electric, 5 nonelectric energy supplies in energy module
Technical change	in energy	endogenous	n.a.	<ul style="list-style-type: none"> • nonelectric and electric carbon-free backstops (high prices) • global constant AEEI in the aggregated sector
	other	endogenous	region-specific growth in total factor productivity, exogenous trend corrected by energy prices ("crowding-out wise")	n.a.
Carbon trade	modeling	as a carbon tax harmonized within trading limits, with impact on GNP	as a carbon tax harmonized within trading limits, with impact on GNP	Regional endowments are traded on an interregional market
	market powers	n.a.	n.a.	n.a.
	supplementarity	n.a.	n.a.	n.a.
	geographic restrictions	no trading, double bubble, Annex 1	no trading, double bubble without trade in the EU, Annex 1	Annex 1, global trading
	CDM	n.a.	n.a.	n.a.
International linkage	trade	<ul style="list-style-type: none"> • Armington specification for all goods • international transport priced 	Armington specification for the single output	Carbon permits, the nonenergy good, oil and gas, and synthetic fuel are perfectly substitutable
	finance	imperfect global investment market	perfect global investment market	n.a.

Experimental Methods for Research into Trading of GHG Emissions

R. Andrew Muller



RESOURCES
FOR THE FUTURE

Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202-328-5000
Fax: 202-939-3460
Internet: <http://www.rff.org>

Experimental Methods for Research into Trading of Greenhouse Gas Emissions

R. Andrew Muller

McMaster University, Department of Economics

Hamilton, Ontario, Canada

mullera@mcmaster.ca

I will organize my comments in this paper around three themes: first, some comments on the experimental method generally; secondly, a quick review of some of the things we have learned from experimental economics about trading greenhouse gas emissions; and thirdly, a few comments on research gaps that remain.

Why Conduct Experiments?

Why should we conduct experiments in economics? Ultimately, we wish to test whether the predictions developed through *a priori* economic reasoning can safely be applied in field conditions that are generally much more complicated than the abstract environment in which the theorizing occurred. To test the theory we must collect data. Frequently naturally occurring data is not appropriate for testing theory. There may be too little variation in the variables of interest or too many extraneous variables changing. Experiments are conducted to provide the investigator with control over the conditions under which data are collected. This allows the investigator to ensure sufficient independent variation in significant variables and to hold extraneous influences constant. For example, an investigator interested in the effect of banking tradable emission permits can set up a laboratory environment in which all agents have known costs, all agents are motivated by monetary rewards, and all the features of the trading environment are fixed. The investigator can then vary whether banking coupons is permitted or not. Comparing the outcomes under these two treatments permits very strong statistical conclusions. These conclusions can often be reached by simple graphical or tabular summaries of the data, without recourse to elaborate econometric techniques.

It is worth distinguishing field experiments from laboratory experiments. Field experiments are conducted in naturally occurring environments. For example, low-income families can be randomly assigned to alternative income support programs and their experience tracked over a number of years. Well-designed experiments of this kind are invaluable in assessing policies under actual field conditions. However, they are expensive and often politically difficult to implement. It is difficult, for example, to picture how one could have conducted field trials of alternative rules for the sulphur dioxide allowance trading program introduced by the U.S. Environmental Protection Agency (EPA) (Schmalensee 1998). Moreover, it is hard to maintain experimental control over all factors that may affect the outcome of the experiment. A cheaper, more flexible complement for field experiments is needed. This is provided by laboratory experiments.

In laboratory experiments human subjects are brought together to interact under strictly defined conditions. For example, eight subjects may participate in a double auction that reflects the key characteristics of an emissions trading market. Subjects are motivated by the prospect of substantial monetary rewards that are dependent on their performance in the market. Data on the performance of the market under alternative trading rules are easily collected; outcomes under the alternatives easily compared. This approach to testing theory is cheaper and more flexible than field experimentation.

Experimentalists differ as to how closely the laboratory environment should resemble the field. It is clearly impossible—and probably undesirable—to mimic the field environment precisely. Some researchers have tried hard to make their laboratory environments parallel to the field. For example, Peter Bohm (1997a, 1997b) has conducted emissions trading experiments in which the distribution of permits is closely patterned after the allocation expected under the Kyoto Protocol. In contrast, some argue that the role of experimentation lies chiefly in testing the relevant theory or institution without trying too hard to mimic other aspects of the field. My colleagues and I, for example, closely modeled some policy suggestions for trading both long-term shares and annual permits under an emissions trading plan, but we did not attempt to implement them in an environment reflecting conditions in any actual market (Godby et al. 1997). Laboratory experiments will yield information about probable field outcomes to the extent that their design parallels the field. Each investigator needs to determine the nature of that parallelism.

What then are the best uses of laboratory experimentation? Friedman and Sunder (1994) consider this issue at length. From their list, I would identify three uses that are particularly appropriate to emissions trading. First, laboratory markets can be used to test the applicability of known theory. For example, Cason and Plott (1996) test a specific theory about the influence of EPA trading rules on the transactions prices for emission permits. Second, experiments can provide heuristic exploration of possibilities where theory is weak. For example, one can investigate whether the double auction institution can constrain market power in the context of emissions trading (e.g., Muller et al. 1999). Finally, one can try to capture the key features of a proposed institution and test whether it will work in a market that resembles the expected field environment. (e.g., Hong and Plott 1982; Bohm 1997a, 1997b). This last application is often called “test-bedding.”

What Have We Learned From Emissions Trading Experiments?

A substantial number of laboratory experiments related to emissions trading have been undertaken over the past ten years or so (Muller and Mestelman 1998). What have we learned from them? Basically, they demonstrate the importance of three market design issues that are frequently ignored or downplayed in discussions of emissions trading programs. First, the design of the instrument being traded matters. Secondly, the market institution in which trading occurs matters. Finally, market power on either the buying or selling side of the market matters.

Market Instruments Matter

I would like to give you a brief flavor of the evidence supporting these three lessons. Consider the first: market instruments matter. By a “market instrument,” I mean the contract that conveys the right to emit a specified quantity of a pollutant. Two dimensions of the market instrument are whether or not the permits for any one time period can be banked for use in a subsequent period and whether or not time streams in entitlements to future permits can be traded. My colleagues and I report an experiment designed to investigate the effect of these two dimensions of instrument design on the performance of emissions trading markets (Godby et al. 1997). In our study annual permits were called coupons. Entitlements to a time stream of permits were called shares. Each share entitled a subject to two coupons in the first four periods of the experiment and one coupon per period in the last. The subjects’ control over their emissions was imperfect; accordingly, they sometimes needed to purchase extra coupons in a reconciliation market at the end of each compliance period.

Figure 1 shows that the choice of instrument affects price stability and trading volumes. The

small dots represent contract prices for two different sessions. Under a no-banking, no-share trading treatment, there is a high volume of trade. Prices converge to the predicted equilibria, rising rapidly after the fifth period to reflect the increased scarcity of coupons. There are large price spikes in reconciliation periods. When banking and share trading are allowed, prices stabilize at the predicted levels, trading volume is much reduced, and the price spikes are greatly reduced.

Figure 2, drawn from the same experiment, shows that the choice of instrument affects efficiency. Efficiency is measured by the gains from trading realized by the subjects expressed as a percentage of the maximum available gains. In the no-banking sessions, efficiency is low because coupon endowments are misallocated across time. If we correct for this reduction, we see that coupon trading actually achieves a very high fraction of the gains that are available solely from trading within individual periods. Banking increases apparent efficiency by allowing intertemporal reallocation of coupons, but actually decreases the percentage of available gains realized by the traders. The striking finding in this experiment is that share trading enhances efficiency, especially in the presence of banking. There is no obvious theoretical reason why this should be so. Thus test-bedding of the share trading instrument demonstrates an advantage that has not previously been predicted.

Market Institutions Matter

Other experiments have shown that outcomes in emission permit markets depend on the nature of the market institution through which trades are conducted. Figure 3 (drawn from Muller and Mestelman 1998) shows the efficiency of seven experimental emissions trading markets conducted at various laboratories in the United States and Canada using three different market institutions. All but one of these experiments used the same set of underlying cost parameters. Four used the University of Arizona's RNA (revenue neutral auction) institution, which attempted to model proposals for U.S. EPA's sulfur dioxide allowance market. A key feature was the expected co-existence of a private market with an official EPA revenue-neutral, sealed-bid auction, in which all permit holders would be required to offer a specified fraction of their permit holdings. The private market was represented by a double auction. The efficiencies of the four experiments using this dual institution (FIPR2A, FIPR2C, CEVM-USC and CEVM-UM) are the four lowest in Figure 3 (Franciosi et al. 1993; Franciosi et al. 1999; Cason et al. 1999). An alternate representation of the EPA market, which allowed a revenue-neutral, sealed-bid auction but no double auction (CBK) achieved somewhat higher efficiencies (e.g., Cronshaw and Brown-Kruse 1999). The two highest efficiencies (experiments ET1 and ET3) were gained in market institutions that used the same cost parameters as the other experiments but allowed double auction trading of shares and coupons (e.g., Muller and Mestelman 1994; Godby et al. 1997). The wide variation in observed efficiencies can most credibly be ascribed to differences in the market institutions.

Cason and Plott (1996) provide further evidence of the importance of market institutions in determining the outcome of emissions trading market. This experiment investigated a special feature of U.S. EPA's sulphur dioxide auction: a sealed-bid auction, in which buyers and sellers of emission permits submit bids and "asks" and describe their offered price for specified quantities of units. EPA prescribed a discriminative auction, in which bids and asks are ranked in descending or ascending order respectively; highest bids are matched with lowest prices, and the buyer pays his offered price. Cason and Plott compared this market institution with a uniform price auction (UP) in which bids and asks are aggregated to determine a market clearing price at which all transactions occur. Figure 4 shows that the UP auction led to the prices predicted for perfect competition, with essentially complete revelation of demand and supply schedules. The EPA auction, however, provides an incentive for both buyers and sellers to understand their true values. This experiment supported Cason and Plott's argument that

relatively low observed prices in the field could be explained by peculiarities of EPA's market institution.

Market Power Matters

The third lesson from laboratory experiments is that market power can affect the outcome of emissions trading markets. Some have argued that double auction markets provide a degree of protection against monopolistic or monopsonistic manipulation. Several experiments suggest this may not be true. Figure 5 (Brown Kruse et al. 1995; Godby 1997) shows a competitive price level of 105. When there is one seller, the predicted price level is 110, except when the seller has the opportunity to manipulate a downstream market by withholding emission permits from his rivals. In this case the predicted price level is 180. Similar predictions of 75 and 90 (with and without downstream manipulation) can be derived for a single seller. Observed prices tend to agree very much with theoretical predictions. This experiment clearly suggests that market power in emissions trading markets may not be constrained by the double auction institution. Note that monopsonists were particularly successful in maintaining low prices relative to competitive levels.

