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ECONOMIC IMPACT OF MITIGATION MEASURES

PROCEEDINGS OF IPCC EXPERT MEETING ON ECONOMIC IMPACT OF MITIGATION MEASURES

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Edited by: Jiahua Pan, Nico van Leeuwen, Hans Timmer and Rob Swart

This meeting was hosted by CPB, Netherlands Bureau for Economic Policy Analysis, in cooperation with Intergovernmental Panel on Climate Change and Energy Modelling Forum

Programme Committee: Terry Barker, Jean-Charles Hourcade, Priyadarsi Shukla, Rob Swart, Hans Timmer, John Weyant.

Local Organizing Committee: Johannes Bollen ,Casper van Ewijk, Arjen Gielen, Jiahua Pan, Nico van Leeuwen, Rob Swart, Hans Timmer

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Cover and Lay-out: Martin Middelburg (RIVM)

CPB Contact Information:
Netherlands Bureau for Economic Policy Analysis
Van Stolkweg 14 , 2585 JR THE HAGUE
The Netherlands
Email: n.i.m.van.leeuwen@cpb.nl
http://www.cpb.nl

rivm
onderzoek in dienst
van mens en milieu

IPCC WG III Contact Information:
Technical Support Unit
IPCC Working Group III
RIVM
Email: ipcc3tsu@rivm.nl
http://www.rivm.nl/env/int/ipcc/

Preface

One key element of the IPCC Third Assessment Report (TAR) on mitigation of climate change is to evaluate the economic impact of policies and measures taken by industrialised countries to address climate change. The IPCC Expert Meeting on Economic Impact of Mitigation Measures and Policies, organised by IPCC Working Group III and hosted by the Netherlands Bureau for Economic Policy Analysis (CPB) in collaboration with the Energy Modelling Forum, was intended to focus on the consequences of abatement policies in industrialised countries. Among the major objectives were examination of the current findings and issues arising from recent economic research in the area, both in the context of the Kyoto Protocol and in the context of possible future agreements beyond Kyoto, identification of key areas of uncertainties, and generation of input for assessment in IPCC's Third Assessment Report on Mitigation.

With the generous co-sponsorship from the Dutch Ministry of Economic Affairs and the Dutch Ministry for Housing, Spatial Planningand the Environment, the meeting took place in The Hague, 27-28 May 1999. A broad set of experts from both developed and developing countries, and from international organisations such as the International Energy Agency and the UNFCCC, participated in the discussion. The findings from the meeting are preliminary and highly uncertain but they can be of value for a better understanding of the possible direction and overall trend of such impacts. These proceedings consist of a summary report, the full papers and the contribution by discussants. Although most abstracts of papers were reviewed by the Programme Committee before acceptance, no arrangement has been made for a thorough review of the full papers as included in this volume.

The activity was held pursuant to a decision of the Working Group III of the IPCC, but such decision does not imply the Working Group or Panel endorsement or approval of the proceedings or any recommendations or conclusions contained therein. In particular, it should be noted that the views expressed in this volume are those of the authors and not those of the IPCC Working Group III or those of other sponsors.

Bert Metz　　　　Ogunlade Davidson

Co-Chairs IPCC Working Group III

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Summary Report

Jiahua Pan[1]

Goal and Background

With the Kyoto Protocol entering into force, Annex B countries are obliged to comply with quantitative limitations of GHG emissions. In the agreement, "flexible" instruments are suggested to help achieving these limitations. As the first budget period of the Kyoto Protocol is only up to 2012, there is also a need to consider the architecture of the future agreements. In both the short- and long-run cases, the policies and measures in developed countries will have economic consequences upon both the developed and the developing economies. One key element of the IPCC Third Assessment Report (TAR) on mitigation is to evaluate the likely economic impacts of policies and measures taken by industrialised countries to meet their Kyoto target. There have been a few research programs on these issues and a discussion on the findings from these projects can be of great help to better understanding of the problems. Also, the direction and key issues for future research on these areas need to be identified. It is against the above background that the IPCC Expert Meeting on Economic Impact of Measures and Policies taken by Annex B countries was organised by IPCC Working Group III and hosted by the Netherlands Bureau for Economic Policy Analysis (CPB) in collaboration with the Energy Modelling Forum, with financial support from the Dutch Ministry of Economic Affairs and the Dutch Ministry for Housing, Regional Development and the Environment.

The objectives for the meeting were set to:

- Present the findings and issues arising from recent economic research in the area;
- Discuss the possible architecture of future agreements beyond Kyoto;
- Identify key issues for future research; and
- Provide input into IPCC's Third Assessment Report on Mitigation.

The meeting took place in The Hague, 27-28 May 1999. On the first day the economic impact of policies agreed upon or discussed at COP3 and COP4 was addressed. On the second day the discussion was on the architecture of future agreements with a longer-term view. The meeting was divided into four sessions with 12 papers presented. After each paper, discussants were invited to provide comments and suggestions on the paper, followed by overall questions and a discussion. At the meeting, experts from CPB and the Energy Modelling Forum were invited to provide overviews on key issues at the beginning of morning sessions on both days. A panel discussion was arranged before the wrap-up session on the second day. See the meeting program in Appendix A for details.

About 45 participants were present at the meeting, coming from both developed and developing countries, and from international organisations such as the International Energy Agency and the

[1] This report was drafted by Jiahua Pan of the WG III TSU on the basis of the papers and outlines received at and after the expert meeting and the notes taken during the meeting, and reviewed by the Programme Committee.

UNFCCC. Annemarie Jorritsma, the Dutch Minister of Economic Affairs addressed the audience during the opening session on the first day. A full list of participants is given in Appendix B.
These proceedings consist of a summary report and the full papers (including one invited but not presented at the meeting) by speakers and review papers by discussants. Papers presented at the meeting but not submitted in writing other than in the form of an outline are not included. However, efforts have been made to cover the key points of these presentations in this summary report.

Issues of the Economic Consequences of Kyoto

Introduction

There were two half-day sessions on 27 May, chaired by Casper van Ewijk and Richard Richels respectively. In the opening part of the morning session, Minister Jorritsma delivered a welcome speech in her capacity as the Netherlands Minister of Economic Affairs. She emphasised that climate change is an area where the policy areas of environment, energy and economics are closely intertwined. She suggested that the focus of the climate change assessment be placed on both the first budget period of the Kyoto Protocol called the short run as it refers to the years up to 2012 and the architecture of future agreements referred to as the long run. In her opinion, both the quantitative commitments and the flexible instruments are important for the success of the Kyoto Protocol. Therefore, she suggested that compliance issues be included as an explicit part of the research agenda on the future of climate change policy. In addition to address compliance with the quantitative commitments and active implementation of the flexible instruments both within Annex B and globally, the Minister also considers it important to discuss possible future quantitative commitments for non-annex B countries.

After the welcome speech by Minister Jorritsma, Hans Timmer from CPB and John Weyant of the Energy Modelling Forum provided overviews on the issues regarding the economic consequences and the results from earlier modelling exercises. Among the issues covered by Timmer were baseline problems, uncertainty aspects, endogenous growth, international linkages such as trade and capital flows, and their economic consequences on non-Annex B countries. He argued that market failures should be taken full account of in the overall institutional design in addition to market mechanisms such as emission rights and taxes. The Clean Development Mechanisms as defined in the Protocol are an example of institutional frameworks that are designed to create efficiency gains like those that can be achieved in tradeable permit markets. This new institutional frameworks should be excamined further because they can also lead to new coordination problems. Weyant briefly outlined the major issues addressed by and results from 10 models[2] in the literature, including AIM, CETA, FUND, G-Cubed, GRAPE, GTEM, MERGE3, MS-MRT, RICE and Worldscan developed in the United States, Europe, Australia and Japan. These macro top-down models conclude that, with few exceptions, there would be a loss in GDP in Annex B countries for emissions reduction without trading. With respect to the reference case, leakage is likely to result from Annex B to non Annex B regions in the no trading case. The results for consumption losses in comparison with the reference case are somewhat mixed, with net losses for OECD countries in most cases with and without trading but with a net gain in a couple of cases for non-Annex B countries and the former eastern block countries. Without trading, the hot air in Eastern Europe and the Former Soviet Union would be reduced. World oil prices appeared to fluctuate over time. The economic impacts of Annex B actions on non-Annex B nations as calculated by the models are difficult to generalise, with both positive and negative spillover effects.

[2] For details, please see individual papers.

Global Impacts of the Kyoto Agreement

Thomas Rutherford presented the results from the MS-MRT model, co-authored with researchers at Charles River Associates. The discussant for this paper was Snorre Kverndokk. In the context of a global agreement to limit carbon emissions, a multi-sector, multi-region trade model (MS-MRT) has been developed that focuses on the international trade aspects of climate change policy, including the distribution of impacts on economic welfare, international trade and investment across regions, the spillover effects of carbon emission limits in Annex B countries on non-annex B countries, carbon leakage, changes in terms of trade and industry output, and the effects of international emissions trading.

The MS-MRT results suggest that imposing emissions limits on industrial countries with no international emission trading has negative impacts on the welfare of industrial and some developing countries, including all the oil-producing countries, and positive welfare effects on China and India. According to the authors' calculations, Annex B trading moderates the impacts, and greatly improves welfare for Russia. Global trading was calculated to be worse for China and India than no trading. Russia would be considerably worse off under global than Annex B trading. Terms of trade would generally move against developing countries in favour of industrial countries when the former do not participate in international emission trading because the cost in industrial countries increases, driving up the price of their exports, and their income and import demand fall, driving down the price of their imports. This is the principal reason for the negative impacts on developing countries, according to Rutherford. Some developing countries can offset these terms of trade losses because of their gains in terms of trade with OPEC and ability to shift to production of energy intensive goods where they have increased comparative advantage over the industrial countries. This would also increase their gains from trade relative to OPEC. The shift of energy intensive industries of Annex B countries to non-Annex B countries when the latter do not participate in emission trading would be significant. As a result, carbon leakage could also be significant in these model results, because of reduced energy efficiency and fuel substitution due to lower fuel prices in developing countries. Investment would fall in all regions, less in non-annex B countries and more in Annex B countries. However, the shift of industry would be moderated by Annex B emissions trading.

These results are based on the analysis that takes into account the differences in energy intensity across industries in different countries, and actual data on the share and energy content of imports and exports. They suggest the need to avoid competitive distortions and carbon leakage. With global trading, energy intensive industries could move out of developing countries, because the data show that those countries have the least energy efficient industries and therefore are the most vulnerable to a uniform, global increase in energy costs. However, the political opposition to this de-industrialisation process is likely to be strong even if there might exist a net economic benefit from such a process.

Emissions Trading, Capital Flows and the Kyoto Protocol

Warwick McKibbin presented a paper he co-authored with M. Ross, R. Shackleton and P. Wilcoxen on emission trading and capital flows under the Kyoto mechanisms. Ben Geurts of the Netherlands provided comments as a discussant. The theoretical appeal of an international permit program is strongest if participating countries have very different marginal costs of abating carbon emissions – in that situation, the potential gains from trade are largest. The results show that within Annex B and globally, abatement costs can indeed be quite heterogeneous. These differences in abatement costs are caused by a range of factors including different carbon intensities of energy use, different substitution possibilities and different baseline projections of future carbon emissions. Because of these differences, international trading offers large potential benefits to parties with relatively high mitigation costs.

The results also highlight the potentially important role of international trade and capital flows in global responses to the Kyoto Protocol. Regions that do not participate in permit trading systems, or that can reduce carbon emissions at relatively low cost, will benefit from significant inflows of international financial capital under any Annex B policy, with or without trading. It appears that the United States is likely to experience capital inflows, exchange rate appreciation and decreased exports. In contrast, the ROECD[3] region as the highest cost region, will see capital outflows, exchange rate depreciation, increased exports of durables and greater GDP losses. Total flows of capital could accumulate to roughly half a trillion dollars over the period between 2000 and 2020. Global participation in a permit trading system would substantially offset these international impacts, but is likely to require additional payments to developing countries to induce them to forgo the benefits that accrue to them if they do not participate.

The model's results are sensitive to assumptions that determine the mitigation cost differences among regions. With a smaller relative control cost differential between the U.S. and other countries in the OECD, the magnitude of capital flows to the U.S., and the costs and benefits of those flows, would all be smaller.

In the analysis, there are unavoidable uncertainties in the values of the model's behavioural parameters and the future values of exogenous variables. As shown by the sensitivity analysis, the results should be interpreted as point estimates in a range of possible outcomes. It is clear, however, that in an increasingly interconnected world in which international financial flows play a crucial role, the impact of greenhouse abatement policy cannot be determined without paying attention to the impact of these policies on the return to capital in different economies. Focusing only on domestic effects would miss a crucial part of the economy's response to climate change policy. To understand the full adjustment process to international greenhouse abatement policy it is essential to model international capital flows explicitly.

AIM-based Analysis of the Economic Consequences of Kyoto – Energy Exporters vs. Importers

The UNFCCC stipulates in Article 4 that the Parties should consider the specific needs and concerns of developing countries arising from the adverse effects of climate change and/or the impact of mitigation measures. Such a requirement is further reiterated in the Kyoto Protocol in its Articles 2 and 3. As the energy sector is likely to be most seriously affected by compliance with the Kyoto mechanism, a better understanding of the possible impacts on energy importers and exporters would be of great relevance to the successful implementation of the necessary policy measures. Tsuneyuki Morita from the Japanese National Institute for Environmental Studies reported the modelling results on such possible impacts. Jan Willem Velthuijsen acted as the discussant for this paper.

The key findings from the modelling exercise show that the reduction of carbon is projected to incur a net cost to Annex B countries. The marginal cost per ton of carbon for Japan was calculated as high as $234 while that for the United States was $153, with the EU in between ($198). As a result, the projection indicates that the price of crude oil would be lower under Kyoto than the business-as-usual scenario. The price could be slightly increased if trading among Annex B countries and/or at global scale would be allowed. However, the price under trading could still be lower than the business-as-usual case. One direct consequence of the price change would suggest that the Kyoto accord would reduce global energy trade once it is implemented.

[3] Rest of the OECD countries.

The possible impact resulting from the reduction in oil trade may not be evenly distributed. Oil exporters, especially Middle East countries, would reduce their GDP and consumption level. On the other hand, part of energy importers including the dynamic Asian countries would benefit from the Kyoto mechanisms. As to the question of how to mitigate the impacts, the model results show that emission trading among Annex B countries would slightly increase the demand for energy and thereby a higher price of crude oil would help reduce the possible adverse impact on oil exporters. Other possible mechanisms suggested in the presentation include the role of Clean Development Mechanism and compensation schemes. However, the discussion did not go into details on how these approaches would work under the Kyoto Protocol.

Kyoto and Carbon Leakage

The issue of carbon leakage was investigated using the simulation model Worldscan, a dynamic applied general equilibrium model, developed at CPB and discussed in a paper co-authored by Johannes Bollen, Ton Manders and Hans Timmer. The results were presented by Ton Manders at the meeting and discussed by Jean-Marc Burniaux from France. Two scenarios, A1 and B1, were tentatively used as "business as usual" or the baseline scenarios. These scenarios have been developed as part of a set for consideration by the IPCC for its Special Report on Emissions Scenarios[4]. Both scenarios assume high growth rates, especially in non-Annex B countries. The main difference is that in B1 very rapid autonomous improvements in energy efficiency are assumed. That makes the necessary reductions to comply with the Kyoto Protocol smaller and it generates a substantial amount of hot air in the former Soviet Union, even in 2020. The two scenarios turn out to generate similar leakage rates to non-Annex B regions. However, a large difference in leakage within the Annex B region was calculated. In 2020, reduction in Annex B countries would still be partly offset by induced increases of emissions in the Former Soviet Union in the model. Typical values for the leakage rate to non-Annex B turn out to be around 20 %. Leakage in case of free emission trade could be lower compared to the case with unilateral mitigation policies.

In the analysis, the leakage was split in three different ways. First, the well-known Kaya identity was used in which a change in emissions is disentangled into a change in production, a change in energy intensity of production and a change in the carbon intensity of energy. The calculations suggest that changes in energy intensity of production are more important for the amount of carbon leakage than changes in carbon intensity of energy. The latter is more important in countries that reduce their emission than in countries that increase their emissions. Changes in the level of total production are negligible as cause of leakage. Then the emissions were decomposed into emissions that are used for net exports of goods and services. To this end, the implicit carbon content was computed for all sectors, taking into account all intermediate deliveries and all imports. Most of the leakage was implicitly used for final demand in Annex B countries. That means that leakage, or the increase in emissions in non-Annex B countries, is mainly due to more energy intensive exports to Annex B countries and less energy intensive imports from Annex B countries.

In a sensitivity analysis, changes in emissions were split into changes that result from shifts over sectors and changes that result from shifts in production technologies. Crucial for the process are trade elasticities and production substitution elasticities. Higher trade elasticities tend to lead to higher leakage as a result of shifts over sectors, but slightly smaller leakage through changes in input structures of production. Lower substitution elasticities in the production process tend to decrease

[4] These scenarios are preliminary, have not been approved by IPCC at the time when the presentation was made and are subject to change.

leakage through changes in the input structures, but increase leakage significantly as a result of shifts over sectors.

Clean Development Mechanism

There were two presentations on this important issue: Thomas Heller from Stanford University and Priyadasi Shukla from the Indian Institute of Management, representing views from developed and developing country perspectives respectively. These two presentations[5] were discussed by two discussants, Robert McDougall and Terry Barker, with substantive comments.

The presentation by Heller examined the institutional aspects of the mechanism. For effective and efficient GHG reductions, proposals for and experiments with co-operative efforts have evolved from joint implementation (JI) to activities implemented jointly (AIJ) and the clean development mechanism (CDM). The discussion about the CDM itself has also been evolving from compliance to a more flexible trading regime. However, there exist many issues to be negotiated, including the scope of the mechanism (sequestration), capping vs. unlimited use, hot air in Article 17 vs. additionality in Articles 12 and 6, the allocation of credits, market allocations, overall equity and equity in the CDM, multilateral mechanism vs. framework rules, private surveillance vs. administrative monitoring, the place of CDM in the long run design of a mitigation regime and ratification issues.

In the institutional design of the CDM, problems are associated with adverse selection (sequestration and conservation), moral hazard (dynamic baselines), leakage issue, and that of wasting assets and the management of a scarce pool of mitigation opportunities. The commercial viability of CDM will depend on the potential of energy efficiency, technological improvement, institutional reform, and the management of financial risks. In addition, administrative feasibility is an important element for its success. Based on the past experience in JI and AIJ activities, institutional constraints, especially those in developing countries, will have to be removed or at least relaxed for an effective- institutional environment for CDM implementation.

The concerns over institutional issues were further emphasised in the comments provided by McDougall. In fact he believed that too high a hope had been placed on the CDM by some of its proponents. Rather it is argued that the CDM is likely to play only a modest role in both climate change and sustainable development action. In his estimation, the CDM is likely to prove contentious, because it is essentially a proposal for acting “out of natural sequence” and because the system is to come into operation too soon for the rules to be well defined. Most fundamentally, the CDM is the product of two different agendas, the sustainable development agenda of the developing countries, and a cost minimisation agenda by some industrialised countries. The harmonisation of these two agendas seems rather difficult, since large gaps remain in the two sides’ views on the role of the industrialised countries in supporting sustainable development. Participants in the CDM may be disappointed because the incentive to participate in the CDM is weak. On the contrary, effective safeguards to ensure additionality may impose burdensome delays and costs on would-be participants. Unlike other mechanisms, CDM projects are to be taxed to meet administrative expenses and to fund unrelated adaptation projects. If CDM activity will be modest, its effectiveness in promoting development in the Third World will also be modest.

The above critical view is further shared by Shukla from the perspective of the specific need of developing countries. The CDM is likely to contribute to cost-effectiveness of GHG reductions in

[5] No written paper has been submitted.

developed countries due to the wide differences in marginal abatement costs among countries, but the actual benefits envisaged for developing countries seem to be rather limited. On the contrary, low global CDM supply might be beneficial to a developing country like India. If there is no CDM, the oil price is likely to be low. This means to India three possible outcomes: net GDP gain, savings in foreign exchange, and enhancement of competitiveness. Domestic action in Annex B countries may also bring about favourable spillover effects to India as a result of improvement in mitigation technologies and reductions of future mitigation cost. Distributional issues constitute further concerns for developing countries. In case of India, the gains and losses under different permit schemes could account for several percentage points of its GDP and it is emphasised that the stakes for India could be “high”. The conclusion was drawn from his presentation that fairness must be ensured for the CDM, which requires burden sharing, fair competition, minimisation of welfare losses and the adoption of a precautionary principle.

Together with other participants, Barker joined the interesting debate as a discussant to Shukla’s presentation. Three sets of comments were added to the debate on the effects of the CDM as a flexible instrument on the Kyoto Protocol. The first issue is concerned with uncertainty of the size and scale of incremental abatement costs. There will be huge differences in costs depending on the technologies involved, the information available, the incomes of those making the mitigation decisions, and the time available for the schemes to be planned and to operate. The usual assumption on lower incremental costs in developing countries can be questionable. The second point concerns macroeconomic and environmental effects. Learning-by-doing and economics of specialisation and scale may well mean that the net benefits increase or the costs decrease. On the other hand if the revenues from the use of fiscal instruments e.g. carbon taxes are used to reduce one distortionary tax after another, starting with the most distortionary, then as the taxes are removed, the net benefits should decrease. Environmental effects of CDM schemes such as reductions in other emissions and damages associated with the reduction in GHG emissions should also be taken into account in the calculation of the social net benefits of CDM schemes.

The third point touched upon relates to additionality: how can participants be assured that the outcomes of a CDM scheme will indeed be additional to those which would otherwise have occurred? In the case of a CDM project there are two sides to the additionality problem: i) how can the non-Annex B country be assured that the CDM funding will not replace other financial assistance? And ii) how can the Annex B country be assured that the mitigation will be additional? The problems here can be alleviated by two requirements. One is that a proportion of the funding for the CDM scheme (say 50%) should be available to the receiving country for discretionary use. And the other suggests that Only 50% of the GHG savings be available to the Annex B country as a contribution to its Kyoto mitigation requirements.

Beyond Kyoto

Introduction

The sessions on Beyond Kyoto were chaired by Mohan Munasinghe of Sri Lanka and Bert Metz of the Netherlands. A longer-term view is necessary as the Kyoto commitments are set up to the period 2008-2012 only. In addition to six presentations, an overview on the EMF – 17 model comparison was presented and panel discussion conducted.

John Weyant briefly reviewed the results of the Energy Modelling Forum models, discussed the post-Kyoto frontiers and suggested directions for future research. The challenges ahead would include three issues. One is the flexibility issue: where, when, how and why flexibility. The how question would involve research and development, technology transfer, information programs, sinks etc. More comprehensive approaches are indicated. Second, the issue of sustainability, equity and development attracts lively debates in both the academic and the policy circles. The solutions to these issues are complicated by the differences in views and in many cases conflict among economic, ethical, social, political and ecological principles. Incentive compatibility constitutes the third key issue. Coalitions are likely to be formed and linkages to other global issues must be established. Three areas of future directions are suggested, notably the basic models, international trade and technological issues.

Developing Economies, Capital Shortages and Transnational Corporations (TNCs)

Transnational companies may have a major role to play within and beyond Kyoto. A majority of transnational corporations are based and controlled in industrialised countries. They are equipped with advanced technologies, capital resources, and managerial skills. There is an incentive for them to invest in developing countries for higher returns. In developing countries, there is usually a shortage of capital and lack of appropriate technology. Through direct foreign investment in developing countries, ancillary benefits are likely to be accrued, including additional supply of scarce capitals, transfer of technology and management know-hows, promotion of trade and exports, and generation of employment opportunities and training of skilled workers. All these would contribute to GHG reduction in developing countries in the long run. However, Leena Srivastava argued in her presentation that negative effects also exist because of conflicts of interest. The rising power of the transnational companies is also considered a cause of concern as they dominate the production and trade at global level. Considering the positive impact of TNCs on GHG reductions, they should be treated more explicitly in future agreements on climate change. However, issues regarding the role, position and entitlement of TNCs should be further investigated in the design of emission trading regimes. The views were partly shared by Thomas Heller, the discussant for the presentation, although more emphasis was on institutional constraints in the discussion.

Future Agreements

James Edmonds discussed principles upon which future agreements to mitigate greenhouse gas emissions might be framed. The current foundation for international action is the Framework Convention on Climate Change (FCCC), whose ultimate objective is: the stabilisation of concentrations of greenhouse gases at levels, which would prevent dangerous anthropogenic interference with climate systems. Neither the FCCC nor the 1997 Kyoto Protocol contains provisions sufficient to achieve this objective. Further agreements will be needed. These agreements must confront three broad challenges: extension of the reference time frame to a century;control of costs; and expansion of the list of nations with quantifiable emissions limitations.

Several research findings are relevant. First, stabilisation of CO_2 concentration implies that net global emissions may grow for a time, but must eventually peak sometime in the next century and then decline thereafter. But, economic theory suggests that global cost minimisation requires that everyone value a tonne of carbon equally, and that the common value initially be small but rise at the rate of interest plus the rate of removal of carbon from the atmosphere. This allows for the orderly turnover of capital stock, time to conduct R&D, prevents lock-in to early versions of new technologies, which are rapidly improving, and provides time for infrastructure development. Achieving these conditions requires the development of mechanism, which are consistent with principles of fairness and equity, by which non-Annex B nations can participate. Two examples were discussed. Expanded programs to develop and deploy technologies including conservation, non-carbon emitting energy forms, and mechanisms for the capture and sequestration of carbon are also needed.

The logic and comprehensiveness of the architecture proposed by Edmonds was highly appreciated by Thomas Rutherford as discussant, with further suggestions to improve the framework.

Developing Country Effects of Kyoto Emissions Restrictions

The paper by Mustafa Babiker and Henry Jacoby on developing country effects was presented by Mustafa Babiker and discussed by Mohan Munasinghe. The magnitudes of the long-term economic impacts are highly uncertain, but the analysis gives an idea of what these impacts might be, as well as how they are transmitted through the international trade system. The greatest loss would be imposed on energy exporters, and the more dependent a country is on these exports the greater the percentage effect on its economic welfare. So a country like Mexico, with a large and diversified economy would be much less influenced than the nations of the Persian Gulf (RME), for whom oil revenues constitute a large faction of GNP. The elasticities of demand by importing countries, and of supply by the non-OPEC exporters, combine to produce a market condition where efforts to resist the fall in oil price resulting from Kyoto restrictions could lead to still lower overall OPEC revenue. Attempts to do the same by a smaller group within OPEC would lead to even worse results for those taking action to support the price. The distribution of burdens differs depending on the treatment of existing fuels taxes in the enacting of carbon policies; and the presence or absence of emissions trading is even more significant. In general, those importing energy would benefit from more stringent the policies, and the energy exporters would lose. Moreover, emissions trading and tax harmonisation would look different depending on a nation's position on this scale. The intensity of the response will be approximately in proportion to the weight of the energy sector in the national economy.

Economic Analysis of the IPCC – SRES Stabilisation Scenarios Using Worldscan

The newly produced IPCC emission scenarios[6] were preliminarily used as the basis for a simulation analysis using the Worldscam model developed in the CPB. The work was undertaken by Johannes Bollen, Tom Manders and Hans Timmer of the CPB and presented at the meeting by Johannes Bollen.

There were three policy cases in the simulation exercise: early versus delayed response; the Kyoto Protocol with Annex B trading; and global trading after the first Kyoto budget period. Two sets of conclusions were drawn from the study. Within the "A1" scenario, it appears from the modelling results that (1) 550 ppmv could be achieved at moderate costs; (2) delayed response may have negative economic consequences for non-Annex B countries; (3) early response may have negative economic consequences for Annex B countries; (4) the income effects could be reversed through permit allocation schemes; (6) a delayed response seems globally beneficial from an economic perspective; and (7) the price distortion in the end may be large. The second set of conclusions suggest that delaying the global response is likely to be beneficial at global level because it presents overshooting in the medium run and free-riding behaviour due to discounting future cost/benefits. However, due to income transfers from permit trade, conflict of interests may occur.

The comments by Steve Lennon from South Africa and other experts question some of the conclusions while acknowledging the vigorousness of the modelling method. Some of the key

[6] These scenarios were developed in the IPCC Special Report on Emissions Scenarios and not yet approved by the Panel at the time of the meeting.

features are still to be fully incorporated. Examples include technological progress during the period for over one-century, leakage of GHGs, the learning-by-doing losses under delayed response, and ancillary benefits. In the proposed IPCC SRES scenarios, A1 is characterised with rapid growth, technologically optimistic, major reductions in per capita income. If other scenarios were used, the conclusions could be very different.

The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?
For many Annex B countries, the cost involved in compliance with the Kyoto Protocol is a major source of concern. The presentation by Richard Richels was helpful for improving the understanding of compliance costs. Three questions were examined in the study by Alan Manne and Richard Richels: What are the near-term costs of implementation? How significant are the so-called "flexibility provisions"? And, is the Protocol cost-effective in the context of the long-term goals of the Framework Convention? This analysis was based on MERGE (a model for evaluating the regional and global effects of greenhouse gas reduction policies), an intertemporal market equilibrium model. Three scenarios were explored using the model for answering the questions: 1) no trading, 2) Annex 1 trading plus CDM, and 3) full global trading. These three options are representative of alternative implementations of the Kyoto Protocol, with the last as an upper bound on the CDM's potential to reduce GDP losses.

In the no trading case, the value of emission rights in the United States in 2010 would approach $240 per ton. With Annex 1 trading plus CDM, the value would drop to slightly less than $100 per ton. As might be expected, the value of emission rights would be lowest with full global trading. Here, it would fall below $70 per ton. In terms of the GDP losses, details were calculated for the US. The highest losses would occur in the absence of trade, exceeding $80 billion dollars in 2010, accounting for about one percent of US GDP. To the extent that trade is introduced, losses would decline. In the most optimistic scenario (full global trade), losses were estimated to be approximately $20 billion or one-quarter of one percent of GDP in 2010.

Assuming full global participation in an international market for carbon emission rights, the impacts of limits on emission rights one country could buy were analysed. The losses in 2010 would be two and half to three times higher with the constraint on the purchase of carbon emission rights. As no specific obligations are imposed on countries outside Annex 1, there is the possibility of "leakage". The overall results indicate that permit trading does not seem to lead to a dramatic increase in carbon emissions outside Annex 1, suggesting that an international leakage problem could be manageable.

With respect to the long-term stabilisation objective, there are different pathways for stabilising concentrations at 550ppmv (twice pre-industrial levels) by 2100, including 1) "Kyoto followed by arbitrary reductions"; 2) "Kyoto followed by least-cost"; and, 3) "least-cost". Following a least-cost strategy suggests that a gradual transition to a less carbon-intensive economy is preferable to one involving sharper near-term reductions. With the least-cost paths, the value would be relatively low in the early years ($11 per ton of carbon in 2010), and it would rise gradually over time. With "Kyoto followed by least-cost", the value was calculated at $130 per ton in 2010 and then would track the least-cost path thereafter. In the case labelled "Kyoto followed by arbitrary reductions", the incremental value of emission rights would start at about $160 per ton and it would remain high. In terms of the economic impact on the global economy, "Kyoto followed by arbitrary reductions" would be the most expensive of the three paths. "Kyoto followed by least-cost" could be a considerable improvement, but would still be 40% more expensive than embarking on the most cost-effective mitigation pathway from the outset.

The results appear rather indicative of the policy directions, but there are several concerns over the results presented by Richels. As commented by ZhongXiang Zhang, emphasis on global cost-effectiveness tends to underplay distributional issues. The authors also acknowledge the critics that MERGE tends to overestimate the costs of mitigation because of the assumptions used in the model. In addition, issues regarding the power of the market, short-term macro shocks and effectiveness of domestic policies may need further investigation before a firm conclusion can be drawn on the practically achievable benefit from emissions trading.

The above issues are partly explored in the paper submitted by Ruqiu Ye of China and the comments on that paper by ZhongXiang Zhang. Although the paper was not presented due to travel problems by Ye, it is included in the proceedings.

Climate Policies Beyond Kyoto?

Panel discussants presented their views on climate policies beyond Kyoto. Yvo de Boer from the Netherlands Ministry of Environment suggested that the targets for the second budget period be differentiated in accordance with income level, types of commitments and time of commitments. It is also noted that the divergence of the targets in the early period should be converged at later stages. The modelling exercises have touched upon many important issues regarding economic impacts from policies and measures from Annex B countries, but further efforts would be required to examine more explicitly the impacts on non-annex B countries and on the impact of 1st commitment period on the 2nd budget period. In particular, de Boer points out that much of the modelling work has been undertaken for and in developed countries and therefore more work should be planned and carried out for and in developing countries.

Bill Hare from Green Peace stressed that concentration limits are inadequate to drive policies designed to avoid dangerous climate change for the 2nd budget period, because of economic, environmental and policy uncertainties. Due to the constraints faced by developing countries, they as a group are more vulnerable and at risk. With the materials from recent literature, Hare considers that there exists an urgency to take policy measures to mitigate climate change. If emissions are too high then achievement of climate objectives much below 500 ppmv CO_2 could become extremely difficult. A number of suggestions were offered: (1) economic decision making under uncertainty frameworks needs to be developed further and main-streamed in the IPCC assessment; (2) "short" term climate policies (e.g. next 10-15 years) need to preserve capacity for future policy makers to meet strong climate policy goals and (3) analysis needs to be oriented at achieving both long and short term goals simultaneously. Jonathan Pershing from the International Energy Agency points out that there are limitations using the modelling approaches. New technologies are developed and brought into use and the behaviour of the consumers will become more climate friendly. Carbon has been valued in many current investment decisions. In designing future agreements, many factors should be taken into account, including participation, timing, development and environment, legislative issues, and coverage of GHGs. It is also necessary to consider the interaction between the short and long term targets.

Mohammad Al Sabban and Priyadarsi Shukla participated in the panel discussion from a developing country perspective. Al Sabban believes that oil producing, especially OPEC, countries are likely to suffer from any policy measures for meeting the Kyoto commitments by Annex B countries. As indicated in many of the studies, oil price is likely to be lowered due to adoption of mitigation policies. He suggested that the tax system on energy should be reconsidered. Oil in the EU is heavily taxed while on the other hand subsidies to fossil fuels especially coal prevail in many countries. The oil exporters should be partly compensated with the reform of the current tax system. Also the issue of carbon sequestration should be further examined. Shukla made three sets of comments. The first one states that any post-Kyoto agreement should take into account the principles of equity and sustainability. Regarding the policy alternatives, Shukla indicated that they should consider the different needs, different stages of development and the specific circumstances of developing countries. In the modelling exercise, other considerations including environmental and equity in addition to economic goals should be incorporated. Any policies for the post Kyoto period are likely to result in gainers and losers and the third set of comments from Shukla are concerned with distributional problems. We should not only consider how to compensate but also consider how to distribute compensation.

Key Conclusions and Points for Further Research

At the meeting a questionnaire was distributed asking for information on the major points and issues from this expert meeting. Hans Timmer on behalf of the organising committee summarised a few key points from the meeting and for the follow-up work.

- *Methodologies:* modelling approaches are very useful tools to analyse the possible outcomes from different policy choices under a given set of conditions. However, there is a lack of communication between the modellers and policy makers. The component of “development” is not explicitly included in the models. Therefore, there is a need to integrate the economic development component into the climate change simulations. In addition, non CO_2 GHGs and non energy CO_2 need to be included in the modelling exercises while acknowledging the weak knowledge base regarding the costs of sink enhancement and of controlling of the relevant trace gases. The models should be improved to take into account sequestration technologies, burden sharing and equity

- *Costs of mitigation:* International cooperation through trade in emission rights is likely to reduce mitigation costs. The magnitude of the savings will depend on several factors. These include the number of countries participating in the trading market, the shape of each country’s marginal abatement cost curve, the extent to which buyers can satisfy their obligation through the purchase of emission rights, and the impacts on the financial markets. However, model results should be interpreted carefully with essential understanding of the assumptions and conditions.

- *Economic impact on developing countries*: The results of modelling analyses show a mixed picture with respect to the impact on GHG-mitigation in Annex-I countries on developing countries. Vulnerable countries include oil exporting countries. Impacts through changes in capital flows and instabilities of exchange rates can be significant.

- *Emissions trading:* Theoretically, global intertemporal trading is economically the most efficient solution to limit GHG emissions and eventually stabilise GHG concentrations. Partial steps in that direction may introduce undesirable distortions. However, because of current realities, the discussions concluded that a rapid introduction of a global market for emissions rights is probably more dangerous than a first incomplete move towards that ultimate goal.

- *Carbon leakage:* Mitigation of GHG emissions in Annex-B countries will probably lead to increased emissions in other countries. The extend to which this may happen, according to the economic models used in the presentations, is very uncertain and depends on issues such as the baseline scenario used, the level of integration of non-Annex-B countries in the world economy, and the price elasticity of energy supply.

- *Clean development mechanism (CDM):* As an important flexibility mechanism, it may have the potential for cost-effective compliance with the Kyoto targets. However, the realisation of such potential will have to depend on a well designed and functioning institutional framework and political feasibility. A point of concern is that CDM, being not a general but a projects related mechanism, leads to unequal marginal abatement costs within developing economies. This would introduce economic inefficiencies. Issues like the business-as-usual baseline, leakage and the role of transnational companies will have to be addressed to make the mechanism work effectively.

- *Baseline issues:* For modelling exercises, usually a reference scenario or baseline has to be assumed. Such a baseline depends on assumptions with respect to issues such as globalisation trends, the international division of labour and the relative growth rates of emerging economies. It has large implications for model results. The baseline is not only an assumption in the models, but also a key issue for negotiators to be agreed upon, e.g. for the implementation criteria of the Kyoto mechanisms or other possible future agreements. Some factors such as international leakage, institutional aspects, and change of behaviour are important for the understanding of the baselines, especially for the long-term baselines.

- *Future agreements:* The time path for GHG stabilisation has important policy implications. Both intra- and inter-generational burden sharing should be taken into account. Point of departure is that GHG concentrations have to be stabilised according to the UNFCCC. And in order to stabilise GHG concentrations, all countries would eventually have to be part of a future agreement. Equity considerations should primarily focus on the entry time, but more on the permit allocation as permits are actually a tradable asset or good in the international market. From an analytical and political point of view, a rigid distinction between the Kyoto Protocol and future agreements is unsatisfactory.

- *Treatment of ancillary benefits:* Ancillary benefits may take a large share of the total benefit resulting from mitigation policies, but inadequate treatment has been given to this in the modelling exercises

Part II

Issues of the Economic Consequences of Kyoto

Opening Address

Annemarie Jorritsma, Minister of Economic Affairs

Ladies and Gentlemen,

I am pleased and honoured to have the privilege to open this Expert Meeting of the Intergovernmental Panel on Climate Change. Climate change is an area where the policy areas of environment, energy and economics are closely intertwined. As Minister of Economic Affairs - responsible for both energy and economic policy - I am therefore intensively involved in climate change policy.

This type of meeting allows for an open discussion on a very important matter. Unfortunately, as climate policy is now a highly political issue, such open discussions are quite rare. Being an economics Minister, I know that anything that is rare is highly valued. I was therefore more than willing to invest both time and money in the organisation of this meeting. I am sure that for the Environment Minister Mr. Pronk, it was this high rate of return to investment that did the trick.

However, others have contributed much more than Mr. Pronk and I have done. For instance:
The Stanford Energy Modeling Forum, which already commenced last night and will continue until Saturday morning; the Technical Support Unit of Working Group III of the IPCC, which also participates in the organising committee and the Netherlands Bureau for Economic Policy Analysis, which, as Chair of the organising committee, has successfully prepared the ground for this important meeting. Many people from all these organisations have worked hard to ensure the success of this meeting.

The participation of speakers and discussants from a broad range of countries is essential for this type of meeting. I am therefore very pleased to see so many guests from across the globe, and I wish to thank you all for coming. Your contribution to the debate will be the central product of these two days.

The purpose of this meeting is to design proposals for future research and inputs for the Third Assessment Report on Climate Change, to be published by the IPCC in the near future. The focus was placed on both the first budget period of the Kyoto Protocol - called the short run, as it refers to the years up to 2012 - and the architecture of future agreements – referred to as the long run. I firmly believe that the longer-term perspective is of the utmost importance for our views on the short run. Therefore, I express my hope that today again, the long-run focus is taken as a starting point in the discussions.

Regarding the relationship between the long run and the short run - or preferably, a not so long run - I wish to make two comments:

In my opinion, the flexible instruments are as important to the success of the Kyoto Protocol as the quantitative commitments. They are the two pillars on which the Protocol rests. By agreeing to the quantitative commitments, the Annex I parties have acknowledged their historical responsibilities for the current concentration of greenhouse gases in the atmosphere. By agreeing to the flexible instruments, the non-Annex I parties have shown that they, too, are serious about the global nature of the problem. I believe that we should focus on compliance with the quantitative commitments and on actively implementing the flexible instruments, both within Annex I and globally. This is just as important for the long run as is a serious discussion about future quantitative commitments for non-Annex I countries. I sincerely hope that the discussions today and tomorrow will provide new insights on these matters. Looking at the program, the speakers and the discussants, I have no doubt that the meeting will be of a high standard.

A second point that I believe to be very important is enforcement of the protocol. As we all know, it is difficult to ensure compliance with an international treaty, even after the parties have ratified it. We need an effective compliance regime for the Kyoto protocol, with clear-cut sanctions for cases of non-compliance. I honestly do not believe that the protocol can be used to tackle climate change effectively in the long run if this precondition is not met. It simply lacks credibility. I know that for scientists, the compliance issue is a difficult topic to deal with. However, I wish to point out that many analyses start with the implicit assumption that compliance is guaranteed. I would like to suggest that compliance matters be an explicit part of the research agenda resulting from this meeting.

Ladies and Gentlemen,
I think this meeting will be most interesting and very useful for all those concerned with the international issues of climate change policy. I hope that the discussions will lead to a robust research agenda on the future of climate change policy. I for one will be looking forward to learning the results. For the present, I wish you much inspiration for the discussions.

Thank you.

Effects of Restrictions on International Permit Trading: The MS-MRT Model[1]

Paul M. Bernstein, W. David Montgomery, Thomas F. Rutherford, Gui-Fang Yang

Abstract

A number of proposals to restrict international emissions trading have emerged in negotiations dealing with implementation of the Kyoto Protocol. This paper uses a Computable General Equilibrium (CGE) model of international trade developed by the authors to analyze some of these proposals. The proposed restrictions include limits on the share of a country's obligation to reduce emissions it may satisfy through purchases of permits, restrictions on the ability of the Soviet Union to sell permits in excess of those needed to cover its baseline emissions, other restrictions on permit sales, potential exercise of monopoly power by sellers of permits, and restriction of permit trading with developing countries to permits generated through the Clean Development Mechanism (CDM). Unrestricted trade among Annex I countries can reduce costs present in the case of no permit trading by about 50 percent, and would remove some of the trade distortions created by the asymmetric obligations of Annex I and non-Annex I countries. Unrestricted global trading is necessary to eliminate trade distortions fully and would produce another 50 percent cost reduction.