This finding of market power seems robust. Godby (1997) replicated and extended the Brown Kruse design, finding similar results. Ledyard and Szakaly-Moore (1994) also found some evidence of successful exercise of market power in double auction markets. In recent work, Hizen and Saijo (1998) and Carlén (1998) find some evidence that a monopsonist reaps profits greater than competitive levels in the context of emissions markets modeled after the Kyoto agreement.

Research Gaps

In this brief presentation I have tried both to motivate the use of laboratory experiments as vital tools in testing proposed institutions for emissions trading and to give a flavour of some of the results obtained from past experiments. Much work on emissions trading systems remains to be done, of course, and I believe that conducting laboratory experiments can be a useful tool in approaching it. I will content myself with pointing out two general areas that would repay systematic investigation.

The first is the need for further investigation of market instruments. Two of the three flexibility mechanisms under the Kyoto Protocol, namely Joint Implementation and the Clean Development Mechanism, envisage trade not in actual quotas for the discharge of greenhouse gases, but of emission reduction credits that reflect deviations in an agent's GHG emissions relative to a specified baseline. Although these instruments have similar theoretical properties in the context of a single period trading system with fixed baselines, they may have quite different results in a market in which the baselines vary with growth of output in the affected industries. Integration of credit systems with traditional cap-and-trade systems poses further problems. Here is an opportunity for effective test-bedding of proposed designs.

A second area for further investigation relates to the role of market power in emissions trading markets. Further investigation is required to assess the ability of alternative institutions to constrain the exercise of market power, especially on the buying side of the market. Recent experiments by Hizen and Saijo (1998), Carlén (1998), and Muller et al. (1999) move in this direction. Since so many factors interact in determining the extent of market power, a well-funded systematic investigation might reap economies of scale from exploiting factorial and partial factorial designs.

To conclude, laboratory experiments are particularly well-suited for heuristic exploration of complex trading environments and for test-bedding proposed market institutions. Past experiments have shown clearly that market instruments, market institutions, and market structure all influence the outcome of emissions trading markets. Finally, high priority research directions include the investigation of the properties of emissions trading plans, investigation of market institutions for the control of market power, and large-scale test-bedding using powerful experimental designs.

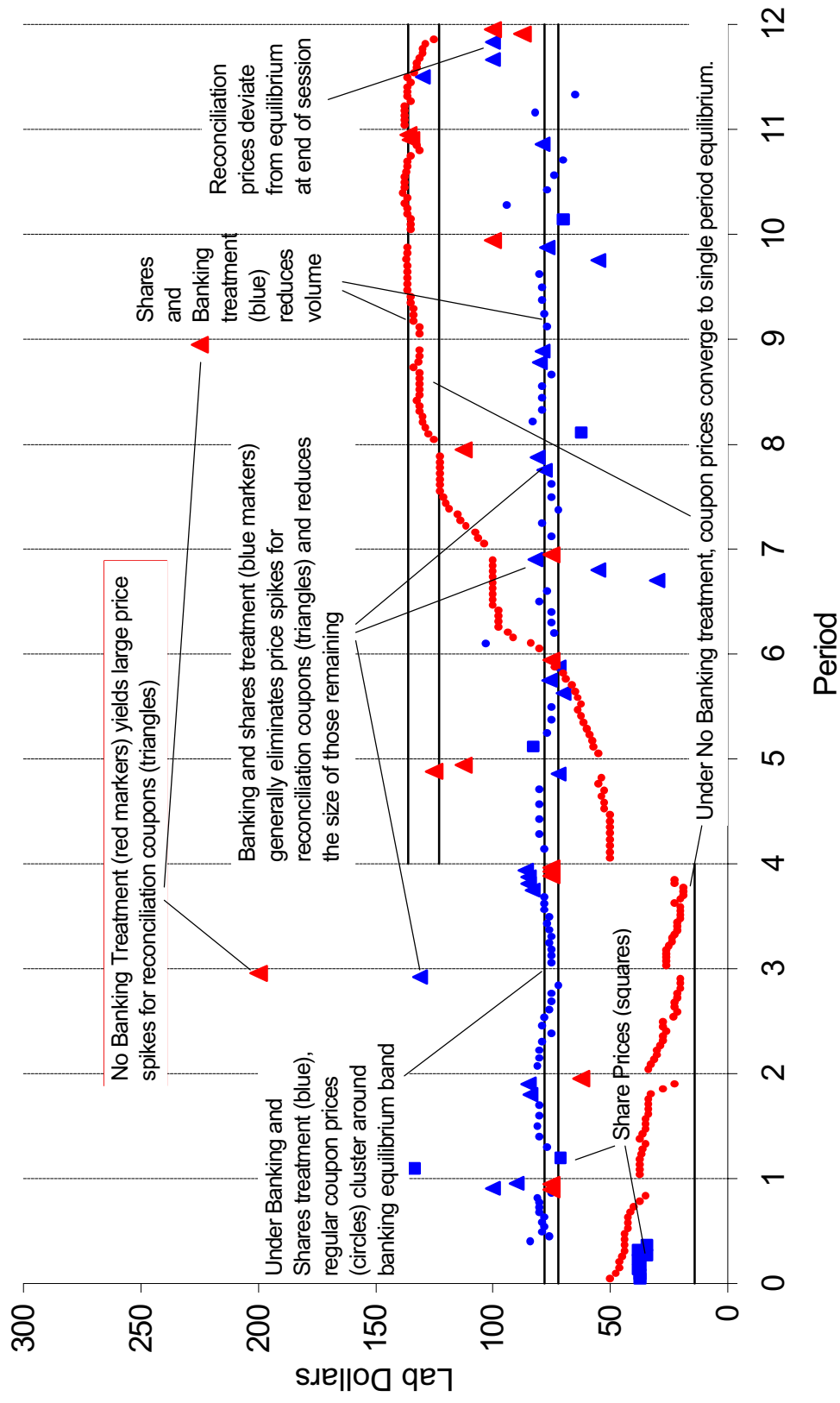
References

- Bohm, Peter. 1997a. Are tradable carbon emission quotas internationally acceptable? An inquiry with diplomats as country representatives. Paper Nord 1997:8. Copenhagen, Nordic Council of Ministers.
- . 1997b. A joint implementation as emission quota trade: An experiment among four Nordic countries. Paper Nord 1997:4. Copenhagen, Nordic Council of Ministers.
- Brown-Kruse, Jamie, Steven R. Elliott, and Robert Godby. 1995. Strategic manipulation of pollution permit markets: an experimental approach. Working Paper 95-10, Department of Economics, McMaster University, Ontario, Canada.
- Carlén, Björn. 1998. Effects of dominant countries on a tradable quota market for carbon emissions: A laboratory test. Manuscript, Department of Economics, Stockholm University, Sweden.
- Cason, Timothy N., Steven R. Elliott, and Mark R. Van Boening. 1999. Speculation in experimental markets for emission permits. In *Emission Permit Experiments*, edited by R. Mark Issac and Charles Holt, vol. 7 of *Research in Experimental Economics*.
- Cason, Timothy N., and Charles R. Plott. 1996. EPA's new emissions trading mechanism: A laboratory evaluation. *Journal of Environmental Economics and Management* 30: 133-160.
- Cronshaw, Mark B., and Jamie Brown-Kruse. 1999. An experimental analysis of emission permits with banking and the Clean Air Act Amendments of 1990. In *Emission Permit Experiments*, edited by R. Mark Issac and Charles Holt, vol. 7 of *Research in Experimental Economics*.
- Franciosi, Robert, R. Mark Isaac, D.E. Pingry, and Stanley S. Reynolds. 1993. An experimental investigation of the Hahn-Noll revenue neutral auction for emissions licensees. *Journal of Environmental Economics and Management* 24: 1-24.
- Franciosi, R., R. Mark Isaac, and Stanley S. Reynolds. 1999. Experimental Research on the EPA's "Two-Tier" System for Marketable Emissions Permits. In *Emission Permit Experiments*, edited by R. Mark Issac and Charles Holt, vol. 7 of *Research in Experimental Economics*.
- Friedman, D., and S. Sunder. 1994. *Experimental Methods*. Cambridge, UK: Cambridge University Press.
- Godby, Robert. 1999. Market power in emission permit double auctions. In *Emission Permit Experiments*, edited by R. Mark Issac and Charles Holt. Research in Experimental Economics, vol. 7. Stanford, Connecticut: JAI Press.

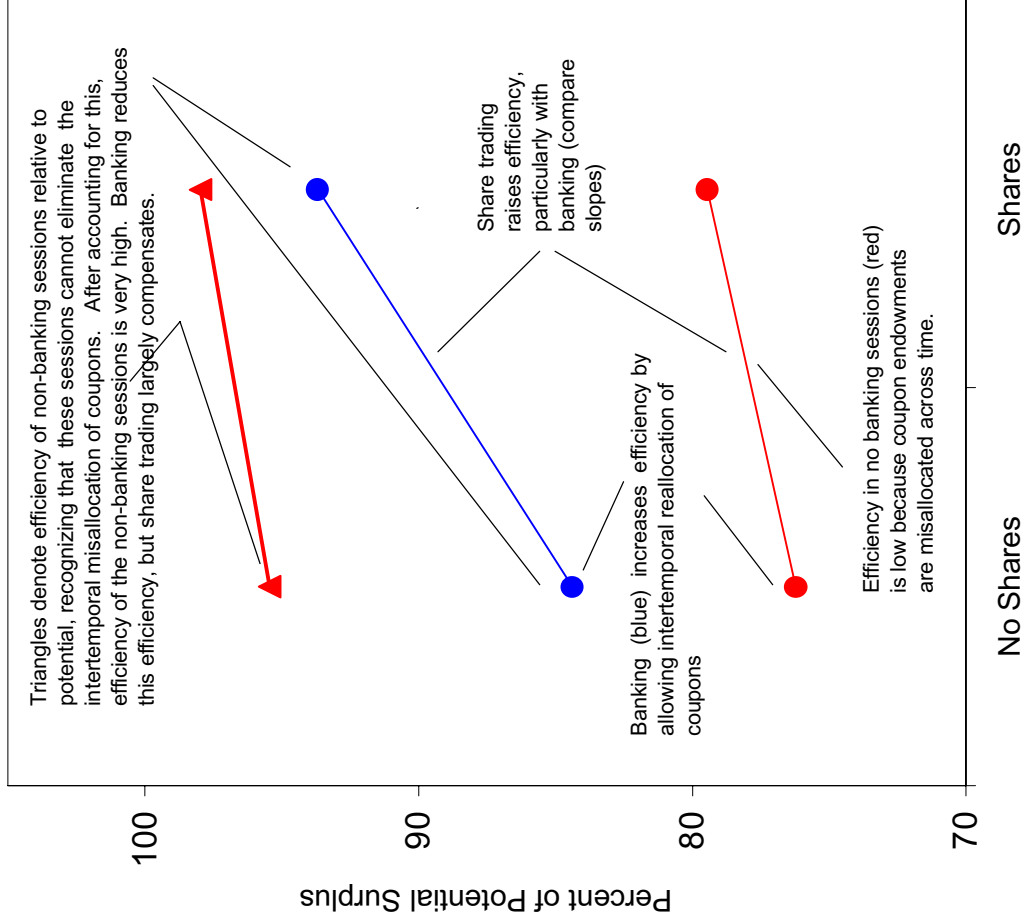
- . 1997. *The Effect of Market Power in Emission Permit Markets*. Ph.D. thesis, McMaster University, Ontario, Canada.
- Godby, Robert, Stuart Mestelman, R. Andrew Muller, and Douglas Well. 1997. Emission trading with shares and coupons when control over discharges is uncertain. *Journal of Environmental Economics and Management* 32: 359-381.
- Hizen, Yoichi, and Tatsuyoshi Saijo. 1998. Designing GHG emissions trading institutions in the Kyoto protocol: An experimental approach. Manuscript, Graduate School of Economics, Osaka University, Japan.
- Hong, James T., and Charles R. Plott. 1982. Rate Filing Policies for Inland Water Transportation: An Experimental Approach. *Bell Journal of Economics* 13: 1-19.
- Ledyard, John O., and Kristin Szakaly-Moore. 1994. Designing organizations for trading pollution rights. *Journal of Economic Behavior and Organization* 25: 167-196.
- Mestelman, Stuart, Rob Moir, and R. Andrew Muller. 1999. A laboratory test of a Canadian proposal for an emissions trading program. In *Emission Permit Experiments*, edited by R. Mark Issac and Charles Holt, vol. 7 of *Research in Experimental Economics*.
- Muller, R. Andrew, and Stuart Mestelman. 1994. Emissions trading with shares and coupons: a laboratory experiment. *Energy Journal* 15: 185-211.
- . 1998. What have we learned from emissions trading experiments? *Managerial and Decision Economics* 19: 225-238.
- Muller, R. Andrew, Stuart Mestelman, John Spraggon, and Robert Godby. 1999. Can double auctions control market power in emissions trading markets? Manuscript, Department of Economics, McMaster University, Ontario, Canada.
- Schmalensee, R., et al. 1998. An Interim Evaluation of Sulfur Dioxide Emissions Trading. *Journal of Economic Perspectives* 12(3): 53-68.

Banking and Shares affect Price Stability and Trading Volumes

Godby, Mestelman, Muller, and Welland (1997)

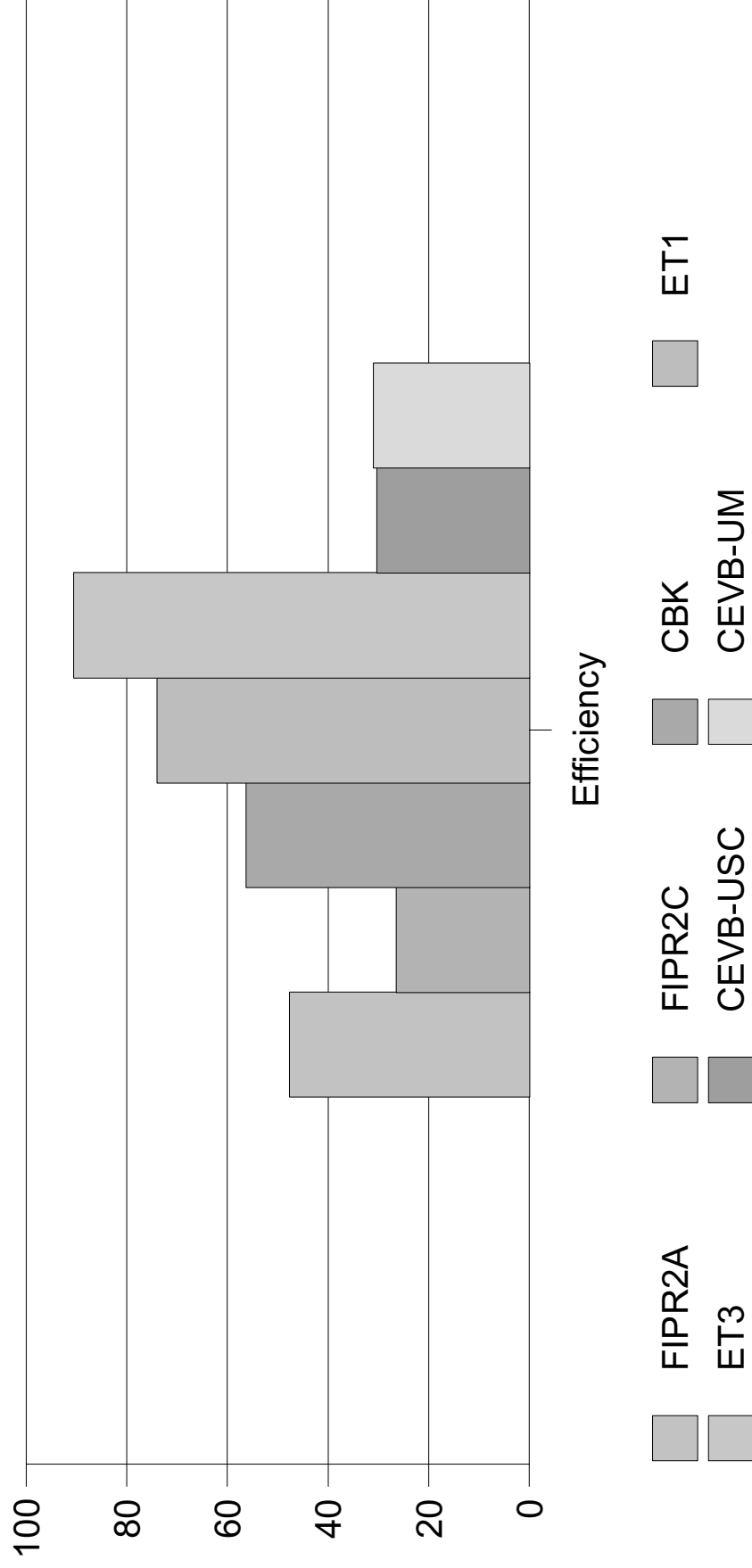


Banking and Shares affect Efficiency



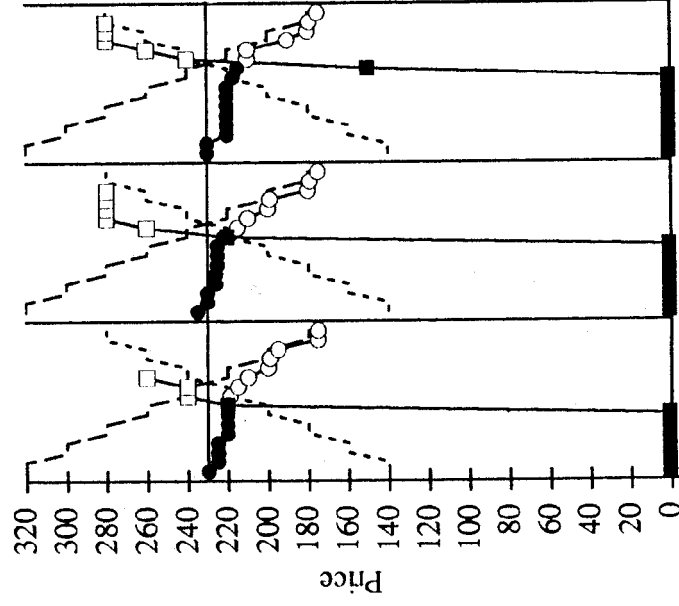
Efficiency Varies with Auction Institution

Testbedding Permit Markets With Banking

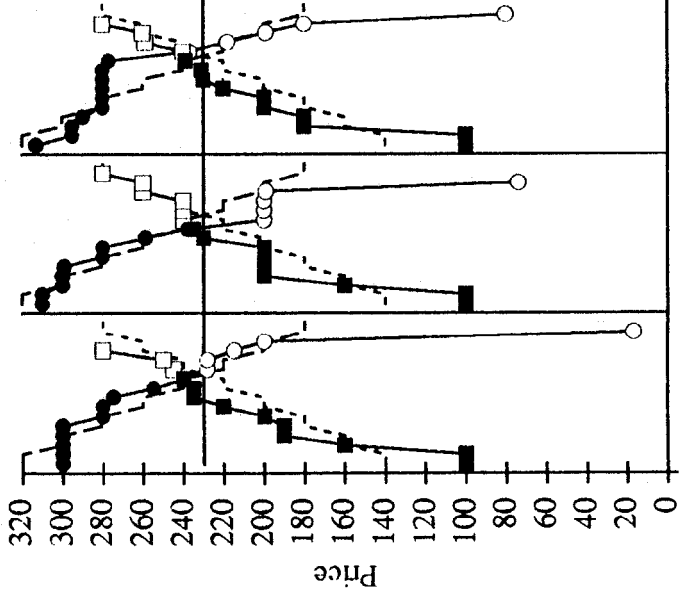


Further Evidence on Auction Markets

Cason and Plott (1996)



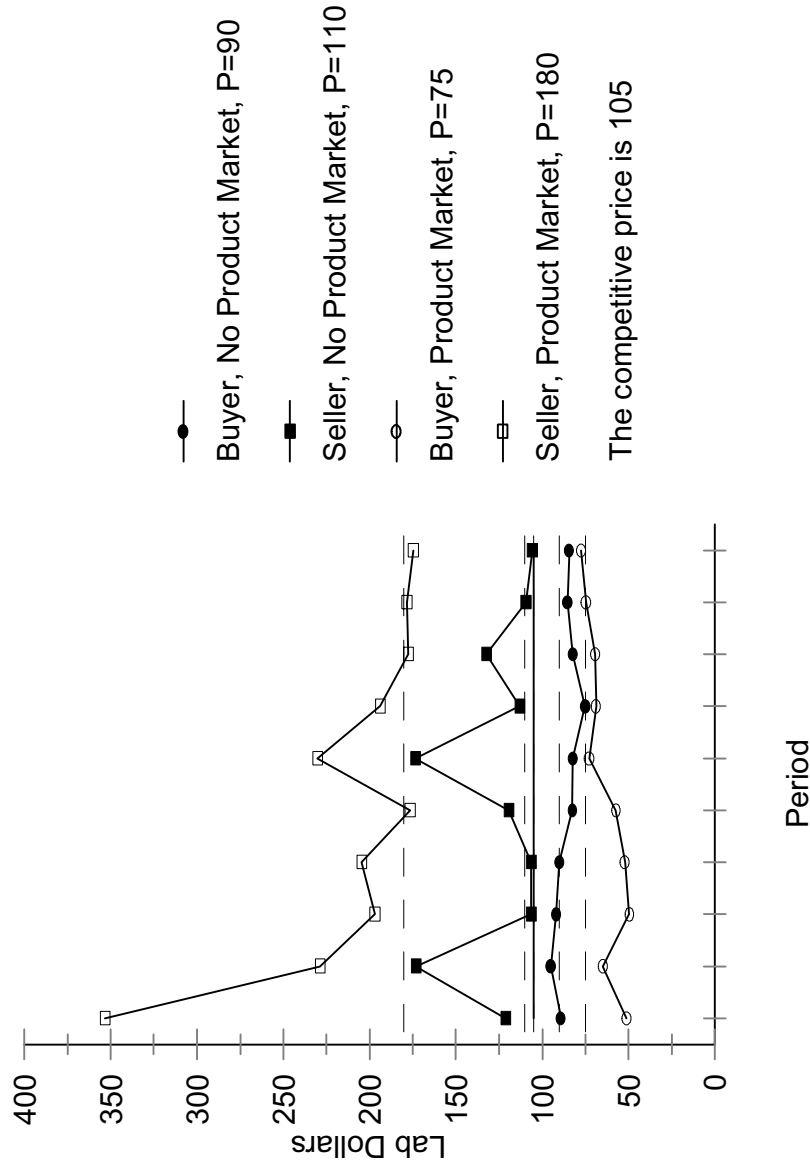
EPA Auction, Periods 9-11



UP Auction, Periods 9-11

Market Power Can Emerge in Double Auctions

Brown-Kruse, Elliott, and Godby (1995).