Restrictions on Annex I countries' purchases and sales of emissions permits could eliminate half or more of the possible gains from emissions trading. Although Russia could exercise monopoly power by restricting sales and raising permit prices, proposed limits on sales would result in even greater output restraint and raise prices still higher. Banning sales of excess permits by Russia would make all countries, including Russia, worse off because that limit greatly exceeds the level of sales restrictions that a monopolist would choose. At the same time, the restriction would economically harm all purchasers. Limiting emissions purchases affects regions differently but depresses welfare globally. If permit purchases were limited to 50 percent of a country's emissions reduction obligation, the U.S. might even benefit under Annex I trading at the expense of Japan and Europe, who purchase proportionately more permits than the U.S. Purchase restrictions would be particularly damaging to the U.S., however, if trading were extended to developing countries because, under unrestricted global trading, the U.S. would want to satisfy 70 percent or more of its obligation through purchases of emissions permits. Finally, the CDM would fail to reduce much of the costs or competitive distortions that exist under unrestricted Annex I trading because the CDM would not correct the disparity in energy prices applying to all industries and activities not included in CDM projects.

[1] The authors are grateful for comments and suggestions from the participants in the EMF 16 workshops in Washington, DC, and at Stanford University and Snowmass during 1998, as well as to Edward Balistreri of CRA for his contributions to developing both consistent measures of welfare and an approach to treatment of international trade issues. We gratefully acknowledge financial support from the Business Roundtable, the Electric Power Research Institute, and the American Petroleum Institute. All statements and findings are the sole responsibility of the authors.

Overview

The Kyoto Protocol, signed in December 1997 but not yet ratified by a number of countries including the United States, defined the next steps to be taken to reduce global greenhouse gas emissions. It also left unsolved a wide range of questions about the future course of climate change policy. The Protocol calls for the majority of industrialized countries to limit their emissions of greenhouse gases by the first decade of the next century, and includes several "flexibility mechanisms" that could significantly reduce costs for some countries. Developing countries undertook no commitments to limit their emissions, and insisted that proposed procedures under which such commitments could be made be deleted from the Protocol. Flexibility mechanisms included coverage of six greenhouse gases, provisions for international emissions trading, credits for reforestation and other actions that remove greenhouse gases from the atmosphere ("sinks"), and a "Clean Development Mechanism" under which industrial countries could finance and gain credit for emissions reductions in developing countries. Virtually all of the details concerning the flexibility mechanisms were left open for further negotiation. These include such issues as the role of developing countries in the overall emissions reduction effort, and the scope and design of an international emissions trading system.

In the aftermath of the Kyoto negotiations, countries have argued extensively over the equitable structuring of an international permit trading protocol. Unrestricted, comprehensive, and properly designed, an international emissions trading system would significantly reduce the global costs of limiting greenhouse gas emissions. Nevertheless, parties to the ongoing negotiations have taken mutually incompatible positions on how emissions trading should be implemented. The United States has advocated unrestricted emissions trading, extended as rapidly as possible to include key non-Annex I countries. The European Union and a number of developing countries have proposed tight restrictions on emissions trading, and oppose any efforts to include non-Annex I countries. Russia has made it clear that its participation in the Kyoto Protocol is contingent on its unrestricted ability to sell permits to other Annex I countries. Furthermore, all sides debate the meaning of language in the Protocol that emissions trading must be "supplementary" to domestic abatement efforts.

Restrictions on emissions trading could eradicate most of such a system's potential benefits. Curtailing Russia's ability to sell permits or, conversely, efforts by Russia to restrict sales in order to raise prices could have a major negative impact. Imposing a ceiling on purchases by the U.S. or other countries to enforce a restrictive notion of "supplementarity" would probably have a similar effect. Ultimately, such restrictions would lead to higher permit prices in the United States, lower purchases of permits on international markets, and losses in GDP and exports that would approximate levels to be expected in a no-trade regime.

Currently, the outcome of the Kyoto Protocol remains highly uncertain; thus, the final form of emissions trading is unclear. Because of the great uncertainties involved, this paper analyzes three possible emissions trading regimes under a number of different trading restrictions. To assess the possible impacts on world regions from this diverse set of possible outcomes, we employed our Multi-Sector, Multi-Region Trade (MS-MRT) model. Since this model is a fully dynamic, general equilibrium model of trade, it accounts well for the interactions among industries and regions that result from international policies.

In the next section, we describe the MS-MRT model, providing an overview of the model structure and key elements. We then report the results from three basic emissions trading regimes that we denote as our core scenarios: no trading among regions in emissions permits, unrestricted trading among Annex I countries, and unrestricted trading among all regions. After presenting results from these scenarios, the paper analyzes a number of different restricted trading scenarios. First, it describes the modeling methodology for these scenarios, then presents results and discusses how restrictions on trading affect the level and distribution of costs of compliance with the Kyoto Protocol.

Description of the MS-MRT Model

The Multi-Sector Multi-Region Trade (MS-MRT) Model is a dynamic, multi-region general equilibrium model that is designed to study the effects of carbon restrictions on trade and economic welfare in different regions of the world. The model includes a disaggregated representation of industries, based on the GTAP4 dataset, so that differences in energy intensities across countries and differences in the composition of industry can be taken into account. It can represent a wide variety of international emissions trading regimes, define trading blocs composed of any grouping of regions, and place any set of constraints on both purchases and sales of emissions permits. The model computes changes in welfare (calculated as the infinite horizon equivalent variation), national income and its components, terms of trade, output, imports and exports by commodity, carbon emissions, and capital flows. It is fully dynamic, with saving and investment decisions based on full intertemporal optimization.

Conceptually, the MS-MRT model computes a global equilibrium in which supply and demand are equated simultaneously in all markets. The model assumes full employment and there is no money. There is a representative agent in each region, and goods are indexed by region and time. The budget constraint in the model implies that there can be no change in any region's net foreign indebtedness over the time horizon of the model. Even though there is no money in the model, changes in the prices of internationally traded goods produce changes in the real terms of trade between regions. All markets clear simultaneously, so that agents correctly anticipate all future changes in terms of trade and take them into account in saving and investment decisions. The MS-MRT model is calibrated to the benchmark year 1995, and solves in five-year intervals spanning the horizon from 2000 to 2030.

In order to capture some of the short-run costs of adjustment, elasticities of substitution between different fuels and between energy and other goods vary with time. The model is benchmarked to assumed baseline rates of economic growth and a common rate of return on capital in all countries. The rate of growth in the effective labor force (population growth plus factor-augmenting technical progress) and the consumption discount rate are computed to be consistent both with the assumed rates of growth and return on capital, and with zero capital flows between regions on the balanced growth path.

In the form used for the EMF study, the MS-MRT model divides the world into ten geopolitical regions (see Table 1).

Six industries are represented in the MS-MRT model structure:
- Four energy forms: oil, coal, natural gas, and electricity; and
- Two non-energy goods: Energy-Intensive Sectors (EIS), and All Other Goods (AOG).

The MS-MRT model uses an Armington structure in its representation of international trade in all goods except crude oil, and places no constraints on capital flows. Crude oil is treated as a homogeneous good perfectly substitutable across regions. For all other goods, we assume that

Table 1 Regions in the MS-MRT Model

		Member of	
Code	Region	OECD	Annex I
USA	United States	Yes	Yes
JPN	Japan	Yes	Yes
EUR	Europe Union of 15	Yes	Yes
OOE	Other OECD	Yes	Yes
FSU	Eastern Europe and Former Soviet Union	No	Yes
CHI	China and India	No	No
SEA	Korea, Singapore, Taiwan, Thailand, and Malaysia	No	No
OAS	Other Asia	No	No
MPC	Mexico and OPEC	No	No
ROW	Rest of world	No	No

domestically produced goods and imports from every other region are also differentiated products. Domestic goods and imports are combined into Armington aggregates, which then function as inputs into production or consumption.

The model includes the markets for the three fossil fuels. Electricity is produced using these fuels, capital, labor, and materials as inputs. Crude oil trades internationally under a single world price. Natural gas and coal are represented as Armington goods, to approximate the effects of infrastructure requirements and high transportation costs between some regions. Depletion is assumed to lead to rising fossil fuel prices under constant demand, but the relation between depletion effects on the supply of oil, gas, and coal and the actual supply of these fuels is ignored. That is, the model does not keep a record of the current stock of each fuel in each time period. World supply and demand determine the world price of fossil fuels. Current energy taxes and subsidies are included in each country's energy prices. The carbon-free backstop, represented as a carbon sequestration activity that requires inputs of non-energy goods, establishes an upper bound on world fossil fuel prices.

Non-Technical Discussion of the MS-MRT Model Structure

This section offers a non-technical discussion of the important elements of the MS-MRT model: production, household behavior/consumer choice, international trade, savings and investment, and carbon restrictions. It relies largely on diagrams to illustrate the nesting structures used in the utility and production functions and the definitions of markets.[2]

Production of the Non-Energy Goods

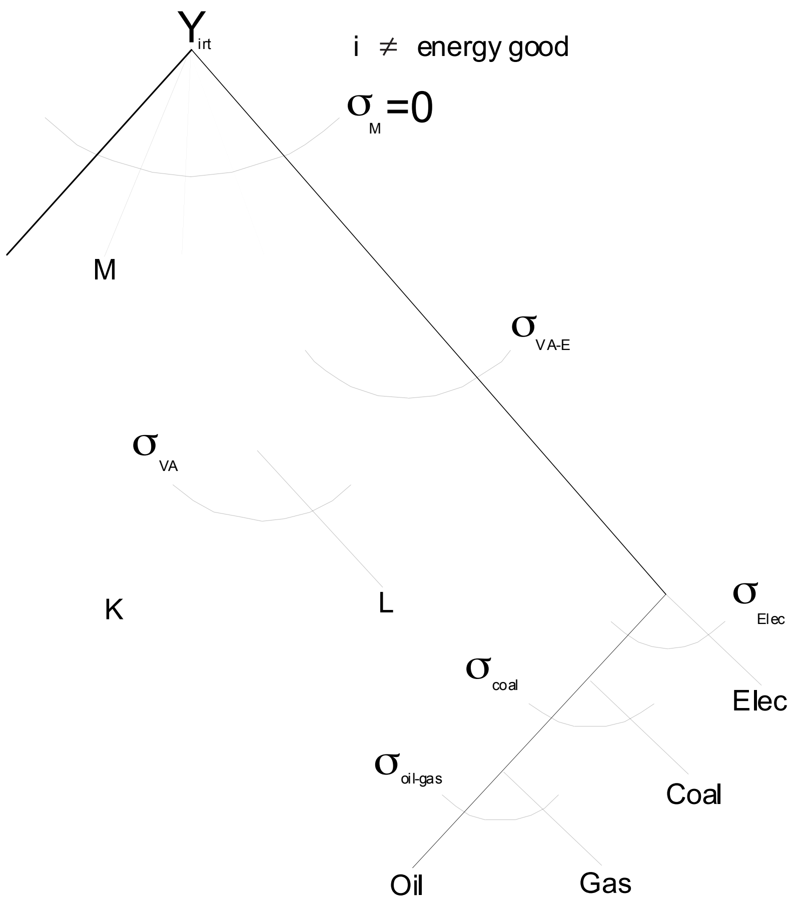
The MS-MRT model represents non-energy production in two sectors. In producing non-energy goods, the model accounts for regional differences in factor intensities, degrees of factor substitutability, and the price elasticities of output demand in order to trace back the structural change in industrial production that is induced by carbon abatement policies.

[2] For a mathematical description of the model, see Bernstein, Rutherford, and Montgomery, "Trade Impacts of Climate Policy: The MS-MRT Model," in review, *Energy and Resource Economics*, 1998.

All non-energy industries have a similar production structure (see Figure 1). Materials (outputs of the two industries used as inputs in other industries) enter the production function in fixed proportion with a value-added aggregate and an energy aggregate. The value-added aggregate comprises capital and labor. When the energy value share of an industry is small, the elasticity of substitution between the value-added aggregate and the composite energy good is equal to the own-price elasticity of demand for energy. This elasticity determines how difficult or easy it is for a region to adjust its production processes in response to changes in energy prices. Higher values of the energy substitution elasticity imply that a region can more easily substitute value-added for energy as the price of energy increases. This elasticity is time varying to reflect capital stock turnover and the ease of deploying new technology. For OECD countries, this elasticity begins at a value of 0.35 in the year 2000 and rises linearly to 0.6 by 2030; in non-OECD countries, it starts at 0.3 and rises linearly to 0.5 over the 30-year time horizon.

Capital and labor are nested as Cobb-Douglas. They may be substituted directly for each other through activities such as the automation of labor-intensive tasks. Therefore, the higher the wage rate, the more attractive it becomes to adopt automation. Labor inputs in this model are measured in efficiency units, so that one unit of labor supply is the same as ten billion dollars of base-year wages.

Figure 1 Production Structure for AOG, EIS, and Electricity



Labor supply is inelastic. Growth rates in the labor force are exogenously specified, so that the effective labor endowment for each region increases over time with labor force efficiency and population growth along the region's baseline growth assumptions. Labor is regionally immobile, and the labor force is fully employed at all times.

Capital stocks evolve through geometric depreciation of existing capital stocks and new investment of sector-specific capital (within countries). The rates of return on capital are determined in an international market by endogenous levels of lending and borrowing. We assume perfectly competitive capital markets in which the rate of return adjusts so that supply equals demand. The model is calibrated to an equalized net rate of return equal to 5 percent in all regions.

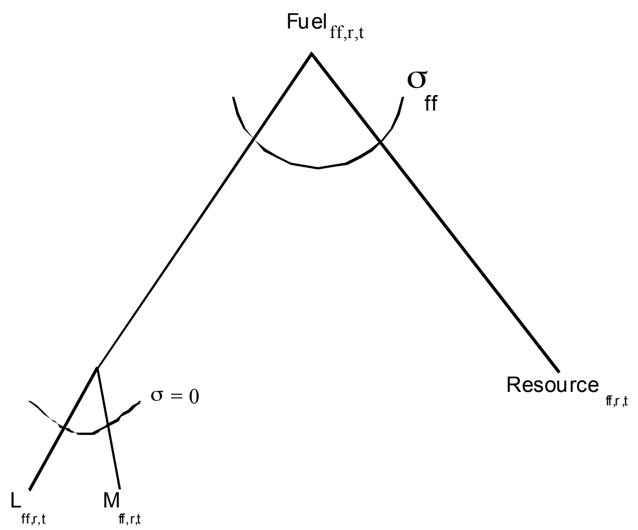
Armington composites enter the material nest, so that intermediate inputs from domestic industry j are imperfect substitutes for imports of good j. Material inputs are complements among each other; all other inputs are substitutes.

Production of Fossil Fuels

The production of fossil fuels requires inputs of the aggregate non-energy good and a fuel-specific factor of production that can be thought of as a sector-specific resource. In solving for the baseline, this resource is used to match the level of fossil fuel production to the U.S. Department of Energy's projections for fossil fuel production (EIA, *International Energy, Outlook 1998*) through 2020 and to the IPCC IS92a scenario from 2020 to 2030. This matching is achieved by requiring that this resource be used in fixed proportions ($\sigma_{ff} = 0$) with the aggregate good (see Figure 2). Then, defining the level of available fixed resource for each fuel determines the level of each region's oil, gas, and coal production. After we solve the baseline scenario, we solve the fossil fuel production equations for the non-zero value of σ_{ff} required to arrive at the same fuel prices and fuel production levels. This value for the fuel supply elasticity is used when we solve the model under the carbon abatement scenario. Therefore, the level of production is allowed to vary in the scenario solve.

The value of the elasticity of substitution between inputs $L_{,r,t}$ and $M_{,r,t}$ and the $\text{Resource}_{ff,r,t}$ determines the price elasticity of supply at the reference point.

Figure 2 Energy Production Structure for Fossil Fuels – Oil, Natural Gas, and Coal



Household Behavior, Consumer Choice, and the Representative Agent

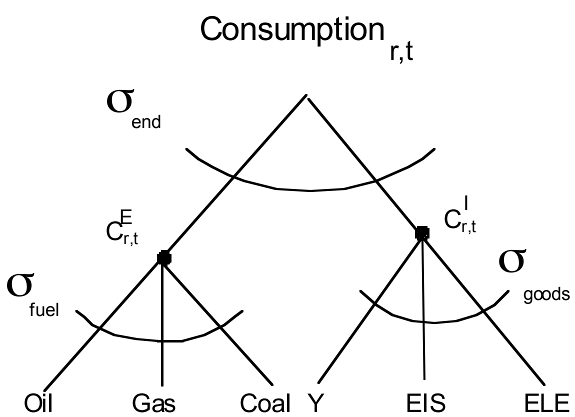
For each region, there is one infinitely-lived "representative" agent who chooses to allocate its region's entire lifetime income across consumption in different time periods in order to maximize welfare. In each period, the consumer faces the choice between current consumption and future consumption that is purchased via savings. The pure rate of time preference between current and future consumption determines the intertemporal allocation of consumption. In equilibrium, the agent is indifferent between consuming one unit of consumption today or consuming the value of one unit of consumption that is adjusted for time preference tomorrow. We employ an intertemporal separable utility function where the intra-period utility from consumption is based on a nested CES function over imported and domestic commodities. The representative agent maximizes utility subject to an intertemporal budget constraint.

The budget constraint equates the present value of consumption demand to the present value of wage income, the value of the initial capital stock, and the present value of rents on fossil energy production, less the value of post-terminal capital. In this formulation savings are determined implicitly so as to equalize the marginal utility of a unit of investment and current consumption. Savings are used for future consumption.

Current consumption is a CES aggregate of energy and non-energy goods (see Figure 3). Consumers substitute between the end-use energy aggregate and the industry good aggregate with an elasticity of substitution $\sigma_{end.}$ This elasticity varies over time to reflect capital stock turnover and the ease of deploying new technology. For OECD countries, this elasticity starts at a value of 0.35 in the year 2000 and rises linearly to 0.6 in 2030; for non-OECD countries, it has an initial value of 0.3 and rises linearly to 0.5 over the 30-year time horizon. This elasticity approximately equals the own-price elasticity of demand for energy because energy represents only a small fraction of total consumption.

Aggregate end-use energy is composed of the fossil fuel aggregate. The aggregate comprises oil, gas, and coal; these fuels substitute against each other with an interfuel elasticity of substitution equal to σ_{fuel}. Electricity is nested together with the non-energy goods. Each non-energy good in the fuel nest is an Armington composite, in which domestic and imported goods are combined in the manner described below. Purchase of the good is financed from the value of the household's endowments of labor, capital, energy-specific resources, and revenue from any carbon permit sales.

Figure 3 Consumption Nest



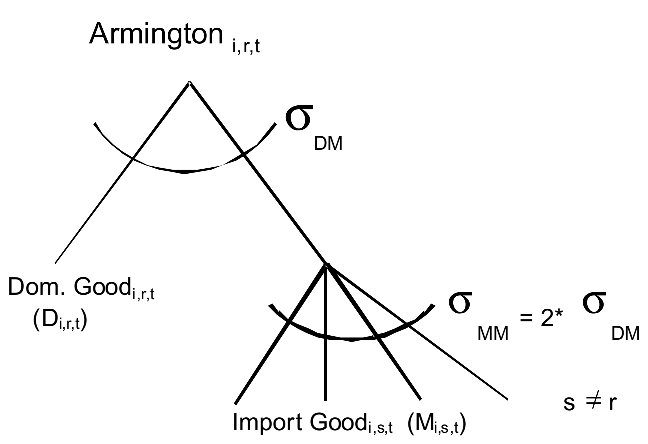
International Trade
Trade takes place in the fossil fuels and in the composite non-energy goods. All bilateral trade flows for the non-energy goods are represented in the MS-MRT model.

$$\sum_r X_{rt}^j = \sum_r M_{rt}^j \quad \forall\, t, j \in \{\text{energy goods, non-energy goods}\}$$

On the import side, consumers and industries choose between these domestically produced goods and imports. Demands for imports stem from cost-minimizing producer behavior and utility-maximizing household behavior. For the non-energy goods, an Armington trade structure is used so that the model differentiates between domestic and foreign goods. Therefore, domestically produced goods and imports are imperfect substitutes. Small cost differences across regions for a good do not lead to a total shift in demand from one region to another, and small changes in costs lead to small movements away from existing trade patterns. In addition, the Armington structure accommodates both imports and exports of the same commodity across regions (cross-hauling).
To create the Armington aggregate, imports of each non-energy good from each region substitute against each other with an elasticity of substitution equal to the Armington elasticity, σ_{MM}, and the aggregate import good substitutes against the comparable domestic good with an elasticity of substitution (σ_{DM}) equal to half of σ_{MM}. The Armington elasticity σ_{DM} is set at 4 for this model with two non-energy goods because those composite goods are not likely to be identical across countries. This elasticity measures how easily imports can substitute for domestically produced goods. The Armington elasticity affects the potential gains in non-Annex I export sales that will occur when lower energy costs give these non-participating countries a competitive advantage. Figure 4 displays this structure. $A_{i,r,t}$ represents either consumer or industry demand for the non-energy good i in region r in time period t. Industries and consumers consume an Armington aggregate of domestically produced goods ($D_{i,r,t}$) and goods imported ($M_{i,s,t}$) from regions s ≠ r.

The models incorporate international markets for all goods. For these goods, we have a global market-clearing condition for the MS-MRT model:

Figure 4 Armington Nest Trade Structure for Consumption and Production



The model is closed with respect to international trade through the intertemporal budget constraint. The intertemporal budget constraint for the representative agent in each region requires that the net present value of international borrowing or lending remain equal to the baseline level over the model's time horizon. This implies that any change in capital flows must net to zero (in present

value terms) over the time horizon. Since the current account surplus or deficit (equal to the value of net exports) equals net international lending or borrowing, this also implies that the net present value of the change in the current account must be zero over the time horizon. The imposition of an intertemporally balanced trade account is linked to an implicit exchange rate that reconciles the present value of each region's domestic import demands with the present value of its exports.

This budget constraint allows changes in capital flows to play a part in determining the trade impacts of carbon limits. In contrast, the EPPA model assumes a period-by-period balance-of-payments constraint so that the current account deficit or surplus must equal baseline levels in each year. The G-Cubed model imposes a constraint on capital flows, so that a region's net foreign indebtedness can change over the model time horizon. G- Cubed accounts for the effects of changes in indebtedness by calculating GNP, in which interest payments on foreign debt are deducted from domestic output (GDP).

Savings and Investment (Dynamics)
MS-MRT is a fully dynamic general equilibrium trade model. The model structure incorporates forward-looking investment and savings behavior, so that businesses, individuals, and governments anticipate the effects of announced policies that are to take effect in the future. The level of savings and investment in a given period is endogenously determined by entrepreneurs and households that maximize the firm's value and the representative agent's lifetime consumption. Entrepreneurs choose investment levels to maximize the net present value of profits, and savings behavior is determined by intertemporal utility maximization. Therefore, investment dollars are placed in the area where they will receive the highest return. Physical capital stocks depreciate at a constant geometric rate, and they are incremented by investment from domestic output. The finite horizon poses some problems with respect to capital accumulation. In the absence of any terminal adjustment, agents would consume all capital stock in the terminal period and thus let the value of the capital stock decline to zero after 2030. This would have significant repercussions for rates of investment in the periods leading up to the end of the model horizon. To correct for these effects, we apply an auxiliary equation dealing with the terminal capital stock.

It should be emphasized that we apply this side constraint along with the other economic equilibrium conditions (zero profit, market clearance, and income balance), but the application of this constraint has no implications for investment and consumption activities because these impacts do not enter into the zero-profit conditions for these activities. Instead, we close the model by including a terminal capital stock variable, the quantity of which is determined so that the rate of growth of terminal investment is balanced. That is, the shadow price of the above auxiliary constraint is the price of the terminal capital stock.

Carbon Restrictions
To comply with the Kyoto Protocol, the model places a carbon emissions limit on the participating countries. The model endows these countries with emissions permits that allow them to emit carbon up to the level to which they agreed. In the MS-MRT model, it is assumed that, under the no-trade scenario, the emissions permits are tradable within each Annex I region but not across regions. Under the trading scenarios, emissions permits can be traded among the different blocs: for the Annex I trading scenario, only Annex I countries face carbon limits, and the permits are tradable

across all Annex I countries; for the global trading scenario, all countries face carbon limits, and the permits are tradable throughout the world.[3]

Benchmarking and Calibration[4]

This section describes how the MS-MRT model was benchmarked and calibrated. As is customary in applied general equilibrium analysis, the MS-MRT model is benchmarked to economic transactions in a particular year (1995). Benchmark data determine the parameters and coefficients (value shares) of the CES production, demand, and utility functions. Base-year finance statistics indicate the value of payments to capital across sectors and the gross value of capital formation. For calibration, we needed to determine a reference level of emissions growth, GDP growth, energy production, energy, and non-energy trade. This entailed assigning values to key elasticities, such as end-use demand, Armington, oil supply, and the Autonomous Energy Efficiency Improvement (AEEI).

To develop a consistent database for energy and non-energy trade and input-output data, we merged non-energy trade data, input-output data, and input-output coefficients for energy from the GTAP database with data from the International Energy Agency (IEA). (See Babiker and Rutherford [1996] for details.)

For carbon emissions forecasts, the model was calibrated to the projections of both DOE and the International Panel on Climate Change. The reference or business-as-usual (BAU) level growth path for world emissions is taken to be the IPCC's reference scenario IS92A. The IS92A scenario corresponds to the IPCC's baseline (medium growth) scenario, which calls for worldwide carbon dioxide emissions to grow from 6.0 billion tonnes in 1990 to 10 billion tonnes by the year 2020. The reference level emissions growth determines the amount of emissions reduction required to meet the carbon limits called for by any carbon abatement policy.

The energy production and consumption forecasts as well as regional emissions were obtained from the Department of Energy's *International Energy Outlook, 1998.* These forecasts were then calibrated to current EIA data and the IS92A scenario so that energy consumption was consistent with carbon emissions. The business-as-usual GDP growth rates were taken from MERGE (a Model for Evaluating the Regional and Global Effects of greenhouse gas reduction policies), which was developed by Alan Manne and Richard Richels.

Selecting Elasticity Values and Backstop Prices

Selecting elasticity values affects the dynamics of the model and how the model responds under a carbon abatement policy. The choice of values has no effect on the baseline level of energy production and consumption, which is benchmarked through choice of other free parameters so that the chosen baseline is replicated as a market equilibrium. There are several key elasticities that need to be chosen for an MS-MRT simulation, including the oil supply price elasticity, Armington elasticity, end-use demand elasticity, interfuel elasticity of substitution, and the cost of the carbon-free backstop technology.

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[3] In the MPS/GE framework in which MRT-MS is written, creating a market for carbon permits and imposing a cap on carbon emissions for each country is straightforward. See the web site, www.gams.com, for a description of the MPS/GE modeling language.

[4] For further technical details on how the MS-MRT is benchmarked, see Bernstein, Rutherford and Montgomery, 1998.

Table 2 Kyoto Protocol's Emissions Targets for Annex I Regions

Region	2010 Target (% Change from 1990)
U.S.	-7%
Japan	-6%
Canada	-6%
European Union of 15	-8%
Other OECD	+1.1%
EE/FSU	-2%

Core Scenarios

For a point of reference, the MS-MRT model was run under three different emissions trading scenarios: No trading, trading only among Annex I countries (Annex I trading), and full global trading (Global trading). These three trading regimes provide a basis for understanding the opportunity cost of restrictions on emissions, so we refer to them as the core scenarios. The first two scenarios are possible outcomes of the Kyoto Protocol, unlike the third, which is impossible given the Protocol's current wording. Under Annex I and global trading, no restrictions on sales or purchases of emissions permits were applied. Each Annex I region was assigned emissions limits for 2010 consistent with its obligation under the Protocol (see Table 2). Under the global trading scenario, non-Annex I countries assume an emissions target equal to their emissions under the no-trading scenario.

Results for Core Scenarios

In the core scenarios, the MS-MRT model consistently finds that emissions limits on industrial countries with no international emissions trading have negative impacts on the welfare of industrial and oil-producing countries, and both positive and negative welfare effects on energy-importing non-Annex I countries (see Table 3). Annex I trading improves the situation for all regions, except China and India, but only changes the sign for EE/FSU. All regions benefit under global trading as compared to no trading; only EE/FSU is worse off under global trading than under Annex I trading.

Table 3 Welfare under the Three Benchmark Trading Cases (Percentage Change from Baseline)

	Trading Scenarios		
Regions	No Trading	Annex I	Global
USA	-0.56%	-0.36%	-0.14%
JPN	-0.64	-0.23	-0.03
EUR	-0.45	-0.25	-0.05
OOE	-0.92	-0.76	-0.30
SEA	-0.18	-0.04	0.25
OAS	-0.10	-0.01	0.19
CHI	0.34	0.22	0.34
EE/FSU	-0.42	4.44	0.48
MPC	-1.39	-1.15	-0.36
ROW	-0.10	-0.08	0.03

Table 4 Carbon Permit Price under Three Benchmark Scenarios (1995 U.S. Dollars per Metric Ton)

Scenario	Region	2010	2020	2030
No Trading	USA	$275	$314	$356
	JPN	468	523	526
	EUR	209	309	430
	OOE	249	363	505
	EE/FSU	0	10	49
Annex I Trading	Annex I	90	151	225
Global Trading	World	31	36	32

Carbon permit prices differ across regions when international permit trading is not permitted (Table 4). Annex 1 trading lowers permit prices for all Annex 1 regions except the EE/FSU, which is the sole seller of permits. Global trading further lowers prices for Annex 1 regions, but raises permit and energy prices for non-Annex 1 regions.

Terms of trade generally move against developing countries and in favor of industrial countries when developing countries do not participate in international emissions trading. This is because industrial countries' costs increase, driving up the price of their exports, and their incomes and import demand fall, driving down the price of their imports. This is the reason for the negative welfare impacts on developing countries noted above. Some developing countries (e.g., China) can offset these terms-of-trade losses with industrial countries because of their gains in terms of trade with OPEC and ability to shift to production of energy-intensive goods where they have increased comparative advantage over the industrial countries (see Table 5).

When non-Annex I countries do not participate in emissions trading, the shift of energy-intensive industries, from baseline levels, out of Annex I countries into non-Annex I countries is significant.

Table 5 Terms of Trade under the Three Core Scenarios (Percentage Change from Baseline)

	No Trading	Annex I	Global	No Trading	Annex I	Global
Region	2010	2010	2010	2020	2020	2020
USA	0.04%	-0.14%	-0.08%	-0.03%	-0.14%	-0.10%
JPN	0.11	-0.05	-0.05	0.44	-0.01	-0.05
EUR	0.02	0.04	-0.05	0.07	0.07	-0.06
OOE	0.00	-0.08	-0.08	0.15	-0.09	-0.12
SEA	-0.27	-0.10	0.08	-0.29	-0.15	0.11
OAS	-0.14	0.04	0.09	-0.21	-0.02	0.09
CHI	-0.19	-0.04	0.44	-0.28	-0.14	0.57
EE/FSU	-0.44	1.71	0.27	-0.76	1.99	0.23
MPC	-0.60	-0.44	0.10	-0.89	-0.69	0.05
ROW	0.28	0.22	0.13	0.13	0.18	0.08

Table 6 Output from Energy-Intensive Industries in 2010 and 2020 (Percentage Change from Baseline)

	No Trading	Annex I	Global	No Trading	Annex I	Global
Region	2010	2010	2010	2020	2020	2020
USA	-7.87%	-2.43%	-0.59%	-7.66%	-3.62%	-0.51%
JPN	-1.06	0.10	0.18	-1.82	-0.15	0.15
EUR	-0.17	0.50	0.44	-1.56	0.33	0.45
OOE	-2.69	-0.32	0.35	-5.98	-1.04	0.50
SEA	4.69	2.01	0.07	4.21	2.55	-0.06
OAS	2.51	0.56	0.07	2.26	0.87	0.12
CHI	1.94	0.89	-0.57	2.01	1.32	-0.85
EE/FSU	5.87	-10.22	-2.98	6.42	-13.93	-2.78
MPC	4.67	2.51	-0.15	5.65	4.10	0.04
ROW	1.32	0.52	-0.04	1.53	0.89	0.03

Annex I emissions trading moderates the shift of industry by reducing production costs in most Annex I countries. Interestingly, the U.S. and EE/FSU, the lowest-cost providers of permits, suffer the greatest losses in their energy-intensive industries under Annex I trading. With global trading, production from non-Annex I energy-intensive industries declines from the levels it reaches under no trading and Annex I trading. For a subset of these countries and in certain time periods, some EIS production relocates to Annex I countries as reported by the negative percentage changes in Table 6. This occurs because the GTAP data show that many of the Non-OECD countries have the least energy-efficient industries and, therefore, are the most vulnerable to a uniform, global increase in energy costs (see Table 6).

Carbon leakage is also significant. It is connected with shifts in energy-intensive industries, reduced energy efficiency, and fuel substitution due to lower fuel prices in developing countries (see Table 7). Leakage is affected very little by Annex I trading, because it arises mostly from differences in energy prices between Annex 1 and non-Annex 1 countries. With Annex I trading, global emissions also increase because of hot air sales by EE/FSU, increasing apparent leakage to developing countries in percentage terms. Global trading, by definition, eliminates leakage because all regions face emissions caps.

Table 8 illustrates that there is a direct relationship between the spillover effects as measured by carbon leakage and the number of non-energy sectors included in the model. Dis-aggregating the non-energy sectors allows for more heterogeneity among these sectors and hence more and better

Table 7 Carbon Leakage under No Trading and Annex I Trading Regimes (Change in Non-Annex I Emissions Divided by Change in Annex I Emissions)

	2010	2015	2020	2025	2030
No Trading	18	19	20	21	21
Annex I Trading	16	18	19	21	22

Table 8 The Effect of Carbon Leakage under Different Aggregations (2010 for No Trading and Annex I Trading Regimes)

	Number of Non-Energy Sectors		
Scenario	1	2	4
No Trading	16.2	17.9	19.3
Annex I Trading	15.1	15.8	16.5

opportunities for countries to shift production between energy-intensive industries and industries that use little energy. As the number of non-energy sectors increases from one to two to four, the ratio in energy-intensity for the U.S. among the non-energy sectors increases from one to 3.4 to 6.8, respectively. Therefore, with more non-energy sectors, the Annex I countries have more incentive to decrease production in their most energy-intensive industries and import these goods from non-Annex I countries which now have a greater competitive advantage.

The results in Table 8 would be more dramatic if the Armington elasticities varied across the cases. In theory, the Armington elasticities should be smaller with fewer sectors since goods are more aggregated and hence poorer substitutes. As one moves to more sectors so that goods are closer substitutes, the Armington elasticity should increase. Increasing the Armington elasticity as one increases the number of non-energy sectors would magnify the difference among leakage rates from those in Table 8.

Measures of Welfare

There are a number of alternative measures of economic impacts that appear in different studies: change in consumers' surplus measured by the equivalent variation, the discounted present value of consumption (DPVC), GDP, and direct cost. In general, for an optimization model there is one theoretically consistent measure, which is based on the value of the objective function maximized in the model. In our model, this measure is the intertemporal equivalent variation.[5] If we had implemented this model with an infinite horizon (difficult computationally), changes in welfare could be taken directly from the value of the intertemporal utility function. Since we terminate the model in 2030, we must add to the utility experienced during the period an adjustment that represents the change in the value of the terminal capital stock that is left for future generations. This adjustment makes our calculation of the infinite horizon welfare approximate, because to value the terminal capital stock we need to employ some assumptions about how close the temporary equilibrium in 2030 is to one on a balanced growth path.

The same issue about terminal capital stock applies to calculating the discounted present value of consumption as a welfare measure. These considerations about the terminal capital stock are

[5] For a discussion of how this welfare measure is computed in the MRT-MS, see Thomas F. Rutherford, "Constant Elasticity of Substitution Functions: Some Hints and Useful Formulae," Notes prepared for GAMS General Equilibrium Workshop, held December 1995, in Boulder, Colorado; available from http://www.gams.com/solvers/mpsge/cesfun.htm. For a general discussion of this welfare measure, see Hal Varian, Microeconomic Analysis, Third Edition, New York, 1992, pp. 160-171.

important, because emissions limits produce large drops in investment (as high as 2.5 percent under no trading in the U.S.), which imply very different capital stocks in 2030 in the baseline and the policy cases. Agents buffer consumption during the shock period by reducing investment, and the effects of this reduced investment on their future welfare need to be taken into account.

GDP, the other common measure, has classic index number problems, that in our model appear in sensitivity of the results to choice of numeraire. GDP includes both consumption and investment, so that over short periods of time GDP may increase due to a stimulus to investment even though consumption falls. In addition, GDP is a measure of gross, not net, income, in the sense that it does not account for depreciation of capital. When policies lead to large reductions in investment for a sustained period of time, they lead to lower levels of capital stock and to reduced capital consumption allowances (CCA). As a result, GDP falls because of both contemporaneous reductions in investment and lower CCA. This effectively double-counts the reduction in investment and produces a larger percentage reduction in GDP than in net national income. GDP also fails to account for net interest payments on foreign debt, so that if a policy causes a significant change in foreign debt, GDP will inaccurately measure the change in real income for residents of a country.[6]

Finally, it is possible to produce an approximate measure of the direct cost of a policy by estimating the area under the curve for the marginal cost of carbon abatement. This measure equals one-half the carbon tax times the reduction in emissions plus the net receipts or payments for international permits. Some models (e.g., the SGM) use this measure.[7]

The values of these different measures are provided in Table 9. GDP and "direct cost" are all annual measures, while EV and discounted present value of consumption are present value measures. Thus, we present GDP and "direct cost" for different years (2010 and 2020) and welfare and DPVC as a single number. For welfare, DPVC, and GDP, the numbers report the percentage change from baseline numbers whereas direct cost reports the cost in units of billions of 1995 U.S. dollars.[8]

Comparing these measures illuminates three critical issues. First, one measure can imply a country benefit under a specific scenario while another measure implies a loss. Second, the measures can produce different policy rankings for a specific region. Third, the magnitudes of these measures are incomparable unless all of them are in the same units (see Table 10).

Table 9 points out the problems of reporting welfare measures that are not directly connected to the model's objective function. As mentioned, for our model, equivalent variation of welfare is the only self-consistent welfare measure. In general, DPVC closely approximates welfare, but the sign differs for ROW in the no trading and Annex I trading scenarios and for SEA under the Annex I trading scenario. This inconsistency arises because of the difference between the implicit discount rate (intertemporal rate of substitution) in the welfare function and the specified discount rate for DPVC.

For Annex I countries, the direct cost is consistent with equivalent variation (welfare) both within and across emissions trading scenarios. But this measure reveals little about the welfare of non-Annex I countries because it leaves out the terms-of-trade effects that are responsible for spillover

6 William Nordhaus deserves the credit for this observation.

7 This measure is reported by the SGM and in the Administration's economic analysis of the Kyoto Protocol. See "The Kyoto Protocol and the President's Policies to Address Climate Change," Administration Economic Analysis, July 1998; and J.A. Edmonds, et al., "Return to 1990: The Cost of Mitigating United States Carbon Emissions in the Post-2000 Period," October 1997.

8 Costs are reported as negative numbers.

Table 9 Comparison of All Four Welfare Measures for Selected Regions

	Welfare	DPVC	Direct Cost		GDP	
			2010	2020	2010	2020
No Trading	(%)	(%)	(Billions of U.S. $s)		(%)	(%)
USA	-0.56%	-0.41%	-$45.20	-$43.55	-1.88%	-2.33%
SEA	-0.18	-0.03	NA	NA	0.51	0.01
CHI	0.34	0.59	NA	NA	0.64	0.21
MPC	-1.39	-1.65	NA	NA	-0.99	-1.60
ROW	-0.10	0.10	NA	NA	0.71	0.17
Annex I						
USA	-0.36	-0.31	-36.39	-57.53	-0.91	-1.27
SEA	-0.04	0.04	NA	NA	0.47	0.50
CHI	0.22	0.33	NA	NA	0.53	0.60
MPC	-1.15	-1.45	NA	NA	-0.64	-0.91
ROW	-0.08	0.01	NA	NA	0.60	0.60
Global						
USA	-0.14	-0.14	-15.41	-21.91	-0.29	-0.33
SEA	0.25	0.36	1.33	2.63	0.06	0.02
CHI	0.34	0.52	4.55	13.58	-0.17	-0.07
MPC	-0.36	-0.42	1.40	3.02	-0.45	-0.48
ROW	0.03	0.08	2.42	5.02	0.06	0.04

effects. Furthermore, under global trading, direct cost reports a gain for MPC, but MPC experiences a loss in welfare due to the fall in world oil prices.

Comparing GDP results among countries or across scenarios may not present a clear picture of whether one country does better compared to another, or whether a particular scenario is beneficial for a country because the change in GDP may be positive in one period but negative in the next. Also, to compute GDP, one needs a numeraire; there is no theoretically correct choice for this. Therefore, depending on the choice of numeraire, one arrives at different results for GDP. This leads to some of the inconsistencies when comparing impacts on CHI across scenarios. Using GDP as the welfare measure, CHI is better off under no trading and Annex I trading than under global trading, whereas EV (welfare) implies the opposite conclusion. This problem arises when comparing results for many of the non-Annex I, non-energy exporting regions and is due to the large changes in investment that increase GDP in some countries for a period of time at the expense of consumption.

Table 10 Comparison of Four Welfare Measures for the U.S.
(Percentage Change from Baseline – Cumulative and Discounted to 2000)

Scenario	EV (Welfare)	DPVC	Direct Cost	GDP
No Trading	-0.56%	-0.41%	-0.19%	-1.31%
Annex I Trading	-0.36	-0.31	-0.07	-0.75
Global Trading	-0.14	-0.11	-0.01	-0.18

The magnitudes of the welfare measures as reported in Table 9 are not directly comparable. GDP and direct cost are annual measures, whereas EV welfare and DPVC measure the discounted present value of impact over a horizon. Furthermore, the units of direct cost are dollars. To eliminate these differences, we computed the discounted PV of the direct cost and GDP for the scenarios over the full time horizon. Then, to compute the percentage change from baseline, these are divided by the DPV of the baseline GDP (see Table 10). The EV Welfare still differs from the other measures since it approximates the impacts over the infinite horizon rather than the model's 30-year horizon.

The GDP measure shows the largest impacts, partly because of the double counting of investment impacts noted above. Direct cost shows the smallest impacts since it leaves out effects on investment, terms of trade, and other general equilibrium effects, and also because it is not based on the compensated demand curve required theoretically to approximate consumer surplus. Welfare and DPVC are close, with slight differences caused by discrepancies between the discount rate assumed in calculating the DPVC and the internal discount rate used in the welfare calculation. The EV welfare measure could be closer to GDP if its denominator were limited to welfare during the model horizon, rather than the infinite horizon.

Restricted Trading Cases

The Kyoto Protocol did not reconcile the positions of the U.S. and other Annex I nations on emissions permit trading. Three unresolved issues are especially important: 1) the extent to which a country may satisfy its obligation through permit purchases, 2) the amount of paper tons or permits for "hot air"[9] EE/FSU countries will be allotted, and 3) how market power will be exercised. Two other questions also arise: What will be the economic impacts of restricting the sales of emissions permits, and what will be the potential benefits to the Annex I countries of instituting the CDM?

To address the first three issues, we consider several different Annex I trading regimes. First, we consider three regimes in which Annex I regions are limited in how many permits they can purchase. Proponents of restricted emissions trading cite the Kyoto Protocol language that trading should be "supplementary" to domestic efforts in support of these limits. The EU and several of its member countries have proposed that a "concrete ceiling" be imposed on the percentage of a country's emissions obligation that may be satisfied through the purchase of emissions permits. These countries have suggested a limit of 50 percent or less. In addition, some have advocated a system of buyer liability that would so burden buyers of permits with potential liabilities that only the most attractive trades would have any likelihood of being accomplished.