Exploring the Behavioral Underpinnings of Carbon Trading

Jason Shogren



RESOURCES
FOR THE FUTURE

Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202-328-5000
Fax: 202-939-3460
Internet: <http://www.rff.org>

Exploring the Behavioral Underpinnings of Carbon Trading

*Jason F. Shogren, Distinguished Professor of
Natural Resource Conservation and Management
Department of Economics and Finance, University of Wyoming
jramses@uwyo.edu*

Ongoing debate over policies to restrict emissions of greenhouse gases (GHGs) such as carbon dioxide (CO₂) and methane (CH₄) has stimulated investigation into the pros and cons of various options for GHG emissions trading. Economists have long argued that emissions trading programs can provide a nation with greater flexibility to achieve nearly all environmental targets cost-effectively (Crocker 1966). Emissions permits specify a predetermined total level of emissions or emission concentrations for a specified region. Permits equal to the total emissions allowed under the regulatory program are distributed among producers in the region. Permits act as incentives for reducing pollution control to socially desirable levels, because total emission levels within a given region are limited, making permits valuable to producers. This scarcity value creates an incentive to trade permits. The permits can be traded among plants of a single producer as well as among producers. Producers that keep their emissions levels below their allotted permit level can sell or lease their surplus permits to other producers or use them to offset emissions in other parts of their own facilities.

In the context of GHGs, the government can issue to the private sector GHG or carbon emission permits that equal some national target. Permits could then be freely bought and sold domestically between firms. The trading price induces sources to reduce their greenhouse gas emissions so long as the permit price exceeds the incremental costs of emissions reductions. This would stimulate fossil fuel users to improve energy efficiency, use less carbon-intensive fuels, and consume less of the goods and services

produced in more carbon-intensive ways.¹ Domestic permits for CO₂ (the most plentiful human-created emission) could be applied directly to emissions sources or indirectly to supplies of fossil fuels based on their carbon content. Other sources of GHGs (for example, landfill CH₄) and carbon “sinks” such as reforestation projects could be included to the extent that they can be adequately quantified and monitored.

The United States already makes limited use of marketable permits for pollution control. Experience with the national SO₂ trading program for electric utilities, the regional NO_x control program in the Los Angeles area, and a variety of more source-specific emission credits programs suggests that this suite of policy tools can contribute greatly to achieving environmental goals cost-effectively (e.g., Stavins 1998). This is the case even with imperfect policies and real-world market frictions.

GHG control with emissions trading introduces some new features that must be considered. The first is the possibility of controlling multiple gases as well as creating sinks. The second is the sheer scale of even a domestic program, given the ubiquity of sources. How would such a program be implemented in practice? The third is the possibility of pursuing emissions trading internationally, given the uniform mixing of CO₂ in the atmosphere. Given this property, control of CO₂ anywhere in the world has the same environmental impact; but international trading would expand both the opportunities and the challenges of implementing such a control program.

The 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change provides several possible avenues for international carbon trading (see <http://www.unfccc.de> for the Protocol text). The “Annex I” countries that would have

¹ For a detailed review of domestic and international GHG policy design questions, as well as other aspects of the climate change issue, see Shogren and Toman (2000).

numerical emissions control targets if the Protocol is implemented can trade domestic emissions permits among themselves or trade project-specific emissions credits through joint implementation (JI) of emissions reductions. The Annex I countries also can invest in or purchase emissions credits created through emissions control activities in developing countries under the Clean Development Mechanism (CDM). These potential mechanisms have stimulated much of the current analytical interest in the design and operation of both domestic and international trading systems. But emissions trading remains an important topic for researchers independent of the Protocol.

The Protocol left specific rules about international emissions trading to be resolved at a future date. Although both Annex I trading and the CDM have the potential to generate low-cost emissions reductions for developed countries and tangible benefits to CDM host countries in the developing world, two factors limit their scope — transaction costs and additionality. Transaction costs consist of the time, effort, and other resources needed to search out, negotiate, consummate, and get governmental approval for heterogeneous deals. Additionality reflects the fear that people will try to use the CDM to get credit for emissions changes that would have happened anyway. Options to address additionality range from detailed scrutiny of every project before approval to the development of simple formulae applied across all projects. An obvious tradeoff exists between reliability and cost among these options. How the rules for trading and CDM will eventually be defined, with or without the Protocol, will determine the efficacy of these tools. In particular, the developers of the CDM will need to consider and possibly pre-test the institutional, administrative, and financial arrangements; the guidelines on the

criteria for eligibility and certification; and the ways to verify and monitor emissions reductions.

The economists in the other essays presented explore the current state of knowledge regarding the structure and performance of carbon trading systems and the gaps in knowledge about these instruments. Economics can help guide climate policy by providing insight into how a proposed change in incentives or benefits could affect behavior. This insight could be useful in understanding the consequences of flexible incentive systems, which are being negotiated right now. These big questions can be stripped down and addressed systematically with quantitative models, theoretical intuition, or laboratory experiments.

The papers by Tietenberg and by Toman and Gherzi in this digital monograph discuss the first two strands that are the traditional focus of economics research on climate policies. These papers discuss the theory and practice of quantity rationing with emissions permits. Evidence from the United States suggests that permits have not achieved significantly more reductions in emissions than standard regulatory systems, but that the unit costs of reductions are reduced. The evidence is ambiguous as to whether emissions permits have stimulated any more innovation in pollution control technology than the command-and-control technological restrictions. Early experiments with emission permits have proven to be administratively cumbersome. Their application has been hindered by debates about baseline emissions levels, the need for government approval at all stages of policy formulation, and the process in which producers must engage as they exchange proposals for carrying out a permit trade. In addition, the permit trading process has

technical, financial, and legal dimensions that have to be addressed before each trade in permits occurs.

Regulators must have sufficient knowledge to design the market. If the regulator knows the marginal costs and benefits of pollution control with certainty, the level of marketable permits can be set such that they lead to an economically optimal reduction in emissions based on the present value of compliance costs and avoided damages. The number of permits would be set at the control level where marginal benefits equal marginal cost. Since the permits can be freely traded, supply and demand would set the permit market price to a level where marginal costs would equal marginal benefits of control. To accomplish this requires knowing the appropriate time frame for the permits, such as weekly or monthly; the kinds of information required to allocate permits efficiently and fairly; how monitoring data will be obtained and tested; and what the inspection schedule should be. Private sector decisionmakers also needs to know these things if they are to make good decisions about buying or selling permits. Marketable permits need a legal structure to define the property rights of permit trading and to assure that these rights are well-defined and enforceable.

Consider now in more detail a third, less developed strand of emissions trading research, the contribution of experimental economics. This is the theme of the paper by Muller in this volume (also see Shogren and Hurley 1999). Experimental economics can play an important role in reducing the uncertainty associated with alternative plans to operationalize carbon trading. Numerous questions persist about emission tradings. Will it work? How well will it work, in light of concerns about transactions costs,

additionality, and other factors? How much flexibility will it provide? How do we monitor and enforce trading violations, especially in the international context?

Experimental methods are well-suited to test institutional design of emission markets. These methods can be used to explore the efficiency costs of deviations from an ideal emissions permit system like the system proposed by Hahn and Noll (1990). The number of permits should be limited and well-defined so as to give them a value that can be accurately estimated. Permits should be freely tradable with limited restrictions on the scope of trading, thereby guaranteeing that those producers who value the permits the most will be able to buy or keep them. Permits should be storable to maintain their usefulness in times of thin buying and selling. The trading of permits should not be expensive due to transaction costs, thereby opening up entry into the market and promoting efficiency. Penalties for violating a permit must be greater than the permit price to give producers the incentive to play within the rules of the market. Permits should only be expropriated in extreme circumstances to maintain the stability of the market. And producers must be allowed to keep any profits they earn from the trade of permits.

The usefulness of experimental economics is illustrated by work on the design of the acid rain trading program (Cason 1995; Cason and Plott 1996; Bjornstad et al. 1999). That work revealed a flaw in the original design of the permit auction run by the Environmental Protection Agency. Rational sellers saw quickly through this auction, and began capturing rents by making offers that understated their true value so they could be matched with a high bidder. The lab results confirmed this intuition—sellers undercut each other to get into the high end of the market. The end result was an inefficient auction. The lab results showed that the efficiency of the auction could be improved by

changing how permits were allocated.² The lessons learned in the lab thus can prove profitable. But these lessons should be available before the regulatory tool is already in place and resources are wasted due to inefficient design features. This is especially true for global climate change policy—an environmental question mark that dwarfs acid rain in scope and impact.

A testbed carbon emission trading system designed in laboratory markets can evaluate the institutional factors that will influence the effectiveness of carbon trading. Experiments can be designed to consider how flexibility in trading, imperfect information, multi-gas trading, links between domestic and international trading, and other factors affect the potential efficiency of trading (e.g., Bohm and Carlen 1999). Experimental work could prove useful in understanding what elements of emissions trading would reduce the efficiency of climate change policies.

Such work could first design and parameterize a testbed market that reflects the costs and productivity of the countries or regions that might participate in an emission trading initiative if the Kyoto Protocol is implemented. The lab could be used to explore how an emissions trading system might draw in new buyers and sellers, or how a trade might be self-enforcing given different penalty schemes. The lab can be used to find alternative exchange institutions that would increase the ability to buy and sell the low-cost carbon emissions reductions from around the globe. Researchers can examine what conditions are necessary to create and evaluate the performance of either a domestic or international emissions trading system or both simultaneously.

² Originally, buyers and sellers submitted bids and offers for emission permits, and the EPA set the market price discriminatively off the demand curve by first matching the seller with the lowest offer to the buyer with the highest bid. The matching then continued with the second lowest offer to the second highest bid, and so on, until the equilibrium quantity is reached.