In our scenarios, the limits are set at 10 percent, 30 percent, and 50 percent of each country's obligation. A country's obligation is defined to be the difference between its baseline emissions and its target under the Kyoto Protocol. Since the limits are placed only on the demand side, countries can sell as many permits as they like but are restricted by how much of their commitment they can satisfy through the purchase of permits. We also consider a case in which a 50 percent limit exists under a global trading system, since it is under global trading that our benchmark results suggest that the U.S. would want to purchase more permits than this limit would allow.

[9] This positive difference between the EE/FSU's Kyoto emissions targets and its actual forecasted emissions is referred to as "hot air" or "paper tons." Because the EE/FSU's economy has been in a decline since 1990, its carbon emissions are forecasted to be below its 1990 emissions level until somewhere in the 2020 to 2025 time period.

Table 11 EE/FSU's Carbon EmissionsTargets (Millions of Metric Tons)

	2000	2005	2010	2015	2020	2025	2030
Baseline	870	940	1,023	1,094	1,174	1,267	1,371
Kyoto Target	N/A	N/A	1,240	1,240	1,240	1,240	1,240
Hot Air	N/A	N/A	217	146	66	0	0
No Hot Air	N/A	N/A	1,023	1,094	1,174	1,240	1,240

Second, we consider the impacts of prohibiting the EE/FSU region from selling its "hot air." Russia, and possibly some of the former Soviet Republics and other Eastern European countries, will clearly be the least-cost suppliers of permits in an Annex I trading system in 2010. Because its economic collapse has reduced current emissions to levels well below its 1990 baseline, Russia's emissions in 2010 are projected to be about 20 percent below its Kyoto target.[10]

Most of the members of the EU, and many developing countries, are opposed to a system that allows Russia to sell its hot air, arguing correctly that hot air sales would raise total world emissions above the levels they would reach without such sales[11]. Table 11 helps illustrate the concept of hot air. The line titled "Baseline" shows that, until 2020, EE/FSU's emissions are below its Kyoto target of 1990 emissions levels ("Kyoto Target" line). This gap between the region's Baseline emissions and its target (line titled "Kyoto Target") is referred to as "hot air." In 2010, the EE/FSU is forecasted to have about 220 million metric paper tons. In the No Hot Air case, EE/FSU is restricted from selling their paper tons of carbon. Under this case, EE/FSU's emissions target is denoted by the "No Hot Air" line, which equals the smaller of EE/FSU's business-as-usual emissions or its Kyoto target of the1990 emissions level. Therefore, under the Annex I trading regime, the emissions cap for the entire Annex I bloc is lower under the No Hot Air case than under the other cases.

Third, we address the issue of market power. As the only net seller of permits under a trading system limited to Annex I countries, Russia would be in a position to restrict output and charge monopoly prices for its emissions permits. We consider one scenario in which EE/FSU is able to exercise some market power. We also describe a method for estimating the output restriction that would maximize benefits to EE/FSU and the resulting prices. This case is intended to provide an illustration of how monopoly power could be exercised if Eastern Europe and the FSU maximize profits jointly.

Fourth, we consider other restrictions on sales. We analyze a case where countries are allowed to sell only 30 percent of the permits that they would sell under unrestricted Annex I trading. This case is designed to examine whether proposed restrictions on sales would achieve the same result as exercise of monopoly power, and whether restrictions on sales could produce worse outcomes than unilateral exercise of monopoly power.

Finally, we examine how closely the CDM approximates the benefits of full global trading. CDM is designed to support projects to reduce emissions from developing countries, with funding from industrial countries that would receive emission credits. We limit permit sales from each of the non-Annex I regions to 15 percent of their total permit sales under full global trading. This differs from

[10] U.S. Department of Energy, *International Energy Outlook*, 1998.

[11] This assumes no banking of carbon emissions by EE/FSU.

full global trading because it leaves most of the price differentials between Annex I and non-Annex I countries in place.

Modeling of Restricted Trading Cases

To model restricted trading in the framework of complete markets, one needs to create markets for import and export quota coupons in addition to markets for permits. The permit is a normal traded good, subject to a nontradable quota. These coupons must be used when either importing or exporting emissions permits. In the case of unrestricted permit trading, every region is endowed with an excess of quota coupons so that the price of coupons is zero. In the restricted trading cases, however, each region that is a member of the trading bloc is endowed with a fixed number of quota coupons equal to the limit of its restriction. For example, if the final version of the Protocol were to limit each Annex I country's permit purchases to 30 percent of its obligation, then each country would be given quota coupons equal to 30 percent of its obligation. Restricting permit sales works the same way except, now, sellers must use quota coupons to vend permits.

Under the CDM case, the non-Annex I countries are allowed to sell 15 percent of their permits that they would have sold under the unrestricted global trading case. This is a modeling convenience and could not be implemented in reality. But this case serves to estimate the effect of implementing the CDM in a way that would allow non-Annex I countries to participate in the process of reducing global emissions, but with costs and restrictions that render 85 percent of the trades possible under global trade no longer economic. To model this proxy for the CDM, the non-Annex I countries are endowed with quota coupons equal to 15 percent of their emissions permit sales under unrestricted global trading. There are no restrictions on permit trading among Annex I regions.

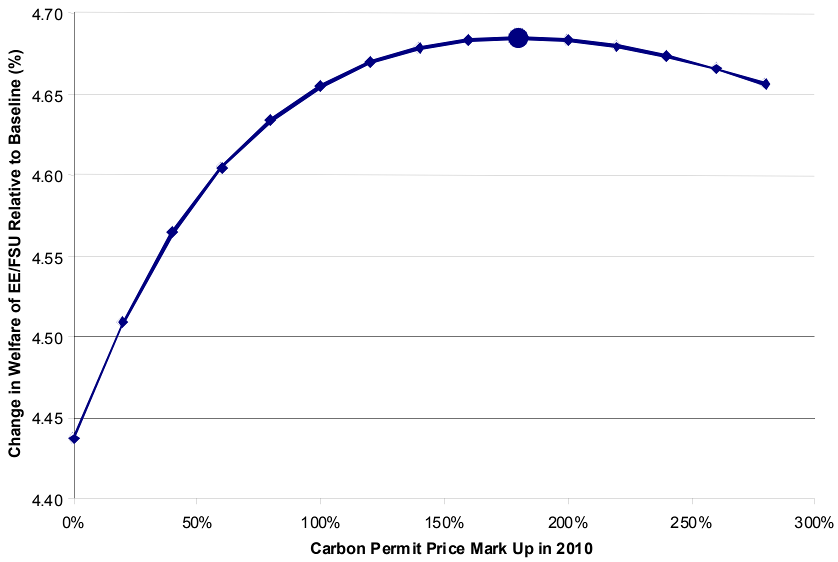
By treating limits on purchases and sales of emissions permits as, respectively, import and export quotas, the international price of permits is set by the holder of the quota coupons. Therefore, when purchases are restricted, the international price is determined by the market supply curve for permits; but when the sales are limited, the international price is determined by the market demand curve for permits.

Modeling Russian Exercise of Monopoly Power

Because EE/FSU is the sole seller under Annex I trading, the potential arises for this group of countries to exercise market power. To estimate the possible effects of this event, we allow the EE/FSU to maximize its welfare by selling permits above competitive price levels. In the MS-MRT model, a markup is added to the EE/FSU's domestic price of permits, much like an export tariff. Other Annex I regions pay the EE/FSU this marked-up price. The markup drives a wedge between the price received by sellers of permits in Russia and the price received by Russia on the international market. The markup thus reduces the EE/FSU's incentive to sell permits and (consistent with standard trade theory) has the same effect as a quota on the sales of permits (see Figure 5).

To analyze whether the EE/FSU could benefit from acting as a monopolist, we imposed different markups on the price of permits offered for sale by the EE/FSU. This treatment is similar to letting a country charge a tariff where the country captures all the revenues from the levy. In order to determine the optimal tariff (the one that maximizes EE/FSU's welfare), we investigated several markup formulas. Intuitively, the optimal tariff should decline over time as the EE/FSU's baseline emissions increase relative to its target and the difference between the OECD's marginal cost of abatement and that of the EE/FSU decreases. From the tariffs tried, the following markup schedule yielded the greatest welfare gains for EE/FSU: 180% in 2010 declining to 18% in 2030.

Figure 5 Optimal Permit Price Markup in 2010 for EE/FSU (Percentage Increase from EE/FSU's Domestic Price)



Modeling of No Hot Air

In this scenario, EE/FSU is prohibited from selling permits that are the result of hot air. Equivalently, EE/FSU's emissions target becomes the lesser of its baseline emissions and its Kyoto target. For the period 2010 to 2020, EE/FSU's new emissions target equals its baseline emissions. After 2020, its target reverts back to its assigned target under the Kyoto Protocol – its 1990 emissions level (see Line titled "No Hot Air" in Table 11).

Results for Restricted Trading Cases

This section reports results for three different sets of restrictions. First, restrictions on Annex I trading are compared to the case of unrestricted Annex I trading. Second, the effect of EE/FSU exercising market power and restricting permit sales is examined. Third, the impacts of imposing trade restrictions under the global trading regime are studied.

Restricted Annex I Trading Scenarios

This section presents the results from the five Annex I restricted trading scenarios. These results are compared to the unrestricted Annex I trading scenario. Trading is restricted in three different ways: purchases, sales, and allowable permits. Three scenarios that limit purchases are considered. The limits are set at 10 percent, 30 percent, and 50 percent of each country's obligation. These scenarios are named, respectively, Annex I-10B, Annex I-30B, and Annex I-50B. One scenario (Annex I-30S) considers limits on sales where Annex I countries are allowed to sell only 30 percent of the permits that are assigned to them which equals 30 percent of their Kyoto targets. Finally, in the policy "No Hot Air," we consider the impacts of prohibiting the EE/FSU region from selling its "hot air."

Table 12 displays the range in welfare impacts under the different trading regimes. For the OECD countries, unrestricted Annex I trading is better than either the Annex I-10B, Annex I-30S, or No Hot Air scenarios. Depending on the region's marginal cost of abatement, its welfare under Anne I-30B (USA, OOE) or Annex I-50B (EUR) exceeds that in the unrestricted Annex I scenario. While

Table 12 EV Welfare for all Regions under Different Annex I Trading Regimes (Percentage Change from Baseline)

	Annex I	Annex I-10B	Annex I-30B	Annex I-50B	Annex I-30S	No Hot Air
USA	-0.36%	-0.43%	-0.34%	-0.35%	-0.43%	-0.39%
JPN	-0.23	-0.52	-0.31	-0.24	-0.30	-0.24
EUR	-0.25	-0.33	-0.25	-0.24	-0.30	-0.25
OOE	-0.76	-0.78	-0.71	-0.75	-0.80	-0.82
SEA	-0.04	-0.13	-0.07	-0.05	-0.08	-0.02
OAS	-0.01	-0.08	-0.05	-0.02	-0.05	0.03
CHI	0.22	0.31	0.25	0.22	0.23	0.26
EE/FSU	4.44	0.05	2.18	4.18	4.57	4.27
MPC	-1.15	-1.26	-1.17	-1.15	-1.13	-1.23
ROW	-0.08	-0.08	-0.08	-0.08	-0.08	-0.06

limited trading is better for the United States than no trading, a system of unrestricted trading is not necessarily the best regime for the U.S. In fact, the optimum policy for the U.S. would be one that limits the purchase of emissions permits by countries with higher marginal costs of abatement than the U.S. without restricting U.S. purchases of permits. Other countries, that more urgently need permits, would not be allowed to bid up their price, while the U.S. would gain more from lower prices on the permits it buys than it loses on restricting emissions. Out of the Annex I trading regimes considered, Annex I-30B best matches this requirement. Obviously, this result is very sensitive to assumptions about baselines and a variety of elasticities and other parameters, and should not be taken as a strong guide to policy.

Table 13 helps explain the relationship of U.S. GDP losses under the unrestricted, 10 percent limit, 30 percent limit, and 50 percent limit cases. The 10 percent limit case is the worst for the United States because, under unrestricted trade, the U.S. always wants to satisfy more than 10 percent of its obligation through permit purchases (55 percent in 2010 declining to 22 percent in 2030). Thus, a 10 percent limit restricts U.S. permit purchases and leads to GDP losses close to those in the no-trade case.

At the other end, in the unrestricted case, the United States only satisfies more than 50 percent of its obligation through permit purchases in 2010; therefore, a 50 percent limit places little restriction

Table 13 U.S. GDP under Different Annex I Trading Regimes (Percentage Change from Baseline)

Scenario	2000	2010	2020	2030
Annex I	-0.1%	-0.8%	-1.1%	-1.4%
Annex I-50B	-0.1	-0.9	-1.1	-1.4
Annex I-30B	-0.1	-1.2	-1.2	-1.2
Annex I-10B	-0.1	-1.6	-1.7	-1.6
Annex I-30S	-0.1	-1.1	-1.4	-1.6
No Hot Air	-0.1	-1.1	-1.2	-1.4

Table 14 International and U.S. Domestic Price of Carbon Permits (1995 U.S. Dollars per Metric Ton)

Scenario	International Permit Price ($ per Metric Ton)			U.S. Domestic Permit Price ($ per Metric Ton)		
	2010	2020	2030	2010	2020	2030
Annex I	$90	$151	$225	$90	$151	$225
Annex I-50B	72	150	225	104	150	225
Annex I-30B	27	95	201	159	178	201
Annex I-10B	0	33	89	230	263	293
Annex I-30S	123	193	275	123	193	275
No Hot Air	130	164	227	130	164	227

on the U.S. and only limits the purchase of permits by other Annex I regions. As a result, the demand for permits declines and the price drops relative to the regime of unrestricted Annex I trading. Therefore, the permit price to the U.S. under the 50 percent case is always less than or equal to the price under the unrestricted case (see Tables 14).

Applying this analysis to the 30 percent case explains why, after 2015, the minimum weighted-average permit price[12] for the United States occurs under the 30 percent limit case. After 2015, this case places no restrictions on the U.S.'s purchase of permits. But it does limit Europe and the OECD regions from purchasing as many permits as they would like; hence, they do not bid up the price of permits as high as in the 50 percent case. In the 30 percent case, the EE/FSU sells fewer permits and, hence, their marginal cost of abatement is lower than in the 50 percent case. Consequently, after 2015 the U.S. pays the least for emissions permits under the 30 percent limit case — less even than under the 50 percent case, because the demand for permits by other Annex I countries is restricted while the U.S. demand is unaffected. This translates directly into less GDP loss for the United States under the 30 percent case than under any of the other Annex I trading cases.

Currently, the U.S. government is advocating unrestricted emissions trading while many European countries are calling for at least 50 percent of emissions reductions to be achieved through domestic actions. Interestingly, the above results show that the United States and the EU would stand to benefit most from what the other wants: the U.S. would experience smaller GDP losses with limited trading, while the EU would benefit more from unrestricted trading.

Restricting the EE/FSU's sale of hot air reduces the pool of emissions permits in the years 2010 to 2020. Therefore, the price of permits under this case is higher during that period than under the unrestricted case. After 2020, the EE/FSU has no more hot air, and the pool of emissions permits is identical under the no hot air and unrestricted cases. This leads to nearly identical carbon permit prices and GDP losses.

[12] The Annex B weighted average permit price equals the price of international permits times the number of international permits purchased plus the price of domestic permits times the number of domestic permits purchased all divided by the total number of permits purchased.

Table 15 Welfare Differences under Different Elasticity Assumptions (Percent Change in Welfare in the Annex I Case Less That in Annex I-10B Case)

Region	High Arm-Low Esub	High Arm-Med. Esub	Low Arm-High-Esub
USA	0.092%	0.068%	-0.025%
JPN	0.291	0.287	0.236
EUR	0.072	0.083	0.053
OOE	0.003	0.024	0.048
SEA	0.095	0.082	0.070
OAS	0.080	0.066	0.029
CHI	-0.104	-0.091	-0.066
EE/FSU	4.890	4.389	4.265
MPC	0.081	0.118	0.266
ROW	-0.019	0.000	0.030

Sensitivity Analysis of Results to Assumptions about Elasticity Values
To determine the robustness of the results about the benefits of unrestricted trading over restricted trading, we varied the values of the Armington (Arm) elasticities and the elasticity between energy and value-added (Esub) in the production and consumption nests. Raising the value of the Armington elasticity reduces the magnitude of price changes needed to induce countries to substitute between domestically produced goods and imports. In general, higher values of Armington elasticities will allow non-Annex I countries to capture more export markets and will cause Annex I countries to lose market share in the export markets in the presence of carbon abatement policies. Raising the value of Esub makes it easier for producers and consumers to substitute energy for non-energy in production and consumption, respectively. Table 15 presents the difference in the percentage change in welfare between the unrestricted Annex I trading scenario and the 10 percent permit purchase restricted Annex I trading scenario under different elasticity assumptions.

Under the Low Arm-High Esub case, the U.S. is actually better off if permit purchases are restricted to 10 percent of a country's obligation rather than being unrestricted. These results occur because of the shape of the U.S.'s marginal cost curve relative to that of the OECD's aggregate marginal cost curve and the EE/FSU's supply curve. Under the other elasticity assumptions, the expected result that restricted trading hurts the U.S. appears. This sensitivity analysis emphasizes the importance of particular elasticity values in evaluating restricted trading regimes.

Russian Exercise of Monopoly Power

To analyze Russia's ability to exercise monopoly power, we run the global model repeatedly with different markups and then choose the markup under which Russia's welfare is maximized. Table 16 reports this markup and the carbon prices under this markup schedule. For comparison, Table 16 also states the international carbon price in the competitive Annex I trading scenario. The size of the markup (or export tariff) determines the restriction on Russian sales. As the markup decreases over time, EE/FSU sells more permits (see Figure 5 and Table 16).

Table 16 Permit Price under Monopolistic and Competitive Annex I Trading

	2010	2015	2020	2025	2030
International Permit Price - Monopoly ($/tonne)	129	150	172	195	239
EE/FSU Domestic Permit Price ($/tonne)	46	79	119	160	202
International Carbon Price – Competitive Market ($/tonne)	90	119	151	182	225
Mark-up (%)	180	90	45	23	18

In 2010, the optimal markup is about 180 percent (see Figure 5), implying that it could be in Russia's interest to restrict sales by as much as 150 million metric tons (see Figure 6) and raise prices by $39 per metric ton above competitive levels (rising from $90 to $129 per tonne). Permit prices in Russia would be driven down to $46 per tonne (see Table 16). Given the assumptions underlying the MS-MRT model, the demand curve for permits is relatively flat at this point, so that EE/FSU must restrict output considerably in order to raise prices.

In this calculation, Russia is a very sophisticated monopolist, taking into account not only the normal calculation of a price that maximizes revenue given demand elasticities, but the effects of higher permit prices on economic performance of Russia's trading partners and the resulting feedback effects on Russia. This is the same sophistication that analysts speculated that Saudi Arabia showed during the 1970s in moderating oil price increases.

We also carried out a partial equilibrium analysis by using repeated model runs to construct a supply curve for permits from Russia and a demand curve for permits in the rest of the Annex I. The monopoly solution is where marginal revenue equals the supply curve. Figure 7 shows that this partial equilibrium analysis predicts higher prices in both the competitive and monopoly cases for Annex I trading than does the general equilibrium analysis, but the output restriction and price increase are about the same.

Figure 6 EE/FSU Permit Sales under Monopoly and Competitive Market Scenarios

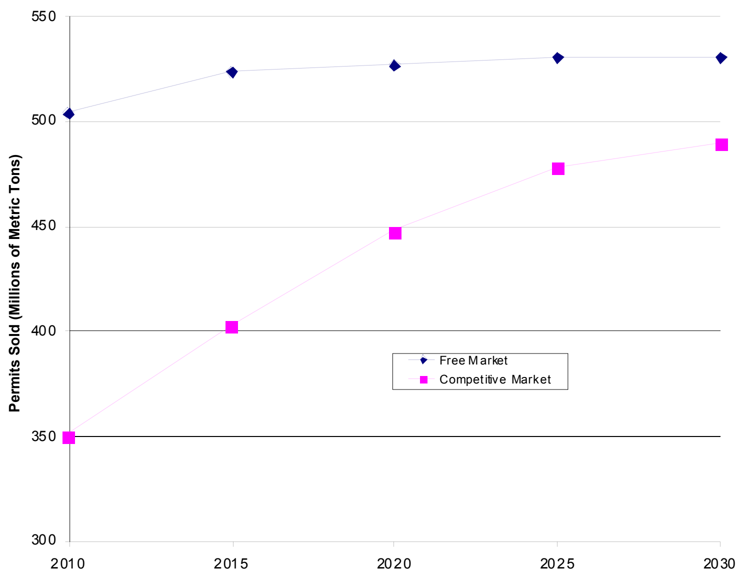
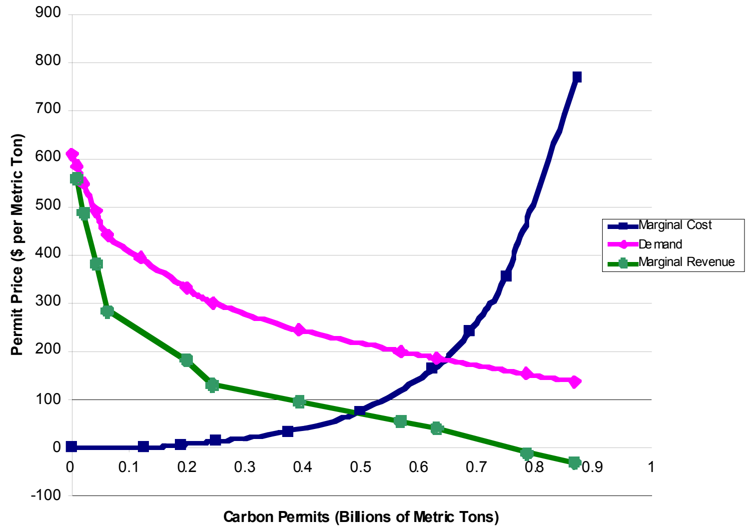


Figure 7 Partial Equilibrium Model of Permit Price under Monopoly and Competitive Market Cases



In both the monopoly and competitive cases, EE/FSU would sell considerably more permits than its endowment of "hot air." Its high ratio of energy consumption per dollar of output makes EE/FSU the lowest-cost supplier of permits until it has achieved a significant reduction in emissions below baseline levels.

Comparison of Annex I Restricted Sales Scenarios: Monopoly vs. Annex I-30S

Under the 30 percent restricted sales case, the international permit price is higher after 2010 than in the monopoly case (see Tables 14 and Table 16, respectively). But the EE/FSU region sells fewer permits and receives less revenue than if its sales are unrestricted and it can exercise market power. Under the monopoly case, the EE/FSU chooses the permit selling price so as to maximize its welfare, which is basically the same as maximizing its revenues from the sale of permits.

The higher permit price harms the OECD countries' economies. This negative income effect on Annex I countries spills over to non-Annex I countries and causes their welfare to be lower under the 30 percent case than the monopoly case. Compared to the case where EE/FSU exercises monopoly power, welfare for all countries is lower under the 30 percent restricted sales case.

Comparison of Global Trading Scenarios

This section compares the difference in welfare impacts, domestic carbon permit prices, and U.S. GDP for the following three global trade scenarios: Unrestricted global trading (global), permit purchase-restricted global trade (global-50B), and global trade under a CDM (global-CDM). Under the global-50B case, all regions are prohibited from satisfying more than 50 percent of their obligation through permit purchases. Under the CDM case, the non-Annex I countries are allowed to sell 15 percent of their permits that they would have sold under the unrestricted global trading case. There are no restrictions on permit trade among Annex I regions.

Since, under unrestricted global trading, the U.S. would be purchasing over 80 percent of its 2010 obligation on the international permit market in all years, the 50 percent purchase limit is binding on the U.S. as well as other Annex 1 regions under global trading. This is seen in the regional permit

Table 17 Domestic Permit Price under the Different Global Trading Regimes (1995 U.S. Dollars Per Tonne)

	Unrestricted Global		50% Purchase Limit		CDM – 15% Sales Limit	
Region	2010	2030	2010	2030	2010	2030
USA	$31	$32	$102	$112	$79	$181
JPN	31	32	117	224	79	181
EUR	31	32	85	134	79	181
OOE	31	32	90	132	79	181
SEA	31	32	13	19	0	2
OAS	31	32	13	19	0	3
CHI	31	32	13	19	3	5
EE/FSU	31	32	13	26	79	181
MPC	31	32	13	19	1	5
ROW	31	32	13	19	0	5

prices shown in Table 17. U.S. GDP losses are much larger in the 50 percent limit case than in the unrestricted global trading case. These results show that EU proposals for limiting purchases of permits would negate many of the benefits of U.S. efforts to bring developing countries into the trading system.

All OECD countries are better off under global and global-50B than global-CDM because more permits are available, the international price of permits is lower, and the domestic permit prices are lower after 2010 (see Tables 17 and 18). The global-50B scenario essentially limits the non-Annex I countries' permit sales by 50 percent; whereas, the global-CDM limits their sales by 85 percent. These limits on non-Annex I sales affect the EE/FSU's welfare in the opposite direction as that of the OECD countries. EE/FSU benefits more under scenarios that limit the sale of low-cost permits from other parties. Consequently, EE/FSU experiences the largest welfare gains under Annex I trading (100 percent limit on non-Annex I sales) since all non-Annex I regions are excluded from selling permits. Therefore, the EE/FSU countries and the OECD countries desire vastly different trading regimes. This will further impede the U.S. efforts to expand emissions trading to non-Annex I countries.

Table 18 Welfare for the Three Global Trading Scenarios (Percentage Change from Baseline)

Region	Global	Global-50B	Global-CDM	Annex I
U.S.	-0.14	-0.13	-0.32	-0.36%
Japan	-0.03	-0.11	-0.18	-0.23
EU 15	-0.05	-0.09	-0.20	-0.25
O-OECD	-0.30	-0.35	-0.67	-0.76
S.E. Asia	0.25	0.09	0.06	-0.04
O-Asia	0.19	0.08	0.09	-0.01
CHN & IDI	0.34	0.21	0.55	0.22
EE/FSU	0.48	-0.04	3.47	4.44
M-OPEC	-0.36	-0.62	-0.92	-1.15
ROW	0.03	-0.02	0.01	-0.08

Table 19 Percentage Change in U.S. GDP

Scenario	2000	2010	2020	2030
Global	-0.1%	-0.3%	-0.3%	-0.3%
Global-50B	-0.2	-0.8	-1.0	-1.0
Global-CDM	-0.2	-0.8	-1.1	-1.3
Annex I	-0.2	-0.9	-1.3	-1.5

The CDM does little to improve the welfare of Annex I regions above the level they reach under unrestricted Annex I trading because the CDM greatly restricts permit trade. Under unrestricted global trading, non-Annex I regions account for 59 and 99 percent of permit sales in 2010 and 2030, respectively; however, under the global-CDM scenario, non-Annex I regions account for only 12 and 32 percent of permit sales in 2010 and 2030, respectively. This equates to loss in permits of 380 million and 1,230 billion metric tons in 2010 and 2030, respectively.

For most regions, the change in welfare under the Global-CDM scenario is close to that in the unrestricted Annex I trading scenario (see Table 18). Furthermore for the U.S., its GDP is only one-tenth to two-tenths of a percentage point better under the CDM scenario.

Although the EMF scenario is only an example of how the limited possibilities of the CDM could work out, it captures some real problems with the CDM. Many layers of approval are likely to be required for any project. These could include the host country government, the sponsoring country government, the private party in the host country, the private party planning the investment in the sponsoring country, and the CDM bureaucracy. A requirement contained in the language of the Kyoto Protocol that appears to encourage spreading investment across all non-Annex I countries could make it impossible to allocate investment where it would achieve the largest or most cost-effective emissions reductions. Project content restrictions (such as discouragement of nuclear power or encouragement of unrelated social objectives) are possible given the sentiments expressed on these topics throughout both the Kyoto negotiating process and the earlier IPCC process. Language suggesting that projects approved under the CDM should supplement baseline activities may lead to large administrative costs to justify the difference a project will make; it may also cause adjustment of credits for reductions included in the baseline. A tax on projects for administrative costs and the adaptation fund will be collected by the CDM, creating the equivalent of a tax wedge between the selling price and buying price of permits.

The CDM is seen by some as providing a form of partial global emissions trading, so that its adoption might lead to an outcome between Annex I and full global trading. Given its restrictions, extensive bureaucracy, and other potential pitfalls, however, the CDM in its current manifestation differs greatly from agreements to abide by emissions caps and participation in international emissions trading.

Conclusion

Several broad observations about effects of restrictions on trading emerge from our analysis. The first is that emissions trading has significant potential to improve welfare for all parties, and the broader and less restricted trading is, the greater is that potential.

The second is that developing countries will not escape costs, even if they do not participate in emissions trading because changes in the terms of trade shift some of the cost of Annex I-only emissions reductions onto developing countries. In general, less restricted trading has the potential to benefit developing countries. In our results, developing countries are potentially better off under global trading than under no trading and in general they are better off under Annex I trading than under no trading. Achieving this potential will require delicate negotiations about the initial allocation of permits – the cap assigned to developing countries.

In general, restricting emissions trade reduces global welfare, but within that global total some countries gain and some lose from restrictions. In many cases, the countries advocating restrictions are those most harmed by them. How impacts are distributed depends strongly on assumptions about baselines and elasticities, suggesting that distributional issues are likely to remain contentious.

Exercise of market power is clearly possible under policies like Annex I trading that create markets with a single seller, but our estimates suggest that it is easy to choose policies that are worse than the exercise of market power. For example, prohibiting sales of hot air would restrict sales and raise permit prices higher than it would ever be in the interest of Russia acting as a monopolist. Choosing not to interfere with the possibility of market power may be better for the world than capping the sales of permits.

In terms of restrictions on trading that includes developing countries, CDM would provide small benefits relative to global trading, if its operations are subject to constraints now under discussion. Limits on purchases of permits by Annex 1 countries would largely eliminate benefits the U.S. could achieve by extending permit trading to developing countries.

Finally, Annex 1 trading does not significantly reduce leakage. Full global trading is required to prevent increases in emissions in non-participating countries.

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Discussion

Snorre Kverndokk

The paper by Bernstein et al. (1999) presents economic impacts of the Kyoto agreement using a dynamic general equilibrium model (MS-MRT model). The model is a multi-sector, multi-region trade model, and simulations are run for the period 2000-2030. The focus of the model is the effects of emission permit trading, and three different regimes are studied. In the first regime, there is no trading, while trading only among Annex 1 countries is allowed in the second regime. Finally, in the third regime, full global trading is allowed. Impacts on such variables as economic welfare, international trade and investments across regions, the spillover effects of carbon emission limits in Annex 1 countries on non-Annex 1 countries, carbon leakage, changes in terms of trade and industry output are studied under the different regimes. The results are well documented, and sensitivity analyses are made to test the robustness of the results.

The paper analyses a very important question, namely the impacts of the Kyoto agreement. This is an important task as it provides useful background information for the forthcoming negotiations, both for the final framing of the Kyoto agreement, and also for the discussions of an agreement after the Kyoto period of 2008-2012. However, one question the reader asks himself when studying a model simulation of the Kyoto agreement is what does this paper tell me that I have not read somewhere else? What is new in this study, and does the model provide some new insight? Unfortunately the authors do not help us very much in answering these questions. They do not refer to similar analyses, or compare their results. Over the last year or so, several modellers around the world have made simulations of the Kyoto agreement on their national, regional or global models, and some of these papers will be published in a forthcoming number of the *Energy Journal*. What I think is the main contribution of this study is that the model is both dynamic, and also rich in sectoral and regional specification. Besides this, trade with several goods is modelled. Thus, the model covers several important aspects at the same time, maybe more than other global models, and I therefore think that it makes an important contribution to study the impacts of the Kyoto agreement. In the following, I will not comment so much on the specific results, but focus on subjects that I feel is important, is a bit unclear or maybe not satisfactory studied by the analysis.

One reason to have a dynamic model is the *fossil fuel markets*. The aspects of non-renewable goods require a dynamic model. This is especially important when analysing climate treaties, as about 75 per cent of CO_2 emissions are due to the combustion of fossil fuels. However, fossil fuels are not fully modelled as non-renewable resources as the depletion effects are ignored. This leaves out the question of the rational distribution of production over time. Another important question is strategic type of the markets. As far as I understand, perfect competition is assumed in all markets, also the oil market. But imperfect competition is a characteristic of the oil market. As documented in Berg et al. (1997), whether there is perfect or imperfect competition in the oil market have large impacts on the effects of a climate treaty, for instance the effects on the oil price. With imperfect competition (OPEC as a cartel), the producer price of oil is not much affected the first years after an agreement has come into force, and the carbon leakage may therefore also be minor. The significant leakage in Bernstein et al. in the scenario with no international permit trading may, therefore, partly be explained by perfect competition in the oil market.

Even if the model has a high number of sectors, one important sector is not modelled, namely *forestry*. Land use changes are included in the Kyoto protocol, which makes this sector interesting in an analysis like this. A national CGE model where emissions from the use of timber and carbon accumulation in the forest are taken into account, thus calculating net emissions, is Pohjola (1999). If net emissions are taxed, Pohjola (1999) finds that the carbon tax needed to reduce net emissions by the same amount as emissions from fossil fuels is significantly lower.

International trade is an important aspect of the model. However, the paper could focus more on how international trade can reduce economic costs of a climate treaty, especially when permit trading is not allowed. One example is *electricity trade*. Electricity is produced using a number of production technologies, and the amount of carbon emissions per unit of electricity varies a lot between the technologies. One example is electricity trade in Scandinavia, where electricity in Norway is based on hydropower, while it is mainly based on coal in Denmark. Norway can increase its production of hydropower without increasing CO_2 emissions. If Denmark imports electricity from Norway, Danish emissions will be reduced. Thus, as demonstrated in Hauch (1999), if national emission targets are imposed, Danish emissions can be reduced at a lower cost if electricity is traded compared to a situation with no trade. Electricity trade can actually work as a substitute to permit trading and equalise marginal abatement costs. Natural gas is another good that may help equalising marginal abatement cost via international trade.

The model includes a *backstop technology*, which sets an upper limit on the price of fossil fuels. That the backstop technology is important for future carbon emissions is demonstrated in, e.g., Chakravorty et al. (1997). As far as I understand, the technological change in the backstop technology is exogenous in the model. However, there is a possibility that a carbon treaty speeds up research and development for alternative energy resources, and therefore, reduces the costs of future abatement. This is an important subject, and I hope to take a further look at this issue in the near future.

The paper calculates the *welfare impacts* under alternative trading arrangements. The welfare concept in this analysis does not include environmental impacts. Personally, I do not like to use the word welfare when environmental impacts are not included, as the main reason for reducing emissions is the well being or welfare of people. Environmental impacts can include both primary and secondary benefits. As demonstrated by several CGE models, the secondary benefits from greenhouse gas abatement may actually outweigh the abatement costs, see, e.g., Ekins (1996). One interesting aspect is the feedback from the environment to the economy. A few CGE models have incorporated this. One example is Glomsrød et al. (1998) that studies the impacts of traffic injuries on labour supply and public health expenditures in a CGE model for Norway. A carbon tax reduces the fossil fuel use and thus the traffic volume, leading to fewer accidents and increased labour supply.

One of the permit trading regimes in the paper is *global permit trading*. However, it is a bit hard to see from the paper how this actually is specified, and also how the emission targets are specified after 2010. It would help the reader if graphs showing carbon emissions were included. How this regime is specified is important. One of the flexible mechanisms in the Kyoto protocol is the Clean Development Mechanism (CDM). This may be interpreted as a kind of global permit emission trading. However, this mechanism may lead to higher global emissions as it gives the non-Annex 1 countries an incentive to delay investments as Annex 1 countries may pay for the investments in a future period. One of the conclusions in the paper is that global permit trading is worse for China and India than no permit trading, which may explain their attitudes towards permit trading. However, this is very dependent on how the emission permits are distributed after the Kyoto period

2008-12, and this should, therefore, be made clearer in the paper. As demonstrated in, e.g., Kverndokk (1993), different permit allocation rules give very different transfers between countries, and allocation rules may be constructed that actually benefit countries like India and China (e.g., a population rule). Therefore, I think a discussion on emission targets after the model period of 2010 is important, and different regional targets could also be analysed.

I have made several comments on how the analysis could be broadened. However, this does not mean that I do not find the paper interesting, or that I think a general equilibrium analysis should include all this aspects. Anyway, I think that the paper may be improved if some of the aspects are mentioned and relevant comparisons are made.

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Emissions Trading, Capital Flows and the Kyoto Protocol

Warwick J. McKibbin, Martin T. Ross, Robert Shackleton, and Peter J. Wilcoxen

1 Introduction

As part of an effort to reduce global emissions of greenhouse gases (GHGs) that are expected to contribute to a significant warming of the earth's climate, the Kyoto Protocol to the United Nations Framework Convention on Climate Change, signed in Kyoto in December 1997, includes binding GHG emissions targets for the world's industrial economies ("Annex I" countries) for the period 2008-2012. The Protocol also provides for international trading of emission allowances among the countries that accept binding targets, in recognition of the theoretical efficiency benefits of allowing emission reductions to be obtained at least cost. In addition, the Protocol provides for a Clean Development Mechanism, under which agents from industrial countries can earn emission credits for certified reductions from investments in "clean development" projects in developing countries that have not taken on binding targets.

In this paper we present estimates of the potential economic effects of the Kyoto Protocol, using the G-Cubed multi-region, multi-sector intertemporal general equilibrium model of the world economy.[1] We examine and compare four potential implementations of the Protocol involving varying degrees of international permit trading, focusing particularly on short term dynamics and on the effects of the policies on output, exchange rates and international flows of goods and financial capital. We present calculations of some of the gains from allowing international permit trading, and examine the sensitivity of the results to changes in the most important assumptions.

2 Model Structure

In this section we give a necessarily brief overview of the key features of the model underlying this study, that are important in understanding the results. For a more complete coverage of the model, please see McKibbin and Wilcoxen (1995b).[2]

The G-Cubed model consists of a set of eight regional general equilibrium models linked by consistent international flows of goods and assets. We assume that each region consists of a representative household, a government sector, a financial sector, twelve industries, and two sectors producing capital goods for the producing industries and households, respectively. The regions and

[1] G-Cubed stands for "Global General Equilibrium Growth Model." An earlier draft of this paper used version 31 of the model. This draft uses version 39, which includes significant data updates and has emission coefficients on gas and oil separately rather than on the crude oil and gas extraction sector

[2] This and other papers describing the model are available at http:\www.msgpl.com.au.

Table 1 Regions and Sectors in G-Cubed

Regions	Sectors
1. United States	1. Electric utilities
2. Japan	2. Gas utilities
3. Australia	3. Petroleum refining
4. Other OECD countries	4. Coal mining
5. China	5. Crude oil and gas extraction
6. Former Soviet Bloc	6. Other mining
7. Oil exporting developing countries	7. Agriculture
8. Other developing countries	8. Forestry and wood products
	9. Durable goods
	10. Nondurables
	11. Transportation
	12. Services

sectors are listed in Table 1. The regions are similar in structure (that is, they consist of similar agents solving similar problems), but they differ in endowments, behavioral parameters and government policy variables.[3] In the remainder of this section we present the key features of the regional models.

2.1 Producer Behavior

Within a region, each producing sector is represented by a single firm which chooses its inputs and investment in order to maximize its stock market value subject to a multiple-input production function and a vector of prices it takes to be exogenous. We assume that output can be represented by a constant elasticity of substitution (CES) function of inputs of capital, labor, energy and materials:

$$Q_i = A_{iO} \left(\sum_{j=K,L,E,M} \delta_{ij}^{1/\sigma_{iO}} X_{ij}^{(\sigma_{iO}-1)/\sigma_{iO}} \right)^{\frac{\sigma_{iO}}{(\sigma_{iO}-1)}}$$

where Q_i is output, X_{ij} is industry i's use of input j (i.e. K,L,E and M), and A_{iO}, d_{ij}, and s_{iO} are parameters. Energy and materials, in turn, are CES aggregates of inputs of intermediate goods: energy is composed of the first five goods in Table 1 and materials is composed of the remaining seven:

$$X_{iE} = A_{iE} \left(\sum_{j=1}^{5} \delta_{ij}^{1/\sigma_{iE}} X_{ij}^{(\sigma_{iE}-1)/\sigma_{iE}} \right)^{\frac{\sigma_{iE}}{(\sigma_{iE}-1)}}$$

$$X_{iM} = A_{iM} \left(\sum_{j=6}^{12} \delta_{ij}^{1/\sigma_{iM}} X_{ij}^{(\sigma_{iM}-1)/\sigma_{iM}} \right)^{\frac{\sigma_{iM}}{(\sigma_{iM}-1)}}$$

Intermediate goods are, in turn, functions of domestically produced and imported goods.

[3] This is enough to allow the regions to be quite different from one another. For example, even though all of the regions consist of the twelve industries in Table 1 we do not impose any requirement that the output of a particular industry in one country be identical to that of another country. The industries are themselves aggregates of smaller sectors and the aggregation weights can be very different across countries: the output of the durable goods sector in Japan will not be identical to that of the United States. The fact that these goods are not identical is reflected in the assumption (discussed further below) that foreign and domestic goods are generally imperfect substitutes.

We use a nested system of CES equations rather than a more flexible functional form because data limitations make even the CES model a challenge to estimate. In principle, to estimate a more flexible specification we would need time-series price and quantity data for 14 inputs (twelve goods plus capital and labor) in each of 96 industries (12 industries in 8 regions). Unfortunately, no country collects annual data on intermediate inputs, and most developing countries collect almost no industry data at all.

The scarcity of input-output data requires us to restrict the model further by imposing the assumption that each industry has the same energy, materials and KLEM substitution elasticities no matter where it is located (although the elasticities differ across industries).[4] However, even though the substitution elasticities are identical across countries, the overall production models differ because the CES input weights are taken from the latest available input-output data for each country or region.[5] Thus, the durable goods sectors in the United States and Japan, for example, have identical substitution elasticities but different sets of input weights. The consequence of this is that the cost shares of inputs to a given industry are based on data for the country in which the industry operates, but the industry's response to a given percentage increase in an input price is identical across countries. Taken together, these assumptions are equivalent to assuming that all regions share production methods that differ in first-order properties but have identical second-order characteristics. This approach is intermediate between one extreme of assuming that the regions share common technologies and the other extreme of allowing the technologies to differ across regions in arbitrary ways.

The regions also differ in their endowments of primary factors, their government policies, and patterns of final demands, so although they share some common parameters they are not simple replicas of one another.

To estimate the elasticities we have constructed time-series data on prices, industry inputs, outputs and value-added for the country for which we were able to obtain the longest series of input-output tables: the United States. The following is a sketch of the approach; complete details are contained in McKibbin and Wilcoxen (forthcoming).

We began with the benchmark input-output transactions tables produced by the Bureau of Economic Analysis (BEA) for years 1958, 1963, 1967, 1972, 1977 and 1982.[6] The conventions used by the BEA have changed over time, so the raw tables are not completely comparable. We transformed the tables to make them consistent and aggregated them to twelve sectors. We then shifted consumer durables out of final consumption and into fixed investment.[7] We also increased the capital services element of final consumption to account for imputed service flows from durables and owner-occupied housing. Finally, we used a data set constructed by Dale Jorgenson and his colleagues to decompose the value-added rows of the tables,[8]and a data set produced by the Office of Employment Projections at the Bureau of Labor Statistics to provide product prices.

4 This assumption is consistent with the available econometric evidence (see for example Kim and Lau, 1994).

5 Input-output tables were not available for the regions in the model larger than individual countries. The input weights for those regions were based on data for the United States.

6 A benchmark table also exists for 1947 but it has inadequate final demand detail for our purposes. Subsequent to our estimation work a 1987 table has become available.