For example, the efficiency of emissions trading can be enhanced by providing so-called “when” flexibility, in which firms can bank and borrow emission permits by either carrying permits forward to or drawing permits from a future compliance period. Using a series of double auction experiments, Godby et al. (1997) have shown that banking had strong positive impacts on the efficiency of the emissions market. Two reasons drive this finding: firms can mitigate the distortion caused by an initial allocation of permits that is sub-optimal over time; and firms already planning to bank some permits have less incentive to hoard additional permits as a hedge against bad states of nature. They have also shown that the introduction of a futures market will increase efficiency. The question remains as to how robust these results are with imperfect enforcement.

Unlike the U.S. SO₂ trading program, an international trading environment cannot be realistically expected to include a central enforcement agency to ensure that emissions created by countries will be within the allowable levels defined by their permit holdings. One possible solution is to make buyers of permits liable for excess emissions generated by those from whom they buy permits. Given that a country is actually purchasing permits and committing finances to limiting its emissions to the level that it has permits for, the country has demonstrated its willingness to meet the emissions targets. But a country selling permits in the absence of an enforcement agency might have an incentive to cheat by selling permits and emitting anyway.

The seller who cheats could cause global trading to unravel. Those spending money to meet their agreed upon emissions obligations will recognize that emissions are not being reduced, at least not as much as intended when they purchased permits. Such firms might then only be willing to buy permits at very low prices, stop trading, or

abandon their emissions control efforts altogether. Buyer liability could avoid this problem by holding the firms purchasing permits responsible for any excess emissions created by the seller. Such responsibilities could create increased incentives for sellers to meet their revised emissions targets after trade to avoid developing a negative reputation and causing buyers to avoid dealing with them and reducing their permit revenues. An additional benefit of such liability is that it could reduce speculation in permit markets. However, buyer liability also could require those with less expertise in evaluating the “quality” of permit offers to make such evaluations. Also, the need to establish liability through a chain of transactions could limit market liquidity and increase transactions costs. Laboratory experiments can provide concrete insights into all these issues.

Much work remains in understanding the behavioral underpinnings of carbon trading. Effective institutional design would benefit greatly from commissioning testbed studies on emissions markets. We can construct specific examples to understand how general institution-building efforts might work or fail given different levels of wealth. We can consider the incentives for technological progress created by different climate policies over the long term, including the opportunity cost of inducing innovation in climate protection versus other deserving goals. Finally, we should be vigilant that economists who are interested in trading institutions are not talking only to themselves as new climate events unfold and new research results emerge from the field and the lab.

References

- Bjornstad, D., S. Elliot, and D. Hale. 1999. Understanding Experimental Economics and Policy Analysis in a Federal Agency: The Case of Marketable Emission Trading. In *Research in Experimental Economics, Volume 7*, edited by C. Holt and R.M. Isaac. Greenwich, Connecticut & London, England: JAI Press, 163-180.
- Bohm, P., and B. Carlen. 1999. Emission Quota Trade among the Few: Laboratory Evidence of Joint Implementation among Committed Countries. *Resource and Energy Economics* 21:43-66.
- Cason, T. 1995. An Experimental Investigation of the Seller Incentives in the EPA's Emission Trading Auction. *American Economic Review* 85:905-922.
- Cason, T., and C. Plott. 1996. EPA's New Emissions Trading Mechanism: A Laboratory Evaluation. *Journal of Environmental Economics and Management* 30:133-160.
- Crocker, T. 1966. The Structuring of Atmospheric Pollution Control Systems. In *The Economics of Air Pollution*, edited by H. Wolozin. New York: Norton, 61-86.
- Godby, R., S. Mestelman, R. A. Muller, and J. D. Welland. 1997. Emission Trading with Shares and Coupons when Control over Discharges is Uncertain. *Journal of Environmental Economics and Management* 32:359-381.
- Hahn, R. 1989. Economic Prescriptions for Environmental Problems: How the Patient Followed the Doctor's Orders. *Journal of Economic Perspectives* 3:95-114.
- Hahn, R., and R. Noll. 1990. Environmental Markets in the Year 2000. *Journal of Risk and Uncertainty* 3:351-367.
- Muller, R. A., and S. Mestelman. 1994. Emission Trading with Shares and Coupons: A Laboratory Experiment. *Energy Journal* 15:185-211.
- Shogren, J., and T. Hurley. 1999. Experiments in Environmental Economics. In *Handbook of Environmental and Resource Economics*, edited by J. van den Bergh. Cheltenham, UK: Edgar Elgar Publishers.
- Shogren, J., and M. Toman. 2000. Climate Change Policy. *Public Policies for Environmental Protection*, 2nd edition, edited by P. Portney and R. Stavins. Washington, D.C.: RFF Press.
- Stavins, R. 1998. What Can We Learn from the Grand Policy Experiment? Lessons from SO₂ Allowance Trading. *Journal of Economic Perspectives* 12:69-88.

**Greenhouse Gas Trading:
Design Issues Seeking Research Answers**

Tom Tietenberg and Mitchell Family



RESOURCES
FOR THE FUTURE

Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202-328-5000
Fax: 202-939-3460
Internet: <http://www.rff.org>

GREENHOUSE GAS TRADING: DESIGN ISSUES SEEKING RESEARCH ANSWERS

Tom Tietenberg, Mitchell Family Professor of Economics

Colby College, Department of Economics

Waterville, ME

thtieten@colby.edu

Introduction

BACKGROUND

The 1992 United Nations Framework Convention on Climate Change (UNFCCC) recognized the global cost-effectiveness of emissions reductions in Article 3.3 and thus opened the way for flexibility in compliance strategies. As it did not fix a binding emissions target for any country, the need to invest in emissions reduction either at home or abroad was not pressing. In December 1997, industrial countries and countries with economies in transition agreed to legally binding emission targets at the Kyoto Conference and negotiated a legal framework as a protocol to the UNFCCC - the Kyoto Protocol (UNFCCC 1997). This Protocol will become effective once it is ratified by at least 55 parties representing at least 55% of the total carbon dioxide (CO₂) emissions of Annex B countries¹ in the year 1990.

Article 3 of the Kyoto Protocol defines the five-year commitment period (2008-2012) in which emissions targets set for individual Annex B countries have to be reached. Together, Annex B countries must reduce their emissions of six greenhouse gases (GHGs)—CO₂, methane, nitrous oxide, HFCs, PFCs and sulfur hexafluoride—by about 5% below 1990 levels over the commitment period 2008-2012. Participating countries use 100-year Global Warming Potentials to convert gases into a common unit. Emissions targets relate to the base year 1990 whereas countries in transition can use a different base year if established in their first national communication.

Besides emissions reduction, “verifiable” sequestration through afforestation and reforestation taking into account deforestation can be used to meet the targets. Further sequestration activities, such as increased carbon stored in soils, could also be authorized later. If emissions during the commitment period are lower than the target, the difference may be banked for the next commitment period.

Article 3.3 of the UNFCCC states, “policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.” To implement this provision, four provisions for cooperative implementation mechanisms have been included in the Kyoto Protocol.

- The Kyoto Protocol incorporates the “bubble” concept into the final text of Article 4. Although originally conceived to allow the European Community, a regional organization of

¹ Annex B countries refer to the countries in the Organisation for Economic Cooperation and Development (OECD) and countries with economies in transition. These countries have committed themselves to legally binding greenhouse gas emissions targets. The countries were originally referred to as Annex I countries under the Protocol, and the terms are often used interchangeably.

integrated economies to accommodate its internal burden sharing of the Kyoto commitments among its member states, the final wording of the Article is framed in general terms. It allows a group of Annex B countries to jointly fulfill their commitments under Article 3, provided that their total combined aggregate GHG emissions do not exceed their assigned amounts.

- The Kyoto Protocol also accepts the concept of emissions trading under Article 17. Annex B countries will be allowed to purchase the rights to emit GHGs from other Annex B countries that are able to cut GHG emissions below their “assigned amounts” (AAs). Although countries in Annex B of the Kyoto Protocol and Annex I to the UNFCCC are now the same, the Annex B list could expand to allow a developing country to engage in emissions trading if it voluntarily adopts an emissions target and is inscribed in Annex B. Emissions trading transfers “assigned amount units.”
- The third option involves project-oriented emission reduction credited to the investing country. This possibility was named “Joint Implementation” (JI) in the negotiations leading to the Rio Conference. The Kyoto Protocol allows JI between Annex I countries to produce “emission reduction units” (ERUs).
- The Kyoto Protocol also includes a “Clean Development Mechanism” (CDM). Countries that fund projects through the CDM can get credit for “certified emission reductions” (CERs) from these projects. In contrast to the other flexibility mechanisms, CERs accrue for the whole period 2000-2012, not just for the commitment period.

AN OVERVIEW OF THIS PAPER

When the Kyoto meetings left the details of implementing the emissions trading article up to subsequent meetings, the UNFCCC Secretariat asked UNCTAD (United Nations Conference on Trade and Development) to produce a background report which could be used to facilitate the discussion of implementation procedures by the delegates (UNCTAD 1998).

The UNCTAD report discusses the establishment of a trading system. It was based upon two specific sources of evidence—the historical experience with existing trading programs and existing international agreements. The objective was to derive lessons that should prove useful in designing a workable system.

As team leader of that project I became acutely aware of how limited our information was and how difficult it was to craft an optimal system in the face of this information void. In this paper, I use my experience in writing that report to extract a few key areas where I believe additional research information would be helpful. Thus my suggestions are derived from very practical considerations of how we might design a trading system to implement the Kyoto Protocol.

Basic Design Research Issues

INTERPOLLUTANT TRADING ISSUES

Under Article 17 the tradable commodity would be a carbon dioxide equivalent allowance. Each allowance would authorize the emission of one metric ton of CO₂ or an equivalent gas. The total number of allowances a party would hold at any time would consist of (1) the assigned amounts (AAs) (appropriately adjusted to reflect the net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced, land-use change, and forestry

activities, as authorized by Article 3.3), plus (2) allowances acquired from other Annex B parties, plus (3) certified emission reductions (CERs) acquired from non-Annex B countries under Article 12, minus (4) any allowances transferred to other Annex B parties.

The cost advantages from Article 17 would be greatest if all gases identified under Annex A would be eligible to be included in trades on a carbon equivalent basis. On the other hand none of the existing emissions trading systems allow inter-gas trading, so we have little experience with its benefits and costs in practice. Some have suggested that the varying degrees of uncertainty associated with the various gases open the possibility that trading could result in real increases in gases with reliable monitoring in return for “apparent” reductions in gases in which the monitoring uncertainty is high (Lanchbery 1998).

The ultimate question therefore is what gases should be traded? Should the trading system include all six gases or some subset of those gases? A number of suggestions have been floated, but very little hard research is available on the benefits and costs of following these suggestions.

One option would be to limit trading to GHG sources that may be readily and accurately monitored. Some have suggested, for example, that only energy-related CO₂ and CH₄ emissions should be eligible for trading (Lanchbery 1998).

Limiting trading to a subset of gases is not likely to be effective unless the Protocol is further amended to partition the assigned amounts into two categories—tradable and nontradable gases—with separate assigned amount goals assigned for each. In accordance with Article 5.3, Global Warming Potentials (GWPs) are to be used to convert non-CO₂ gases into carbon equivalent terms to verify compliance and define the trading baseline and adjustments to it as a result of trades.² With the current lack of separation of categories it would be easy for countries to use the flexibility inherent in the equivalence process to substitute freely among the gases regardless of the trading rules.

Another possible strategy for coping with emissions uncertainty involves adjusting the emissions inventories or adjusting the trading ratios in the emissions trading program to reflect the uncertainty in monitoring³ (Sussman 1998). The presence of uncertainty implies that a distribution of possible estimates exists. The range of that distribution will reflect the degree of uncertainty. This variation is an additional source of information that could be used in the monitoring process if the Conference of Parties deemed it necessary.

An alternative approach would involve imputing conservative presumptive values for emissions factors. Presumptive values could considerably reduce the cost of developing more sophisticated (and more accurate) measures or act as a stop gap measure until more accurate data can be obtained. The values chosen for these imputed factors could be intentionally conservative, thereby assuring environmental quality and providing an incentive for developing more accurate monitoring techniques.⁴ How conservative these should be, however, would presumably depend on the cost. Without further research the cost implications of various strategies are unknown.

² Section 5.3 of the Protocol requires that the GWP factors used in the conversion should be fixed for the first commitment period.

³ Since the net change in uncertainty depends both on the uncertainty associated with the reductions achieved by the seller and the increases in emissions authorized for the buyer, both aspects should figure into the process for adjusting the trading ratio. Yet as a practical matter it may not be possible to identify the specific emissions associated with the trade for either the buyer or the seller.

⁴ Notice that conservatism means different things depending on whether these methods are used to define the emissions inventory or to define the reductions that qualify for CERs or ERUs. In the case of

All of these possibilities provide a menu of possible research areas. How much interpollutant trading is likely to take place? How large is the environmental risk posed by trading pollutants with various levels of monitoring uncertainty? How effective are the various remedies? What price (in terms of increased costs) is paid to achieve these results?

FUTURE COMMITMENT PERIODS

One of the conclusions of the UNCTAD (1998) report was that multiple commitment periods offer significant opportunities to improve compliance in a weak enforcement environment. Principal tools that capitalize on the availability of multiple commitment periods include declaring noncompliant parties (those with resolved overages in the current commitment period) ineligible for trading and reducing assigned amounts of noncompliant parties in subsequent commitment periods.

One important element of an international enforcement system for allowance trading is establishing a credible system for restoring any ton of excess emissions by a noncomplying party. The most common way this has been done in past trading programs has been to require the noncomplying party or source to purchase or restore the ton of excess emission in the next budget period, usually the next year. This protects the environmental objectives of the Protocol by ensuring that the total cap on GHG is not exceeded. However, some problems arise in applying this system to GHG trading under the Kyoto Protocol.

- The first is the nature and length of the commitment period, a single, 5-year period. The long length means compliance is not determined until the end of the commitment period. Unlike existing trading programs the Kyoto commitment period is not divided into several (annual) budget periods.
- In addition, the Protocol mandates no subsequent budget periods or assigned amounts after 2012.

Both of these aspects of the Protocol create uncertainty for a methodology that would require excess tons of emissions to be taken from a subsequent commitment period. Currently the Protocol anticipates negotiations that will set assigned amounts in subsequent commitment periods, but currently those negotiations have not resulted in assigned amount goals beyond the initial commitment period.

Future commitment periods cannot be defined until the assigned amount goals for signatories are determined. Research should play a significant role in providing the information necessary to set future assign amount targets. What are the benefits and costs of the assigned amount trajectories in the short run and long run? How might the benefits and costs be affected by certain amounts of leakage from nonsignatory nations? Should allowance entitlements over time converge to a common metric?⁵ If so, what should that metric be?

inventories, a value in the higher range would be conservative while in quantifying emission reductions a value in the lower range would be conservative.

⁵ Some have suggested, for example, that over the long run all assigned amount obligations should converge to a common per capita entitlement (Centre for Science and the Environment 1998).

ROLE OF TECHNICAL PROGRESS

One of the determinants of the costs of various trajectories will be the amount of technical progress promoted by the Protocol. One recent study (Dowlatabadi 1998) considers control of CO₂ emissions so that GHG concentrations are limited to no more than 550 ppm. In exploring the consequences of delaying the onset of controls from 2000 to 2025 the author notes that “If endogenous technical change is assumed, expected business-as-usual emissions are higher than otherwise estimated—nevertheless, while 25% greater CO₂ control is required for meeting the CO₂ concentration target, the cost of mitigation is 40% lower.”

The theoretical literature also emphasizes that the form of the policy instruments should make a difference in the rate of technical change (Jaffe and Stavins 1995; Jung et al. 1996; Laffont and Tirole 1996; Maleug 1989; Milliman and Prince 1989). At this point, those theoretical predictions remain largely unsupported by evidence. We need to develop a series of studies that can provide empirical evidence of the relationship between instrument choice and technical progress. Is it possible to empirically show not only that instrument choice matters in determining the rate of technical progress, but that it matters in the same direction suggested by theory? And last but not least, are the effects of instrument choice on technical progress of sufficient magnitude that these effects should actually be a conscious element in the choice of instruments?

A related issue is the degree that outside influences would inhibit the market penetration of energy-saving technological progress in both signatory and nonsignatory nations. One major influence is the expected decline in oil prices for non-Annex B nations in response to the lower demand for oil induced by implementation of the Kyoto Protocol. Presumably the market penetration of energy substitutes or of energy-saving production processes will depend on the cost of fossil fuels. Low cost fossil fuels would presumably retard entry of these technologies. How serious a barrier is this?

Early Transition Issues

EARLY ACTION INCENTIVES

Reducing emissions frequently involves capital investments. The magnitude of the reductions anticipated by the Kyoto Protocol certainly suggests that GHG-saving investments will probably play a prominent role.

GHG-saving investments can be classified into two categories. The first, known popularly as “no regrets” investments, offer a sufficient rate of return regardless of the ultimate fate of the Protocol. The second category of investments only makes economic sense if the Protocol is implemented.

The first research question is how much of the total reductions can be achieved by “no regrets” investments. Significant differences of opinion currently exist (American Council for an Energy Efficient Economy et al. 1991; Energy Information Administration 1998). To the extent that “no regrets” investments are sufficient, then early action initiatives are less important.

If it turns out that “no regrets” strategies are not sufficient, then the current political climate creates several obstacles to additional investments. First of all it is by no means clear that the United States will ratify the agreement. The U.S. Senate stipulated in the 1997 Byrd-Hagel

Resolution that the participation of the developing countries would be a necessary condition for ratification. Developing countries have stated that won't happen. Second, if the United States—arguably the major emitter—does not ratify, it is not clear the agreement will take effect.⁶

If the agreement does not take effect, the mandates for greenhouse gas reductions that are contained within the agreement will not be binding. Investments made specifically to meet those mandates would have been unnecessary in retrospect. Recognizing this possibility in advance undermines the incentive to invest.

A class of early reduction schemes has been proposed to encourage investments in the face of this political uncertainty. The earliest U.S. legislative initiative was S. 2617, a bill introduced by Senator Chafee. After significant opposition to that bill because it would amend the Clean Air Act, a replacement (S.547) was introduced. Generally this legislation, if enacted, would provide the President with the authority to establish “binding” agreements with businesses. Those businesses would be encouraged to reduce their greenhouse gas emissions in return for early recognition in the event that domestic mitigation policy is mandated.

The credits would be based on reductions below a predetermined baseline of current emissions—an annual average of 1996-1998 emissions levels or an earlier target date such as 1990 levels. The companies would be awarded one-for-one credits, which could be sold or traded for voluntary cuts below that baseline, multiplied by the number of years in the program.

Participants would be responsible for annually measuring, tracking, and reporting their levels of greenhouse gas emissions. Credits would also be available for actions taken overseas—subject to certain conditions—for carbon sequestration via forests and farmlands and for reductions made through the use of nuclear power.

Implementing this effort would be facilitated by research into these various schemes. Significant questions remain. Credits are to be created when emissions fall below prespecified baselines. What should the baselines be? Research can help to define appropriate baselines by tracing out the implications of various choices.

Before early credits are issued, however, the type of system must be defined. Two major possibilities exist. An “upstream” trading system would target fossil fuel producers and importers as regulated entities, thus it would reduce the number of allowance holders to oil refineries and importers, gas pipelines, LNG plants, coal mines, and processing plants (Kopp et al. 1999). In contrast, a “downstream” trading system would be applied at the point of emissions. As such, a large number of diverse energy users would be included.

In the event that the United States ratifies the agreement and chooses to implement an early reduction system, the credits would, in principle, be designed to ensure favorable treatment of early investors in the initial allocation of allowances. Accepting the principle of “favorable treatment,” however, does not provide much guidance for how to implement the principle. And if the Protocol is not ratified, what becomes of the credits?

Working out an acceptable early reduction system is not a trivial exercise. However it would certainly facilitate the implementation of the Kyoto Protocol.

⁶ As noted above, this Protocol will become effective only when it has been ratified by at least 55 parties representing at least 55% of the total carbon dioxide (CO₂) emissions of Annex I countries in the year 1990.

Subsequent Transition Issues

EXPANDING TO THE DEVELOPING COUNTRIES

Article 12 of the Kyoto Protocol does not prevent a host country from financing projects on its own and selling credits earned under the CDM. As host countries in the developing world have no targets under the Protocol, however, they have an incentive to maximize credit sales. Here the baseline issue becomes crucial; the CDM should not reward inflated claims of emission reductions. Moreover, when assigned amounts are to be based upon historical emissions, an incentive is created to boost emissions to qualify for a higher assigned amount (Michaelowa 1997).

This baseline problem could only be fully solved by providing an incentive for developing countries to adopt limitation targets voluntarily and participate in emissions trading and JI under Articles 17 and 6. In the medium and long term, emissions trading could be instrumental in establishing an international climate change policy that fully accommodates developing country economic growth, while requiring this growth to be achieved in a carbon-efficient manner.

The key questions are: (1) How can the developing countries be made full partners in Article 17 of the Kyoto Protocol? (2) How can the transition from the CDM to Article 17 be accommodated? Research can facilitate this process by expanding the menu of possibilities and by clarifying the consequences of various choices.

Plenty of options are already on the table. According to one model, developing countries should be able to “opt in” the allowance trading system by adopting “growth baselines” (Center for Clean Air Policy 1998). Countries opting in would not only have to prove that their GHG emissions grew at a slower rate than their economic output in the near term, but would also have to accept the inevitability of an eventual cap on emissions. Developing country economic growth would thus not be constrained initially, but countries would commit to improving the “carbon efficiency” of this growth in the short run and accepting an ultimate limit on emissions in the long run. The key benefit to developing countries of adopting growth baselines would be the substantial capital inflows promoted by emissions trading.