7 The National Income and Product Accounts (and the benchmark input-output tables as well) treat purchases of consumer durables as consumption rather than investment.

8 This data set is the work of several people over many years. In addition to Dale Jorgenson, some of the contributors were Lau Christiansen, Barbara Fraumeni, Mun Sing Ho and Dae Keun Park. The original source of data is the Fourteen Components of Income Tape produced by the Bureau of Economic Analysis. See Ho (1989) for more information.

Table 2 Production Elasticities

Sector	Energy		Materials	Output	
	Estimated	Imposed		Estimated	Imposed
Electricity	0.200		1.000	0.763 (0.076)	0.200
Natural Gas	0.933(0.347)	0.200	0.200	0.810 (0.039)	0.200
Petroleum Refining	0.200		0.200	0.543 (0.039)	0.200
Coal Mining	0.159 (0.121)		0.529 (0.018)	1.703 (0.038)	0.200
Crude Oil & Gas	0.137 (0.034)		0.200	0.493 (0.031)	
Other Mining	1.147 (0.136)	0.500	2.765 (0.028)	1.001 (0.315)	
Agriculture	0.628 (0.051)		1.732 (0.105)	1.283 (0.047)	
Forestry & Wood	0.938 (0.138)	0.400	0.176(0.000)	0.935 (0.080)	
Durables	0.804 (0.058)	0.500	0.200	0.410 (0.019)	
Nondurables	1.000	0.400	0.057 (0.000)	1.004 (0.012)	0.410
Transportation	0.200		0.200	0.537 (0.070)	
Services	0.321 (0.045)		3.006 (0.073)	0.256 (0.027)	

Table 2 presents estimates of the substitution elasticities for each industry; standard errors are shown in parentheses.[9] The elasticity of substitution between capital, labor, energy and materials (KLEM) for each sector, parameter s_{iO} in (1), is shown in the column labeled "Output"; the columns labeled "Energy" and "Materials" give the elasticities of substitution within the energy and materials node, s_{iE} and s_{iM}.

A number of the estimates had the wrong sign or could not be estimated (the estimation procedure failed to converge). In such cases we examined the data and imposed elasticities that seemed appropriate; these values are shown in the table without standard errors.[10] For most of the imposed parameters, the data suggest complementarities among inputs, which is incompatible with the CES specification. If more data were available, it would be worthwhile to use a more flexible functional form.

Finally, in order to improve the model's ability to match physical flows of energy we have imposed lower energy and output elasticities in a few sectors. These are shown in the columns labeled "Imposed." For example, the estimated KLEM elasticity in the electric sector was 0.763 but we have imposed an elasticity of 0.2 in order to help the model more accurately track the physical quantities of energy inputs and outputs to the sector.

Maximizing the firm's short run profit subject to its capital stock and the production functions above gives the firm's factor demand equations. At this point we add two further levels of detail: we assume that domestic and imported inputs of a given commodity are imperfect substitutes, and that imported products from different countries are imperfect substitutes for each other. Given the model's level of aggregation these are more a simple acknowledgment of reality than an assumption.[11] Thus, the final decision the firm must make is the fraction of each of its inputs to buy

[9] The parameters were estimated using systems of factor demand equations derived from the KLEM portion of the production function and the dual versions of the energy and materials tiers.

[10] For this study we also imposed lower KLEM substitution elasticities on a few of the energy industries where it seemed that the estimated elasticities might overstate the true ability of the industry to shift factors of production.

[11] This approach is based on the work of Armington (1969).

from each region, including the firm's home country. Due to data constraints we impose a unitary elasticity of substitution between domestic and foreign goods. The significance of this is examined in Section 5, which presents results for several alternative elasticities. In addition, we assume that all agents in the economy have identical preferences over foreign and domestic varieties of each particular commodity.[12] We parameterize this decision using trade shares based on aggregations of the United Nations international trade data for 1987.[13] The result is a system of demand equations for domestic output and imports from each other region.

In addition to buying inputs and producing output, each sector must also choose its level of investment. We assume that capital is specific to each sector, it depreciates geometrically at rate d, and that firms choose their investment paths in order to maximize their market value. Following the cost of adjustment models of Lucas (1967), Treadway (1969) and Uzawa (1969) we assume that the investment process is subject to rising marginal costs of installation. To formalize this we adopt Uzawa's approach by assuming that in order to install J units of capital the firm must buy a larger quantity, I, that depends on its rate of investment (J/K) as follows:

$$I = \left(1 + \frac{\phi}{2}\frac{J}{K}\right)J$$

where ϕ is a non-negative parameter and the factor of two is included purely for algebraic convenience. The difference between J and I may be interpreted many ways; we will view it as installation services provided by the capital vendor.

Setting up and solving the firm's investment problem yields the following expression for investment in terms of parameters, the current capital stock, and marginal q (the ratio of the marginal value of a unit of capital to its purchase price):

$$I = \frac{1}{2\phi}\left(q^2 - 1\right)K$$

Following Hayashi (1979), and building on a large body of empirical evidence suggesting that a nested investment function fits the data much better than a pure q-theory model, we extend (5) by writing I as a function not only of q, but also of the firm's current profit, p, adjusted by the investment tax credit, t_4:

$$I = \alpha_2 \frac{1}{2\phi}\left(q^2 - 1\right)K + \left(1 - \alpha_2\right)\frac{\pi}{\left(1 - \tau_4\right)P^I}$$

This improves the empirical behavior of the specification and is consistent with the existence of firms that are unable to borrow and therefore invest purely out of retained earnings. The parameter a_2 was taken to be 0.3 based on a range of empirical estimates reported by McKibbin and Sachs (1991).

In addition to the twelve industries discussed above, the model also includes a special sector that produces capital goods. This sector supplies the new investment goods demanded by other industries. Like other industries, the investment sector demands labor and capital services as well as

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12 Anything else would require time-series data on imports of products from each country of origin to each industry, which is not only unavailable but difficult to imagine collecting.

13 Specifically, we aggregate up from data at the 4-digit level of the Standard International Trade Classification.

intermediate inputs. We represent its behavior using a nested CES production function with the same structure as that used for the other sectors, and we estimate the parameters using price and quantity data for the final demand column for investment. As before, we use U.S. data to estimate the substitution elasticities and country or region data to determine the share parameters.

2.2 Households

Households consume goods and services in every period and also demand labor and capital services. Household capital services consist of the service flows of consumer durables plus residential housing. Households receive income by providing labor services to firms and the government, and by holding financial assets. In addition, they receive imputed income from ownership of durables and housing, and they also may receive transfers from their region's government.

Within each region we assume household behavior can be modeled by a representative agent with an intertemporal utility function of the form:

$$U_t = \int_t^\infty (\ln C(s) + \ln G(s))\, e^{-\theta(s-t)}\, ds$$

\where $C(s)$ is the household's aggregate consumption of goods at time s, $G(s)$ is government consumption, which we take to be a measure of public goods supply, and q is the rate of time preference and is equal to 2.5 percent.[14] The household maximizes its utility subject to the constraint that the present value of consumption be equal to human wealth plus initial financial assets. Human wealth, H, is the present value of the future stream of after-tax labor income and transfer payments received by households. Financial wealth, F, is the sum of real money balances, real government bonds in the hands of the public (Ricardian neutrality does not hold in this model because some consumers are liquidity-constrained; more on this below), net holdings of claims against foreign residents and the value of capital in each sector. A full derivation can be found in McKibbin and Sachs (1991) and McKibbin and Wilcoxen (forthcoming).

Under this specification, it is easy to show that the desired value of each period's consumption is equal to the product of the time preference rate and household wealth:

$$P^C C = \theta (F + H)$$

There has, however, been considerable debate about whether the actual behavior of aggregate consumption is consistent with the permanent income model.[15] Based on a wide range of empirical evidence in the macroeconomics literature (see Campbell and Mankiw, 1990), we impose that only a fraction b of all consumers choose their consumption to satisfy (8) and that the remainder consume based entirely on current after-tax income. We have deliberately chosen to depart from the theoretical elegance of (8) because we are evaluating real-world policy and it is absolutely clear from empirical data that (8) alone is not a satisfactory model of aggregate consumption. This is an important difference between our approach and many of the other models used to study climate change policy, where theoretical elegance has often been given greater importance than realism.

[14] This specification imposes the restriction that household decisions on the allocations of expenditure among different goods at different points in time be separable. Also, since utility is additive in the logs of private and government consumption, changes in government consumption will have no effect on private consumption decisions.

[15] Some of the key papers in this debate are Hall (1978), Flavin (1981), Hayashi (1982), and Campbell and Mankiw (1990).

Whenever we have had to choose between theoretical elegance and empirical relevance, we have chosen the latter.[16]
The empirical finding that pure permanent income models such as (8) are rejected by the data while nested functions that include a large weight on current income fit much better could be interpreted in various ways, including the presence of liquidity-constrained households or households with myopic expectations. For the purposes of this paper we will not adopt any particular explanation but simply take b to be an exogenous constant.[17] This produces the final consumption function shown below:

$$P^C C = \beta\theta(F_t + H_t) + (1 - \beta)\gamma\, INC$$

where g is the marginal propensity to consume for the households consuming out of current income. Following McKibbin and Sachs (1991) we take b to be 0.3 in all regions.[18]

Within each period, the household allocates expenditure among goods and services in order to maximize $C(s)$, its intratemporal utility index. In this version of the model we assume that $C(s)$ may be represented by a nested CES function. At the top tier, consumption is composed of inputs of capital services, labor, energy and materials. Energy and materials, in turn, are CES aggregates of inputs of individual goods.[19] The elasticities of substitution at the energy and materials tiers were estimated to be 0.8 and 1.0, respectively. In this version of the model the top tier elasticity has been imposed to be unity.

Finally, the supply of household capital services is determined by consumers themselves who invest in household capital. We assume households choose the level of investment to maximize the present value of future service flows (taken to be proportional to the household capital stock), and that investment in household capital is subject to adjustment costs. In other words, the household investment decision is symmetrical with that of the firms.

2.3 Labor Market Equilibrium

We assume that labor is perfectly mobile among sectors within each region but is immobile between regions. Thus, within each region wages will be equal across sectors. The nominal wage is assumed to adjust slowly according to an overlapping contracts model (adjusted for different labor market institutional structures in different economies) where nominal wages are set based on current and expected inflation and on economy-wide labor demand relative to labor supply. In the long run labor supply, which is specified in terms of labor efficiency units, is given by the exogenous rate of population growth, but in the short run the hours worked can fluctuate depending on the demand for labor. For a given nominal wage, the demand for labor will determine short-run unemployment.

Relative to other general equilibrium models, this specification is unusual in allowing for involuntary unemployment. We adopt this approach because we are particularly interested in the

[16] One complication of introducing a nested specification for consumption is that traditional welfare evaluations are difficult. However, we view it as far more important to take empirical facts into account than for it to be easy to calculate equivalent variations.

[17] One side effect of this specification is that it will prevent us from using equivalent variation or other welfare measures derived from the expenditure function. Since the behavior of some of the households is implicitly inconsistent with the previous equation, either because the households are at corner solutions or for some other reason, aggregate behavior is inconsistent with the expenditure function derived from our utility function.

[18] Our value is somewhat lower than Campbell and Mankiw's estimate of 0.5.

[19] This specification has the undesirable effect of imposing unitary income and price elasticities. There is abundant empirical evidence against this assump-tion and we intend to generalize it in future work.

transition dynamics of the world economy. As in the case of consumption behavior, we are deliberately choosing to make the model less theoretically elegant in order to better represent reality. The alternative of assuming that all economies are always at full employment, which might be fine for a long-run model, is clearly inappropriate during the first few years after a shock. Unemployment is very likely to be an important part of the adjustment of the global economy of the short to medium term, and it is hard to justify assuming it away simply because it is inconvenient for theory. This is by no means a new idea, but despite its long and empirically robust standing in mainstream macroeconomics it is rarely implemented in a general equilibrium model.

2.4 Government

We take each region's real government spending on goods and services to be exogenous and assume that it is allocated among final goods, services and labor in fixed proportions, which we set to 1990 values for each region. Total government spending includes purchases of goods and services plus interest payments on government debt, investment tax credits and transfers to households. Government revenue comes from sales, corporate, and personal income taxes, and from issuing government debt. In addition, there can be taxes on externalities such as carbon dioxide emissions.

The difference between revenues and total spending gives the budget deficit. Deficits are financed by sales of government bonds. We assume that agents will not hold bonds unless they expect the bonds to be serviced, and accordingly impose a transversality condition on the accumulation of public debt in each region that has the effect of causing the stock of debt at each point in time to be equal to the present value of all future budget surpluses from that time forward. This condition alone, however, is insufficient to determine the time path of future surpluses: the government could pay off the debt by briefly raising taxes a lot; it could permanently raise taxes a small amount; or it could use some other policy. We assume that the government levies a lump sum tax in each period equal to the value of interest payments on the outstanding debt. In effect, therefore, any increase in government debt is financed by consols, and future taxes are raised enough to accommodate the increased interest costs. Thus, any increase in the debt will be matched by an equal present value increase in future budget surpluses. Other fiscal closure rules are possible such as always returning to the original ratio of government debt to GDP. These closures have interesting implications but are beyond the scope of this paper.

Finally, because our wage equation depends on the rate of expected inflation, we need to include money supply and demand in the model. The supply of money is determined by the balance sheet of the central bank and is exogenous. We assume that money demand arises from the need to carry out transactions and takes the following form:

$$M = P\,Y\,i^{\varepsilon}$$

where M is money, P is the price level, Y is aggregate output, i is the interest rate and ε is the interest elasticity of money demand. Following McKibbin and Sachs (1991) we take e to be -0.6.

2.5 International Trade and Capital Asset Flows

The eight regions in the model are linked by flows of goods and assets. Each region may import each of the 12 goods from potentially all of the other seven regions. In terms of the way international trade data is often expressed, our model endogenously generates a set of twelve 8x8 bilateral trade matrices, one for each good. The values in these matrices are determined by the import demands generated within each region.

The trade balance in each economy is the result of intertemporal saving and investment decisions of households, firms and governments. Trade imbalances are financed by flows of assets between countries: countries with current account deficits have offsetting inflows of financial capital; countries with surpluses have matching capital outflows. Global net flows are constrained to be zero. We assume that asset markets are perfectly integrated and that financial capital is freely mobile.[20] Under this assumption, expected returns on loans denominated in the currencies of the various regions must be equalized period to period according to a set of interest arbitrage relations of the following form:

$$i_k + \mu_k = i_j + \mu_j + \frac{\dot{E}_k^j}{E_k^j}$$

where i_k and i_j are the interest rates in countries k and j, m_k and m_j are exogenous risk premiums demanded by investors (possibly zero), and $E_k j$ is the exchange rate between the two currencies. The risk premiums are calculated in the course of generating the model's baseline and are generally held constant in simulations. Thus, if, in the base year, capital tended not to flow into a region with relatively high interest rates, it will not do so during the simulation. Finally, we also assume that OPEC chooses its foreign lending in order to maintain a desired ratio of income to wealth subject to a fixed exchange rate with the U.S. dollar.

Although financial capital is perfectly mobile, it is important to remember that *physical* capital is specific to sectors and regions and is hence *immobile*. The consequence of having mobile financial capital and immobile physical capital is that there can be windfall gains and losses to owners of physical capital. For example, if a shock adversely affects profits in a particular industry, the physical capital stock in that sector will initially be unaffected. Its value, however, will immediately drop by enough to bring the rate of return in that sector back to into equilibrium with that in the rest of the economy. Because physical capital is subject to adjustment costs, the portion of any inflow of financial capital that is invested in physical capital will also be costly to shift once it is in place.[21]

2.6 Constructing the Base Case

To solve the model, we first normalize all quantity variables by the economy's endowment of effective labor units. This means that in the steady state all real variables are constant in these units although the actual levels of the variables will be growing at the underlying rate of growth of population plus productivity. Next, we must make base-case assumptions about the future path of the model's exogenous variables in each region. In all regions we assume that the long run real interest rate is 5 percent, tax rates are held at their 1990 levels and that fiscal spending is allocated according to 1990 shares. Population growth rates vary across regions as shown in Table 3.

A crucial group of exogenous variables are productivity growth rates by sector and country. The baseline assumption in G-Cubed is that the pattern of technical change at the sector level is similar to the historical record for the United States (where data is available). In regions other than the United States, however, the sector-level rates of technical change are scaled up or down in order to match the region's observed average rate of aggregate productivity growth over the past two

[20] The mobility of international capital is a subject of considerable debate; see Gordon and Bovenberg (1994) or Feldstein and Horioka (1980).

[21] Financial inflows are not necessarily invested entirely in physical capital. Because of adjustment costs, part of any given inflow goes toward bidding up the stock market value of existing assets.

Table 3 Population Growth Rates

Region	Population Growth Rate
United States	0.5
Japan	0.0
Australia	0.8
Other OECD	0.7
China	1.5
Former Soviet Union	0.5
Other developing countries	1.0

decades. This approach attempts to capture the fact that the rate of technical change varies considerably across industries while reconciling it with regional differences in overall growth.[22] This is clearly a rough approximation; if appropriate data were available it would be better to estimate productivity growth for each sector in each region.

Given these assumptions, we solve for the model's perfect-foresight equilibrium growth path over the period 1990-2050. This a formidable task: the endogenous variables in *each* of the sixty periods number over 6,000 and include, among other things: the equilibrium prices and quantities of each good in each region, intermediate demands for each commodity by each industry in each region, asset prices by region and sector, regional interest rates, bilateral exchange rates, incomes, investment rates and capital stocks by industry and region, international flows of goods and assets, labor demanded in each industry in each region, wage rates, current and capital account balances, final demands by consumers in all regions, and government deficits.[23] At the solution, the budget constraints for all agents are satisfied, including both intratemporal and intertemporal constraints.

3 The Effects of the Kyoto Protocol

We now explore the effects of the Kyoto Protocol in five different scenarios. In the first, the United States meets its commitment under the Protocol but no other regions take action. This scenario is presented not as a practical proposition but as a benchmark against which multilateral scenarios can be compared. In the remaining four scenarios we examine the effects of the Protocol when all regions meet their commitments but the extent of international emissions permit trading varies.

The model only accounts for emissions of carbon dioxide from fossil fuel combustion, while the Protocol specifies targets for all greenhouse gases in carbon equivalent units.[24] Accordingly, we

[22] For a more detailed discussion of the importance of accounting for heterogeneity in sector-level productivity growth rates see Bagnoli, McKibbin and Wilcoxen (1996).

[23] Since the model is solved for a perfect-foresight equilibrium over a 60 year period, the numerical complexity of the problem is on the order of 60 times what the single-period set of variables would suggest. We use software developed by McKibbin (1992) for solving large models with rational expectations on a personal computer.

[24] The carbon equivalent units are specified in terms of the 100-year global warming potentials (GWPs) of carbon; e.g. a ton of methane emissions are counted as the equivalent of 21 tons of carbon (or 21 times 3.67 tons of carbon dioxide), since a ton of methane contributes roughly the same amount of radiative forcing over a century as 21 tons of carbon in the form of carbon dioxide. The permits are sold and used annually; we do not allow for banking or borrowing of emissions between years within the 2008-2012 budget period although this is permitted under the Protocol.

make the simplifying assumption that reductions in fossil-related carbon dioxide emissions will be made in proportion to the reductions required in total GHGs, and set the carbon target accordingly. For instance, the Protocol specifies a 2008-2012 average annual target for the United States of 93% of 1990 GHG emissions, which were approximately 1,600 million metric tons of carbon equivalents (MMTCe). The overall U.S. greenhouse gas target is therefore roughly 1,490 MMTCe. However, the share of fossil-related carbon dioxide in this target will depend on the marginal cost schedules for all of the gases, not just CO_2. To simplify, we assume that the fossil CO_2 target will be 93% of 1990 fossil CO_2 emissions, or approximately 1247 MMTC. This approach ignores the likelihood that relatively inexpensive GHG reductions will be available from non-energy and non-carbon sources, but provides a useful first approximation of the costs of achieving the Kyoto targets.

In each scenario, Annex I regions hold annual auctions of the specified quantity of carbon emissions permits in each of the years from 2008 to 2020.[25] The permits are required for the use of fossil fuels (coal, refined oil and natural gas) in proportion to the average carbon content per physical unit of each fuel. Revenues from the permit sales are assumed to be returned to households via a deficit-neutral lump sum rebate.[26] The policy is announced in 2000 so that forward-looking agents have a nearly decade to anticipate the policy and adapt to it.

Because G-Cubed represents each region as a competitive market economy in dynamic equilibrium with other regions, its representation of the former Soviet Bloc does not capture the shock associated with the institutional collapse of the formerly planned economy, the consequent dramatic decrease in emissions, or the fact that the region's emissions are likely to be well below the limit mandated by the Kyoto Protocol a decade from now. However, except for the reunification of Germany and the extensive development of parts of Eastern Europe, and the fact that crude oil and gas exports have continued, much of the region has remained substantially independent of the global economy since 1990; and it seems unlikely that international trade and capital flows between this region and the rest of the world will be large enough over the next decade to be a first-order concern. Since the region has relatively little interaction with the rest of the world in the model (as a consequence of the calibration that renders it in equilibrium in the base year), we treat the former Soviet Bloc exogenously in this analysis. (However, we account for income flows from the international sale of permits.) Taking these observations into account, in each of these scenarios, emission reductions in the former Soviet Bloc (encompassing the former Soviet Union and Eastern Europe) are specified exogenously, drawing on mitigation supply curves constructed mainly from the results of the Pacific Northwest National Laboratory's Second Generation Model (SGM). Furthermore, since former Soviet Bloc GHG emissions are expected to remain well below the targets mandated by the Kyoto Protocol, our exogenously specified supply curve for this region includes mitigation of greenhouse gases other than carbon. Thus the analysis assumes a former Soviet Bloc mitigation supply curve with roughly 300 MMTC of "paper tons" (emission allowances that would otherwise remain unused) available in 2010, declining to about 220 MMTC in 2015 and 140 MMTC in 2020, and roughly an additional 220 MMTC available in each year at a cost of less than \$50/MTC (95\$).[27]

[25] Beyond 2020 the supply of permits is allowed to increase at such a rate as to leave the real permit price at its 2020 value.

[26] The rebate is chosen to leave the deficit unchanged. It is not necessarily equal to the revenue raised by permit sales because other changes in the economy may raise or lower tax revenue. This formulation is not equivalent to free distribution of permits ("grandfathering") – that would be represented in a similar fashion in the model but the rebate would be set to the gross revenue raised by permit sales. Other uses of the revenue, such as cutting income taxes or reducing the fiscal deficit, would change some of the results substantially.

[27] The SGM numbers, in turn, are based partly on the results of a joint project between the OECD, the World Bank and the Office of Policy Development at US EPA (see OECD document OECD/GD(97)154 "Environmental Implications of Energy and Transport Subsidies" or Chapter 6 of OECD publication "Reforming Energy and Transport Subsidies." Our estimates ignore a projected ~140 MMTCe of other GHG "paper tons" available in 2010.

Taken together, the G-Cubed baseline and additional simplifying assumptions lead to reduction requirements in 2010 of 526 million metric tons of carbon (MMTC) for the United States, 67 MMTC for Japan, 48 MMTC for Australia, and 461 MMTC for the Other OECD countries; with approximately 27% of those reductions potentially offset by paper tons from the former Soviet Bloc.

We first present a scenario with unilateral U.S. commitment to meeting its Kyoto target, with no action undertaken by other regions. The remaining four scenarios involve the attainment of Annex I targets specified in the Protocol with:

1. no international permit trading between regions;
2. international permit trading permitted between all Annex I countries;
3. international permit trading permitted within the Other OECD region, and among the other Annex I regions (the U.S., Japan, Australia, and the former Soviet Bloc), but prohibited between the Other OECD region and the rest of the Annex I countries – the so-called “double umbrella” or “double bubble;” and
4. global permit trading; that is, the developing regions accept an emissions allocation consistent with their modeled baselines, and allow sales from their permit allocations to Annex I countries.

Graphs illustrating the most important impacts of the Protocol under different assumptions about the extent of international permit trading are provided at the end of the paper. The variables illustrated include regional emission permit prices; emission reductions; international permit sales and purchases; impacts on OPEC oil prices, sales and revenues; changes in international investment and exchange rates; and changes in regions’ exports, gross domestic products and gross national products.

Since neither the model’s behavioral parameters nor the future values of tax rates, productivity, or other exogenous variables can be known with complete certainty, the results presented here should be regarded as point estimates within a range of possible outcomes. The results do, however, give a clear indication of the mechanisms through which the economy responds to climate change policy. Section 5 will examine the sensitivity of the results to key parameters.

3.1 Unilateral Emissions Stabilization by the United States

Key macroeconomic results for the United States in the case of unilateral action by the United States are shown in Table 4. The figures shown are either percent deviations from a “business as usual” baseline or as changes from the baseline in units of 1995 dollars. Results are presented for a selection of years, although the model itself is annual.

In order to achieve the Kyoto target, emissions in the United States would need to drop by about 30 percent relative to the baseline in 2010 and by 42 percent in 2020.[28] The resulting price of carbon emissions permits would be $80 per metric ton (95$) in 2010 rising to $94 per ton in 2020.[29] Most of the drop in emissions comes about through a decline in coal consumption as total energy use drops and the fuel mix shifts toward natural gas, the least carbon-intensive fuel. This is reflected in

[28] Some of the emissions eliminated within the United States – roughly 10% in 2010 – are offset by increases in emissions elsewhere. Initially, over half of this "leakage" is due to the fact that other countries buy and burn the oil that the U.S. stops importing. This effect diminishes over time: by 2020 about two-thirds of the leakage is due to higher energy demand resulting from greater economic activity.

[29] Throughout the paper carbon will be measured in metric tons (tonnes) and prices will be in 1995 U.S. dollars.

Table 4 Aggregate Effects of Unilateral U.S. Action

	2005	2010	2015	2020
Permit price (95$)	—	$80	$85	$94
Carbon emissions	0.6%	-29.6%	-35.7%	-41.5%
Coal consumption	0.1%	-48.0%	-56.2%	-64.5%
Oil consumption	1.0%	-18.8%	-22.9%	-26.7%
Gas consumption	0.6%	-13.9%	-19.2%	-23.0%
GDP	0.2%	-0.7%	-0.8%	-0.7%
Consumption	0.7%	-0.4%	-0.2%	0.1%
Investment	1.0%	-1.1%	-0.7%	-0.5%
Exchange rate	3.5%	3.5%	4.6%	5.4%
Exports	-2.8%	-3.3%	-4.5%	-5.4%
Imports	-0.7%	-3.7%	-4.2%	-4.7%
Net foreign assets (Bil. 95$)	-$77	-$124	-$73	-$21
GNP	0.1%	-0.7%	-0.8%	-0.7%

Figure 1 2010 Gross National Product

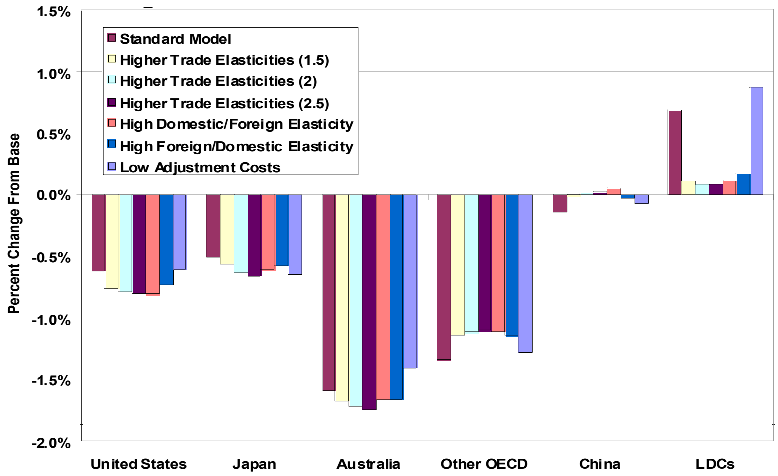

Figure 2 2010 Exports

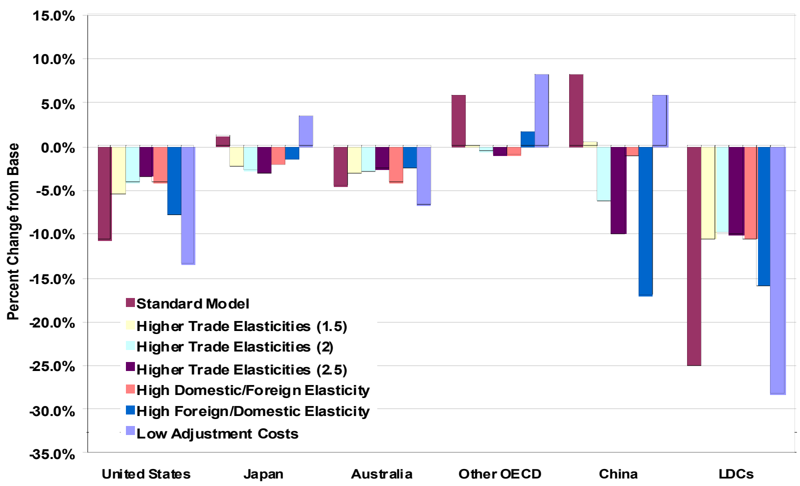

Table 5 Industry Effects of Unilateral U.S. Action

	2005	2010	2020			
	Price	Qty	*Price*	Qty	*Price*	Qty
Energy Industries						
Electric utilities	*-0.1%*	0.4%	*7.2%*	-6.2%	*12.6%*	-9.5%
Gas utilities	*-0.2%*	0.4%	*14.3%*	-13.6%	*26.0%*	-22.7%
Petroleum refining	*-0.5%*	0.4%	*19.6%*	-16.2%	*27.6%*	-24.4%
Coal mining	*0.1%*	-0.1%	*235.4%*	-40.3%	*375.6%*	-56.0%
Oil and gas extraction	*-0.2%*	0.0%	*-8.1%*	-10.4%	*-7.0%*	-19.7%
Other Sectors						
Other mining	*-0.4%*	-0.3%	*0.7%*	-2.6%	*0.7%*	-3.3%
Agriculture	*-0.3%*	0.2%	*-0.2%*	-1.2%	*-0.7%*	-0.8%
Forestry and wood	*-0.4%*	0.1%	*-0.4%*	-1.2%	*-0.9%*	-1.0%
Durable goods	*-0.6%*	-0.2%	*-0.6%*	-1.4%	*-1.2%*	-1.4%
Nondurables	*-0.3%*	0.3%	*-0.5%*	-1.0%	*-0.9%*	-0.6%
Transportation	*-0.2%*	0.3%	*-0.1%*	-1.6%	*-0.6%*	-1.3%
Services	*-0.2%*	0.4%	*-0.9%*	-0.2%	*-1.4%*	0.5%

the industry-level results shown in Table 5: the after-tax price of coal rises by more than 235 percent relative to its baseline level, while coal output declines by 40 percent in 2010 and by 56 percent in 2020. Output of petroleum products falls by 16% in 2010 and 24% in 2020; while natural gas output falls by 14% in 2010 and 23% in 2020. The crude oil and gas sector is somewhat less affected, suggesting that declines in demand fall disproportionately on imports: domestic output declines by 10 to 20 percent over the period.

Outside the energy industries, prices and output are affected very little. The only noteworthy result is that investment rises by about one percent during the period before the policy is implemented (2000-2007). This stems from the fact that the demand for services increases slightly when households and firms substitute away from energy. As a result, investment by the service industry increases as well, in anticipation of the increase in demand. The increase in investment is financed by an inflow of foreign capital, as aggregate national savings decline slightly. The capital inflow causes the exchange rate to appreciate by about 3.5 percent over that period. The exchange rate appreciation reduces exports, primarily of durable goods, and enables the capital inflow to be reflected in a worsening of the current account.

The international effects of the US policy vary across regions. Most Annex I countries experience mild decreases in GDP on the order of -0.1 percent, mild exchange rate depreciation, and increases in their net investment positions. China's exports rise by 4 to 6 percent in the early years of the policy. Other developing countries receive minor capital inflows after 2010, experience very slight exchange rate appreciation and end up with slightly higher GDPs, but also have lower production and exports of durable goods due to the change in exchange rates.

3.2 Annex I Targets Met Without International Permit Trading

In the second scenario, all Annex I regions meet their commitments under the Protocol. Each region is restricted to use of their allocated emissions; the permits can be traded within regions but not from

Table 6 Annex I Commitments Without International Permit Trading

	United States	Japan	Australia	Other OECD	China	LDC's
2005						
Permit price (95$)	—	—	—	—	—	—
Carbon emissions	1.9%	-2.4%	-0.1%	-1.8%	-0.9%	1.7%
Coal consumption	0.7%	-0.8%	0.0%	-0.6%	-0.8%	0.2%
Oil consumption	3.1%	-3.3%	-0.1%	-2.4%	-1.0%	2.6%
Gas consumption	1.9%	-0.7%	0.0%	-1.5%	-1.5%	1.8%
GDP	0.4%	-0.3%	0.1%	-0.2%	-0.3%	0.3%
Investment	2.9%	-0.5%	0.6%	-2.0%	-1.0%	2.7%
Exports	-8.6%	3.4%	-0.3%	7.6%	17.2%	-21.5%
Exchange rate	10.8%	-6.5%	0.7%	-12.9%	-4.7%	15.4%
Net foreign assets (Bil. 95$)	-$244	-$49	$16	$184	$20	$78
GNP	0.3%	-0.3%	0.1%	0.0%	-0.2%	0.5%
2010						
Permit price (95$)	$87	$112	$181	$261	—	—
Carbon emissions	-29.6%	-20.6%	-37.5%	-32.7%	-0.7%	3.3%
Coal consumption	-51.9%	-43.6%	-55.1%	-49.6%	-0.8%	0.3%
Oil consumption	-15.6%	-14.2%	-18.4%	-29.5%	-0.4%	5.1%
Gas consumption	-12.6%	-4.6%	-19.4%	-18.2%	-1.2%	3.4%
GDP	-0.4%	-0.6%	-1.8%	-1.5%	-0.2%	0.4%
Investment	0.8%	-1.3%	0.2%	-3.8%	-0.4%	2.9%
Exports	-10.7%	1.2%	-4.5%	5.8%	8.1%	-25.1%
Exchange rate	10.5%	-5.8%	2.1%	-13.5%	-4.7%	15.9%
Net foreign assets (Bil. 95$)	-$451	-$55	$29	$370	$34	$141
GNP	-0.6%	-0.5%	-1.6%	-1.3%	-0.1%	0.7%
2020						
Permit price (95$)	$101	$162	$230	$315	—	—
Carbon emissions	-35.7%	-27.6%	-44.1%	-39.1%	-0.7%	3.1%
Coal consumption	-59.7%	-56.5%	-64.7%	-58.4%	-0.7%	0.2%
Oil consumption	-19.8%	-19.6%	-21.2%	-35.1%	-0.4%	4.8%
Gas consumption	-17.9%	-6.7%	-23.9%	-24.0%	-1.1%	3.4%
GDP	-0.5%	-0.7%	-1.8%	-1.6%	-0.2%	0.4%
Investment	0.9%	-1.4%	0.3%	-3.5%	-0.7%	2.5%
Exports	-12.2%	1.3%	-6.7%	4.1%	4.7%	-20.7%
Exchange rate	11.0%	-7.0%	5.0%	-13.0%	-5.0%	15.7%
Net foreign assets (Bil. 95$)	-$489	-$104	$48	$490	$43	$184
GNP	-0.7%	-0.7%	-1.5%	-1.3%	-0.1%	0.7%

one region to another.[30] This simulation allows us to measure the heterogeneity of the Annex I regions. Differences in baseline emissions growth, endowments of fossil fuels, reliance on fossil fuels for energy generation and initial fossil fuel prices mean that the regions face substantially different costs of achieving stabilization. This will be reflected in the pattern of permit prices (which will indicate the cost of stabilization at the margin) and GDP losses across regions.

The results for the Annex I policy without international permit trading are shown in Table 6. Key results are presented for 2005, 2010 and 2020 for the four OECD regions in the model (United

[30] Even though there is no trading between regions, trading is implicitly allowed between the countries within a region. In particular, the "Other OECD" region lumps together the European Union, Canada and New Zealand, so trading is implicitly allowed between these countries.

States, Japan, Australia and other OECD, hereafter referred to as ROECD), as well as China and the less developed countries (LDCs).

The effects of the policy differ substantially across the regions: in 2010, permit prices per metric ton of carbon range from a low of $87 in the US to a high of $261 in the ROECD region. These results show that both marginal and average costs of abating carbon emissions differ substantially across

countries. Since, by assumption, all regions have access to the same technologies, the differences in permit prices reflect differences in mitigation opportunities: regions which have relatively low baseline carbon emissions per unit of output, and are thus relatively sparing in their use of fossil fuels, have relatively fewer options for reducing emissions further. The differences among regions stem in part from differences in the fuel mix but also depend on the availability of alternative fuels and the extent to which baseline emissions rise above the stabilization target. Thus Australia, which has relatively few substitution possibilities and a high baseline emission trajectory (due to fairly high population growth and strong productivity growth) finds it costly to reach the 1990 stabilization target. The United States, with low energy prices, a high reliance on coal and abundant natural gas, finds it relatively cheap to change the composition of energy inputs.
The table shows results for both GDP and GNP. The GDP results indicate the extent of international shifts in production but are a poor measure of national welfare. The GNP figures are a better (although far from perfect) welfare measure because GNP reflects the total income accruing to the residents of a country, including net income transfers to and from factors of production located abroad. Savers in countries with high costs of abatement shift some of their financial capital overseas, maintaining rates of return that otherwise would be much lower. The ordering of countries by GNP loss is the same as that by GDP loss but the dispersion of GNP losses is smaller because of the ability of agents to shift capital into higher return activities abroad.

The effect on GDP follows a pattern similar to that of mitigation costs: GDP in 2010 falls slightly in the US and Japan while in Australia and ROECD it falls by 1.8 and 1.5 percent, respectively. Comparing this simulation with the previous one shows that the United States is better off under the Annex I policy than it is when it reduces emissions on its own: in 2010, U.S. GDP 0.4 percent below its baseline value while under the unilateral policy it would have fallen by 0.7 percent. One reason for the lower costs is that U.S. exports are more competitive relative to those from other OECD economies when more countries impose carbon constraints. Another reason for the reduction in GDP loss lies in the fact that the United States has substantially lower marginal costs of abating carbon emissions than other OECD economies. Stabilizing emissions requires a smaller price increase in the U.S. than it does in other countries. Also the policy directly reduces rates of return in each economy, and relatively more so in sectors that are relatively carbon intensive. Lower abatement costs in the U.S. mean that rates of return to capital in the U.S. fall less than in other OECD countries. This shift in rates of return induces investors to shift their portfolios toward U.S. assets, leading to an increase in U.S. investment. Thus, production tends to fall less in the U.S. than it does in other OECD economies. The effect is particularly apparent in the years immediately before the policy takes effect: U.S. investment is three percent above baseline in 2005. In addition, the U.S. also benefits from lower world oil prices as Annex I oil demand falls. The boost in investment and lower oil prices both tend to raise energy demand and cause permit prices to rise relative to the unilateral stabilization scenario – from $80 to $87 in 2010 and from $94 to $101 in 2020. U.S. income, as measured by GNP, rises slightly in the period before the policy takes effect and then falls by 0.5 to 0.6 percent in 2010-2020.

Examining the effect of the policy on different regions raises a number of interesting results that tend to be ignored in popular discussion of the impacts of emission permit trading. Those regions that have

the largest relative abatement costs, such as Australia and ROECD, have large capital outflows because of the fall in the rate of return to capital in high abatement cost countries. ROECD, which faces the greatest cost of stabilizing emissions, has a large capital outflow, accumulating to roughly $490 billion (95$) by 2020. Most of this capital outflow goes to the United States, and some also goes to developing countries, which are not controlling emissions at all. Capital flows to developing countries are limited by adjustment costs, however: it is expensive for a region with a relatively small capital stock to absorb a large flow of new capital.[31] It is relatively cheap for a large country such as the United States to absorb capital for the same reason: the costs of a given absolute change in a particular capital stock decrease with the size of the stock. Thus, relatively small capital inflows can exhaust arbitrage opportunities in developing economies. This is an important insight because it contradicts the popular perception that greenhouse abatement policies will lead to wholesale migration of industries from developed countries to non-abating developing countries. Our results show this is quite unlikely; moreover, most of the financial capital reallocation is between OECD economies.
Capital flows cause the exchange rates of countries receiving financial capital, such as the Untied States and developing countries, to appreciate, and cause the Japanese and ROECD currencies to depreciate. The dollar appreciates by 25 percent relative to the ROECD currencies, but depreciates by 5 percent relative to the currency of developing countries. The ROECD currency depreciates by 30 percent relative to the developing countries. These changes lead directly to changes in export patterns. By 2010, ROECD exports of durable goods increase by about 6 percent over baseline while U.S. exports of durables fall by 11 percent. At the same time, capital flows cause Australian and ROECD GNP to fall by less slightly than GDP, since these countries' increased foreign investments offset some of the lost income from domestic production.

Overall, the effect of achieving the Kyoto targets is to reduce GDP in countries with high abatement costs, cause an outflow of capital, depreciate their exchange rates and stimulate exports. The effect on low-cost countries is the opposite: capital inflows tend to raise GDP by reducing real interest rates and stimulating domestic demand in the short run, and by raising the capital stock in the medium to long run. Capital inflows also appreciate the exchange rate and diminish exports.

The effect of the Protocol on developing countries is particularly interesting. In the case of the LDCs, the exchange rate appreciation has multiple costs and benefits. Exports become less competitive but imports become cheaper and the dollar value of LDC international debt falls dramatically, leading to a net *improvement* in the LDCs' net international investment position in spite of significant capital inflows, as mentioned above. LDC gross domestic product rises by three percent in 2010, and gross national product rises by 0.7 percent. Clearly, the absence of commitments under the Kyoto Protocol confers significant benefits to LDCs through international policy transmission.

In addition, the decline in Annex I oil demand leads to a 10 percent decline in OPEC oil exports and a 17 percent decline in world oil prices. The decline in oil prices benefits the LDCs, whose increased oil consumption causes an increase in LDC carbon emissions equivalent to approximately 6 percent of Annex I emission reductions. This 6 percent "leakage effect," however, does not translate into increased LDC exports of carbon-intensive durable goods, which are significantly dampened by the impact of capital inflows on LDC exchange rates. Instead it is the region most adversely affected by mitigation policy – ROECD – which experiences an increase in exports. It may seem surprising that export performance should improve in the country most hurt by climate change policy but it is

[31] In apparent contradiction to this statement, the results in Table 6 show an apparent net capital outflow from the LDCs rather than a capital inflow. The improvement in the LDCs' net foreign asset position is due to the fact that their real exchange rate appreciation leads to a decrease in the dollar value of their outstanding debt. The decrease in the value of outstanding debt outweighs policy-induced the capital inflow, leading to an apparent capital outflow.

simply the result of consistent international accounting: countries which experience capital outflows must experience trade surpluses, while countries which experience capital inflows must experience trade deficits.

3.3 Annex I International Permit Trading

The third scenario is identical to the second except that we allow international trading in emissions permits among Annex I countries. The effect of allowing trading is twofold. First, arbitrage will cause the price of a permit to be equal in all Annex I countries. This will ensure that marginal costs of carbon abatement will be equal across countries and that Annex I emission reductions will be achieved at minimum cost. Countries with relatively low abatement costs will sell permits and abate more than in the previous scenario; countries with high costs will buy permits and undertake less domestic abatement.

In addition, trading makes possible a relaxation of the overall constraint during the 2008-2012 period because the emissions of one Annex I region, the former Soviet Bloc, are likely to be below the limit specified under the Protocol. The relaxation of the constraint means that actual emission reductions under the Protocol will be considerably lower – perhaps as much as 40% lower – with international permit trading than without it, at least during the first budget period. The particular circumstances of the former Soviet Bloc thus make it difficult to determine the pure gains from permit trading, independent of the relaxation of the constraint.[32]

Results for this scenario are shown in Table 7. In contrast to independent mitigation, international permit trading leads to a uniform permit price throughout the Annex I that rises from about $61 per ton in 2010 to $109 per ton in 2020. These prices, lower than any OECD region's marginal mitigation cost in the absence of international permit trading, lead to lower increases in fossil fuel prices and considerably lower domestic reductions than in the previous case since reductions can be avoided by purchasing allowances from the former Soviet Bloc. At the 2010 permit price of $61 per ton, the former Soviet Bloc sells not only its excess allowances, 293 MMTC, but also reduces emissions to sell an additional 253 MMTC of allowances. Thus the OECD countries purchase nearly 550 MMTC of emission allowances from the former Soviet Bloc rather than undertake domestic reductions, thereby dramatically reducing the cost of meeting their commitments. These purchases particularly benefit ROECD, which uses internationally purchased allowances to meet 72 percent of its obligations and thus achieves a 77 percent reduction in its marginal abatement costs. The United States and Australia use internationally purchased allowances to meet 29 percent and 65 percent of their respective obligations, and benefit from 30 percent and 66 percent reductions in marginal abatement costs. International purchases of former Soviet Bloc allowances amount to nearly $33 billion (95$) in 2010 and rise to nearly $54 billion by 2020.

Interestingly, as the regional economies continue to grow after 2010, the demand for emission allowances increases while the former Soviet Bloc's willingness to supply them declines. As a consequence, international permit prices rise continuously after 2010, and by 2020, prices rise to $109 per ton. At this price, the United States becomes a net permit *seller*, supplying about 83 MMTC of allowances to Japan, Australia and ROECD at a total cost of nearly $9 billion, and taking an equivalent quantity of domestic emission reductions in excess of its international commitment.

[32] Previous analysis using the G-Cubed model indicates that the pure gains from trade are on the order of 20 to 25 percent in the case OECD international permit trading. See McKibbin, Shackleton and Wilcoxen (1998b).

Table 7 Annex I Commitments With International Permit Trading

	United States	Japan	Australia	Other OECD	China	LDC's
2005						
Permit price (95$)	—	—	—	—	—	—
Annual permit sales (Bil. 95$)	—	—	—	—	—	—
Carbon emissions	1.4%	-2.7%	-0.3%	-2.1%	-0.6%	1.8%
Coal consumption	0.6%	-1.0%	-0.3%	-0.6%	-0.6%	0.2%
Oil consumption	2.3%	-3.7%	-0.7%	-2.9%	-0.8%	2.7%
Gas consumption	1.5%	-0.7%	-0.8%	-1.7%	-1.2%	1.9%
GDP	0.3%	-0.2%	0.0%	-0.2%	-0.2%	0.3%
Investment	2.3%	-0.6%	-0.3%	-2.2%	-0.6%	3.0%
Exports	-6.9%	3.6%	1.1%	8.9%	11.5%	-22.8%
Exchange rate	8.9%	-7.1%	-0.6%	-14.4%	-2.4%	16.6%
Net foreign assets (Bil. 95$)	-$139	-$28	$22	$242	$16	$67
GNP	0.2%	-0.2%	0.0%	-0.1%	-0.2%	0.5%
2010						
Permit price (95$)	$61	$61	$61	$61	—	—
Annual permit sales (Bil. 95$)	-$9.4	-$1.5	-$1.9	-$20.3	—	—
Carbon emissions	-20.9%	-13.0%	-13.0%	-9.1%	-0.5%	2.6%
Coal consumption	-36.0%	-24.2%	-18.7%	-12.1%	-0.5%	0.4%
Oil consumption	-11.8%	-10.4%	-6.7%	-9.0%	-0.4%	4.0%
Gas consumption	-8.8%	-2.9%	-6.8%	-5.6%	-0.7%	2.9%
GDP	-0.2%	-0.4%	-0.7%	-0.6%	-0.1%	0.4%
Investment	0.8%	-1.0%	-0.3%	-2.4%	-0.3%	2.8%
Exports	-7.6%	2.5%	-0.8%	8.0%	5.7%	-23.7%
Exchange rate	8.5%	-6.7%	-0.4%	-14.7%	-2.1%	17.5%
Net foreign assets (Bil. 95$)	-$304	-$12	$36	$476	$29	$121
GNP	-0.5%	-0.4%	-0.8%	-0.6%	-0.1%	0.7%
2020						
Permit price (95$)	$109	$109	$109	$109	—	—
Annual permit sales (Bil. 95$)	$9.0	-$4.4	-$4.6	-$53.7	—	—
Carbon emissions	-33.3%	-18.6%	-18.4%	-13.0%	-0.4%	2.7%
Coal consumption	-54.5%	-35.4%	-26.8%	-17.8%	-0.4%	0.4%
Oil consumption	-19.9%	-14.3%	-9.2%	-12.3%	-0.3%	4.2%
Gas consumption	-16.6%	-4.5%	-10.0%	-8.3%	-0.6%	3.1%
GDP	-0.5%	-0.5%	-0.9%	-0.7%	-0.1%	0.5%
Investment	0.5%	-1.1%	-0.2%	-2.4%	-0.4%	2.7%
Exports	-9.1%	2.2%	-1.9%	7.3%	2.7%	-20.2%
Exchange rate	9.1%	-7.1%	0.5%	-15.0%	-2.1%	17.9%
Net foreign assets (Bil. 95$)	-$390	-$22	$47	$614	$40	$165
GNP	-0.7%	-0.5%	-1.1%	-0.7%	0.0%	0.7%

The economic impacts of the Protocol are generally significantly reduced by both the equalization of marginal mitigation costs and permit prices under an international permit trading regime, as well as by the reduction in overall mitigation due to the sale of former Soviet Bloc's excess allowances. U.S. GDP costs in 2010 are cut from 0.4 percent to 0.2 percent. Japanese GDP costs are cut from 0.6 percent to 0.4 percent, Australia's from 1.8 percent to 0.7 percent, and ROECD's from 1.5 percent to 0.6 percent. Permit trading has little effect on non-participants: results for China and the developing countries are very similar to the no-trading case.

Exchange rate changes are similar in sign but generally larger in magnitude than under the no-trading scenario. The Japanese and ROECD currencies, in particular, depreciate somewhat more, while the currency of the developing region has a larger appreciation. This happens because the countries buying permits must ultimately pay for them with additional exports, either immediately or in the future. Thus, the purchasing country's current account must eventually move toward surplus by an amount corresponding to the value of the permits.[33] The changes in real exchange rates are necessary to accommodate the changes in trade balances.

Permit trading reduces the OECD's overall GNP costs of meeting their commitments under the Kyoto Protocol by about 63 percent in 2010, from $272 billion to $128 billion, or by $143 billion.[34] On the basis of previous analysis using G-Cubed of OECD permit trading without former Soviet Bloc participation, we estimate that roughly 60 percent of these benefits are due to relaxation of the constraint, while the other 40 percent constitute true gains from trade. If we also take into account the spillover effects on China and the LDCs, the world GNP costs of meeting Kyoto commitments is cut by 52 percent from $241 billion to $115 billion, or by $125 billion. These 2010 GNP gains are very unequally dispersed, however: the U.S.[35] gains only $14 billion, and Australia and Japan only $5 billion each; while the ROECD region gains $102 billion. Chinese and LDC GNPs are almost completely unaffected.

3.4 The "Double Umbrella"

In the fourth scenario, the ROECD countries engage in exclusive permit trading and the rest of the Annex I countries engage in permit trading independently of the ROECD countries. Results from this scenario are contained in Table 8. The key difference between this scenario and full Annex I trading is that ROECD no longer buys 327 million tonnes worth of permits from the former Soviet Bloc. As a result, the effects on ROECD look much like the no-trading case and abatement costs in the rest of Annex I fall substantially. Permit prices fall to $32 in 2010 and $71 in 2020. The U.S. benefits in two ways: from lower permit prices and also from relatively large capital flows from ROECD to the U.S (because high energy prices reduce returns to capital in ROECD). As a result, U.S. GDP remains at its baseline level in 2010 and falls by only 0.2 percent in 2020.

It is interesting to note that the ROECD region is slightly better off in the initial years of the double umbrella simulation than under Annex I trading. In 2005, GDP and GNP are slightly higher (that is, they fall slightly less), fuel consumption and investment are both higher, and capital outflows are smaller. The reason for this is somewhat subtle. When the ROECD region adopts carbon controls under either simulation, one effect is to shift some investment to other regions, especially the United States. Under Annex I trading, other countries are also subject to relatively tight carbon controls and are attempting to do the same thing. This causes the U.S. dollar to appreciate substantially, rising by 23% relative to the ROECD currency in 2005. Under the double umbrella, however, carbon controls are much looser in regions other than the ROECD so there is less competition to shift capital into the United States. There is less appreciation of the dollar, which rises by only 16% relative to the ROECD currency. This makes it less expensive for ROECD investors to convert part of their portfolios to U.S. investments.

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33 This shifting of resources between economies due to changes in property rights is known in international economics as the "transfer problem," and is the subject of a large literature dating back to the early 1920s when the effects of German war reparations were hotly debated.

34 We do not provide estimates of GNP effects for the former Soviet Bloc because of the difficulties mentioned previously.

35 The U.S. experiences a small GDP loss from trading in 2010, due to business cycle effects stemming from our assumption that wages adjust slowly: the sharp increase in U.S. energy prices under the trading scenario temporarily reduces labor demand relative to the no-trading case, leading to a decline in GDP.

Table 8 Annex I Commitments With "Double Umbrella"

	United States	Japan	Australia	Other OECD	China	LDC's
2005						
Permit price (95$)	—	—	—	—	—	—
Annual permit sales (Bil. 95$)	—	—	—	—	—	—
Carbon emissions	1.2%	-2.0%	-0.3%	-1.3%	-0.5%	1.1%
Coal consumption	0.5%	-0.7%	0.0%	-0.5%	-0.5%	0.1%
Oil consumption	1.9%	-2.9%	-0.7%	-1.8%	-0.6%	1.8%
Gas consumption	1.2%	-0.6%	-0.4%	-1.1%	-0.9%	1.3%
GDP	0.3%	-0.2%	-0.1%	-0.1%	-0.2%	0.2%
Investment	1.8%	-0.5%	-0.5%	-1.4%	-0.6%	1.9%
Exports	-5.4%	3.2%	1.1%	5.3%	10.5%	-14.8%
Exchange rate	6.9%	-5.7%	-1.3%	-9.1%	-2.7%	10.5%
Net foreign assets (Bil. 95$)	-$137	-$18	$20	$139	$13	$53
GNP	0.2%	-0.2%	0.0%	0.0%	-0.1%	0.3%
2010						
Permit price (95$)	$32	$32	$32	$263	—	—
Annual permit sales (Bil. 95$)	-$11.4	-$1.6	-$1.3	—	—	—
Carbon emissions	-9.2%	-5.7%	-6.7%	-32.7%	-0.4%	2.2%
Coal consumption	-18.2%	-11.9%	-9.6%	-49.8%	-0.4%	0.3%
Oil consumption	-3.3%	-4.1%	-3.2%	-29.5%	-0.3%	3.4%
Gas consumption	-3.1%	-1.5%	-3.6%	-18.1%	-0.7%	2.2%
GDP	0.0%	-0.3%	-0.4%	-1.4%	-0.1%	0.3%
Investment	1.3%	-0.6%	-0.2%	-3.4%	-0.2%	2.0%
Exports	-6.9%	1.9%	-0.5%	4.3%	5.3%	-16.7%
Exchange rate	6.6%	-5.4%	-1.3%	-9.3%	-2.5%	11.0%
Net foreign assets (Bil. 95$)	-$281	-$1	$32	$298	$23	$103
GNP	-0.2%	-0.2%	-0.5%	-1.3%	-0.1%	0.5%
2020						
Permit price (95$)	$71	$71	$71	$318	—	—
Annual permit sales (Bil. 95$)	-$19.8	-$5.7	-$3.9	—	—	—
Carbon emissions	-18.6%	-10.4%	-11.0%	-39.9%	-0.3%	2.2%
Coal consumption	-32.3%	-21.3%	-16.1%	-60.0%	-0.4%	0.3%
Oil consumption	-9.6%	-7.3%	-5.3%	-35.7%	-0.2%	3.5%
Gas consumption	-8.5%	-2.6%	-6.1%	-24.2%	-0.4%	2.4%
GDP	-0.2%	-0.3%	-0.6%	-1.5%	-0.1%	0.3%
Investment	0.7%	-0.8%	-0.3%	-3.1%	-0.3%	1.8%
Exports	-7.7%	1.7%	-1.2%	2.4%	2.7%	-14.5%
Exchange rate	6.2%	-6.0%	-1.3%	-8.4%	-2.8%	10.7%
Net foreign assets (Bil. 95$)	-$363	-$15	$41	$440	$29	$141
GNP	-0.5%	-0.3%	-0.7%	-1.3%	0.0%	0.5%

This is entirely a short run effect, however. Once the policy is actually in force, the ROECD is hurt more by high abatement costs under the double umbrella than it gains from changes in the terms of trade. By 2010, ROECD GDP and GNP are about 0.8% below what they would have been under Annex I trading.

Table 9 Annex I Commitments With Global Permit Trading

	United States	Japan	Australia	Other OECD	China	LDC's
2005						
Permit price (95$)	—	—	—	—	—	—
Annual permit sales (Bil. 95$)	—	—	—	—	—	—
Carbon emissions	0.6%	-1.2%	-0.1%	-0.9%	0.9%	0.8%
Coal consumption	0.2%	-0.3%	0.0%	-0.3%	0.9%	0.4%
Oil consumption	1.0%	-1.7%	-0.4%	-1.3%	1.2%	1.1%
Gas consumption	0.7%	-0.3%	-0.4%	-0.8%	1.8%	0.7%
GDP	0.1%	-0.1%	0.0%	-0.1%	0.4%	0.1%
Investment	1.0%	-0.2%	-0.3%	-1.0%	2.4%	1.1%
Exports	-2.9%	1.5%	1.0%	4.1%	-27.2%	-8.7%
Exchange rate	3.7%	-3.1%	-0.6%	-7.0%	12.4%	6.1%
Net foreign assets (Bil. 95$)	-$54	-$8	$12	$106	-$38	$25
GNP	0.1%	-0.1%	0.0%	0.0%	0.3%	0.2%
2010						
Permit price (95$)	$23	$23	$23	$23	$23	$23
Annual permit sales (Bil. 95$)	-$8.9	-$1.2	-$1.0	-$9.3	$7.0	$4.5
Carbon emissions	-7.4%	-4.2%	-4.9%	-3.4%	-19.1%	-7.9%
Coal consumption	-13.3%	-8.9%	-7.0%	-4.5%	-22.0%	-13.3%
Oil consumption	-3.6%	-2.8%	-2.4%	-3.3%	-3.3%	-5.6%
Gas consumption	-3.0%	-1.0%	-2.9%	-2.2%	-10.4%	-2.0%
GDP	-0.1%	-0.1%	-0.3%	-0.3%	-0.6%	-0.2%
Investment	0.4%	-0.3%	-0.2%	-1.0%	0.6%	0.1%
Exports	-3.4%	0.8%	-0.3%	3.6%	-22.6%	-9.7%
Exchange rate	3.6%	-2.8%	-0.6%	-7.2%	10.9%	6.5%
Net foreign assets (Bil. 95$)	-$115	-$2	$20	$208	-$71	$51
GNP	-0.2%	-0.1%	-0.4%	-0.2%	-0.4%	0.0%
2020						
Permit price (95$)	$37	$37	$37	$37	$37	$37
Annual permit sales (Bil. 95$)	-$21.1	-$3.9	-$2.5	-$25.2	$24.3	$17.1
Carbon emissions	-11.4%	-6.1%	-6.5%	-4.6%	-24.9%	-11.1%
Coal consumption	-19.2%	-12.8%	-9.7%	-6.3%	-28.7%	-17.8%
Oil consumption	-6.2%	-4.2%	-3.1%	-4.4%	-4.9%	-8.2%
Gas consumption	-5.5%	-1.5%	-3.5%	-3.0%	-13.5%	-3.6%
GDP	-0.1%	-0.2%	-0.3%	-0.3%	-0.7%	-0.3%
Investment	0.3%	-0.4%	-0.1%	-1.0%	0.3%	0.0%
Exports	-3.9%	0.7%	-0.7%	3.3%	-20.0%	-9.0%
Exchange rate	3.6%	-3.4%	-0.4%	-7.5%	15.0%	7.0%
Net foreign assets (Bil. 95$)	-$155	-$13	$25	$263	-$66	$78
GNP	-0.3%	-0.2%	-0.4%	-0.3%	-0.1%	0.0%

3.5 Global Trading

In the final scenario, we assume that the non-Annex I developing countries agree to distribute annual quantities of domestic emission permits consistent with their baseline emissions, and to allow these permits to be traded on international markets.[36] These results are contained in Table 9. The consequence of bringing developing countries into the trading regime is that Annex I countries

[36] As with the Annex I regions, we assume that developing regions sell a fixed number of permits at auction on an annual basis, and return the revenues to households as a lump-sum payment.

can purchase emission allowances from owners in developing countries. These owners, in turn, would be willing to sell allowances to Annex I buyers only if the allowance price exceeded the marginal cost to the owners of undertaking emission reductions within the developing countries. The market process would thus lead to least cost reductions on a global scale: emission reductions would be taken wherever they are cheapest, but Annex I countries would pay for them.

Full global trading cuts the permit cost to $23 per metric ton of carbon (MTC) in 2010 and $37 per MTC in 2020, and has minor GDP effects in the Annex I economies, ranging from less than -0.1% for the U.S. and Japan to –0.3% for Australia and the ROECD. In 2010, the OECD regions achieve 75 to 90 percent of their targets through international purchases of emission allowances. Moreover, since wider availability of emission allowances reduces permit prices, OECD regions are able to purchase international permits at a lower overall cost than in the preceding scenarios: in 2010, international permit sales total $20 billion in the global trading case, about 60% of the $33 billion value of former Soviet Bloc international permit sales in the Annex I trading case. China provides about 300 MMTC of these allowances, and the other LDCs provide about 195 MMTC; the former Soviet Bloc provides another 410 MMTC. Nearly all of the reductions in China and the LDCs are achieved through reductions in coal use. Thus, one of the crucial effects of expanding from an Annex I trading regime to global trading is to transfer mitigation from oil-related emissions to coal. As a result, oil exporting countries experience only very modest losses in exports and revenues. Finally, global trading eliminates the possibility of carbon leakage.

The reduction in mitigation costs and the equalization of mitigation costs across regions greatly reduces the international macroeconomic effects of the Kyoto Protocol, compared with the previous scenarios. Except for Australia, OECD regions experience GDP and GNP impacts of at most 0.4 percent. Capital flows, exchange rate impacts and trade effects are all considerably lower. Relative to the no-trading case, aggregate OECD GNP costs in 2010 are cut by 78 percent from $233 billion to $51 billion; and relative to the Annex I trading case, costs are cut by 59 percent. All OECD regions benefit from cost reductions.

Relative to scenarios in which they do not participate in controlling emissions, the developing countries are significantly worse off because they no longer experience significant capital inflows, exchange rate appreciations, reductions in the value of their debt burdens, or lower oil prices. GDP in the LDC region falls by 0.2 percent relative to baseline in 2010 instead of rising as it does under the other simulations. Similarly, China's GDP is also lower under global trading than under the other regimes. In terms of GNP, participating in global trading costs the LDCs $26 billion in 2010 relative to both the Annex I no-trading and Annex I trading cases. These results suggest that that the Annex I countries may have to use part of their savings ($73 billion in 2010 from moving from Annex I trading to global trading) simply to induce the developing countries to participate in helping them meet their commitments under the Protocol.

4 Alternative Revenue Recycling Mechanisms

The preceding results are all based on the assumption that countries that undertake commitments to auction emission permits and return the revenues to households in lump-sum payments. We have used the G-Cubed model to perform additional scenarios, using alternative assumptions about the distribution of permits and/or recycling of revenues[37]. While we do not present those results in

[37] See McKibbin and Wilcoxen (1995b) for results on recycling assumptions using an earlier version of the model.

detail here, we note that the results suggest that alternative revenue recycling mechanisms that serve to increase national savings and/or investment do not have any substantial impact on the marginal costs of meeting targets (under any given set of rules about international permit trading), but can have substantially different international macroeconomic effects. For example, when permit revenues are used to reduce fiscal deficits or increase fiscal surpluses, regions' national savings increase and the global cost of capital falls. Changes in the cost of capital leads to different net international capital flows, exchange rate impacts, and GDP/GNP effects. Extending this insight, we note that the distribution of costs and benefits may be substantially affected if regions pursue differing policies, for example if some regions pursue revenue recycling policies that encourage saving and investment and other regions pursue policies that encourage current consumption. We intend to explore these issues further in continued work with the model.

5 Sensitivity Analysis

The results discussed in the preceding sections are conditional on a range of assumptions built into the model. For a model like G-Cubed, which focuses on trade and capital flows, two particularly important sets of parameters are those governing the responsiveness of trade to changes in the prices of traded goods (the "Armington" elasticities) and those governing the ease with which investment can increase industries' stocks of physical capital (capital stock adjustment cost parameters). In this section we examine how changes in these parameters affect both the baseline case and policy scenario results. To keep the discussion manageable, we focus only on the case which the Annex I regions achieve their targets without international permit trading. Because it involves the largest international responses to carbon targets, this No-trade case provides the greatest illumination of the sensitivity of the results to parameter assumptions.

There are two sets of Armington trade elasticities in the model, one specifying the elasticity of substitution between domestic and foreign goods, and the other specifying substitutability between alternative sources of foreign goods. In our standard model, we set both of these elasticities to unity. For comparison, we have conducted two groups of sensitivity analyses: one group which we set both elasticities at values of 1.5, 2.0 and 2.5, and another in which we set one of the elasticities at 1.0 and the other at 2.0. The first group of analyses reveals the importance of the overall responsiveness of trade to policy shocks while the second reveals relative importance of the two tiers in determining that responsiveness.

Like the trade elasticities, the capital stock adjustment cost parameters can strongly influence the results. In our standard model, we specify an adjustment cost parameter f of 0.4. In our sensitivity, we reduce the parameter to 0.2. For an economy with net investment equal to 10% of the capital stock, this sensitivity implies reducing adjustment costs from 20% to 10% of net investment. With these lower adjustment costs it is cheaper to expand a sector's capital stock, all else being equal. Furthermore, for regions with relatively small initial capital stocks, this sensitivity can imply a dramatic reduction in the costs of rapidly expanding the capital stock through foreign investment inflows.

The results for the No-trade scenarios are contained in Table 10 and Table 11, which show, respectively, the effects of varying the parameters on baseline case variables and policy case results. First, higher Armington elasticities permit large baseline capital outflows from developed regions (with relatively modest investment opportunities) to developing regions with greater prospects for productivity growth. This has concomitant effects on the regions' gross domestic and national

Table 10 The Effect of Parameter Settings on Base Case Variables for 2010

	Standard Model	Higher Trade Elasticities (σ=1.5)	Higher Trade Elasticities (σ=2.0)	Higher Trade Elasticities (σ=2.5)	High Domestic/ Foreign Elasticity	High Foreign/ Foreign Elasticity	Low Adjustment Costs
Parameter Settings							
Domestic/Foreign Elasticity	1.0	1.5	2.0	2.5	2.0	1.0	1.0
Foreign/Foreign Elasticity	1.0	1.5	2.0	2.5	1.0	2.0	1.0
Adjustment Costs	20%	20%	20%	20%	20%	20%	10%
United States							
Carbon Emissions (Mil. tonnes)	1780	1771	1776	1783	1763	1782	1816
GDP (Bil. 95 $)	$9,502	$9,479	$9,470	$9,466	$9,468	$9,493	$9,559
GNP (Bil. 95 $)	$9,576	$9,606	$9,625	$9,639	$9,602	$9,608	$9,610
Net Investment Position (Bil. 95 $)	$1,133	$2,250	$2,869	$3,261	$2,394	$2,010	$670
Australia							
Carbon Emissions (Mil. tonnes)	128	129	130	131	129	129	128
GDP (Bil. 95 $)	$592	$590	$590	$591	$590	$590	$590
GNP (Bil. 95 $)	$578	$574	$572	$572	$573	$574	$576
Net Investment Position (Bil. 95 $)	($265)	($314)	($349)	($379)	($331)	($293)	($262)
Japan							
Carbon Emissions (Mil. tonnes)	325	339	346	350	339	338	340
GDP (Bil. 95 $)	$4,675	$4,787	$4,816	$4,827	$4,789	$4,780	$4,805
GNP (Bil. 95 $)	$4,775	$4,904	$4,941	$4,959	$4,916	$4,889	$4,903
Net Investment Position (Bil. 95 $)	$2,377	$2,610	$2,727	$2,810	$2,808	$2,444	$2,154
Other OECD							
Carbon Emissions (Mil. tonnes)	1411	1369	1362	1358	1369	1367	1434
GDP (Bil. 95 $)	$12,973	$12,874	$12,846	$12,832	$12,872	$12,878	$12,997
GNP (Bil. 95 $)	$13,044	$13,020	$13,033	$13,045	$13,012	$13,031	$13,039
Net Investment Position (Bil. 95 $)	$1,180	$2,754	$3,612	$4,160	$2,680	$2,851	$788
China							
Carbon Emissions (Mil. tonnes)	1589	1574	1555	1541	1538	1607	1436
GDP (Bil. 95 $)	$1,673	$1,678	$1,678	$1,678	$1,676	$1,680	$1,617
GNP (Bil. 95 $)	$1,567	$1,521	$1,493	$1,476	$1,519	$1,525	$1,541
Net Investment Position (Bil. 95 $)	-$2,107	-$3,150	-$3,699	-$4,039	-$3,144	-$3,107	-$1,485
LDCs							
Carbon Emissions (Mil. tonnes)	2392	2480	2490	2492	2496	2465	2270
GDP (Bil. 95 $)	$4,451	$4,492	$4,504	$4,510	$4,514	$4,473	$4,357
GNP (Bil. 95 $)	$4,245	$4,188	$4,139	$4,104	$4,198	$4,181	$4,166
Net Investment Position (Bil. 95 $)	-$4,384	-$6,458	-$7,644	-$8,422	-$6,692	-$6,194	-$3,958

Table 11 The Effect of Parameter Settings on No-Trade Results for 2010

	Standard Model	Higher Trade Elasticities (σ=1.5)	Higher Trade Elasticities (σ=2.0)	Higher Trade Elasticities (σ=2.5)	High Domestic/ Foreign Elasticity	High Foreign/ Foreign Elasticity	Low Adjustment Costs
Parameter Settings							
Domestic/Foreign Elasticity	1.0	1.5	2.0	2.5	2.0	1.0	1.0
Foreign/Foreign Elasticity	1.0	1.5	2.0	2.5	1.0	2.0	1.0
Adjustment Costs	20%	20%	20%	20%	20%	20%	10%
United States							
Carbon Permit Price (95 $)	$87	$83	$83	$83	$81	$85	$93
Carbon Emissions Change (MMTC)	-526	-517	-523	-529	-510	-528	-562
GDP, % change	-0.4%	-0.7%	-0.8%	-0.8%	-0.7%	-0.6%	-0.3%
GNP, % change	-0.6%	-0.8%	-0.8%	-0.8%	-0.8%	-0.7%	-0.6%
Change in Net Investment (Bil. 95 $)	-$451	-$233	-$137	-$77	-$257	-$306	-$675
Real Exchange Rate, % change	10.5%	3.3%	1.8%	1.1%	1.9%	5.7%	13.5%
Japan							
Carbon Permit Price (95 $)	$112	$147	$159	$164	$146	$145	$128
Carbon Emissions Change (MMTC)	-67	-81	-89	-92	-81	-80	-82
GDP, % change	-0.6%	-0.5%	-0.6%	-0.6%	-0.5%	-0.6%	-0.8%
GNP, % change	-0.5%	-0.6%	-0.6%	-0.7%	-0.6%	-0.6%	-0.6%
Change in Net Investment (Bil. 95 $)	-$55	-$59	-$67	-$71	-$100	-$55	-$26
Real Exchange Rate, % change	-5.8%	0.7%	1.0%	0.9%	0.6%	-0.2%	-9.9%
Australia							
Carbon Permit Price (95 $)	$181	$182	$185	$188	$181	$184	$181
Carbon Emissions Change (MMTC)	-48	-49	-50	-50	-49	-49	-48
GDP, % change	-1.8%	-2.0%	-2.1%	-2.1%	-2.0%	-2.0%	-1.5%
GNP, % change	-1.6%	-1.7%	-1.7%	-1.7%	-1.7%	-1.7%	-1.4%
Change in Net Investment (Bil. 95 $)	$29	$37	$38	$38	$39	$37	$13
Real Exchange Rate, % change	2.1%	-0.2%	0.1%	0.4%	0.0%	0.3%	4.8%
Other OECD							
Carbon Permit Price (95 $)	$261	$248	$246	$244	$249	$246	$269
Carbon Emissions Change (MMTC)	-461	-419	-412	-409	-419	-417	-484
GDP, % change	-1.5%	-1.2%	-1.2%	-1.2%	-1.2%	-1.3%	-1.5%
GNP, % change	-1.3%	-1.1%	-1.1%	-1.1%	-1.1%	-1.1%	-1.3%
Change in Net Investment (Bil. 95 $)	$370	$220	$160	$122	$240	$274	$516
Real Exchange Rate, % change	-13.5%	-2.4%	-0.9%	-0.3%	-1.4%	-4.4%	-17.1%
China							
Carbon Emissions Change (MMTC)	-12	-3	-2	-1	-3	-4	-15
GDP, % change	-0.2%	-0.1%	0.0%	0.0%	0.0%	-0.1%	-0.2%
GNP, % change	-0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	-0.1%
Change in Net Investment (Bil. 95 $)	$34	$18	$12	$8	$17	$20	$59
Real Exchange Rate, % change	-4.7%	-2.2%	-1.5%	-1.3%	-1.9%	-2.4%	-6.5%
LDCs							
Carbon Emissions Change (MMTC)	79	38	38	39	38	41	96
GDP, % change	0.4%	0.0%	0.0%	0.0%	0.0%	0.1%	0.6%
GNP, % change	0.7%	0.1%	0.1%	0.1%	0.1%	0.2%	0.9%
Change in Net Investment (Bil. 95 $)	$144	$56	$38	$29	$110	$89	$171
Real Exchange Rate, % change	15.9%	0.1%	-0.8%	-1.0%	0.5%	1.0%	23.7%

products, trade, and carbon emissions. Second, this result is influenced by both trade elasticities, although the “top-tier” elasticity of substitution between domestic and foreign goods plays a somewhat greater role in easing baseline capital flows than that between imports from different regions.

Third, note that lower capital stock adjustment costs make it easier for a region to expand its own domestic capital stock. Although intuition suggests that lower adjustment costs might make it easier to invest in developing countries with small capital stocks, and thus further encourage capital flows to developing regions, the opposite appears to be the case: lower adjustment costs also make it easier for regions to expand their own capital stocks. Thus lower adjustment costs tend to reduce baseline international capital flows rather than increase them, and consequently tend to reduce growth prospects in developing regions as well.

Finally, note that Japanese carbon emissions are significantly higher in baselines with higher trade elasticities. In all the baselines, Japan’s real exchange rate depreciates over the next two decades as large quantities of capital flow out of Japan in favor of higher returns in developing countries. With low trade elasticities, the real exchange rate depreciation makes fossil fuels more expensive and tends to moderate energy and carbon emissions. With higher trade elasticities, capital outflows do not have as large an effect on the exchange rate. Since the exchange rate depreciates less, fossil fuel imports are relatively cheaper, which leads to higher Japanese baseline carbon emissions. Higher carbon emissions, finally, require a higher permit price to achieve the Japanese target specified by the Kyoto Protocol.

The policy case sensitivities in Table 11 reveal a number of interesting insights. Perhaps most importantly, larger trade elasticities dramatically reduce the exchange rate adjustment required to generate a capital movement of given magnitude. This is not surprising, since the exchange rate change acts on both imports and exports. As a result, the effect of doubling the Armington elasticity is to cut the exchange rate adjustment required to transfer a given quantity of financial capital by roughly a factor of four. Greater trade responsiveness also reduces the need to relocate physical capital stocks. As a result, the higher the trade elasticities are, the smaller the net foreign asset flows out of regions with high control costs to regions with low or no control costs.

Because higher trade elasticities moderate both capital flows and exchange rate responses to a given set of carbon emission mitigation policies, they have rather dramatic effects on the distribution of costs across regions. With higher trade elasticities, neither the United States nor the developing countries benefit as much from capital inflows and the resulting improvements in their terms of trade. Consequently, developing countries’ GDP and GNP gains from mitigation policies in the Annex I region are dramatically reduced, and U.S. losses are significantly greater. The ROECD region experiences significantly lower declines, and China, which is harmed by Annex I policy when trade elasticities are low, experiences no harm when they are relatively high.

Interestingly, (although we omit the results from the tables to save space) we note that with higher trade elasticities, it is no longer the case that the ROECD region benefits (in the sense of having smaller exchange rate effects and consumption losses) from having the rest of the Annex I form a trading bloc that excludes it. With higher elasticities, and the resulting moderation in exchange rate and capital flow effects, consumption losses are moderated in both the No-Trade and Double Umbrella scenarios, and are almost indistinguishable in the two.

Finally, lower capital stock adjustment costs have the opposite effect of higher trade elasticities. As described above, lower adjustment costs make it easier for a region to expand its own domestic capital stock, and therefore tend to reduce foreign investment in the baseline. However, lowering the adjustment cost parameter has a more profound effect on the investment prospects of developing countries with small capital stocks than it does on the prospects of large developed countries. As a result, in the policy cases in which Annex I regions meet Kyoto commitments, all else being equal, lower adjustment costs lead to larger capital flows from the Annex I regions to the developing regions – with concomitantly larger exchange rate effects and GDP and GNP effects.

It thus appears that the key insights of the G-Cubed model still hold under the sensitivities considered here. It is clear, however, that trade price elasticities and capital stock adjustment costs are important determinants of the magnitudes of capital flow and exchange rate responses to a permit trading regime.

6 Conclusion

The theoretical appeal of an international permits program is strongest if participating countries have very different marginal costs of abating carbon emissions – in that situation, the potential gains from trade are largest. Our results show that within the Annex I and globally, abatement costs are indeed quite heterogeneous. The marginal cost of meeting Kyoto targets in the "Rest of the OECD" region is triple that of United States; and large quantities of relatively inexpensive emission reductions are available from the former Soviet Bloc and non-Annex I developing regions. These differences in abatement costs are caused by a range of factors including different carbon intensities of energy use, different substitution possibilities and different baseline projections of future carbon emissions. Because of these differences, international trading offers large potential benefits to parties with relatively high mitigation costs.

Our results also highlight the potentially important role of international trade and capital flows in global responses to the Kyoto Protocol, a role not adequately captured in any other modeling system of which we are aware. The results suggest that regions that do not participate in permit trading systems, or that can reduce carbon emissions at relatively low cost, will benefit from significant inflows of international financial capital under any Annex I policy, with or without trading. It appears that the United States is likely to experience capital inflows, exchange rate appreciation and decreased exports. In contrast, the ROECD region, as the highest cost region, will see capital outflows, exchange rate depreciation, increased exports of durables and greater GDP losses. Total flows of capital could accumulate to roughly a half a trillion dollars over the period between 2000 and 2020.[38] Global participation in a permit trading system would substantially offset these international impacts, but is likely to require additional payments to developing countries to induce them to forgo the benefits that accrue to them if they do not participate.

Because the model is calibrated to a year in which the former Soviet Bloc and China did not participate extensively in global trade, the model effectively assumes that these regions never experience extensive capital inflows or outflows. If these regions become fully participating members of the international trade and finance system by 2010, then the international trade and capital effects in our scenarios would have to be revised. In particular, the capital that flows to the U.S. and LDCs in these scenarios might be spread to the former Soviet Bloc and China too, with more modest exchange rate and trade balance effects in any given region.

[38] Compare these magnitudes to the more than trillion dollar decline just in the U.S. net international investment position in the past fifteen years. See the U.S. Government's Survey of Current Business (July 1998).

The model's results are also sensitive to assumptions that determine the mitigation cost differences among regions. Different results would be obtained if U.S. domestic mitigation costs were significantly higher but the other regions' permit prices were on the same order of magnitude as in these scenarios (this is the case, for example, in the SGM model from which we derive mitigation cost curves for the former Soviet Bloc). With a smaller relative control cost differential between the U.S. and other countries in the OECD, the magnitude of capital flows to the U.S., and the costs and benefits of those flows, would all be smaller.

Finally, it must be remembered that there are inescapable uncertainties in the values of the model's behavioral parameters and the future values of exogenous variables. As shown by our sensitivity analysis, our results should be interpreted as point estimates in a range of possible outcomes. It is clear, however, that in an increasingly interconnected world in which international financial flows play a crucial role, the impact of greenhouse abatement policy cannot be determined without paying attention to the impact of these policies on the return to capital in different economies. Focusing only on domestic effects would miss a crucial part of the economy's response to climate change policy. To understand the full adjustment process to international greenhouse abatement policy it is essential to model international capital flows explicitly.

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Discussion

Ben Geurts

The G-Cubed multi-region, multi-sector intertemporal general equilibrium model of the world economy, as presented by mr. McKibbin, has a number of striking features. The model inhabits perfect foresight, is claimed to be econometrically estimated and is dynamic in the sense that a year-by-year investment decision is modelled. Moreover capital flows are explicitly modelled. Finally the model claims to provide information not only about the long-run equilibrium but also about the short-run dynamics. Each one of these elements would make a general equilibrium model special. Combining them into a single model turns it into a very ambitious and very difficult modelling exercise.

The comments focus on the non-standard elements of the model. The comments are based on the rather limited information about the model specification available in the paper. In particular I would like to raise attention to the claim that the model inhabits perfect foresight, to the specification of the capital market sub-model and to the short-run dynamics of the model.

The modelling horizon is 2050. Perfect foresight is only possible when, in the end year, the world is on a steady state growth path. For such an end condition all kind of ratio's in the model need to be constant. This, however, is only possible when all kind of growth rates are equal. Since, for instance, labour supply growth and productivity growth in 2050 have not converged in the model, the model can not be in steady state in 2050, which, in my view, makes it impossible to define the proper end condition.

In the capital market sub-model ad-hoc risk premiums are used to explain the uncovered interest rate differentials. The size of these risk premiums is kept constant over the simulation period, but depends strongly on the choice of the base year. Moreover, at least in the model they are not based on real or perceived risks. Since there is no risk associated to investment in the model, from a welfare point of view it would be optimal to invest in the most 'risky' assets. Moreover the impact of a change in interest rate change on the user cost of capital in a region depends upon the size of the risk premium. Since there is no theoretical basis for the risk premiums, and since the empirical basis is rather weak, this relationship is rather coincidental. However it seems to be a crucial relation in the model, since the investment reaction determines the capital flows and provokes exchange rate fluctuations. I would like to suggest to elimate gradually over time the risk premiuns, to ensure that at least in the long run the solution is theoretically optimal.

The third element I like to focus on is the short-run dynamics of the model. The specification of the labour market, of the consumption function and of the investment decision determine the short run dynamics of the model. From a policy-makers point of view, the short-run dynamics is a very interesting feature of the model. Where in general long-run effects of policy measures seem to be negligible, short-run adjustments may be painful. The mere fact that policy makers often seem to focus on these transition problems, make that they deserve more attention in general equilibrium models.

However, at the moment the short term dynamics in the model, are not very sophisticated. To come up with real short-term dynamics, the model should mimic the stylised fact of the real world that long-term elasticity's are much greater than short-term elasticity's. This should, for instance, be reflected in the production function and the trade system. A putty-clay production functions, from this respect, might be preferable over the CES-production which is used now. In the trading system, elements of the new growth and new trade theories could be included. In specifications based on these theories regions might be able to growth faster than their competitors in world trade, without suffering from a continuous and ever increasing terms of trade loss. With the long-term trade elasticity's which are now in the model, terms-of-trade effects are likely to dominate all other effects on welfare.

As said, the G-cubed model is a very interesting and ambitious model. Although it is not clear whether the model is already able to meet all the claims of the authors, I look forward to future work on the model, and for actual analyses done with the model.

Kyoto and Carbon Leakage

simulations with WorldScan

Johannes Bollen, Ton Manders and Hans Timmer

Abstract

The focus of this paper is carbon leakage under the Kyoto protocol. The dynamic AGE model WorldScan is used to analyse the effects of both unilateral action and permit trading within Annex I . Two new scenarios, A1 and B1, are used as ‘Business-As-Usual’ scenarios[1]. The two scenarios turn out to generate similar leakage rates. Furthermore, leakage depends only to a limited extent on the policy applied. Typical values for the leakage rate turn out to be around 20 percent. Income is less affected than GDP. Important channels through which carbon leakage occurs, are the shift in energy-intensive production from Annex I towards non-Annex I and the shift within industries towards cheaper energy in non-Annex I. Crucial for these processes are trade elasticities and production substitution elasticities. A sensitivity analyses is done to assess the importance of these parameters.

1 Introduction

By signing the Kyoto Protocol in December 1997 Annex I countries committed themselves to the reduction of their Greenhouse Gas emissions, with the ultimate goal to stabilize global emissions and to prevent undesirable climate changes. Although the agreement achieved in Kyoto is an important first step towards this ultimate goal, it is clear that also emissions outside the group of Annex I countries (Non-Annex-I) have to be taken into account to assess the contribution of this agreement to the stabilization of global emissions. First of all, the relative importance of Annex-I reductions depends on autonomous increases of emissions in Non-Annex-I. If Annex-I emissions are a smaller part of global emissions, the relative impact of Annex-I reductions on global emissions is automatically smaller. Secondly, the impact depends on induced changes in emissions in Non-Annex-I. An increase in Non-Annex-I emissions as a result of mitigation policies in Annex-I, makes these policies less effective in stabilizing global emissions.

This paper will focus on this induced, so-called leakage effect and especially on carbon leakage. To assess the order of magnitude of this leakage and to unravel the different causes of leakage we use WorldScan, a dynamic AGE model of the world economy, developed at CPB. Besides leakage of emissions to countries outside Annex I, leakage may also occur within the Annex I region. The latter might occur if Annex I countries have emission targets that exceed their expected emissions. This

[1] Please note that the WorldScan team participated in collaboration with the RIVM IMAGE team in the development of the scenarios for the IPCC Special Report on Emissions Scenarios (SRES). Calculations in this paper are based on input from the modeling teams participating in SRES and explore how SRES-type scenarios could be used for mitigation analysis. They are necessarily preliminary, since the SRES scenarios have not been approved by IPCC and are therefore subject to changes.

leaves room, often labelled "hot air", in those countries to increase their emissions as a result of policies in other Annex I countries without violating the Kyoto protocol. This paper will also address the possible hot air, which is expected only to exist in Russia or the Former Soviet Union.