Other options could also serve to provide flexibility in the negotiations over including developing countries in the Annex B list of nations (Joshua 1998).

- Regional groupings such as ASEAN and MERCOSUR could apply to be covered by a regional bubble.
- Developing countries could introduce “partial caps” which, for example, could be based on industrial sector limits, and coupled with JI in the uncapped sectors, as a form of progressive restriction towards the imposition of a national cap involving all sectors. Countries operating industrial sector growth limits could continue to have access to the CDM for investment and trading in credits for uncovered sectors.
- Developing countries could choose different base years for each GHG they propose to bring under a sectoral or national cap.

Presumably allowance trading would result in greater total capital flows under Article 17 than the CDM, because transaction costs would be lower. To participate in trading, a country would simply need to develop an accurate emissions inventory and then compare actual emissions to the emissions budget. To the extent that actual emissions come in under the budget, the country could sell allowances. Issues such as additionality and the development of appropriate project emissions baselines, which may reduce the incentive to invest in CDM projects, would not be present in an allowance trading system.

Fears have been expressed that developing countries will seize the opportunity to negotiate unreasonably large assigned amounts, a phenomenon that has now been labeled the “tropical air” problem. The United Nations Conference on Trade and Development (1998) study suggests that this problem can be diminished by using uniformly-applied specific criteria for defining assigned amounts for those seeking to join Annex B in the future rather than negotiating each situation from scratch on a case-by-case basis.⁷ This two-step procedure—to negotiate fair and appropriate general criteria and to apply them to individual parties—could offer the opportunity to expand the set of Annex B nations without placing the goals of the convention in jeopardy. But what are “fair and appropriate criteria”? Finding the answer to this question is a fair target for further research.

Once the questions about the shape of ultimate integration have been settled, it is still necessary to design the transition process. The major transition question is how certified credits created under the CDM should be incorporated into the definition of an assigned amount when a non-Annex B nation agrees to join Annex B? Suppose a country has leased or sold 30 tons of CO₂ offsets for five years to another country prior to signing the agreement and receives 1000 tons per year of allocated entitlements following acceptance of the agreement. How should the accounting of these two types of entitlements be handled? Can previously transferred credits simply be subtracted from assigned amount allowances as initial analysis suggests?

Accountability Research Issues

THE DEMAND FOR ACCOUNTABILITY

Emissions trading is neither new nor unproven as an instrument of national environmental and resource policy. Issues such as measurement, monitoring, verification, and the institutional requirements governing trading amongst different trading partners have been addressed. (Environmental Law Institute 1996). They have been addressed, however, in the domestic, not the international, context.

It is in the areas of accountability, risk, transparency, reporting, and enforcement that international GHG emissions trading probably differs most fundamentally from any previous experience. Concerning these issues, to a large extent the Kyoto Protocol takes us into *terra incognita*. This is for two main reasons, both of which derive from the fact that the legal basis for international greenhouse gas emissions trading—the Kyoto Protocol—is an agreement between sovereign states. Ultimately, therefore, legal accountability derives from the legal authority of the governmental institutions that sign and subsequently ratify the Protocol.

⁷ The criteria would specify the relevant variables and their weights, while the application would involve inserting the relevant data for each country into the predefined formula.

Resolving issues of accountability is an especially fertile area for the possible contributions of future research. Key questions include: (1) How can an adequate monitoring and compliance system be implemented, given the inherent difficulties posed by operating in an international arena with sovereign states as the Parties? (2) Can liability for short-term noncompliance be assessed in such a way as to preserve the incentives of all parties to comply over the long-term? (3) How can Parties be assured that credits created under the CDM represent real reductions and how can liability for noncompliance be assessed in those cases? (4) How can the “supplemental means” requirement (defined below) be met?

MONITORING AND COMPLIANCE ISSUES

The first line of accountability is, of course, provided by compliance and enforcement procedures. Compliance and enforcement procedures, when they work well, provide complete accountability. It follows that the first step in providing accountability in the case of inadequate compliance and enforcement procedures is to strengthen those procedures to the extent possible. How this can be done has not yet been resolved.

The national reporting system of each Party would have the dual responsibility for tracking both emissions and allowances. Both reports would necessarily be submitted in a standardized format to facilitate comparison of “authorized” emissions with “actual” emissions and to facilitate comparisons with the reports of other parties. The form and frequency of these reports must be decided.

The international authority is expected to perform the following key monitoring and compliance functions: initial approval of a country’s monitoring system that allows it to participate in emissions trading; and receipt and review of the reports generated by countries that provide credible data on monitoring results and methods on an ongoing basis. Procedures for receiving, evaluating, and acting on these reports need to be developed.

Creating layers of veracity checks should strengthen the integrity of the allowance and emissions monitoring systems. Systems of self-reporting are vulnerable to many risks of deception, although analysts may overstate the extent to which purposefully deceptive self-reporting occurs. What should these layers of veracity checks include? Who should oversee their design, construction, and implementation? What role can private organizations play?

Transparency of behavior should be promoted through public availability of collected data. The assurance function is better fulfilled if data are widely available, veracity-checking is easier if multiple sources of information are available, and the involvement of private monitors is frequently heavily dependent upon the existence of rich databases. How far can transparency be pushed before there is reluctance to reveal some information because of privacy and industrial secrets?

Since emission reductions used to generate CDM credits require considerably more scrutiny, a certification function is necessary to assure that only certified credits would become part of the emissions trading system. Certified CDM credits would be treated as homogenous in quality to Article 17 allowances. The certification process provides one concrete means of attempting to assure a smoothly running trading system, while simultaneously assuring that the trading system furthers the goals of the agreement. How should this certification process work? Who should oversee it?

Some certification authority could be delegated to specific governmental units within participating nations or communities or even to private certification entities, providing certain preconditions had been met. These preconditions might include the following: (1) an identified organizational unit willing and able to assume the responsibility for certification, (2) the existence of sufficient enabling legislation to assure adequate powers to carry out its mission, as well as adequate staff and resources, and (3) acceptance of, and willingness to apply, standard certification criteria.

While certification is presumably sufficient for the transfer of a credit, would the use of a credit to fulfill part of an assigned amount obligation also require verification? Whereas certification would provide assurance that a specific emissions reduction or carbon absorption would be forthcoming from the project, verification would provide the assurance that these expectations had in fact materialized. (For example, verification of a forestry project would assure that the planned forest was in existence and was absorbing carbon at the expected rate, while an energy efficiency project would verify that actual emissions mirrored the emissions expected on the basis of design criteria.)

Multiple commitment periods offer significant opportunities to enforce compliance. Principal tools include declaring noncompliant Parties ineligible for trading and reducing assigned amounts in subsequent commitment periods, which work best if subsequent commitment periods are in place and assigned amounts defined. Currently the Protocol establishes a process for further negotiations to set assigned amounts in subsequent commitment periods, but it is not clear how important that task is in promoting compliance within the first commitment period.

A wide range of enforcement and compliance instruments are available to domestic enforcers. The frequency and effectiveness of domestic environmental enforcement varies according to budgets, political will, and legal constraints on the types of penalties that could be imposed. Some countries may favor stiffer penalties, including incarceration and personal liability for actions of organizations and firms, and administrators in these countries now possess a wide array of sanctions they can apply. This is not uniformly true among all parties however.

How about parties with fewer domestic enforcement capabilities? Should strict eligibility requirements be imposed on those parties seeking the right to engage in trading? If eligibility requirements are imposed, parties that fail to comply with reporting or other requirements could be prohibited from trading within the initial compliance period. Once subsequent commitment periods are established, it would also be possible to require that parties be in compliance in the previous commitment period in order to be eligible to trade in a subsequent commitment period. The desirability of eligibility requirements is an appropriate question for further research.

Another possibly important element of an enforcement system would involve establishing a credible system for restoring any ton of excess emission by a noncomplying party. (Environmental Defense Fund 1998). This would protect the environmental objectives of the Protocol by ensuring that the total cap on GHG would not be exceeded. In past trading programs, it was most common to require the noncomplying party to purchase or restore the ton of excess emission in the next budget period, usually the next year. However, the nature and length of the current 5-year commitment period and the lack of a defined commitment period subsequent to 2012 create uncertainty for such a methodology until future periods and targets are defined.

LIABILITY FOR NONCOMPLIANCE

Suppose that at the end of the commitment period, despite the best attempts at erecting a credible and effective enforcement system, some countries have exceeded their assigned amount obligations. For traded tons should the seller, the buyer, or both be held liable for the shortfall?

In general the principle of strict seller liability makes sense in a strong enforcement environment for two reasons. In the first place it significantly enhances the tradability of permits, as it ensures all permits are standard commodities, which reduces the risks and uncertainty in trading. Second, it provides incentives for those creating the credits or transferring the allowances to be sure that the associated emissions reductions are real. Internalizing this externality will reduce the incentive to cheat.

Seller liability systems are all that is needed if compliance mechanisms are strong and any excess emissions are recovered from the environment. In existing allowance programs, the normal compliance procedure is to subtract the deficiency from the assigned amount in the next commitment period and to add a penalty. This method could be used in GHG trading systems as long as exceeded tons could be restored during or shortly after a compliance period.

However, in this Protocol a seller liability policy may not always work because there is only one very long commitment period and, as of now, no additional commitment periods have been defined.⁸ In addition, it has been argued (Grubb 1998) that seller liability could lead to a regime of weak compliance because the lack of strong enforcement at the international level would provide few disincentives for buyers to acquire from sellers who take a lax attitude to compliance. This may create a need for some form of a buyer liability program to assure that tainted acquired allowances could not be used to satisfy the “assigned amount” requirements.

The rationale in adding buyer liability is that it may discourage purchasers from buying tons from countries that appear to be headed towards noncompliance. It may also prompt buyers to make additional emissions reductions toward the end of the commitment period if they perceived that tons they had obtained through trading might not be fully valid.

While adding buyer liability creates some added assurance of compliance, it creates its own set of problems. A major problem is that it erodes the commodity nature of allowances by allowing them to be retroactively devalued, thereby creating uncertainty as to their value until the end of the compliance period. Representatives of trading firms in UNCTAD trading meetings have emphasized that this may interfere with the development of financial markets for allowances and discourage trading.

⁸ As stated in Article 4, bubbles also raise an accountability issue. In the case of a regional economic integration organization (REIO) bubble, such as the EU bubble, each REIO member and the regional organization itself are held accountable for the failure to achieve the required reductions for the REIO. Under the terms of the agreement notified to the UNFCCC Secretariat, the incentive for noncompliance is offset by the joint responsibility of both the individual members and the regional organization.

In contrast, in the case of a non-REIO bubble, the absence of a formal regional organization with enforcement powers means that the seller countries are solely responsible for their own noncompliance. As discussed above in connection with Article 17 trading, these countries may have an incentive to fall short of compliance. To ensure the environmental integrity of the Kyoto Protocol, it is thus desirable to assign some form of joint responsibility for non-REIO bubbles too. However, the countries within a non-REIO bubble should be left free to work out an arrangement to bring the whole group into compliance.