In the analysis we will split up leakage in three different ways. First, we use the well-known Kaya identity where a change in emissions is disentangled into a change into a change in production, a change in the energy intensity of production and a change in the carbon intensity of energy. Secondly, we decompose emissions into emissions that are ultimately used for domestic final demand and emissions that are use for net exports of goods and services. To that end we compute for all sectors the implicit carbon content, taking into account all intermediate deliveries and all imports. With this decomposition we can compute how mitigation policies change the carbon content of final demand in Annex-I and Non-Annex-I. Thirdly, in the sensitivity analysis we split changes in emissions into changes that result from shifts over sectors and changes that results from shifts in production technologies.[2]

There are at least three reasons for leakage. First, as a result of reduced energy demand in Annex-I the producer prices of energy in all regions will decline. Cheaper energy in countries that do not adopt mitigation policies will stimulate domestic energy demand. Secondly, energy taxes in Annex I countries may provoke relocation of energy-intensive production to countries that do not impose energy taxes. Thirdly, income effects in non-complying countries may change their domestic energy demand.[3]

Taking these transmissions into account we can conclude that the leakage rate will depend on a variety of assumptions. Of overriding importance are assumptions about developments in absence of mitigation policies, or the so-called business-as-usual (BaU) baseline. In general one can say that the larger countries without mitigation policies are, relative to countries that realize reductions of emissions, and the more they are integrated into the global economy, the larger will be the leakage rate. Large countries can easily absorb a significant amount of extra energy if energy prices decline. Countries that already have a substantial market share in foreign markets and that are open to imports can easily take over a considerable part of energy intensive production from Annex-I. Also the degree of integration of energy markets in the baseline is important. If trade in fossil fuels is difficult and energy markets are more or less regional markets, the energy prices in Non-Annex-I will hardly be effected. Finally, if the BaU baseline contains hot air within Annex-I, that will generate leakage within Annex-I and as a result the leakage to Non-Annex-I will be smaller.

In this paper we use two scenarios as BaU baselines, acknowledging the fact that there cannot be one "business-as-usual" since the future is inherently unpredictable. These scenarios are based on work that is ongoing in support of the IPCC Special Report on Emissions Scenarios and the Third Assessment Report[4]. They are referred to as A1 and B1. Both scenarios assume high growth rates, especially in Non-Annex-I. The main difference is that in B1 very rapid autonomous improvement in energy efficiency is assumed. That makes the necessary reductions to comply with the Kyoto

[2] The distinction between changes in production technologies and shifts over sectors is a vague one. In every economic model sectoral output consist of heterogeneous products, which implies that production functions always describe, besides technological options, also the consequences of shifts over products. However, in sensitivity analysis the distinction between demand and production functions is a convenient one because both elements refer to specific model parameters.

[3] See also e.g. Oliveira-Martins et.al. (1992).

[4] See Footnote 1.

Protocol smaller and it generates a substantial amount of hot air in the Former Soviet Union, even in 2020. These two scenarios will be described in section 2.

Because in both scenarios are rather similar with respect to the openness of Non-Annex-I and the share of Non-Annex-I in the world economy, mitigation policies will have similar leakage rates. Because towards 2020 the share of Non-Annex-I in the world economy is steadily increasing, the leakage rate differs more in time than between the two scenarios, albeit that the existence of substantial hot air in the B1 scenario reduces leakage towards Non-Annex-I compared to the A1 scenario, where hot air disappears towards the end of the scenario period. Lejour (1999) uses WorldScan to analyse leakage against two other scenarios. These scenarios, developed for the OECD (1997) study, differ significantly with respect to Non-Annex-I. One scenario assumes rapid growth of Non-Annex-I regions and further globalization through the lowering of barriers in international markets for goods, services and financial capital, while the other scenario is much less optimistic about growth and openness of Non-Annex-I. That study shows a significantly larger leakage rate in the first scenario than in the second one.

As starting point of the scenarios we use the GTAP4 database. On the energy side of that database we added some extra information and some modifications. We confronted the value of output per region in GTAP4 with volume data of output provided by the IEA. We assumed that the resulting implicit price can be seen as a producer price which applies to all categories of demand. Only for oil we made a distinction between the price for domestic sales and exports, using IEA price data on exports and imports of oil. Also that method ensures that the model reproduces the IEA volume data of energy production per region. Then we calculated indirect taxes on domestic use, irrespective from the suppliers, so that market prices provided by IEA were reproduced. That procedure assumed that the value data of energy use in GTAP do not contain these indirect taxes. We therefore computed new value data including these revealed domestic taxes.

The leakage rate will not only depend on the BaU scenario, but also on the instruments that are used to reach the targets that Non-Annex-I countries set themselves. In general one can say that the more efficient the instruments are, the lower the leakage rate will be. Efficient instruments will lead to smaller distortions and therefore to less relocation of energy-intensive production to Non-Annex-I. In section 3 we consider two policies: unilateral taxes (UNI) and free emission trade within Annex-I (FTR). The later will show a somewhat smaller leakage to Non-Annex-I, because it leads on average to smaller price distortions. Both UNI and FTR may induce leakage within Annex-I if hot air exists in the baseline. As far as there is still hot air after unilateral policies, this internal leakage will be larger in case of free emission trade.

In the implementation of the Kyoto agreement many other instruments may be used besides unilateral taxes or free trade of emission right within AN-I, but these instruments are beyond the scope of this paper. Some of these instruments we analysed in Bollen et.al. (1999), where we simulated trade within limited clubs, limits to imports or exports of emission right and projects under the clean development mechanism.

To determine the leakage rate, not only the instruments or the magnitude of variables in the baseline are important, but also the assumptions about production possibilities and behavioural relations. In model terms this mainly refers to price elasticities. First of all the price elasticity of energy supply is a key determinant. Inelastic supply, i.e. small price elasticities, will increase leakage. Suppliers of fossil fuels are then prepared to lower their prices drastically in order to maintain output levels as far as possible after the decline in demand from Non-Annex-I countries. Similarly the price elasticity of energy demand in Non-Annex-I is an important determinant of leakage. The higher these price elasticities the larger leakage will be, because the easier Non-Annex-I can increase energy demand as a result of lower prices. Changes in the price-elasticity of energy demand in Annex-I, on the other hand, has an opposite effect on the leakage rate. That would provoke larger shifts over sectors in the trade patterns. Finally, the price elasticities of trade flows of all goods and services are important. The higher these elasticities, the larger leakage. High price elasticities in energy markets imply integrated global energy markets. That means that suppliers of energy in Non-Annex-I are confronted with a decline in demand for their output as a result of mitigation policies in Annex-I and suppliers of energy in Annex-I can easily shift their sales to Non-Annex-I. High price elasticities in other markets facilitate shifts in trade patterns of energy intensive products. To explore the impact of some of these price elasticities we present in section 4 some sensitivity analyses with WorldScan.

Leakage can only occur as a result of trade, trade in energy carriers, or trade in other products. Therefore, to avoid leakage one could see compensating trade policies, like the taxation of energy intensive imports, as an option. Or one could exempt energy-intensive producers in exposed sectors in Annex-I from carbon taxes. Such counter veiling measures or beyond the scope of the current paper. In Tang et.al. (1998) such measures were discussed on the basis of WorldScan simulations.

A short description of WorldScan is given in the appendix. WorldScan contains 12 regions, 6 Annex-I regions and 6 Non-Annex-regions. In this paper we aggregate the results into 4 regions: Western Europe (WE), Eastern Europe + Former Soviet Union (EF), Rest OECD (RO) and Non-Annex-I (NA).

2 The baselines

The effects of CO2 abatement policies depend on the baseline used. The emission targets set in the Kyoto agreement are expressed relative to the emission levels in 1990. The future growth of emissions, as projected in the baseline, is critical in determining the efforts required to meet the Kyoto commitments. There are an infinite number of possible alternative futures to explore. In this paper we follow two scenarios which have been constructed in support of the Special Report on Emissions Scenarios (SRES) for the IPCC[5]. These scenarios are described by the names A1 and B1.

The A1 scenario describes a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are convergence, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The global economy expands at an average annual rate of about 3% to 2100.This is approximately the same as average global growth since 1850, although the conditions that lead to this global economic growth in productivity and per capita incomes in the scenario are unparalleled in history. Energy and mineral resources are abundant in this scenario because of rapid technical progress, which both reduce the resources needed to produce a given level of output and increases the economically recoverable reserves. Final energy intensity (energy use per unit of GDP) decreases at an average annual rate of 1.3%. The A1 scenario is based on a balanced mix of primary energy sources and has an intermediate level of CO2 emissions.

[5] See Footnote 1.

The B1 scenario describes a convergent world with rapid change in economic structures, and introduction of clean technologies. The emphasis is on global solutions to environmental and social sustainability, including concerted efforts for rapid technology development, dematerialization of the economy, and improving equity. Global income per capita is somewhat lower than in A1. A higher proportion of this income is spent on services rather than on material goods The B1 scenario sees a relatively smooth transition to alternative energy systems as conventional oil and gas resources decline. There is extensive use of conventional and unconventional gas as the cleanest fossil resource during the transition, but the major push is towards post-fossil technologies driven in large part by environmental concerns.

Basically, the scenarios focus on the long run and certain aspects become manifest only in the far future. For example, the strong increase in the use of biofuels and non-thermal electricity in B1 takes shape only in the second half of the 21st century. All the same, in the medium run there are important differences, especially concerning fossil energy use and CO2 emissions. In this paper our time horizon is 2020 and we think it useful to take both baselines A1 and B1 into consideration.

The stories behind these scenarios haven been implemented by different modelling groups (RIVM, 1999). This exercise resulted in more detailed trajectories, *e.g.* for GDP, population, emissions and fuel demand. To mimic the given trends in these scenarios in broad outline, we adjusted in

Figure 2.1a Various indicators in A1 scenario (average five year percentage change)

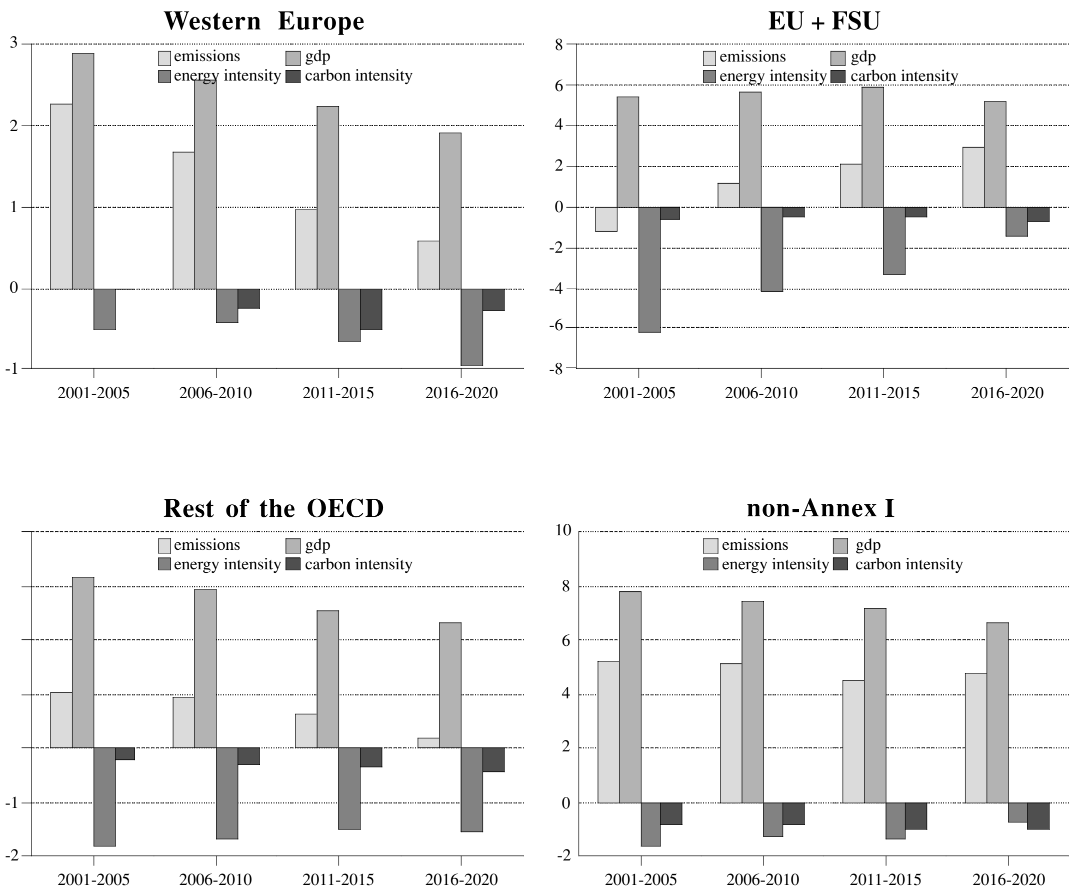
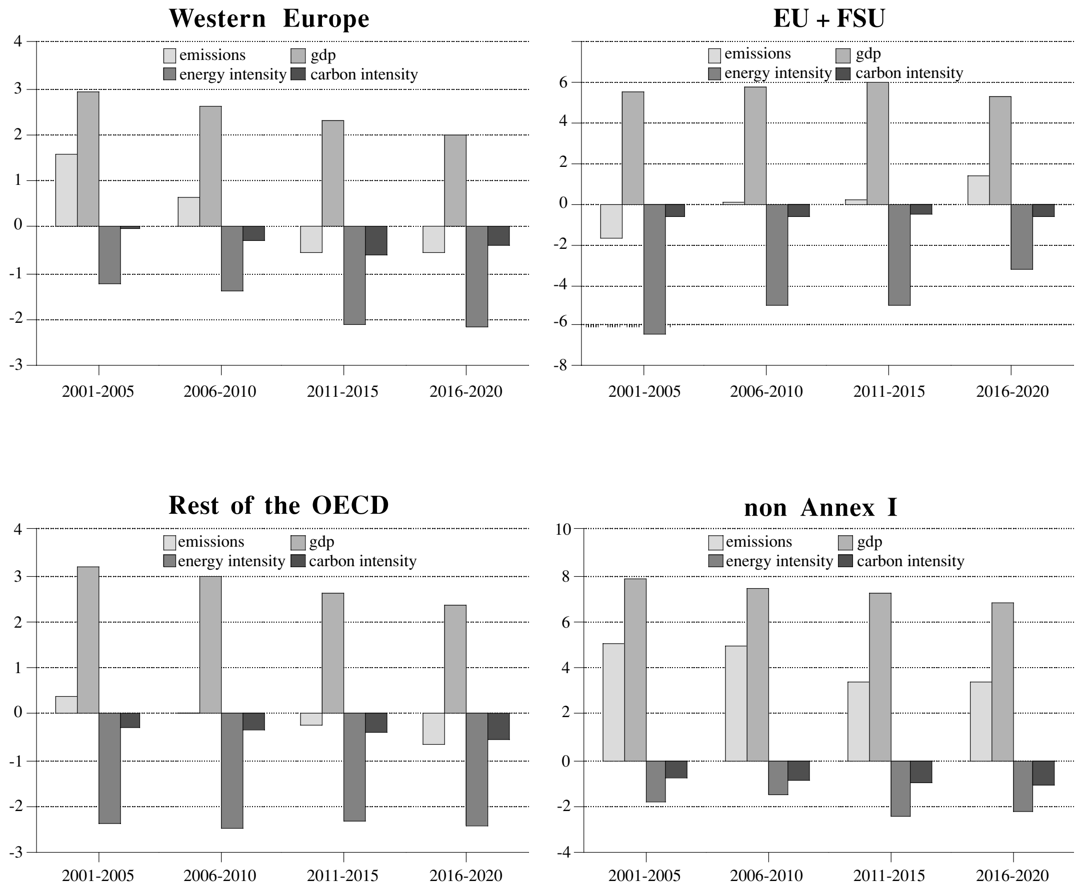


Figure 2.1b Various indicators in B1 scenario (average five year percentage change)



WorldScan the upgrading of the labour force, convergence of consumption patterns and adjustments of interest rates. More attention has been paid to calibrate energy demand. We adjusted the cost parameters in the production function in such a way that WorldScan exactly follows the growth rates of demand for oil, coal, gas, biofuels and non-thermal energy given in A1 and B1.

Figure 2.1 shows for the four aggregated regions the growth in GDP, emissions, energy intensity and carbon intensity. Average growth rates of GDP and CO2 emissions are given in Table 2.1 and Table 2.2.

Both scenarios can be characterised as high growth scenarios. In the time period considered, there is hardly any difference in GDP growth between the A1 and B1 scenario. However, emissions in B1 are much lower than in A1, caused by a both a stronger decrease in energy intensity and a stronger decrease in carbon intensity.

Table 2.1 GDP growth in the A1 and B1 scenarios

	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020
A1			*average annual growth rate in %*		
Western Europe	3.2	2.9	2.6	2.3	1.9
Rest OECD	3.4	3.2	3.1	2.7	2.4
EE + FSU	6.2	5.4	5.8	6.0	5.2
Rest of the World	7.8	7.8	7.4	7.2	6.6
B1					
Western Europe	3.2	2.9	2.6	2.3	2.0
Rest OECD	3.4	3.2	3.0	2.6	2.4
EE + FSU	6.2	5.5	5.7	6.0	5.3
Rest of the World	7.8	7.8	7.4	7.2	6.8

Table 2.2 CO_2 emissions in the A1 and B1 scenarios

	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020
A1			*average annual growth rate in %*		
Western Europe	2.6	2.3	1.7	1.0	0.6
Rest OECD	1.6	1.0	1.0	0.7	0.2
EE + FSU	-3.7	-1.2	1.2	2.1	2.9
Rest of the World	4.9	5.2	5.1	4.5	4.8
B1					
Western Europe	2.0	1.6	0.6	-0.6	-0.6
Rest OECD	1.1	0.4	0.0	-0.3	-0.7
EE + FSU	-3.9	-1.7	0.2	0.2	1.5
Rest of the World	4.7	5.1	4.9	3.4	3.4

3 Simulation results

3.1 Emission reductions and carbon taxes

In this section we will discuss two policy scenarios with the A1 scenario as starting point and the same two policy scenarios with the B1 scenario as starting point. Both policy scenarios impose the Kyoto targets on Annex-I emissions. We assumes that the average Kyoto targets for the first budget period will be realized in 2010 and that from 2000 onwards the targets gradually converge from the baseline emissions to the target in 2010. The targets are kept constant from 2010 till 2020. In the first policy scenario the targets of individual regions are reached by unilateral carbon taxes. In the second policy scenario free trade of emission rights within Annex-I is allowed, which boils down to a uniform tax in Annex-I to reach the overall Annex-I target, combined with transfer payments as a result of trade in emission rights.

Figure 3.1a   Emissions and carbon taxes in A1 scenario

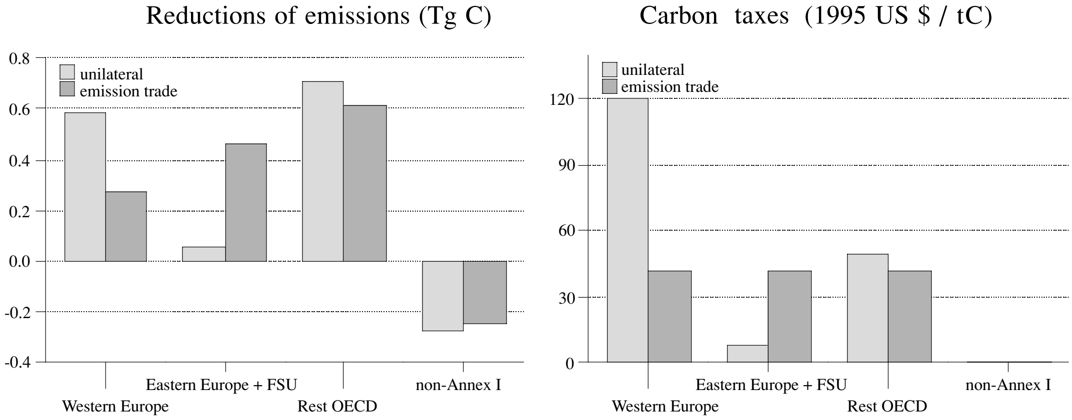


Figure 3.1b   Emissions and carbon taxes in B1 scenario

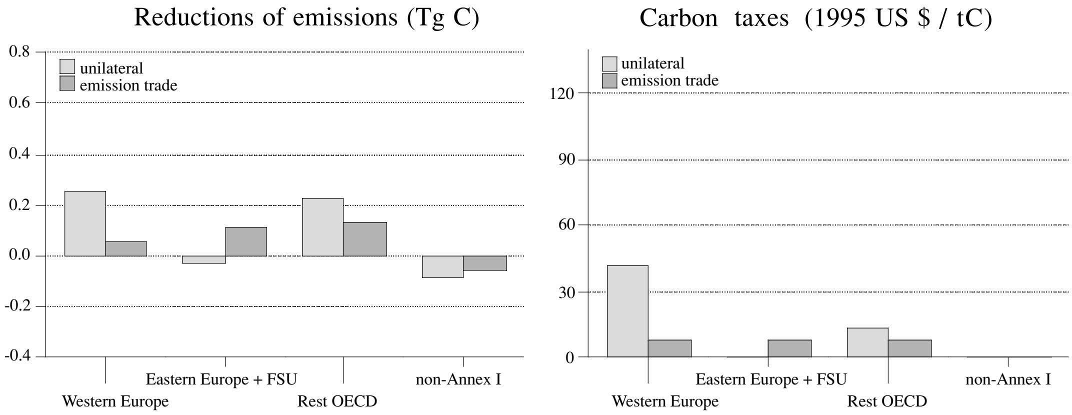


Figure 3.1 shows the resulting emission reductions and carbon prices in 2020. In the A1 scenario Western Europe has to reduce its emissions with .6 TgC, which is almost 40% of the emissions in the baseline. To realize that reduction with unilateral taxes Western Europe needs a carbon tax of 121$/tC[6]. Table 3.1 shows that that tax leads to large increases in the market prices of energy, especially of coal, because the carbon content of coal per US$ is relatively large. Eastern Europe and the Former Soviet Union only have to reduce .06 TgC, about 5% of their baseline emissions. Reductions in the Rest of the OECD are in absolute terms even larger than in Western Europe. But the reduction of .7 TgC is only 25% of their baseline. That means that their carbon tax can be lower than in Western Europe. Another reason for the relatively low carbon tax is the relatively low energy prices in the Rest of the OECD, especially because of low energy prices in the United States. The carbon tax of 50 $/tC leads to relatively large increases in energy prices in the Rest of the OECD. In case of unilateral taxes the carbon leakage in Non-Annex-I is .28 TgC, which is 20% of the Annex-I reductions. As percentage of the baseline emissions the increase in Non-Annex-I is only 3%.

The picture changes radically in case trade in emission rights is allowed. Then the carbon tax is

6 $/tC stands for 1995-US dollars per ton carbon

Table 3.1 Real energy prices in 2020 (cumulated % change)

A1 scenario

	unilateral				emission trade			
	WE	EF	RO	NA	WE	EF	RO	NA
market prices								
Coal	90.8	8.1	70.8	-2.3	-2.2	84.1	58.4	-2.2
Oil	29.6	5.7	15.5	-2.3	-2.4	79.4	12.5	-2.4
Natural Gas	22.3	3.8	16.8	-0.9	-0.9	35.5	13.9	-0.9
producer pr.								
Coal	0.0	-10.0	-10.9	-1.3	-1.2	-16.8	-9.2	-1.2
Oil	-2.8	-5.1	-2.0	-2.3	-2.2	-8.9	-2.0	-2.2
Natural Gas	0.3	-4.3	-2.8	-0.8	-0.7	-10.0	-2.4	-0.7

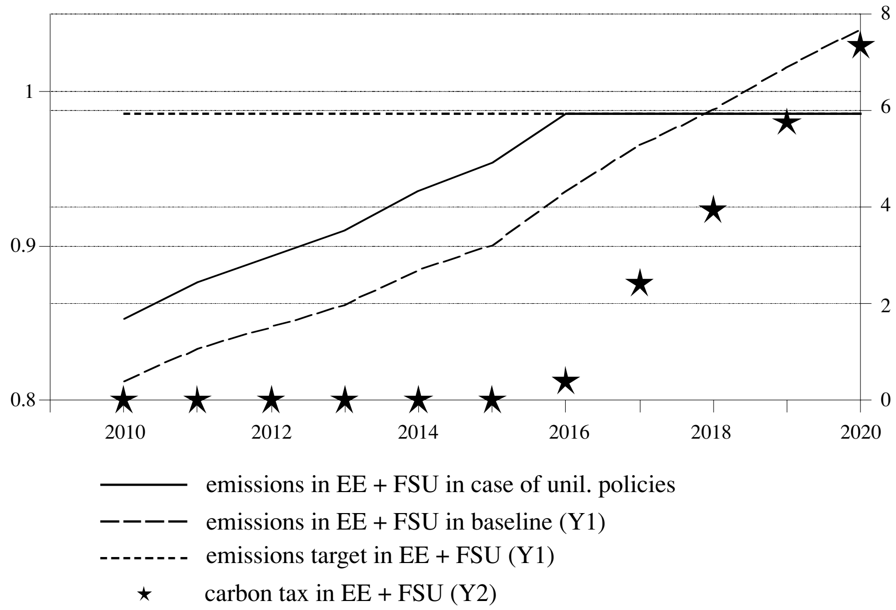
B1 scenario

	unilateral				emission trade			
	WE	EF	RO	NA	WE	EF	RO	NA
market prices								
Coal	35.3	-4.4	20.1	-1.1	-0.6	16.4	11.6	-0.6
Oil	11.3	-2.4	4.6	-0.8	-0.7	22.6	2.5	-0.7
Natural Gas	8.5	-1.3	4.7	-0.3	-0.2	7.1	2.7	-0.2
producer pr.								
Coal	-1.5	-4.4	-5.1	-0.6	-0.3	-2.8	-0.3	
Oil	-1.2	-1.4	-0.7	-0.8	-0.6	-2.8	-0.6	-0.6
Natural Gas	-0.1	-1.3	-1.4	-0.3	-0.2	-2.4	-0.8	-0.2

equal for all Non-Annex-I regions at a level of 42 1995-US$/tC. Because of differences in marginal abatement costs, related to differences in energy prices in the baseline, the impact of this tax on reductions differs across regions. Emissions in Western Europe are reduced by 18% of their baseline level (.27 TgC), in EE+FSU by 45% (.46TgC) and in the Rest of the OECD by 21% (.62 TgC). So, compared to the unilateral case it is mainly a shift of reductions from Western Europe to EE+FSU. The leakage in Non-Annex-I is somewhat smaller in case of emission trade because free trade implies a more efficient reduction of emissions and less improvement of Non-Annex-I competitiveness in energy-intensive goods.

Taking the B1 scenario, with very rapid autonomous increase in energy efficiency, as baseline has two major consequences. First of all, for Western Europe and the Rest of the OECD are only about one third of the necessary reductions in the A1 scenario. That means that also the carbon tax in those regions in the unilateral case are about one third of the levels discussed above. Secondly, EE+FSU has in the B1 scenario in 2020 a significant amount of hot air, 22% of their baseline emissions or .18 TgC. That means that in the unilateral case there is leakage within Annex-I and EE+FSU will

Figure 3.2 Hot air and unilateral policies in the A1 scenario



increase their emissions compared to the baseline. In case of emission trade the increase will be much larger and that will decrease the reductions of Annex-I as a whole. This means that emission trade will lead to more global emissions, even with smaller leakage to Non-Annex-I.

The A1 scenario does not contain hot air in 2020, but it does in the years before. Figure 3.2 shows the dynamics of the emissions in EE+FSU. The bold dashed line indicates the emissions in the A1 baseline without mitigation policies. Only in 2018 these emissions cross the target (the horizontal dashed line). That means that the baseline contains hot air till 2018. The solid line shows the emissions in the unilateral mitigation variant. In the first periods this line lies substantially above the baseline emissions as a result of leakage within Annex-I. Because of mitigation policies in other Non-Annex-I regions EE+FSU increase their emissions. As a result, they will reach their target earlier, already in 2016. From then on also EE+FSU has to introduce a unilateral tax to prevent their emissions from exceeding the target. The tax levels are indicated by stars in the figure. So, part of the hot air that existed in the baseline disappeared in the unilateral variant. Although the tax rate is positive, emissions still lie above the baseline level between 2016 and 2018.

The existence of hot air complicates the analysis of leakage to Non-Annex-I. One is inclined to define the leakage rate as the increase of emissions in Non-Annex-I as share of the reductions in Annex-I. The two lower curves in Figure 3.3 show the leakage rate defined in this way. Both lines refer to unilateral policies. The solid line describes the leakage rate in the A1 scenario and the dashed one the leakage rate in B1. However, in case of hot air and leakage within Annex-I, this definition of leakage is actually not appropriate. The increase of emissions in EE+FSU as a result of leakage within Annex-I is included in the denominator, lowering total Annex-I reductions, and is not part of the numerator describing leakage. The upper two curves in Figure 3.3 are based on an alternative definition. In that definition EE+FSU are part of Non-Annex-I in those periods in which their emissions are below their target. In other words, the alternative definition describes leakage of emissions from countries that apply mitigation policies towards countries that are not restricted in their emissions.

Figure 3.3 Leakage rate

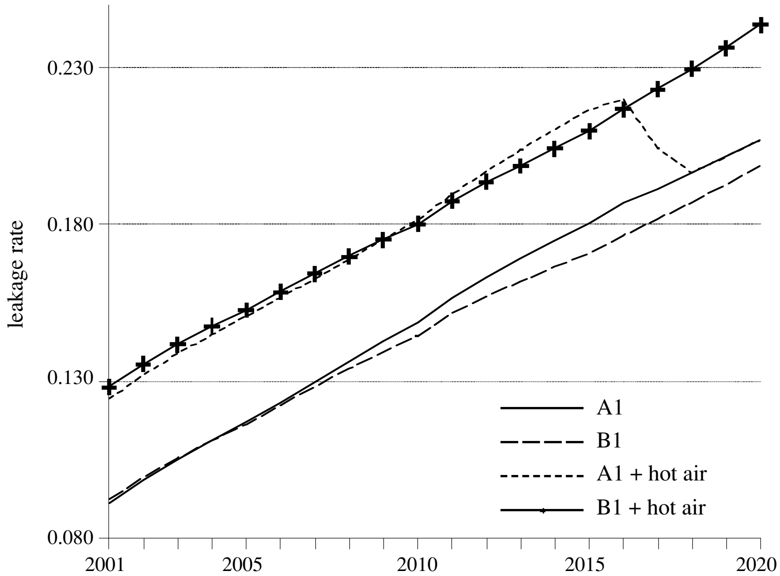


Figure 3.3 shows that the leakage rate hardly differs between the A1 and B1 scenarios. The only important difference occurs at the end of the scenario period when there is still a substantial amount of hot air in the B1 scenario. The similar leakage rate in both scenarios is a manifestation of a similar relative size of Non-Annex-I in both scenarios. That the relative size of Non-Annex-I is important becomes clear in the analysis of the leakage rate over time. The gradual increase in the leakage rate is the result of the gradual increase in the share of Non-Annex-I in the world economy. Also the larger leakage rates in the alternative definition are the result of this mechanism. In the alternative definition the group of not restricted countries is larger than Non-Annex-I and therefore that group is responsible for more leakage. Before we investigate emission reductions and carbon leakage in further detail, first the impact of mitigation policies on production and income will be discussed in the next subsection.

3.2 Impact on production and income

Figure 3.4 shows the impact on real gross domestic product (GDP) and real gross national income (GNI) in 2020 as percentage of the baseline. Unilateral policies in the A1 scenario lead to a decline in European GDP of more than 4%. The forced reduction of energy use can be seen as a negative supply shock, diminishing the production potential. However, the decline in real GNI is with about 0.5 % much less substantial. Change in terms of trade are responsible for 3% of this difference between the impact on real GDP and real GNP. As a result of domestic carbon taxes Western Europe can import cheaper energy while it profits from price increases of their exports.

The remaining 0.5 % of the difference is the result of increased net interest income from abroad. That increase is the result of typical current account dynamics after a negative supply side shock. Figure 3.5 shows the investment dynamics in Western Europe. As a result of the (gradual) reduction in production potential the capital stock is adjusted downwards. This implies in the first years a sharp decline in investments. Lower investment demand manifests itself in a temporary improvement of the trade balance and consequently an improvement of the current account, which increases the stock of net wealth invested abroad. As a result, net interest income from abroad rises.

Figure 3.4a Impact on production and income in A1 scenario (cumulated% change in 2020)

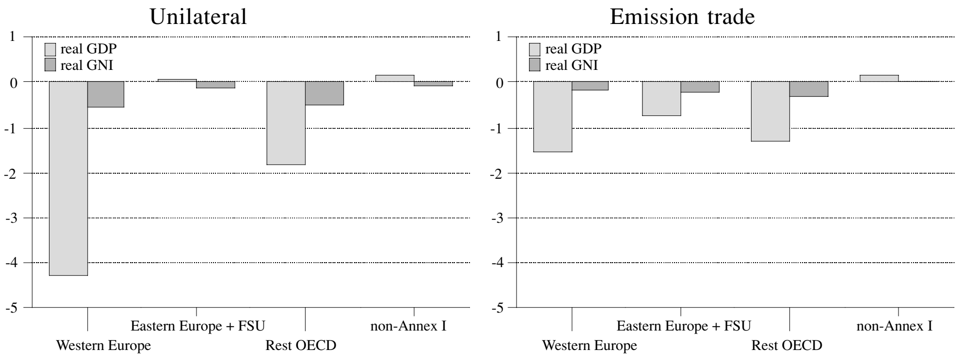


Figure 3.4b Impact on production and income in B1 scenario (cumulated% change in 2020)

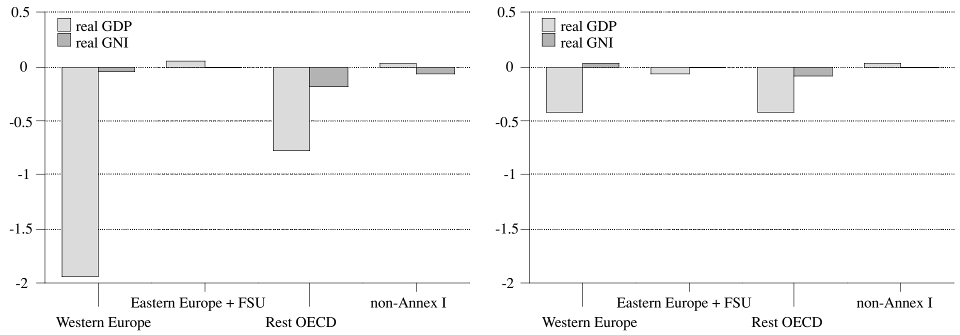
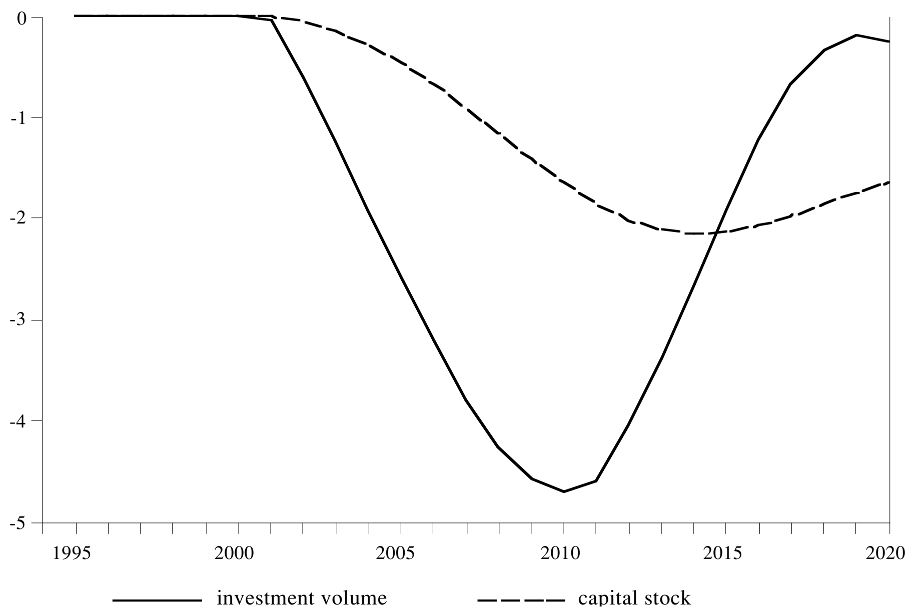


Figure 3.5 Investment dynamics in Western Europe (cumulates% changes)



Once the capital stock is adjusted downwards, investments return to the level needed for structural expansion and replacement of depreciated investments. Also the current account will return to its baseline level, but the composition of the current account will be permanently changed. The temporary increase in net savings leads to a permanent increase in net wealth invested abroad and to a permanent increase in net interest income from abroad. The trade balance not only returns to its baseline level, but ultimately even converges to a level below the baseline, financed by increased interest income.

This mechanism distinguishes models with endogenous current accounts, like WorldScan and G-Cubed (McKibbin et.al., 1998), from models with a fixed current account like GREEN (Van der Mensbrugghe, 1998).

Also for the Rest of the OECD the figure shows a much smaller decline in GNI than in GDP, indicating also for that region an improvement of the terms of trade. The production effect in Non-Annex-I is slightly positive. There the increased energy use can be seen as a positive supply shock. Due to terms-of-trade losses the income effect is negative, but negligible. The EE+FSU are hardly affected in the unilateral case. In the case of emission trade their GDP is negatively affected because they will realize more Annex-I reductions within their borders. The direct impact of these reductions on their income is more than compensated by payments of other Annex-I countries for emission rights. However, free trade has still a slight negative overall impact on their income. The causes lie in their energy markets. Because they are not fully integrated within the world energy market, the decline in domestic energy demand is especially felt by domestic producers. That leads to a sharp decline in domestic energy production, lowering domestic rent income. It also leads to a sharp decline in domestic producer prices of energy, implying a worsening of the terms of trade.

3.3 A further breakdown of emission reductions and leakage

In this subsection we will give two breakdowns of the emission reductions and leakage in the A1 scenario. First we will give a decomposition according to the KayAnnex-Identity. Then we will present a measure for the carbon content of final demand. That measure enables us to split emissions into emissions used for own final demand and for implicit net exports of emissions.

Figure 3.6 Emission reduction split up according to Kaya-identity in A1 scenario (cumulated% change in 2020)

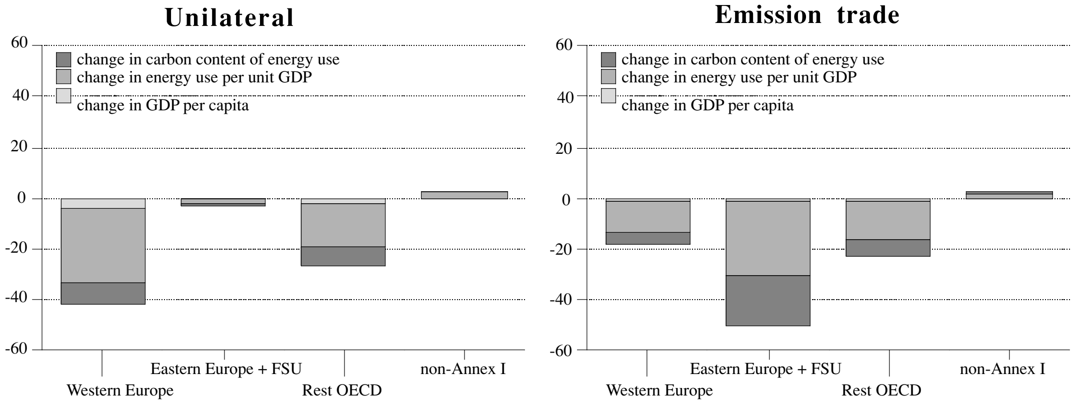


Figure 3.7 Implicit net exports of carbon in A1 scenario in 2020 (TgC)

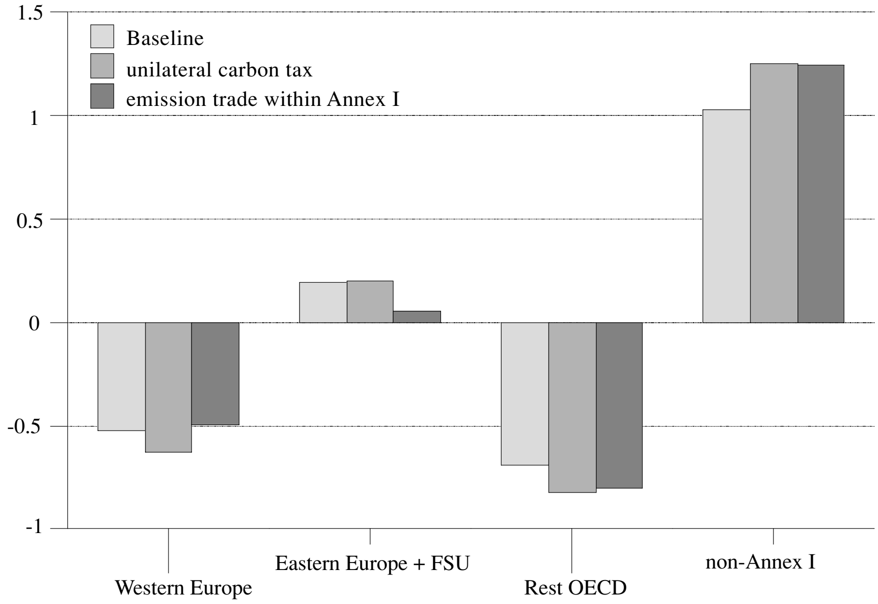


Figure 3.6 contains the decomposition of relative changes in emissions into a percentage change of GDP, a percentage change of the energy intensity of GDP and a percentage change of the carbon intensity of energy use.[7] The figure shows that changes in overall production only to a limited extent count for changes in emissions. More substantial is the contribution of changes in the carbon content of energy. These changes reflect the substitution across energy carriers, from coal to oil and gas and from fossil fuels to bio fuels and non-thermal energy.
The most important cause of changes in emissions is the change in the energy use per unit GDP. This change in energy efficiency reflects shifts over sectors and substitution within production processes. It may also reflect some shifts across different producers of the same fossil fuel. Because of quality differences the energy content of one dollar of coal may differ among producers. As a result of a carbon tax users will shift towards higher quality coal leading to an overall reduction of the energy content of output.

Although the leakage rate is substantial, the percentage change of emissions in Non-Annex-I is very small. This demonstrates the huge relative size of Non-Annex-I at the end of the scenario period.

A second decomposition is based on the analysis of the final use of emissions. To that end we computed for all sectors the implicit carbon content, taking into account all intermediate deliveries and all imports. The results are shown in table 3.2. With the implicit emission coefficients in that table we can compute the implicit use of emissions for final demand in each region. By subtracting these implicit emissions from the emissions that were actually created in that region we get the implicit net exports of emissions. Of course implicit net exports of emissions add up to zero over the regions.

Figure 3.7 shows that in the A1 scenario in 2020 the OECD economies are net implicit importers of carbon. For their final demand globally more carbon is emitted than they emit themselves. Or, in other words, the carbon content of OECD's imports exceeds the carbon content of OECD's exports.

[7] Because the figure neglects second order effects, the three percentage changes only roughly add up to the percentage change of emissions.

Table 3.2 Carbon content of sectoral output in two scenarios (in kg / thz US$)

	Western Europe			Eastern Europe and Former Soviet Union			Rest of the OECD			non_Annex I		
	1995	2020		1995	2020		1995	2020		1995	2020	
		A1	B1		A1	B1		A1	B1		A1	B1
Agriculture	11.1	8.6	6.6	59.5	17.7	14.0	12.5	8.0	6.6	16.9	10.6	9.0
Coal	234.9	199.5	156.3	184.8	43.8	38.9	192.1	107.7	104.6	271.8	126.5	117.1
Oil	51.8	34.9	26.4	109.5	32.3	27.5	7.8	4.1	3.5	84.9	45.7	41.4
Natural Gas	46.2	33.2	25.6	61.4	17.9	14.8	92.3	82.8	67.8	138.7	114.7	101.4
Other Minerals	21.0	15.7	12.2	143.1	37.0	27.9	19.2	11.5	9.5	53.5	32.1	26.6
Intermediate Goods	74.3	55.3	44.0	253.0	76.4	63.0	88.4	56.0	48.5	200.4	138.5	122.6
Consumption Goods	16.4	13.3	10.5	189.6	70.7	57.2	38.4	24.7	20.6	51.0	32.9	27.9
Capital Goods	15.4	12.5	9.9	79.0	25.4	20.1	21.8	14.9	12.5	54.0	36.3	31.4
Electricity	134.7	113.4	88.1	543.1	255.3	206.7	132.5	104.6	84.1	308.8	222.3	195.5
Services	10.4	8.2	6.3	70.9	23.0	18.3	13.9	9.0	7.4	36.5	25.5	21.9
Trade & Transport	7.4	5.9	4.4	62.8	19.0	14.6	8.8	6.2	4.9	28.2	18.6	15.8

The reason is not primarily that the OECD countries are specialized in energy-extensive sectors, but that non-OECD countries are less energy-efficient in all sectors as is shown in table 3.2.

Figure 3.7 also contains the net exports in case of unilateral mitigation policies in the A1 scenario. The net exports of Non-Annex-I increase by .22 TgC. That is only .06 TgC less than the total leakage of .28 TgC. That means that most of the increase in emissions in Non-Annex-I is ultimately used for final demand in Annex-I countries. Annex-I's reductions in emissions is only partly a reduction in implicit final use of emissions. The increase in Non-Annex-I net implicit exports of emissions is the result of three factors. First, in every sector their own production becomes more energy-intensive, as table 3.3 shows. That makes also their exports more carbon intensive. Secondly, the gains in energy-efficiency in Annex-I lowers the carbon content of Annex-I's exports and Non-Annex-I's imports. Thirdly, Non-Annex-I takes over some of Annex-I's production in energy intensive sectors. For as far that production is ultimately again exported to Annex-I countries the mitigation in Annex-I merely is a shift of production across borders.

In case of trade in emission rights, the net implicit exports of emissions of EE+FSU decline significantly. So, while their exports of formal emission rights goes hand in hand with a reduction of implicit exports. Exports of EE+FSU become more energy-intensive, which lowers the implicit carbon content of their exports. The mirror image can be found in Western Europe where net implicit imports of emissions decline, because of the lower carbon content of imports from EE+FSU.

This analysis of implicit carbon use shows the importance of trade in relation to leakage. Trade is not only the ultimate cause of leakage (economies in autarky do not react to policies abroad), but it is also the channel through which leakage is partly exported back to the countries that set themselves targets.

Table 3.3a Carbon content of sectoral output in 2020 with two alternative policies in A1 scenario

	Western Europe		Eastern Europe and Former Soviet Union		Rest of the OECD		non-Annex I	
	unila-teral	emission trade	unila-teral	emission trade	unila-teral	emission trade	unila-teral	emission trade
Agriculture	6.6	7.3	17.2	11.1	6.8	6.9	11.0	10.8
Coal	88.0	134.6	44.8	26.9	61.8	66.8	133.0	131.3
Oil	28.7	33.3	32.9	23.1	3.4	3.4	48.1	47.6
Natural Gas	26.8	31.1	17.9	11.2	75.1	75.8	118.7	117.5
Other Minerals	12.6	13.7	36.2	23.4	9.0	9.3	33.2	32.8
Intermediate Goods	42.1	49.2	74.5	41.3	46.6	47.6	144.1	142.4
Consumption Goods	10.5	11.4	69.5	46.8	21.0	21.4	33.9	33.4
Capital Goods	10.5	11.2	24.9	16.0	13.1	13.2	37.7	37.1
Electricity	56.7	79.7	250.4	159.1	65.6	69.8	230.2	227.6
Services	6.4	7.2	22.6	14.3	7.7	7.8	26.5	26.1
Trade & Transport	4.6	5.1	18.5	11.7	5.1	5.2	19.2	18.9

Table 3.3b Carbon content of sectoral output in 2020 with two alternative policies in B1 scenario

	Western Europe		Eastern Europe and Former Soviet Union		Rest of the OECD		non-Annex I	
	unila-teral	emission trade	unila-teral	emission trade	unila-teral	emission trade	unila-teral	emission trade
Agriculture	5.8	6.3	14.4	12.3	6.2	6.3	9.2	9.1
Coal	103.9	141.8	42.4	33.4	88.2	94.3	120.2	118.5
Oil	24.1	26.2	28.6	25.4	3.2	3.3	42.4	42.0
Natural Gas	23.1	25.3	15.4	12.9	66.1	66.7	103.1	102.2
Other Minerals	10.8	11.8	28.9	24.5	8.6	8.9	27.1	26.8
Intermediate Goods	38.1	42.7	65.5	53.2	45.0	46.3	124.9	123.7
Consumption Goods	9.3	10.0	58.8	51.4	19.4	19.9	28.3	28.1
Capital Goods	9.0	9.6	20.7	17.7	11.9	12.1	31.9	31.5
Electricity	60.1	80.1	217.0	181.4	71.2	76.1	199.1	197.1
Services	5.6	6.1	18.9	16.0	7.0	7.1	22.3	22.0
Trade & Transport	3.9	4.3	15.1	12.8	4.6	4.7	16.1	15.9

4 Sensitivity analysis

Leakage may occur through migration of energy intensive industries away from Annex 1 regions and through substitution within industries in non-Annex 1 countries towards cheaper energy[8]. Armington elasticities rule the substitution between domestic and imported goods. Substitution possibilities within sectors depend on the substitution parameters of the production function. This section explores how sensitive WorldScan results are to these two sets of key parameters: Armington elasticities and substitution elasticities. We run a number of variants with different parameter settings and compare the effects of the policy simulations with the reference case.

[8] Income effects are negligible small, so leakage through this channel is not taken into consideration.

Changing the Armington elasticities
WorldScan contains rather high long-run price elasticities in demand for foreign goods. Elasticities vary between 5 and 16 (in absolute values). In the case of positive carbon prices, sectors with a high carbon content, *e.g.* intermediates, will 'suffer' more. High trade elasticities will induce a strong shift in demand from expensive domestic sectors towards inexpensive foreign sectors. To assess the role of these trade elasticities we halve the long-run Armington elasticities. We calibrate both the A1 and B1 scenario with these lower elasticities, to ensure that the baseline with new parameter values contains the same energy use as the original baseline, and run the unilateral and free trade cases.

Changing substitution parameters
Substitution possibilities depend on structure and parameters of the production function. WorldScan assumes a nested CES structure, which is more or less identical over regions and sectors. Output is a CES-aggregate of value-added and intermediates. Intermediates, for its part, is a CES-aggregate of energy and other intermediates. Next, the energy nest is a CES aggregate of all fossil inputs, electricity, biofuels and non-thermal electricity[9]. Crucial in the simulations we are considering, is how energy demand reacts to price changes (at a given output). The magnitude of this price elasticity of energy demand depends on substitution possibilities within the energy nest and the substitution between the energy nest and other nests in the production function. To assess the sensitivity of these substitution possibilities, we calibrate a model version with lower substitution parameters. The substitution parameter between energy and other intermediaries is halved from 0.8 to 0.4, the intra energy substitution is reduced from 2.0 to 0.8. Again, we calibrate both the A1 and B1 scenarios to target the same energy use and analyse the free trade and unilateral cases.

Some results
Table 4.1 presents the leakage rates under alternative specifications, Table 4.2 presents the corresponding carbon prices.

According to the entries in column 2 of Table 4.1, lower trade elasticities lead to lower leakage rates, in both scenarios and in both policy cases. Although, the effects are modest. Carbon prices are slightly lower. However, one has to realise that the general price level in the Armington variant is lower. Given the stronger home bias in demand, fast growing economies have to lower their prices to create enough export possibilities. Their terms of trade deteriorate. For OECD countries there is a terms of trade gain.

Lowering substitution parameters in the production function gives more ambiguous results. In the unilateral case there is an increased leakage the A1 scenario, but a decrease in the B1 world. In the case of free trade, changing substitution within sectors does not seem to alter the leakage rate. However, carbon prices in all situations rise.

A decomposition
If trade elasticities or production elasticities change, substitution over sectors *and* substitutions within sectors may change. Both effects may have an opposite impact on the leakage rate. For example, lowering the substitution parameters, both the intra energy substitution and the substitution between energy and other intermediaries, hampers the shift towards cheaper energy. This gives a downward pressure on leakage. The price elasticity of demand decreases as a consequence of the lower substitution between the different energy carriers. Hence, a higher price

[9] In the electricity sector, electricity is not included in the energy nest.

Table 4.1 Leakage rate[1] under alternative specifications

	Reference	Low Armington	Low substitution
Unilateral case		%	
A1	20	16	22
B1	20	16	17
Annex 1 trading			
A1	19	15	19
B1	17	16	17

[1] Leakage rate defined as the change in emissions in Non-Annex I as a percentage of the reduction in Annex I.

Table 4.2 Carbon prices in Annex 1 under alternative specifications

	Reference	Low Armington	Low substitution
Unilateral case		*1995 US$ / tC*	
A1			
Western Europe	120	118	220
EE + FSU	50	48	93
Rest OECD	7	7	12
B1			
Western Europe	41	39	75
EE + FSU	14	13	24
Rest OECD	0	0	0
Annex 1 trading			
A1	42	40	77
B1	8	7	14

increase is needed to realize a given decrease in the energy demand. Lowering the substitution possibilities between energy and other intermediaries leads to a further rise in abatement costs. The higher carbon prices induce a larger shift in energy-intensive production from Annex I to non-Annex I, *i.e.* a larger shift over sectors. This gives an upward pressure on leakage.

A decomposition of the leakage rate can shed some light on this issue. We compute the carbon content of fossil energy in all sectors in the base line. Next, we compute the effect of the change is sector structure on emissions using the baseline direct carbon contents[10]. This indicates the effect of substitution over sectors. The complement denotes the effect of changes within sectors. As an illustration, for the unilateral case in the A1 scenario a decomposition has been made. Table 4.3 presents some results.

[10] This measure of carbon content differs from the one discussed in the previous section. Here only the direct emissions used in the production process are taken into account, not the implicit emission related to the intermediary use of other products.

Table 4.3 Decomposition of leakage rate[1] in A1, unilateral case

	Reference	Low Armington	Low substitution
		%	
Total	20	16	22
over sectors	9	3	16
within sectors	11	13	6

[1] Leakage rate defined as the change in emissions in Non-Annex I as a percentage of the reduction in Annex I.

Lowering the Armington elasticities in this variant lowers the effect of shifts over sectors from 9% to 3%. There is a small effect on shifts within sectors. Energy prices in non-Annex I are a bit lower. The lower energy prices will induce substitution within sectors towards fossil fuels and an upward pressure on leakage. Due to substitution within sectors, leakage rises from 11% to 13%.

Lowering the substitution parameters leads to a higher carbon price. The higher carbon prices induce a larger shift in energy-intensive production from Annex 1 to non-Annex 1, *i.e.* a larger shift over sectors (from 9% to 16%). Compared to the reference case, in non-Annex 1 there is less substitution towards cheaper energy, the carbon content. is lower. Due to substitution within sectors, leakage decreases from 11% to 6%.

5 Conclusions

The focus of this paper is carbon leakage under the Kyoto protocol. The dynamic AGE model WorldScan is used to analyse the effects of both unilateral action and permit trading within Annex I . Two new scenarios, A1 and B1, are used as 'Business-As-Usual' scenarios. Both scenarios assume high growth rates, especially in Non-Annex-I. The main difference is that in B1 very rapid autonomous improvement in energy efficiency is assumed. That makes the necessary reductions to comply with the Kyoto Protocol smaller and it generates a substantial amount of hot air in the Former Soviet Union, even in 2020. The two scenarios turn out to generate similar leakage rates to non-Annex I regions. However there is a large difference in leakage within the Annex I region. In 2020 reduction in restricted Annex I countries are still partly offset by induced increases of emissions in the Former Soviet Union. Typical values for the leakage rate to non-Annex I turn out to be around 20 percent. Leakage in case of free emission trade is slightly lower compared to the case with unilateral mitigation policies.

In the analysis we split up leakage in three different ways. First, we use the well-known Kaya identity where a change in emissions is disentangled into a change into a change in production, a change in the energy intensity of production and a change in the carbon intensity of energy. Changes in energy intensity of production are more important than changes in carbon intensity of energy. The latter is more important in countries that reduce their emissions than in countries that increase their emissions. Changes in the level of total production are negligible as cause of leakage.

Secondly, we decomposed emissions into emissions that are ultimately used for domestic final demand and emissions that are use for net exports of goods and services. To that end we computed for all sectors the implicit carbon content, taking into account all intermediate deliveries and all imports. With this decomposition we could compute how mitigation policies change the carbon content of final demand in Annex-I and Non-Annex-I. It turned out that most of the leakage to is implicitly used for final demand in Annex I regions. The implicit net imports of carbon through trade in goods and services increase along with leakage of emissions to non-Annex I.

Thirdly, in sensitivity analyses we split changes in emissions into changes that result from shifts over sectors and changes that results from shifts in production technologies.[11] Crucial for these processes are trade elasticities and production substitution elasticities. In the sensitivity analyses we assessed the importance of these parameters. In these exercises we tried as far as possible to prevent changes in the baseline having an influence on the outcomes. Higher trade elasticities tend to lead to higher leakage as a result of shifts over sectors, but to slightly smaller leakages through changes in input structures of production. Lower substitution elasticities in the production process tend to decrease leakages through changes in the input structures, but a also increases significantly leakage as a result of shifts over sectors.

[11] The distinction between changes in production technologies and shifts over sectors is a vague one. In every economic model sectoral output consist of heterogeneous products, which implies that production functions always describe, besides technological options, also the consequences of shifts over products. However, in sensitivity analysis the distinction between demand and production functions is a convenient one because both elements refer to specific model parameters.

Appendix 1: WorldScan: a global applied general equilibrium model[12]

WorldScan has been developed to construct scenarios. To avoid extrapolation of current trends or mere reproduction of the current situation, WorldScan relies on the neoclassical theories of growth and international trade. Changes in economic growth and international specialization patterns evolve from changes in (relative) endowments. The emphasis on the long run also manifests itself in the broad definition of sectors. WorldScan distinguishes 11 sectors. This is a relatively small number compared to other AGE models. Over a long period of two decades or more the character of products and branches of industry change drastically. Current statistical definitions of products and branches of industry are likely to become irrelevant at the end of scenario period. For this reason, WorldScan uses broad aggregates.

The standard neoclassical theory of growth distinguishes three factors to explain changes in production: the accumulation of physical capital, labour, and a fixed technology trend. WorldScan augments the simple growth model in three ways. First, WorldScan allows overall technology to differ across countries. It also takes up the related idea that developing countries can catch up quickly by adopting foreign state-of-the-art technologies. Second, the model distinguishes two types of labour: high-skilled and low-skilled labour. Sectors differ according to the intensity with which they use high-skilled and low-skilled labour. Countries can raise per capita growth by schooling and training the labour force. Third, in developing countries part of the labour force works in low-productivity sectors. In these sectors workers do not have access to capital and technology. Reallocation of labour from the low-productivity sectors to the high-productivity sectors enables countries to raise per capita growth as well. In principle, all these three factors affect the performance of a region only temporarily. Catching-up, training of low-skilled workers and reallocating labour to the high-productivity sector do not raise the growth rate indefinitely. Nevertheless, they are important. Adjustments in the economies of developing regions take a great deal of time and will surely show up in the growth rates of these regions in the period under consideration.

[12] The model is described extensively in CPB (1999).

Box 1 WorldScan, a global general equilibrium model

At the heart of WorldScan are the neoclassical theories of economic growth and international trade. The core of the model is extended to add realism to scenarios. In doing so, we aim at bridging the gap between academic and policy discussions. The extensions include:

- an Armington trade specification, explaining two-way trade and allowing market power to determine trade patterns in the medium run, while allowing Heckscher-Ohlin mechanisms in the long run;
- imperfect financial capital mobility;
- consumption patterns depending upon per capita income, and developing towards a universal pattern;
- a Lewis-type low-productivity sector in developing regions, from which the high-productivity sector can draw labour, enabling high growth for a long period.

The model distinguishes the following regions, sectors and productive factors (see appendix for a detailed, regional and sectoral classification):

Regions	*Sectors*	*Productive factors*
United States	Agriculture	*Primary inputs*
Western Europe	Services	Low-skilled labour
Japan	Trade and Transport	High-skilled labour
Rest of the OECD	Electricity	Capital
Eastern Europe	Intermediate goods	(fixed factor)
Former Soviet Union	Consumer goods	
Middle East and North Africa	Capital goods	*Intermediate inputs*
Sub-Saharan Africa	Oil	from all sectors
Latin America	Natural Gas	
China	Coal	
South-East Asia	Other Raw Materials	
South Asia & Rest		

Education and reallocation of workers not only explain the performance of developing countries, but also affect specialization patterns. Workers in the informal, low-productivity sector are predominantly low-skilled. When more workers find employment in the high-productivity sectors, the (relative) wage of low-skilled workers falls and mainly sectors that intensively employ low-skilled workers expand. These regions will specialize further in sectors which make a lot of use of the relative abundant factor: low-skilled labour. Obviously, education has an opposite effect. Low-skilled labour will become relatively more scarce and shifts production to sectors which intensively use high-skilled labour. Either effect can dominate. This is also reflected in the relative wages of high and low-skilled. In some developing countries wages of low-skilled workers lag behind the wage of high-skilled workers, whereas in other regions the skill premium decreases.

Sectors in WorldScan have different factor requirements. For a given sector these factor requirements are more or less similar across regions. This means that if a sector is relatively capital intensive in one region, it is also relatively capital intensive in other regions. Agriculture (including food processing) and Consumer Goods employ relatively few high-skilled workers, whereas Capital Goods, Electricity, Trade and Transport and Services (including the government) absorb many high-skilled workers. Sectoral restructuring can easily be linked to changes in relative endowments and changes in (region-specific) demand patterns. This also holds because in WorldScan substitution elasticities between domestic and foreign goods are believed to be high in the long run, at least much higher than in the short run. In principle, all goos are tradable, although trade in services is much lower than in manufacturing and raw materials.

Except for different factor inputs, sectors vary also is some other respects. The sectors Capital Goods and Services are the suppliers of investment goods and the sectors, Oil, Coal, Gas and other Raw Materials only produce intermediate outputs. Consumer demand for electricity also includes demand for other energy carriers. This assumption is made because nearly all demand for Raw materials is intermediate demand.

Data

WorldScan has been calibrated on the GTAP database, see Mc Dougall et all. (1998). The calibration year is 1995. From this data base we derive not only demand, production and trade patterns, but also labour and capital intensity of the various sectors. The sectoral classification according to skill intensity is broadly correct, but the precise differences could very well change, when better data become available.

The data and projections for population size and labour supply are from various sources. The United Nations (1995) provide demographic projections. The ILO (1996) provides projection rates on participation rates until 2010. We extrapolate the regional trends in participation rates between 1950 and 2010 to 2020. The data for the supply of low-skilled and high-skilled workers at a regional level have been taken from Ahuja and Filmer (1995). Workers are labelled high-skilled when they have completed secondary education or a higher level. Ahuja and Filmer provide projections for many developing countries. We lack projections for the OECD, Eastern Europe and the Former Soviet Union. Therefore we use the Barro and Lee (1996) data on education. We derive a trend between OECD and non-OECD regions between 1960 and 1990 and extrapolate this trend until 2020. The data on the size of the informal sector are obtained from the WorldBank (1995) and the ILO (1998). The IEA (1997) provides data on energy volumes and emissions in the base year 1995.

Substitution elasticities

The results of the model depend also on the substitution possibilities in production and consumption. The production possibilities are described by a nested CES function. The upper level distinguishes between value added and intermediate goods. The elasticity between these two broad categories is 0.4. At the lower level value added is described by Cobb-Douglas function of the primary productive factors: capital, low-skilled labour and high-skilled labour. The intermediate goods are described by a nested CES function with a substitution elasticity of 0.8, which aggregates Energy and Other intermediates . The energy nest is a CES function which includes Oil, Petrol, Natural Gas, Electricity, but also Biofuels and Non-thermal electricity. The substitution elasticity between these inputs is 2.0. The second nest is also a CES function with again a substitution elasticity of 0.8, which includes the other intermediate inputs.[13] The utility function, from which demand for different consumption categories is derived, has been given a Cobb-Douglas specification. The substitution elasticity between any pair of consumption categories therefore is unity.

[13] In case of the sector Electricity, the input Electricity is a part of the nest with other Intermediate inputs instead of the nest consisting of Energy.

Traded, foreign goods are not perfect substitutes for domestic goods, and this also affects the outcome of simulations. The substitution between goods from different origin is not perfect. WorldScan employs an Armington-type assumption. However, the price elasticities of demand considerably increase over time. The model employs different assumptions for raw materials, Agriculture, Manufacturing and Services. The long-run substitution elasticities in the benchmark case are 17, 13, 7 and 5, respectively.

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Clean Development Mechanism: Discussion[1]

Robert A. McDougall

Owing to circumstances beyond my control, my remarks this afternoon will not be especially responsive to Professor Heller's. Also, while I have been involved in energy policy modeling for some years, I cannot claim any particular expertise on the clean development mechanism (*CDM*). My remarks then will represent an outside observer's perspective on the CDM debate. As an outside observer of the debate, I am struck by the high hopes placed on the CDM by some of its proponents. Contrary to those, it seems to me rather obvious that the CDM will play only a modest role in both climate change and sustainable development action. In my estimation, the CDM:

- is likely to prove contentious,
- will lead to disappointment,
- may yield some minor but useful reductions in the cost of abatement, but
- will do little to assist development.

These outcomes do not re ect design weaknesses in the CDM, but are inherent in the basic concept.

The CDM is essentially a proposal for acting out of natural sequence. Developing countries are to participate before undertaking abatement commitments or implementing emission monitoring systems. Industrialised countries are to participate in advance of therst commitment period, and without knowing the money value of the certied emission reductions their efforts procure. And the system is to come into operation in the year 2000, too soon for the rules to be well defined, or for the necessary institutional machinery to be put in place.

To say this is not to criticize the CDM but merely to characterize it. The CDM aims at certain objectives|early participation by developing countries, capture of early opportunities for cost-effective abatement action in those countries that would not otherwise be achieved. In pursuing them, it is reasonable to make compromises in administrative tidiness and elegant design. Its out-of-sequence character does not make the CDM a bad nitiative, but an aggressive one, pushing the envelope in terms of what is institutionally feasible. But this aggressiveness has implications for the likely drawbacks and benefits of CDM action.

There are several ways in which the CDM may prove contentious.

- Observers in developing countries have already expressed concern about the capacity of host governments effectively to negotiate CDM contracts, the risk of early sell-off of low cost abatement options, and the possibility of interference in host countries' internal affairs (see for example Zhang, 1999).
- The CDM does not attempt to increase global emissions abatement, but only to reduce the global cost of abatement. Environmentalists are already unenthusiastic about mechanisms for vicarious fulfilment of industrialised countries' commitments.

1 Full paper by Professor T. Heller has not been received.

They will be further disaffected if the CDM acts as a source of hot air. This it is liable to do, since the CDM operates under conditions where additionality is hard to verify, and since investors and host countries have a common interest in colluding to overstate emission reductions.

- If stringent mechanisms are put in place to ensure that additionality is genuine, they will likely be resented by potential investors and by industrialised countries hoping to use the CDM to ease the burden of their Kyoto commitments.

- Most fundamentally, the CDM is the product of two different agendas, the sustainable development agenda of the developing countries, and a cost minimization agenda by some industrialised countries. The CDM specification accommodates both sides' aspirations, in the sense that it leaves room for both sides' aspirations to be fulfilled. But that does not mean that both sides' aspirations will be satisfied by the actionthat in fact takes place under the CDM. In fact, that seems rather unlikely, since large gaps remain in the two sides' views on the role of the industrialised countries in supporting sustainable development (see for example Ye, Jin, and Liu, 1999). More than contentiousness however, the CDM is likely to lead to disappointment. There are several minor reasons why the extent of abatement action under the CDM is likely to be small.

- In the opinion of many observers, non-emission measures such as sequestration are excluded from the CDM.

- Effective safeguards to ensure additionality may impose burdensome delays and costs on would-be participants.

- Unlike other mechanisms, CDM projects are to be taxed, to meet administrative expenses and to fund unrelated adaptation projects.

But the major reason is that (assuming effective limitation of hot air) the incentive to participate in the CDM is weak. The only formal incentive to participate is the certified emission reductions provided to investors. These are not usable until the first commitment period, which begins only in 2008. The value they will bear at that time is unknown. Even the mechanism by which investors may use them is unknown. Until these uncertainties are resolved, the direct incentives to participate in the CDM will remain feeble.

Besides the direct financial incentives created by the CDM, there may also be indirect incentives. There may be some public relations benefits for investors or governments from 2 industrialised countries from participating in clean development projects. The CDM may encourage companies (like Shell) undertaking voluntary abatement on a global basis, to allocate more effort to projects in developing countries. The mere existence of the CDM as a topic of discussion may draw attention to worthwhile potential projects in developing countries. While no doubt useful as far as they go, none of these indirect incentives seems likely to have more than a marginal impact on global abatement or development. We are justified then in expecting that for some time to come, the level of CDM action will be quite modest. Again, this does not mean that the CDM is ill-designed. It is better to do a little good than to do none at all. It means only that, given the difficulty of what is being attempted, too much should not be expected.

If CDM activity will be so modest, clearly its effectiveness in promoting development in the Third World will also be modest. Reinforcing this conclusion, we may note that the incentives for CDM action depend only on the abatement potential, not the development potential, of the project. It has been remarked that the word \development", though it appears in the name of the CDM, is absent from much discussion about the CDM, especially in a modelling context. In view of the nature of the incentives in the CDM, this omission appears realistic.

In summary, the CDM will achieve little cost reduction and little development, and is likely to disappoint many of the hopes placed in it. But realistically, if it achieves even a small amount of cost reduction and a small amount of development, it will deserve to be considered a success.

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Discussion on the CDM[1]

Terry Barker

Three sets of comments are worth making in the debate on the effects of the CDM as a flexible instrument on the Kyoto Protocol.

The uncertainty of the size and scale of incremental abatement costs.

The CDM depends for its success on the identification and existence of large differences in incremental abatement costs between Annex B countries and non-Annex B countries and substantial mitigation schemes at these costs. However, it may be difficult to identify the costs and the schemes. There will be huge differences in costs depending on the technologies involved, the information available, the incomes of those making the mitigation decisions, and the time available for the schemes to be planned and to operate. A usual assumption is that these incremental costs are lower in developing countries, but this can be questioned. It seems likely that there is a huge range on costs in all economies and that there will be an overlap in the cost ranges between countries.

CDM effects as macroeconomic effects and environmental effects

If the CDM is to make a substantial contribution to GHG mitigation, through reducing the costs of mitigation and/or increasing the level of mitigation, then it will have macroeconomic effects on the economies concerned. Although individual projects, programmes and schemes under the CDM may well be assessed on a microeconomic cost-benefit methodology, when they accumulate to make an overall contribution to mitigation they will affect the macroeconomy, and some of the underlying assumptions of the original cost-benefit analyses will be changed.

This macroeconomic impact means that a macroeconomic analysis is necessary to assess the CDM. As such, a large number of mitigation studies have given net incremental benefits of mitigation, in terms of effects on GDP and employment. Obviously the schemes with the largest net benefits should be taken first, ceteris paribus. There is also no indication from these studies that the incremental net benefits will reduce as time passes. Learning-by-doing and economics of specialisation and scale may well mean that the net benefits increase or the costs decrease. On the other hand if the revenues from the use of fiscal instruments eg carbon taxes are used to reduce one distortionary tax after another, starting with the most distortionary, then as the taxes are removed, the net benefits should reduce.

[1] Full paper by Professor P. Shukla has not been received.

Since there are likely to be environmental effects as well as economic effects of CDM schemes, eg reductions is other emissions and damages associated with the reduction in GHG emissions, these should also be taken into account, further raising the social net benefits of CDM schemes.

Additionality and the CDM

There is a problem of additionality for all fiscal incentives, such as those associated with the CDM: how can participants be assured that the outcomes of a CDM scheme will indeed be additional to those which would otherwise have occurred? In national incentive schemes, the problem is alleviated by requiring associated inputs or finance by those who receive the incentive.

In the case of a CDM project there are two sides to the additionality problem: i) how can the non-Annex B country be assured that the CDM funding will not replace other financial assistance? And ii) how can the Annex B country be assured that the mitigation will be additional? The problems here can be alleviated by two requirements.

i) A proportion of the funding for the CDM scheme (say 50%) should be available to the receiving country for discretionary use.
ii) Only 50% of the GHG savings be available to the Annex B country as a contribution to its Kyoto mitigation requirements.

Part III

Beyond Kyoto

Developing Economies, Capital Shortages and Transnational Corporations (TNCs)

Leena Srivastava and Pradeep Dadhich

Developing economies and capital shortages

Poor countries — and poor people — differ from rich ones not only because they have less capital but because they have less knowledge (World Bank 1998/99). The scarcity of capital in developing countries is a well-established fact reflected in the accumulated debt levels of these countries. Economic conditions suggested that borrowing money was a reasonable course of action in the 1970s, particularly for poor countries, which perceived few, if any, alternative ways to address the economic plight of their citizens. The logic of borrowing is simple: one incurs a debt in the hope of making an investment that will produce enough money both to pay off the debt and to generate economic growth that is self-sustaining. Unfortunately, the debt was not used either for developing resources nor for productive investments but more for financing current consumption (Ferraro and Rosser 1994).

In 1970, the fifteen heavily indebted nations (using the World Bank classification of 1989) had an external public debt of $17.9 billion - which amounted to 9.8 percent of their GNP. By 1987, these same nations owed $402.2 billion, or 47.5 percent of their GNP. The most devastating effect of this debt burden is the significant outflows of capital to finance the debt. According to the World Bank (1989): "Before 1982 the highly indebted countries received about 2 percent of GNP a year in resources from abroad; since then they have transferred roughly 3 percent of GNP a year in the opposite direction."

At around this time, the International Monetary Fund (IMF) emerged as the guarantor of the creditworthiness of developing countries. The IMF approved additional loans to those countries that accepted stabilization programs of "structural adjustment." These programs are designed to address balance of payments problems that are largely internally generated by high inflation rates, large budget deficits, or structural impediments to the efficient allocation of resources, such as tariffs or subsidies. The IMF structural adjustment programs highlight "productive capacity as critical to economic performance" and emphasize "measures to raise the economy's output potential and to increase the flexibility of factor and goods markets." They also assume that exposure to international competition in investment and trade can enhance the efficiency of local production and involve the relaxation of foreign exchange controls and privatisation of state enterprises. In a 1996 article, Augustin Oyowe linked the increase in FDI flows to developing countries to the structural adjustment programmes underway in these countries for almost ten years.

FDI in developing economies

An econometric analysis of the determinants of private capital flows shows that a combination of per capita GDP, GDP growth, financial development (as indicated by the broad money GDP ratio) and the openness of a country are important factors in explaining the flow of private capital (Lensink and white ,1998). Low-income countries with severe structural problems are unlikely to be able to sufficiently attract substantial inflows of private capital in the near future.

Since the late 1980s the international private capital flows have been increasing at a remarkable rate. The table below indicates the distribution of private capital flows in the 1990s.

Table 1 clearly shows that private capital flows to the entire group of developing countries increased drastically from 1990 onwards, the share of these flows increasing from 44% in 1990 to over 85% in 1996. The table also brings out the changes in the composition of private flows to developing countries. In the period under consideration, whereas the share of debt flows in total private flows has remained more or less constant, the share of portfolio equity flows has increased from 7% to nearly 19% at the cost of the share of FDI.

While the private financial flows have registered an impressive growth of nearly 33% over the period 1990 to 1996, not all developing countries have benefitted equally from such flows. Lensink and white (1998) have shown that private flows have been concentrated in a small number of countries, which are mostly relatively affluent and are not in Africa or other heavily indebted countries. However, this recent aggregate surge in private capital flows has wrongly led to speculation that aid is redundant. The Asian Development Outlook (ADB 1999) warns that "While capital flows can be an important source of economic dynamism in that they provide resources for investment in countries that lack them, they can also cause excessive economic volatility in in countries with weak domestic financial systems, poor regulatory frameworks, and pervasive policy distortions. Capital flight can wreak havoc, and revolutionary changes in information technology mean that capital can exit at lightning speed."

However, a distinction needs to be made between the types of private financial flows. An increase in short-term portfolio flows is potentially much more volatile than long term investments of the nature of FDI. Within the recipient developing countries, capital flows to infrastructure sectors have witnessed a remarkable growth in recent years from $ 1.3 billion in 1986 to $ 27 billion in 1996

Table 1 Aggregate long term resource flows to low and middle income countries ($ billion)

	1990	*1996*	*% annual growth*
Grants	29.2	31.3	1.16
Loans	27.1	9.5	-16.03
ODA	*56.3*	*40.8*	*-5.23*
Debt flows	16.6	88.6	32.20
FDI	24.5	109.5	28.34
Portfolio equity	3.2	45.7	55.76
Pvt Flows	*44.3*	*243.8*	*32.87*

Source: Global Development Finance, 1997. World Bank

Table 2 Private capital flows to low and middle income countries ($ billion)

	Net private capital flows			*Foreign Direct Investments*		
	1990	1996	% growth	1990	1996	% growth
Sub Saharan Africa	0.3	11.8	84.4	0.9	2.6	19.3
East Asia and the Pacific	19.3	108.7	33.4	10.2	61.1	34.8
South Asia	2.2	10.7	30.2	0.5	2.6	31.6
Europe and Central Asia	9.5	31.2	21.9	2.1	15	38.8
Latin America and the Caribbean	12.5	74.3	34.6	8.1	25.9	21.4
Middle East and North Africa	0.6	6.9	50.2	2.8	2.2	-3.9
All Countries	44.4	243.8	32.8	24.5	109.5	28.3

Source: Compiled from Global Development Finance, 1997 and the World Bank Debtor Reporting System

(Dailami and Leipziger, 1998). Such flows embody certain desirable features, which bode well for their sustainability. In contrast to the short-term capital flows of the 1970s, flows to infrastructure projects are of a long-term nature, with debt maturities of 7 to 15 years, or permanent equity and are invested in assets which underpin long term economic growth and export expansion.

This is reinforced by the statistics in table 2. While Sub Saharan Africa has registered an impressive growth of 84.4 % in net private capital flows in the period 1990 to 1996, the growth in FDI has been a mere 19.3 %. The statistics for Middle East and North Africa tell a similar story and both these groupings of countries would probably feel insecure about their financial positions. On the other hand, Europe and Central Asian region has experienced a much higher growth in FDI as compared to the aggregate net private flows.

Most FDI are based on activities undertaken by multinational corporations, but foreign investors are playing an increasing role in privatisation projects in developing countries. “FDI involves the acquisition of existing businesses or development of new business enterprises in a foreign country with the intent of managing these businesses.” (ADB, 1999) Whereas, during the 1980s most FDI flows were between the countries of the North, by 1996 40% of new FDI flows from the North were headed towards the South (DeMartino, 1998).

Whereas, the attractiveness of FDI for developing countries is obvious in a situation of declining official development finance — share in total financial resource flows down to 14% in 1996 compared to 56% in 1990, the attractiveness for FDI by investor countries, both in developed and developing regions lies elsewhere. “Broadly speaking, FDI takes place to exploit an abundance of natural resources, use a relatively low-wage economy as a base for exports of labour-intensive products, and circumvent trade barriers that limit the direct importation of products.” (ADB, 1999)

The role of TNCs

The increasing reliance on Foreign Direct Investment, and the continued wooing of the same by developing countries through the spiralling move towards restructuring and reforming domestic economies, has propelled the TNCs into a major economic force unrestricted by geographical borders. The 1995 World Investment Report indicated that 40,000 TNCs and their 250,000 foreign affiliates have sales in excess of US$ 5.2 trillion. The same report of 1998, indicates that in 1997 some 53,000 TNCs and their 450,000 foreign affiliates accounted for a global sales valued at $ 9.5 trillion and for $3.5 trillion as measured by the accumulated stock of FDI. Other performance indicators, when looked at in relation to global performance are also very impressive. The ratio of inward plus outward FDI stocks to global GDP in 1997 was 21%, value added by foreign affiliate amounts to 7% of global GDP and their exports account for one-third of world exports!

Undoubtedly, TNCs and the FDI that they bring in is of great importance to the developing countries. This importance has been reinforced by the declining levels of overseas development assistance provided by the OECD countries. As seen in Table 1, during the period 1990 to 1996, ODA declined at an annual rate of a little over 5%. The ODA comprises on average a contribution of around 0.35% of a donor's GNP (UNDP 1992), which compares poorly with the 25% of GNP that the industrialised nations direct to their poor. Amongst the various modes of private financial flows, FDI is relatively attractive for the reasons often quoted:

- provides access to modern technological and management knowhow
- provides investment and employment opportunities
- capacity building and training

That said, it needs to be recognised that there still exists a considerable amount of unease about the role of TNCs in developing countries in particular. Some of these concerns are listed in the following section. This feeling of unease has also been reinforced by what is seen to be a victory of vested interests in scuttling the efforts to institutionalise an international regulatory mechanism for TNCs. "The regulatory situation relating to Transnational Corporations (TNCs) and business in general has worsened greatly in the past five years. The efforts to finalize a code of conduct on TNCs were formally killed in 1993, and the agency in charge of the code, the UN Centre on Transnational Corporations was closed. ... Instead, there has been a strong opposite trend now dominant to reduce and remove more and more regulations that governments have over corporations, to grant them increased rights and powers, while removing the authority of states to impose controls over their behaviour and operations. The Uruguay round has already granted far higher standards of intellectual property rights protection to the TNCs, facilitating further their monopolization of technology and their ability to earn huge rents through higher prices. ... The ability of governments to regulate the operations and effects of TNCs and companies in general is being severely curtailed." (Khor, 1997)

TNCs: In conflict with developing country interests?

Profit maximising behaviour; little support to host countries' economic and social development objectives

Most TNCs perceive the Developing Countries as high-risk investments; especially the new and inexperienced TNCs. FDI coming from such TNCs are associated with high capital costs. These TNCs would like to recoup all their capital within 5-7 years and off load the equity at the end of a short period of about 5 years. Because of the high capitalization rates, the market value of the capital stocks increases significantly. The TNCs make a huge profit not only from the business operations but also from off-loading the equity holding. This leaves the company in the host country with little capital and poor managerial ability. Unless the company is managed extremely thereafter it will generally tend to become a sick company within the next 5-10 years time. This form of investment generally lacks long term vision of social and economic welfare of the community.

Patented products and processes

The issue of intellectual property rights (IPRs) and patents has emerged as a major concern in the process of globalisation. Patents safeguard the results of a company's research but the associated patents and licensing fees can be considered to be very expensive particularly by developing countries. In the instances where FDI flows involve a transfer of technology, the potential for conflicts increases because developing countries may prefer the lower priced, albeit possibly less-efficient, technology alternatives.

Additionally, IPR issues are complex and distinctions as to what actually constitutes an IPR is not quite clear especially in the minds of persons involved in the technology transfer in the DC. An excellent example is a proposed AIJ project between a steel plant in India and an investing country involving the installation of a scrap preheater and modification for continuous feeding of the scrap in an Electric Arc Furnace. In this case both the host country steel plant and the investor agreed that this could be treated as a case of technology transfer and this minor process modification would fall under IPR. In fact, this technology is freely available within India but its capital intensity is the main reason for its low popularity among the mini steel plants.

Research Policy

Another area where interests of TNCs and developing countries do not necessarily assign the same priorities relates to research. A TNC's research policy and strategic direction are, understandably, geared towards furthering their own profit objectives and are determined by the global market rather than by national considerations. As such, the products and processes arising out of such efforts are again not necessarily developed to meet local development priorities or adapted to local situations.

Transfer of technology by the TNC takes place through a licensing process, where the licensee can sell the technology to the user. In most cases there is a lag of about 5-7 years for the technology to be transferred from the main technology generators to the licensees. The host country, in particular if it is a developing country, will have to wait over 10-14 years before they can receive such a technological innovation. In the event that the host country seeks to obtain the technology directly from the main TNC, the significantly high cost of the technology and the royalty charges would become a major barrier to the transfer of technology.

Location policy

This is another major area of contention between TNCs and national governments. While governments would like to see the maximum value addition taking place in-country and strive for self-sufficiency TNCs seek to locate production in the country which gives them the best investment environment and market conditions.

The climate change problem, the Kyoto Protocol and the developing countries

The Framework Convention on Climate Change clearly recognised both historical responsibilities as well as the limited role that developing countries could play in addressing the problem of global warming. It called upon the developed (Annex 1) countries to stabilise their emission of GHGs to

1990 levels by the year 2000 and move towards quantified emission limitation and reduction commitments. It also called upon them to provide the requisite technologies and financial resources that developing countries may need to do their bit, in line with their priorities, to contribute towards the objectives of the convention.
The third meeting of the Conference of Parties (COP-3) at Kyoto adopted a Protocol to the FCCC, quantified the commitment levels of annex 1 countries and, at the same time, identified three mechanisms designed to provide flexibility to the Annex I Parties in order to meet their commitments. These include:

- Joint Implementation between Annex I Parties (though the term has not been explicitly used in the text of the Protocol) (Article 6)
- The Clean Development Mechanism (CDM) (Article 12)
- Emissions Trading (Article 17)

Of these, the Clean Development Mechanism (CDM) holds promise of financial flows to the developing countries, while the other two mechanisms may only influence the level and pattern of financial resource flows.

The CDM defined in the Kyoto Protocol appears to be and is often perceived as a formalized JI mechanism between developed and developing countries with credits. The benefits accruing from CDM to the non-Annex I Parties would be the profits from project activities resulting in certified emissions reduction (CERs), while those to the Annex I Parties would be use of these CERs for achieving compliance with *part* of their quantified emission limitation and reductions.

The Climate change problem, developing countries and TNCs

Quite apart from the conflicts of interest noted in the sections above, several non-governmental organisations have been highlighting the role of TNCs in mitigating climate change. The Third World Network has been one of the most vocal institutions calling for a regulation of TNC activities. In their assessment, “TNC activities generate more than one half of the greenhouse gases emitted by industrial sectors with the greatest impact on global warming” (TWN 1997). In their assessment given on the eve of the Earth Summit in 1992, “the biggest gap in the UNCED documents being signed in Rio is the absence of proposals for the international regulation or control of big businesses and transnational corporations to ensure that they reduce or stop activities that are harmful to the environment, health and development”.

Several issues relating to the climate change debate arise out of the role of TNCs in the global economy. An attempt has been made in the following paragraphs to discuss the significant ones.

TNCs and emissions inventories

The business activities of TNCs are wide spread and diverse. Increasingly there is a complex global scale integration in the production processes, while markets too are globally dispersed. Additionally, depending on the nature of investment, there could be a significant repatriation of profits back to the home countries of the TNCs. All of this, combined with the fact that there is normally no long-term — when seen in the context of the time frame of the climate change problem — commitment of the TNCs to their host countries, makes the issue of accounting for green house gases from TNC activities less than straight forward. A clear set of criteria would have to be identified on the basis of which emissions from TNC activities are budgeted. The criteria set would have to consider the nature of activities, the longevity of investments, the benefit sharing mechanisms, etc.