Buyer liability may throw well-intentioned buyers out of compliance. This is especially troubling since buyers may have difficulty ascertaining whether or not allowances are backed up by real reductions. The seller is in the best position to know.

While buyer liability adds a compliance incentive, it does not solve the compliance problem. Buyers who have relied on traded tons would find themselves out of compliance at the end of the commitment period. The excess tons must still be recovered from the environment, either by the buyer or seller, through one of the aforementioned methods, such as by deducting it from the next commitment period.⁹

Another way to recover the excess tons could be evaluate the parties' efforts towards implementation during the commitment period. This includes annual reporting of the progress of each party in meeting its assigned amounts. If in a given year a party's actual emissions did not exceed its annualized assigned amounts by a certain margin, the seller's tons would be valid. After the year when the seller is found to go beyond that tolerance margin, however, buyers become liable for potential noncompliance by the seller. As such, the allowances acquired prior to that year would not be discounted, thus avoiding the imposition of retroactive liability for the buyer. Under both of these methods the instrument would be targeted on the source of the problem.

If the parties decide that buyer liability is needed to complement traditional compliance procedures, several models of buyer liability are available. Two of the most prominent models are the "vintage model" and "proportionate reduction" model. Under the vintage model, allowances are serialized from the time of initial transfer, with earlier transfers involving lower numbers. In the case of noncompliance of the seller, sufficient transferred allowances are voided to cover the overage, starting with the allowances transferred last.

Under the proportional model, buyer liability is assessed on a proportionate basis. Thus if a country sells 1,000 tons of emissions and has an average excess emissions of 100 tons, 10% of all allowances secured from that party would be invalid and could not be used to demonstrate compliance.

Serialization provides the market with information that apparently is helpful in assessing the magnitude of this risk. It also provides a better means for the market to assess the degree of risk associated with acquired allowances and to discount prices accordingly. The vintage approach distinguishes buyers who acquire allowances from sellers when no implementation problems are on the horizon, and from those buyers who do so when serious implementation problems have arisen in the seller country (Goldberg et al. 1998).

Finally, we must consider situations where parties allow private entities to participate in trading activities. Since private entities are not accountable for the national targets under the Kyoto Protocol, another layer of accountability is necessary for them. Thus they are accountable to their

⁹ A "buyer beware" system that applies to all transactions uses a fairly blunt instrument to solve a specific problem. In the long run it might be more prudent to target the instrument only to those parties that are causing the problem. One way to accomplish this would be to implement a "buyer beware" requirement only for allowances purchased from any party found to be in noncompliance in the previous commitment period. Not only would this provide additional incentives to comply, but it would not saddle the trading system with this additional requirement except for those transactions where it is likely to be an issue. The disadvantage, of course, is the fact that it doesn't provide any help in facilitating compliance during the first commitment period.

governments which in turn assumes the accountability of the aggregation of private entities' trades.

Governments may wish to set rules that protect themselves against noncompliance by private entities. Parties may create a domestic enforcement system that imposes penalties for invalid trades and insures emitted tons are always restored. Another method would be to require private sellers and buyers to obtain insurance for allowances to minimize the risk that parties do not comply because of invalid trades by private entities. Programs such as the U.S. Acid Rain Program show how a domestic cap and trade system could be structured to be extremely effective while minimizing costs. The bottom line is that a varied menu of options exists and some initial insights have been derived. Further research is needed, however, to see whether deeper investigations reinforce or repudiate these tentative initial findings.

ACCOUNTABILITY UNDER THE CDM MECHANISM

Both emissions trading under Article 17 and JI under Article 6 involve the transfer of assigned amounts, creating an enforceable standard that ensures the environmental integrity of the trading systems and the overall cap on emissions. No similar system exists for credits created under the CDM, so an additional level of accountability such as insurance or certification is needed for such credits.

Article 12 provides that Annex I countries can acquire the certified credits obtained from GHG reduction projects with non-Annex I countries under the CDM. Under the system proposed here, only certified credits from CDM projects with developing countries can be incorporated into an international emissions trading scheme.

The certification function could be performed either by an official CDM authority or a private certifier, making either the CDM or a private certifier responsible for CERs sold. The first option would be preferable, as there is a default risk of a possible private certifier in the second option. The CDM could demand insurance from project managers of projects that sell CERs or host country governments. If the CDM credits are ultimately deemed not valid in whole or in part, should the seller, buyer, or both be liable for restoring the tons of excess emissions and any other penalties? Should the certifier bear any of the liability?

THE "SUPPLEMENTARITY" REQUIREMENT

Article 17 specifies that emissions trading "shall be supplemental to domestic actions." What is meant by this provision is an issue in the current international debate on emissions trading, and remains to be defined at future COPs.

The issue of supplementarity is influenced by perceptions of the likely cost of domestic emissions reductions and the affect on international trading. If domestic costs are likely to be low in most countries, as some believe, compliance will take place largely domestically, and the supplementarity provision will never become a binding constraint. Only if domestic compliance costs are high would there be a need to consider mechanisms for promoting domestic compliance.

Following the decision of the EU Council of Environmental Ministers in March 1998, the United Kingdom circulated a "non paper" at the Subsidiary Body for Scientific and Technological Advice (SBSTA) meeting at Bonn on behalf of the EU plus the Czech Republic, Slovakia, Croatia, Latvia, Switzerland, Slovenia, Poland, and Bulgaria. The paper states that

"We believe that domestic actions should provide the main means of meeting commitments under Article 3. This is consistent with the ultimate objective of the Convention. In this context, a 'concrete ceiling' on the use of all the flexibility mechanisms has to be defined. ...The rules governing the international emissions trading system should reflect this principle" (European Union 1998).

The form that such a "concrete ceiling" might take is under active debate and has yet to be defined. One interpretation of the concrete ceiling provision is that the amounts traded should be limited to a fixed percent of the assigned amount. Any quota could either apply to the overall amount of reduction reached through any of the cooperative mechanisms or specific quotas could also be set for each mechanism.

The necessity for and the form of any concrete ceiling is extremely controversial. Yet part of the controversy seems to stem from a lack of information. What would happen in the absence of a concrete ceiling? What alternative approaches to a concrete ceiling exist? What are the consequences of various choices on cost, air quality, likelihood of ratification, and compliance?

References

- American Council for an Energy Efficient Economy et al. 1991. *America's Energy Choices: Investing in a Strong Economy and a Clean Environment*. Washington, D.C.: American Council for an Energy Efficient Economy.
- Center for Clean Air Policy. 1998. *Growth Baselines: Reducing Emissions and Increasing Investment in Developing Countries*. Washington, D.C.: Center for Clean Air Policy.
- Centre for Science and the Environment. 1998. Definitions of Equal Entitlements. CSE Dossier: Fact Sheet 5, Center for Science and the Environment, New Delhi, India.
- Dowlatabadi, H. 1998. Sensitivity of Climate Change Mitigation Estimates to Assumptions about Technical Change. *Energy Economics* 20(5-6):473-493.
- Energy Information Administration, Department of Energy. 1998. *Impacts of the Kyoto Protocol on U. S. Energy Markets and Economic Activity*. Report prepared for the Committee on Science, U.S. House of Representatives, October.
- Environmental Defense Fund. 1998. *Cooperative Mechanisms Under the Kyoto Protocol: The Path Forward*. June. Washington, D.C.: Environmental Defense Fund.
- Environmental Law Institute. 1996. *Implementing an Emissions Cap and Allowance Trading System for Greenhouse Gases: Lessons from the Acid Rain Program*. Washington, D.C.: Environmental Law Institute.
- European Union, Council of Environmental Ministers. 1998. Non paper presented at the Subsidiary Body for Scientific and Technological Advice (SBSTA) meeting. Bonn, Germany.
- Goldberg, D., et al. 1998. *Responsibility for Non-compliance under the Kyoto Protocol's Mechanisms for Cooperative Implementation*. Washington, D.C.: Center for International Environmental Law.
- Grubb, M. 1998. Core Issues in Implementing the Trading Mechanisms of the Kyoto Protocol. *Review of European Community and International Environmental Law* 7 (July/Aug).
- IPCC (Intergovernmental Panel on Climate Change). 1996. *Climate Change 1995: Economic and Social Dimensions of Climate Change*. Cambridge, England: Cambridge University Press.

- Jaffe, A. B., and R. N. Stavins. 1995. Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion. *Journal of Environmental Economics and Management* 29(3 Suppl. Part 2):S43-S63.
- Joshua, F. 1998. International Greenhouse Gas Emissions Trading—Structure and Organization of the Emissions Market (Implications For Developing Countries). UNCTAD, Geneva.
- Jung, C. H., K. Krutilla, et al. 1996. Incentives for Advanced Pollution Abatement Technology at the Industry Level: An Evaluation of Policy Alternatives. *Journal of Environmental Economics and Management* 30(1):95-111.
- Kopp, R., et al. 1999. Proposal for Credible Early Action in U.S. Climate Policy. <http://www.weathervane.rff.org/features/feature060.html> (May 8, 1999).
- Laffont, J.J., and J. Tirole. 1996. Pollution Permits and Environmental Innovation. *Journal of Public Economics* 62(1-2):127-140.
- Lanchbery, J. 1998. Input To The Forthcoming UNCTAD Study On Greenhouse Gas Emissions Trading: Defining The Principles, Modalities, Rules And Guidelines For Verification, Reporting And Accountability. VERTIC, London.
- Maleug, D.A. 1989. Emission Trading and the Incentive to Adopt New Pollution Abatement Technology. *Journal of Environmental Economics and Management* 16(1):52-57.
- Matsuo, N. 1998. Key Elements Related to the Emissions Trading for the Kyoto Protocol. *Energy Policy* 26(3):263-273.
- Michaelowa, A. 1997. Efficient Incentives for Private AIJ and Their Political Implications. In *Proceedings International AIJ Workshop*, edited by Arthur Pelchen. 5-6 March 1997, Leipzig, 123-126.
- Milliman, S. R., and R. Prince. 1989. Firm Incentives to Promote Technological Change in Pollution Control. *Journal of Environmental Economics and Management* 17(3):247-265.
- Sussman, F. 1998. Compliance and Uncertainty in Emissions Inventories. Presentation at the UNCTAD Meeting on Verification and Accountability. 6 April 1998.
- UNFCCC (United Nations Framework Convention on Climate Change). 1997. *Kyoto Protocol to the United Nations Framework Convention on Climate Change*. FCCC/CP/L.7/Add.1. Kyoto: United Nations.
- UNCTAD (United Nations Conference on Trade and Development). 1992. *Combating Global Warming: Study on a Global System of Tradeable Carbon Emission Entitlements*. New York: United Nations.
- . 1998. *Greenhouse Gas Trading: Defining the Principles, Modalities, Rules and Guidelines for Verification, Reporting & Accountability*. New York: United Nations.