TNCs and the CDM

By the very nature of their business, TNCs are well positioned to take advantage of the Kyoto mechanisms, in particular the CDM. As brought out by Casagrande (1996) over 70% of international trade is controlled by TNCs. By 1989 trade between subsidiaries of TNCs accounted for one-third of total world trade (DeMartino, 1998). The CDM mechanism envisages collaborative project-based activities between private companies in the developed countries and partner organizations in the developing countries. In return for flow of investments and technology, Annex 1 partners would receive emissions reduction certificates presumably at costs much lower than if they were to bring about such reductions in their home countries. Obviously, the structure of TNCs places them in a position where they can take maximum advantage of such an arrangement. CDM projects developed between a TNC (or its subsidiary) in a developed country and its subsidiary located in a non-annex 1 country would ensure that technology upgradation and the benefits therefrom would remain within the company while giving the TNC the pick of such opportunities at the least net cost. Given their increasing role and influence in the developing countries, one fear could be that, the negotiating position of the developing countries could be compromised.

While there is no international agreement yet on accrediting projects undertaken on a unilateral basis or on projects based on opportunities for South-South cooperation, several studies have spoken about the contribution that such projects could make to the climate change agenda (Srivastava and Pathak, 1998). TNCs would be well poised to take advantages of such opportunities which might arise in the future. Additionally, if these options are considered, TNCs can play a major role in influencing the trade in, and hence the prices of, CERs.

Apart from the monopolistic advantage of TNCs arising out of such a mechanism, several other issues come to the fore. Most prominent amongst them is the issue of baselines. The question that stares us in the face is whether the baselines for TNC projects should be the one for the host country, or should these be compared with the baselines in their home countries. Presuming that home country emission norms are much more stringent, a baseline based on the host country situation would give a higher advantage to TNCs and may actually act as a disincentive for transfer of better technologies and know-how. Yet another issue that is confounding is whether CDM activities between affiliates could be considered to be a leakage of benefits from the developing countries. This fear would arise from the cozy relationship between TNCs and their affiliates in developing countries that would place the worldwide business interest of the TNC above the development priority of the host country.

TNCs and emissions trading

The author considers the possibility of trading in hot air to be a carbon leakage. This consideration arises from the belief that only those emission reductions would qualify for trading which arise from a conscious effort to reduce such emissions. Reduced emissions arising from an economic slow down or recession cannot, and should not, be traded. The implication of this argument is that:

1. While the countries that are undergoing economic recession would, hopefully, bounce back over a period of time, in the meanwhile they may be so strapped for investment resources as to lend themselves to be exploited. Even if such hot air was to be utilised, it should be used to generate

CERs or ERUs that reflect a tangible benefit to such countries at costs comparable to those in similar projects in other countries.

2. Every unit of emission reduction should reasonably be able to be linked to specific policies or measures adopted or project activities. If such a system is allowed, then emissions trading would be limited, primarily, to certified emission reduction units arising from JI projects and to certified emissions reduction arising from CDM projects. While TNCs would again be a major beneficiary of this development, it needs to be recognised that they can contribute to a significant distortion in the emissions trading market.

Role of TNCs in climate change

By virtue of their advantageous position vis-à-vis the CDM and JI mechanisms, TNCs can emerge as a major player in the emissions trading marketed. As mentioned by DeMartino "governments are finding their policy autonomy constrained by the need to provide an environment conducive to the interests of capital". This is reinforced by Khor who says that "The ability of Governments to regulate the operations and effects of TNCs ... is being severely curtailed." Given such a situation another issue for consideration is whether TNCs should be considered as a 'Party' under the Framework Convention on Climate Change and the Kyoto Protocol. In such a scenario, what entitlement would the TNCs have? And, at the same time, the issue arises on whether such an arrangement would further strengthen TNCs by placing them on the same level as the State?

In sum

This meeting addressed itself to the issue of the architecture of future agreements. Looking into the future, one sees two options:

(i) The Kyoto protocol is ratified

(ii) The Kyoto protocol is not ratified

If the Kyoto protocol is ratified, then the suggestions that follow should be kept in mind for the agreement that would be arrived at for the period beyond the Kyoto agreement. However, if the Kyoto protocol is not ratified, the climate change community should address the roles and responsibilities of TNCs explicity as soon as possible. The architecture of a future agreement should:

- need to work out a basis for equitable allocation of emissions entitlements
- need to recognise the artificiality of divisions between the three Kyoto mechanisms
- explicitly address the issues arising out of the growing power and reach of TNCs
- consider appropriate governance/regulatory mechanisms.

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Future Agreements

James Edmonds[1]

The Framework Convention

The Framework Convention on Climate Change (FCCC) entered into force in 1994. It currently has more than 179 parties.[2] This agreement forms the foundation for current international negotiations on climate change. Its goal is set forth in Article 2:

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, ***stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system****. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. (Emphasis added.)*

The FCCC divides the world into three sets of nations Annex I, Annex II and non-Annex I. Annex I nations are the developed nations of the world plus most of the Former Soviet Union and Eastern European nations.[3] Annex II is a subset of Annex I, which excluding Former Soviet Union and Eastern Europe, lists potential providers of financial assistance to developing nations.[4]

Annex I nations have greater responsibilities under the FCCC than non-Annex I nations. The distinction reflects concerns for differences in ability to participate by non-Annex I nations relative to Annex I nations, as well as differences in historical rates of emission to the atmosphere of greenhouse gases. Annex I nations are to undertake measures with the "the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol." (Article 4)

In 1999 there appears to be little prospect for Annex I nations as a whole to achieve the aim of the FCCC—to return to 1990 emissions levels by the year 2000. In fact only a small number of nations

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[2] As of June 30, 1999.

[3] Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Czechoslovakia [sic], Denmark, European Economic Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and the United States.

[4] Australia, Austria, Belgium, Canada, Denmark, European Economic Community, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom of Great Britain and Northern Ireland, and the United States of America.

with special circumstances such as nations of the Former Soviet Union and Eastern Europe, Germany, and the United Kingdom, have much hope of returning greenhouse gas emissions to 1990 levels by the year 2000.[5]

The Kyoto Protocol

From December 1 through December 11, 1997 participants in the FCCC met in the third Conference of the Parties held in Kyoto Japan to discuss measures that should be taken beyond those included in the FCCC. An agreement was negotiated which established quantifiable emissions limitations for Annex I parties, as well as a set of mechanisms to help reduce the cost of achieving the emissions limitations including emissions trading, joint implementation, a Clean Development Mechanism (CDM), multiple greenhouse gases, and a five-year compliance period.

The Kyoto Protocol Has Not Entered Into Force

The Protocol came open to ratification beginning March 16, 1999. It has not entered into force. To enter into force, the protocol must be ratified by at least 55 Parties to the Convention, and ratifying parties must represent at least 55 percent of the total Annex I carbon dioxide emissions for 1990. This means that if parties representing more than 45 percent of Annex I emissions remain outside the Protocol, it cannot enter into force. It is particularly important whether or not the United States presents an instrument of ratification, acceptance, approval or accession. It alone represents nearly one-third of 1990 Annex I emissions.

For the United States, ratification of the Protocol requires a two-thirds vote of the Senate. It is possible for the agreement to enter into force without the United States. However, without the United States participation it would require the absence of only a small number of additional nations to make it impossible to achieve the 55 percent of 1990 emissions needed to enter into force.

Targets and Timetables

The most prominent feature of the Kyoto Protocol is the quantified emissions limitations and reduction commitments. Thirty-nine parties accepted quantified emissions limitations or reduction commitments. These are given in the Appendix to this paper.

We can summarize obligations as follows.

- Western European nations accepted an eight percent reduction relative to 1990 emissions, with the exception of Iceland and Norway which were allowed 110 and 101 percent of 1990 emissions respectively.
- Eastern European nations generally had the same obligation as Western European nations with some exceptions—Croatia was 95 percent, and Hungary and Poland were 94 percent of base year emissions. Note that the base year for the countries in this region need not be 1990.
- The Russian Federation and Ukraine were allowed 1990 emissions levels, while Latvia, Estonia and Lithuania agreed to eight-percent reductions.
- Japan and Canada agreed to a six percent reduction from 1990 emissions levels.

[5] Restructuring and economic depression are the sources of the ability of Former Soviet Union and Eastern European nations to meet their FCCC aim. For Germany, the reunification of East and West Germany in 1990 provided a base year with abnormally high emissions, which was followed by depression and restructuring in the East. In the United Kingdom, political measures against the coal miners' unions and associated restructuring to natural gas make it possible to return to 1990 emissions in the year 2000.

- The United States of America agreed to reduce emissions seven percent below 1990 levels. And,
- Australia was allowed to increase emissions eight percent above 1990 levels and New Zealand was allowed to emit up to 1990 levels.

The Six Gas Approach

Emissions are defined in terms of a basket of six gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexaflouride (SF_6). Gases are compared to each other using global warming potential (GWP) coefficients as developed by the IPCC. The use of GWPs allows for the aggregation of the six greenhouse gases specified in the Protocol into a singe value based on each gas' carbon equivalent. We will discuss the use of carbon equivalent emissions in this analysis later in the paper.

Land-Use Change Emissions Accounting

One of the most important and controversial features of the Kyoto Protocol is the treatment of emissions of greenhouse gases from land-use change. A very complicated set of rules was developed which addresses both political and scientific concerns. They describe how nations compute their base year emissions, against which all future mitigation is measured, as well as emissions in the compliance years. The rules are complex, highly asymmetrical, and incomplete.[6]

[6] The Kyoto Protocol makes provision for land-use change emissions and sinks and, while net land-use emissions are small relative to fossil fuel carbon emissions, their treatment can have a major impact on the initial cost of achieving any emissions mitigation objective. Land-use emissions are presently treated as a flow in determining the base year (1990) emission rate. Most Annex I nations are in the process of reforesting, and therefore have net accumulation of carbon. This accumulation reduces net anthropogenic emissions.

Although this approach is appropriate for a global accounting of carbon flux, it may not be desirable as a methodology for setting 1990 base year emissions. The implication of this treatment is that if a nation were reforesting in 1990 and were committed to maintaining 1990 emissions rates under the Protocol, it could not reduce the rate of reforestation rate without lowering fossil fuel carbon emissions to below 1990 levels. Thus reforesting is not enough. The rate must be maintained. For nations that were deforesting, this method would create a base year emission target that is the sum of deforestation plus fossil fuel emissions which would in turn implicitly grant those nations a perpetual right to deforest. If the deforestation rate is ever reduced, for example as a consequence of destroying all forested areas, then fossil fuel emissions could be higher than 1990 levels by the 1990 rate of deforestation.

The delegates at Kyoto agreed that if a country in the base year had net land-use accumulation of carbon—negative land-use change emissions—the base year emissions for determining emissions limits would be determined by industrial emissions only. This method was termed the "gross" approach to accounting, a term which is anything but self-explanatory. The idea is that the country would note its stock of terrestrial carbon, not the change in stock. In other words, land-use emissions are ignored in computing the base emissions rate.

On the other hand, if a country were had net land-use carbon release, then it could count both industrial and land-use change emissions in determining its base year emission inventory. This accounting method became known as the "net" approach.

In the budget period, 2008 to 2012, all countries include both industrial and net land-use emissions in their emissions inventory. For those countries with net emissions from land-use change in the base year, the accounting method was then the "net-net" approach in that net emissions flows are used in both the base year and the budget year. If a country has a net accumulation, however, it counts as negative emissions only those accumulations of carbon that are the result of actions taken since 1990 in the areas of afforestation and reforestation. This method has come to be known as the "gross-net" approach in that net emissions are ignored in the base year but counted in the budget period.

Many issues remain to be worked out. The protocol stipulates that

> *The net changes in greenhouse gas emissions from sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks in each commitment period shall be used to meet the commitments in this Article of each Party included in Annex I.*

This presents an interesting problem in what to count. Do soils beneath the forests count? Can normal anthropogenic forest management be counted? Given the nature of forest growth, the rate of carbon uptake in 2008 would be small for a program that began in 1998 due to the carbon absorption cycle by forests. Therefore, to the extent that net carbon uptake by sinks, or stores of carbon, is credited in the first budget period, it will largely be determined by an interaction between the rules and actions that were taken earlier. Unless interpreted very broadly, the language of the Protocol limits the potential impact of new initiatives.

Emissions Trading

The principle of emissions trading was established in the Kyoto Protocol. However, several important issues are left unresolved. Emissions trading could occur within or between Annex I parties. Within a nation, domestic permit trading could take place among firms or other actors to which permits are allocated. Similarly, permit trading could take place among firms or governments of different nations in an international permit market. Specific arrangements under which trade would occur, however, are left to be worked out in the future. The Protocol also established the principle that, "trading shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction." Therefore, limits may be established in the use of emissions trading to satisfy a commitment.

The Clean Development Mechanism

The Protocol also established a Clean Development Mechanism (CDM). The CDM was created "to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3." It allows emissions mitigation credits to be developed by non-Annex I parties beginning in the year 2000, as long as these activities are supplemental to activities that would have been undertaken in the normal course of events. It also identified a certification authority to insure that emissions mitigation activities were in fact real and supplemental. As with emissions trading, the rules are left to be developed in subsequent deliberations, and the degree to which this mechanism can capture emissions mitigation potential outside Annex I remains unclear.

Compliance

Unlike the Montreal Protocol, which established sanctions for non-compliance, the Kyoto Protocol establishes no such penalties.

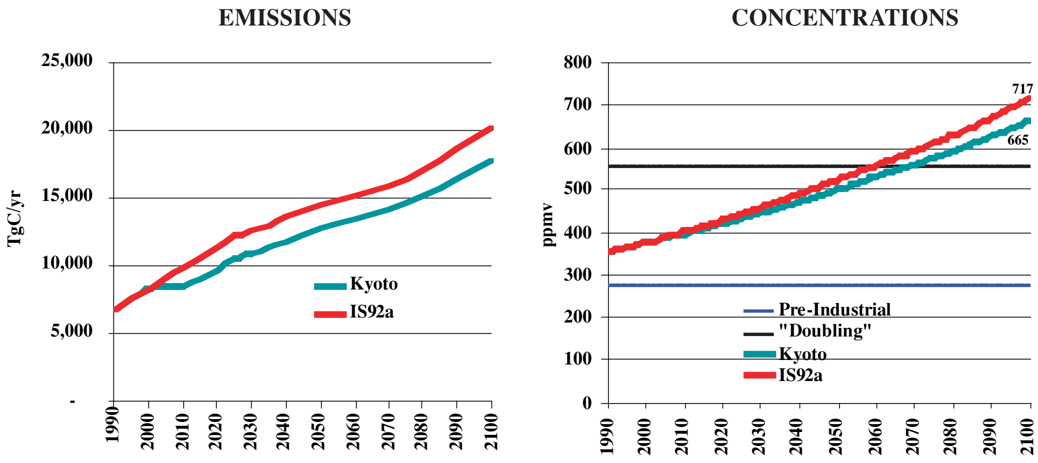
Agreements Beyond Kyoto

Even if it were to enter into force, the Kyoto Protocol could not be expected to achieve the goal of the FCCC. That is, it would not stabilize the concentration of greenhouse gases in the atmosphere, Figure 1.

The Protocol limits emissions controls to Annex B nations.[7] We have calculated the concentration of carbon dioxide in the atmosphere on the assumption that the Kyoto Protocol remains in force beyond the compliance period 2008 to 2012, throughout the remainder of the twenty-first century. We have assumed that there is no "leakage." Leakage occurs whenever the emissions reductions of one party are greater than global emissions reductions. Leakage can occur, for example, through market interactions. Reductions in the demand for oil by mitigating nations can lead to lower oil prices which in turn could stimulate greater oil use in non-mitigating nations. Or, when mitigation

[7] This list is essentially the same as the list of Annex I nations. Annex B nations are: Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom of Great Britain and Northern Ireland, and the United States of America. This list varies somewhat from the countries contained in Annex I to the FCCC. Several countries such as Slovakia, Slovenia, Liechtenstein, and Monaco have been added, while Belarus and Turkey are listed in Annex I of the FCCC but not Annex B of the Kyoto Protocol.

Figure 1 ***Emissions and Concentrations of Carbon Dioxide for the IPCC IS92a Scenario and the Kyoto Protocol***



obligations induce emitting industries to simply move to a non-participating jurisdiction. Thus, actions which produce the emissions mitigation can themselves lead to increased emissions by other, non-mitigating parties. In assuming no leakage, we have assumed that Annex B emissions reductions are equivalent to global emissions reductions.

For our calculations, we have used the Intergovernmental Panel on Climate Change (IPCC) reference emissions path described by their scenario, IS92a (Leggett et al. 1992.). Compared to the IS92a scenario, the Kyoto Protocol reduces both Annex B and global emissions, even though developing countries take no emissions-reducing measures. But, even with these assumptions, the date at which concentrations rise from their pre-industrial levels of approximately 275 parts per million volume (ppmv) to 550 ppmv would be delayed by less than a decade. Furthermore, the concentration of carbon dioxide would continue to rise throughout the twenty-first century and into the twenty-second century.

Clearly, measures beyond the Kyoto Protocol will be needed to achieve the goal of the FCCC.

All of the global emissions trajectories for carbon dioxide which stabilize its concentration have the same characteristic shape. For concentrations 450 ppmv and above emissions rise for some period, peak, and then begin a long term decline. A variety of dates for emissions peaking and rates of subsequent decline have been calculated. Those for the trajectories of Wigley et al (1996) are shown in Table 1.

The Architecture of Future Agreements

Future international agreements will undoubtedly grow out of the foundations of the past. The present architecture which is embedded in the FCCC and Kyoto Protocol embody many principles which may be of use in framing future agreements. First the agreement provides for the negotiation of budgets period by period. This allows participants to take actions, learn more about the costs, benefits, and risks, and then establish the next target. The ability to act, then learn, then act again is an important tool in managing risk.

Table 1 The Relationship Between CO_2 Concentration Ceilings, Maximum Emissions, and the Subsequent Rate of Emissions Decline: Wigley et al. (1996) Cases

Steady-State Concentration →	350 ppmv	450 ppmv	550 ppmv	650 ppmv	750 ppmv
Deflection Date IS92a [a]	2001	2007	2013	2018	2023
Maximum Date	2005	2011	2033	2049	2062
Maximum Emission [b]	6.0	8.0	9.7	11.4	12.5
Rate of Decline [e]	-	*1.1%*	*0.8%*	*0.6%*	*0.5%*

[a] The deflection date is the year in which emissions in the emissions stabilization trajectory first fall below IS92a emissions by more than 0.1 PgC/yr.
[b] PgC/yr fossil fuel carbon emissions on the date of maximum total anthropogenic carbon emissions.
[e] Rate of decline in fossil fuel carbon emissions, in percent per year, over the first 75 years following the date of maximum emissions. Note 350 ppmv not defined as it requires a negative net emission.

Second, the present architecture utilizes recent experience as a reference in establishing limitations on future emissions. Unless future emissions constraints are grounded in near-term reality, there is little hope that they can be achieved in practice.

Third, the present architecture provides for emissions trade between parties. Three institutional mechanisms were incorporated: direct trade of emissions rights, joint implementation, and the CDM. The principle of "where" flexibility is an important tool in controlling the cost of emissions limitation.

The principles that have been developed to date are, however, insufficient to achieve the objectives of the FCCC. These principles must be expanded, and in doing so, they must deal with three critical issues. They must:

- Address the long-term nature of the problem,
- Provide mechanisms to control costs, and
- Provide a mechanism to engage non-Annex I nations in the formal mitigation process.

Developing a Long-term Strategy

One of the most difficult features of the climate issue is the long-term nature of the problem. **The FCCC articulates the ultimate objective of the Convention in terms of concentrations—not emissions.** This framing of the problem reflects the relationship between radiative forcing of climate change and the concentration of greenhouse gases in the atmosphere. Unlike conventional pollution problems with which most negotiators are familiar, the relationship between emissions of greenhouse gases and their concentrations is complex. The removal mechanism for carbon dioxide involves non-linear, global, bio-geo-chemical processes.

Furthermore, significant uncertainty surrounds both the costs and benefits associated with alternative courses of action. Uncertainty is particularly acute with estimates of the benefits of emissions mitigation. First, most of the beneficiaries are not yet alive. The consequences of climate change that the present generation has any hope of significantly affecting lie many decades in the future. The present concentration of greenhouse gases has been largely determined by the actions of preceding generations.

Second, for modest changes in the climate, estimates of costs and benefits disagree even about the sign of the damage. That is, some estimates show net benefits to the aggregate world economy from some additional net warming, though the benefits would not be evenly distributed around the surface of the planet. See for example Mendelsohn et al. (1992, 1996) and Rosenberg (1993). Other studies show damages from even minor changes from present climate. See for example Cline (1993). Much of the net damage is associated with the valuation of unmanaged eco-systems, which ultimately disappear as rising surface temperatures push habitats to increasingly higher latitudes and altitudes. Producing values for the prevention of species extinction is an extremely difficult and highly uncertain enterprise. In addition to these problems of valuing the benefits to emissions mitigation must be added the problem of surprises. As concentrations of greenhouse gases push beyond the bounds with which we have experience, the prospect that some unpleasant surprise may lurk unanticipated looms large.

The climate problem cannot be framed as a simple deterministic cost-benefit calculation. Rather, it must be addressed as a risk management problem. Further, the primary focus must be on the risks associated with alternative **concentrations** of greenhouse gases. This principle, like all good guiding principles must be tempered by the realization that rates of change also matter.

As a consequence of the risk-based nature of the problem, policy decisions depend on the current best available information. Strategies that are developed to address the problem must deal with the need to choose an initial concentration goal, based on the **expected** marginal benefits and marginal costs of alternative concentrations. The quantitative goal established in this process is, of course, subject to change over time as knowledge accumulates.

The principle of **"act, then learn, then act again"** is an essential ingredient in the development of future international agreement architectures. As noted earlier, this principle is already embodied in the international agreement architecture developed within the FCCC and is embodied in Article 3. Interestingly, this is established within the context of the "precautionary principle."

> *The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.*

Controlling Costs

The largest obstacle facing the framers of future agreements is the control of compliance costs—also established as a principle in Article 3 of the FCCC. Without the development of a cost control strategy, no agreement, no matter how well conceived can persist. The control of greenhouse gases is an altruistic enterprise. The present generation cannot affect the concentration of greenhouse gases enough to alter the climate in which it will reside. The benefits to mitigation will be bestowed not on those alive today, but on their descendents.

Trade in emissions rights is a powerful tool for controlling the cost at any given period of time. The gain from trade is one of the most fundamental results of economic science. A wide array of studies confirms this proposition. See for example, Weyant (1999), which confirms this finding for the Kyoto Protocol. The principle of trade in mitigation obligations is established in the present international architecture.

A second tool for controlling costs is to focus on the combined effect of all anthropogenic emissions of greenhouse gases. While carbon dioxide is the most important greenhouse gas, it is not the only one. Methane, nitrous oxide, and a variety of manufactured chemicals also contribute significantly to climate change. Framing emissions limitations in terms of a suite of greenhouse gases rather than focusing on each gas separately provides opportunities to deliver the same environmental benefits at reduced cost. Again, this principle is embodied in the present international architecture.

The Hotelling/Peck & Wan Result

But other issues also need to be addressed. How much mitigation should be done and when looms as the largest issue to be addressed by future agreements. The rate and timing of mitigation is governed by two factors—the basically cumulative relationship between emissions of carbon dioxide and its atmospheric concentration, and the Hotelling/Peck & Wan theorems.

The Hotelling result (Hotelling, 1931) as modified by Peck and Wan (1996) states that the value of a tonne of carbon should rise at the interest rate plus the rate of removal from the atmosphere. The logic of this result is simple. The right to emit carbon is a scarce resource that can be used to produce goods and services. By virtue of the cumulative nature of the relationship between emissions and concentrations, a fixed concentration ceiling implies a fixed cumulative emission over all time. This asset should behave like other economic assets. Those who hold onto the assets should be rewarded at the same rate as those who hold onto other financial assets. The value of a tonne should appreciate at the same rate as other investment such as bonds.[8] Peck and Wan (1996) showed that if carbon is removed from the atmosphere, the price must rise sufficiently faster than the interest rate to compensate those who hold emissions rights for the lost value from their disappearing asset.

The Hotelling/Peck & Wan result has important implications for framing future agreements. It implies that early costs should be low but rise steadily. There is a complementary physical implication of these results. Initial emissions mitigation should be modest, but the deviation from reference should grow steadily. The incremental nature of these results is important and might be summarized as "**small steps before large ones**." It allows for the orderly turn over of the capital stock, the conduct of research and technology development, prevents lock-in to early version of new technologies which are rapidly improving, and allows time for new infrastructure to be developed.

Premature retirement of capital stock adds significantly to the cost of mitigation. Whenever investments must be prematurely scrapped, remaining productivity is lost forever. It is this loss which society feels. Premature retirement of capital is a problem which occurs at the beginning of a policy intervention. Once a policy regime is established, investors can plan accordingly. It is the unanticipated nature of the policy intervention which raises the potential for losses from premature retirement of capital. The gradual and incremental nature of the Hotelling/Peck & Wan principle minimizes such unanticipated losses.

[8] If the value of a tonne of carbon rises at a rate faster than the rate of interest, no one will hold bonds. Bond prices will fall, raising the rate of interest and bringing the markets back into balance. The opposite occurs should the value of a tonne of carbon rise more slowly than the rate of interest.

Technology and Cost

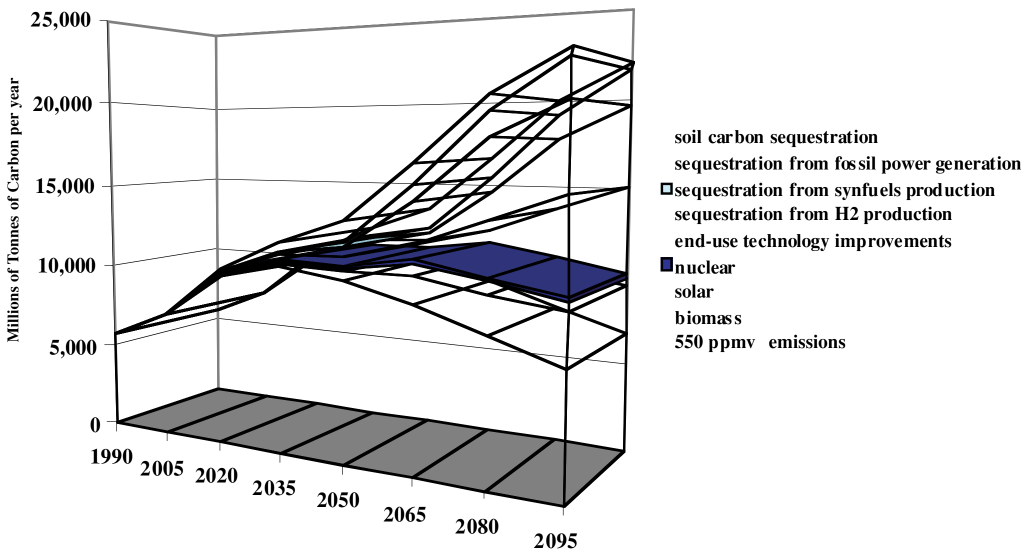
In the near term technology options are limited to those technologies which are currently available. In the long term technology can and will change. The path and rate of technology development will play a large role in shaping the future cost of meeting an emissions limitation requirement.

Edmonds et al. (1999) explored carbon dioxide concentration stabilization scenarios. These scenarios employ the Hotelling/Peck & Wan approach to formulating intertemporal time paths of emissions limitations. Such paths have modest initial emissions mitigation requirements but these requirements grow with time. Figure 2 shows a reference emissions trajectory, an allowable emissions limit (gray) and carbon emissions reductions associated with the expansion of specific energy technologies.

While the magnitude of change in the first half of the twenty-first century is modest, the eventual magnitude of change in the reference case at the end of the twenty-first century is large. Technologies whose activity levels expand to provide the emissions mitigation include those for which no large scale deployment currently exists, for example, solar energy, carbon capture and sequestration from power systems, hydrogen production and power conversion from fuel cells, and commercial biomass energy. Contemporary versions of all of these technologies exist. None, however, are deployed at scale. Since the infrastructure needed to deploy many of these technologies does not currently exist, now only will it be necessary to develop the base technology, but it will also be necessary to simultaneously develop and deploy the supporting capital infrastructure.

Mitigation is not the only policy option. Investments in science and technology provide information about potential impacts—making better evaluations of appropriate risk management responses possible. Investments in science and technology also provide the knowledge base needed to develop new energy technologies.

Figure 2 Global Carbon Emissions in a Reference Case, Emissions Limitations Associated with a 550 ppmv Concentration Ceiling, and Emissions Mitigation Associated with the Expansion of Various Energy Technologies Relative to the Reference Case.



Ultimately, investments in science and technology will be effective only if they are accompanied by policies which demonstrate a commitment to a transition to a world in which emissions are controlled.

Accession

One of the fundamental characteristics of the climate change problem is that greenhouse gases are well mixed in the atmosphere. Thus, the geographical source of greenhouse gases is irrelevant. It is the sum of all sources from all locations over long periods of them that determines their concentrations.

The FCCC accepted the principle of common but differentiated responsibilities and recognized a special responsibility for developed nations.

> *The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the* ***developed country Parties should take the lead in combating climate change and the adverse effects thereof****.* (UN FCCC, Preamble, emphasis added)

The FCCC charged Annex I nations the goal of returning to 1990 emissions levels by the year 2000. The Kyoto Protocol established quantifiable emissions limitations for Annex B nations. Non-Annex I nations have no obligations. While the Kyoto Protocol establishes a Clean Development Mechanism (CDM) to engage developing nations in emissions mitigation, the effectiveness of the CDM is limited by its lack of a clear quantified benchmark against which to measure emissions mitigation and the fact that the Kyoto Protocol has not entered into force.

Emissions of Annex I nations are anticipated to be smaller than those of non-Annex I nations sometime before the year 2030. The IPCC IS92a scenario, for example estimates the crossing point to occur in 2025, Figure 3.

Figure 3 IPCC IS92a Carbon Emissions by Annex I and Non-Annex I Nations

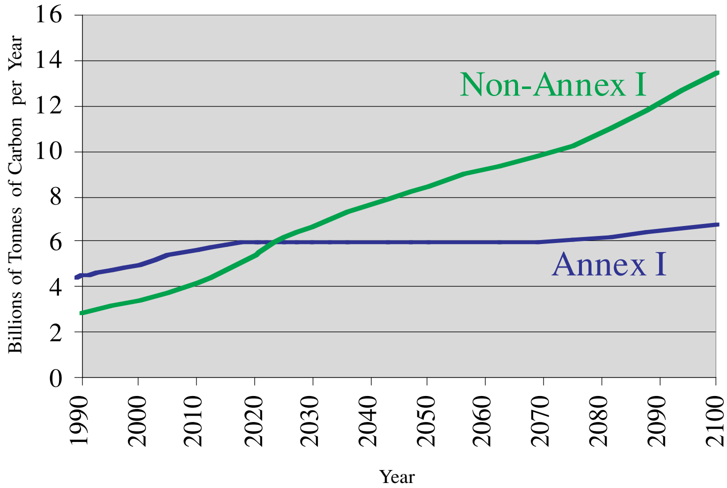


Table 2 Relationship Between Concentration Ceiling and Year in Which Annex I Emissions Mitigation Alone Is Inadequate to Achieve Atmospheric Stabilization

Carbon Dioxide Concentration Ceiling →	450 ppmv	550 ppmv	650 ppmv	750 ppmv
Year in which Annex I emissions mitigation alone is insufficient to maintain global emissions on a path that would stabilize the concentration of atmospheric carbon dioxide, assuming IPCC IS92a emissions paths and no "leakage."	**2035**	**2065**	**2085**	**2095**

It is not difficult to show that there are insufficient emissions in Annex I nations to independently stabilize the concentration of greenhouse gases (Edmonds, et al., 1997). Annex I emissions mitigation alone would eventually be insufficient to stabilize the concentration of carbon dioxide, even if the stabilization ceiling is 750 ppmv (Table 2).

Ultimately Non-Annex I nations must take on obligations if the concentration of carbon emissions is to be stabilized. This raises the question of accession. Accession is a highly sensitive question as it raises issues of fairness, justice and equity. While all nations of the world have a stake in controlling the emissions of greenhouse gases it is not the highest priority of developing countries. Development is the highest priority of the world's poor nations.[9] On a practical level, accession also raises questions about the institutional capacity of non-OECD governments to monitor and enforce obligations.

The present system of quantified emissions limitations established under the FCCC and Kyoto Protocol, is founded on a principle of emission allocation that is based on historical emissions. This is sometimes referred to as a "grandfathered" emissions principle. That is, one has the right to emit in the future what one emitted in the past. This principle has been used in past allocations of emissions rights in both domestic and international contexts and appears to have achieved the status of the practical default principle. It is not the only possible basis for emissions allocations. Many others have been put forward. Other simple principles that could be used include basing emissions allocations on the number of people in a nation, historical cumulative emissions, the scale of economic activity (GDP), and fossil carbon resources.

In a trading regime in which emissions are capped and traded the emissions rights have economic value. The value of emissions rights is the product of allocated emissions and the value of a tonne of carbon. These values can be large. For example, for a 550 ppmv ceiling, the MiniCAM model shows global allowable fossil fuel emissions can rise to one trillion dollars per year (1990 constant US dollars, Edmonds et al., 1999). The allocation of emissions rights determines how this value is distributed. Allocating emissions rights to all of the nations of the world on the basis of 1990 emissions implies a large wealth transfer from developing nations to developed nations. It is not surprising that developing country negotiators find grandfathered emissions unacceptable. In contrast allocating emissions on the basis of population implies a large transfer of wealth from the developed world to the developing nations.

[9] Development may be one of the strongest climate change policy responses. Schelling (1997) has argued that developed nations are far better positioned to cope with the consequences of climate change, and that economic development is therefore a potentially important element of developing nations' climate change response.

Large transfers of wealth to foreign nations can be a domestic political problem even if it occurs in the context of a minimum cost mitigation regime (Victor, 1999). Part of the reason that grandfathered emissions has proved an attractive principle in emissions allocations among developed nations is that even in a cap-and-trade regime it implies relatively small near-term wealth transfers among parties.[10]

The same transfer-of-wealth problems occur within any nation that allocates emissions rights within the context of a cap-and-trade regime.

Accession Strategies—Jacoby et al.

Several research groups have begun to think about developing burden-sharing rules to deal with concerns for fairness and equity. Jacoby et al. (1998) explored a generalized approach based on "ability-to-pay" as a surrogate for "willingness to pay."[11] As the standard of living in a nation rises, the relative value of additional material goods declines relative to environmental services. Richer nations are more willing to take on environmental burdens than poorer nations.

Jacoby et al (1998) demonstrate by example, that it is possible to construct a set of rules which will stabilize the concentration of carbon dioxide in the atmosphere and provide for a gradual transition from non-participation to full participation. They created a, universal formula for emissions limitations:

$$\eta_t = (dC/dt)/C_t = \begin{cases} \gamma - a(w_{t-1} - w^*)w^{ref}_{t-1} \geq w^* \\ \eta^{ref}_t \qquad \text{otherwise} \end{cases}$$

where C = carbon emissions
η_t = rate of emissions change (+ or -) per year
w = a "trigger" defined in terms of some per-capita welfare measure, and
α and γ are parameters which determine the rate of change of burden with change in the welfare measure.

Three things are important about this formulation. First, below some per capita welfare threshold defined by the "trigger" no limits are placed on the rate of growth of emissions. Second, once the threshold is crossed there is a gradual transition from non-participation to full participation. And third, the formulation is general, applying to all participants. It is important to note that this formulation defines an emissions limit for each period relative to its own base. It does not adopt an absolute reference, for example 1990 emissions. Rather, the reference is continually being updated with time.

Using per capita income as the measure of welfare, Jacoby et al. demonstrated that stabilization of the concentration of greenhouse gases is possible. They note, however, that this approach does not attempt to create an inter-temporal, cost-effective trajectory to stabilization of concentrations. They

[10] Victor (1999) points out that one of the problems with the Kyoto Protocol is the disparity in obligations relative to present emissions. This disparity primarily affects the Former Soviet Union, which negotiated an emission allowance equivalent to its 1990 level, but whose emissions have fallen dramatically as a consequence of economic restructuring. A wide array of economic analyses show that free trade in emission allowances among Annex I nations under the Kyoto Protocol implies a sizable transfer of wealth from OECD nations to the Former Soviet Union (***Energy Economics***, 1999, special issue).

[11] There is evidence that ability to pay is a reasonable surrogate for willingness to pay. See for example Grossman and Krueger (1995).

argue that while a century-scale cost minimization calculation is an interesting academic exercise, it is uninteresting in the real world. Within a budget period, however, costs are reduced when trade among parties is allowed.

Trade in emissions rights between participants within budget periods is shown to significantly reduce costs (or increase benefits) to participants. By placing the greatest mitigation burden on the richest countries, which tend also to be the highest emitting countries (per capita), there would also tend to be transfers of resources from the richer nations to poorer nations with trade in emissions rights.

Accession Strategies—Edmonds and Wise

Edmonds and Wise (1999) have also examined alternative emissions mitigation agreement architectures. They demonstrated that an agreement focused on new investments and establishing generic performance standards and income-based accession could also stabilize the concentration of carbon dioxide in the atmosphere. Their approach is built on the observation that in modern societies carbon flows through two sectors—power generation and fuel refining and processing. They create a simple set of rules as follows:

In the first stage emissions from **new** capacity in powerplants and synfuel conversion facilities are controlled in OECD nations. After a fixed date new capacity must be carbon neutral, that is emit no net carbon. For synfuel conversion facilities this means that all carbon released in the upgrade of coal to liquids and gases must be captured and disposed of in an environmentally safe manner. New power generation facilities coming on line after the start-date can either use non-carbon fuels such as nuclear fission, fusion, solar, wind, biomass, or hydro, or they can utilize fossil fuels but capture and sequester the carbon in an environmentally safe manner. Other parties to the agreement take on the same obligations as OECD nations when their per capita income levels reach those of the lowest OECD nations taking on the initial obligation.[12]

The second phase would control refining and processing of fossil fuels. It would begin in the OECD and require new facilities to be carbon neutral after a fixed date. They could use fossil fuels as a feedstock for the production of hydrogen, but could not pass net carbon to the economy. Over the following 45 year period net imports of carbon-based fuels would be phased out. Non-OECD nations would take on the same obligation as OECD nations when their per capita incomes rose to that of the lowest OECD nation which undertook the initial obligation.

Edmonds and Wise examined a variety of cases. Starting the first phase in the year 2035 and the second phase in 2065 results in the stabilization of concentrations of carbon dioxide between 525 and 550 ppmv. Earlier dates of first compliance are consistent with lower concentration ceilings, and later dates are consistent with higher concentration ceilings. Because of the focus on large facilities monitoring and enforcement is made easier. In addition, no international transfers of wealth need occur.

This strategy uses a general performance standard to drive the development and dissemination of technology. One can easily imagine the development of fuel cells to generate carbon-free power, which in turn would generate a demand for hydrogen and the transmission capacity to deliver it.

[12] To prevent manipulation of the income test, for example, through exchange rate policy, incomes would need to be measured in terms of a purchasing power parity index. The income test could be framed in terms of the date of agreement with a fixed "grace" period to follow before new sources need comply

This in turn could result in improved hydrogen fuel cells, which could then be utilized in the transportation sector, and the trunk lines which could become the foundation for a more general hydrogen transmission system.

By focusing on activities which utilize large facilities, monitoring and compliance costs would be reduced. Focusing exclusively on new sources avoids the stranded asset problem.[13] And, since obligations are domestic, no transfers of funds need occur.

The strategy, like the Jacoby et al. approach, does not minimize the present discounted cost of stabilizing concentrations at a given level. Costs could be reduced by giving credit for early action both domestically and internationally.

Both the Jacoby et al. and Edmonds and Wise approaches explore long-term strategies which take seriously the question of fairness and equity. They also show that there are potentially many alternative approaches which build upon the foundations of the present international architecture to address climate change.

Summary

The current set of international agreements is based on the Framework Convention on Climate Change (FCCC). The FCCC has as its ultimate objective the stabilization of concentrations of greenhouse gases at levels which would prevent dangerous anthropogenic interference with climate systems. It establishes a variety of principles which should be utilized in the implementation of this objective, including cost effectiveness, fairness, and equity. Since the FCCC entered into force the parties have met on several occasions to discuss the adequacy of commitments. The 1997 conference of the parties, meeting in Kyoto, drafted the Kyoto Protocol, which focuses on additional commitments to be undertaken during the time period 2008 to 2010.

Even if the Kyoto Protocol enters into force, further agreements will be needed to achieve the goal of the FCCC. These further agreements will have to confront three broad areas of concern:

- Extension of the reference time frame to a century,
- Control of costs, and
- Expansion of the list of nations with quantifiable emissions limitations.

The first issue could be productively addressed by framing the goals of international agreements in terms of an explicit concentration objective for greenhouse gases, recasting the problem in terms of risk management, and broadening the set of tools for controlling emissions to include technology development and deployment.

Control of costs is essential, as mitigation, if it occurs, will be undertaken largely by those who will not benefit from their own sacrifices. Tools for addressing this issue include trade in mitigation obligations, tradeoffs within a group of greenhouse gases, minimizing capital stock turnover, and developing and deploying successive generations of mitigation technologies. The Hotelling/Peck and Wan theorems govern the relationship between the value of carbon in one period compared to the next. These theorems require that the value of a tonne of carbon rise over time at the rate of

[13] To avoid indefinite life-extensions, it is necessary to define "lifetimes" for existing capacity, after which a facility is treated as a new source.

interest plus the rate of removal of carbon from the atmosphere. Initial carbon values are therefore low, requiring modest, but real, early mitigation, minimal premature loss of capital, and steadily rising obligations. It also allows time to develop and deploy new technologies and prevents premature "lock-in" to immature versions of new technologies.

Future agreements must also expand membership in the group of parties with emissions mitigation obligations. Such an expansion will require addressing issues of fairness and equity. Two architectures for accession are discussed. Both use per capita income as the criterion for accession. One sets national mitigation limitations explicitly. The other focuses on the character of new technologies. Either can stabilize concentrations of greenhouse gases.

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Appendix

Qunatifiable Emissions Limitations for Annex B to the Kyoto Protocol

1	**Australia**	**108**
2	**New Zealand**	**100**
3	Bulgaria	92
4	**Croatia**	**95**
5	Czech Republic	92
6	Finland	92
7	**Hungary**	**94**
8	**Poland**	**94**
9	Romania	92
10	Slovakia	92
11	Slovenia	92
12	Estonia	92
13	Latvia	92
14	Lithuania	92
15	**Russian Federation**	**100**
16	**Ukraine**	**100**
17	**Japan**	**94**
18	**Canada**	**94**
19	**The United States of America**	**93**
20	Austria	92
21	Belgium	92
22	Denmark	92
23	European Community	92
24	France	92
25	Germany	92
26	Greece	92
27	**Iceland**	**110**
28	Ireland	92
29	Italy	92
30	Liechtenstein	92
31	Luxembourg	92
32	Monaco	92
33	Netherlands	92
34	**Norway**	**101**
35	Portugal	92
36	Spain	92
37	Sweden	92
38	Switzerland	92
39	United Kingdom of Great Britain and Northern Ireland	92

Developing Country Effects of Kyoto-Type Emissions Restrictions

*Mustafa Babiker and Henry D. Jacoby**

1. The Issue of Burden Sharing

In a world without international trade, the costs of pollution control measures would be pretty well confined to the country taking the action. We live in a world tightly knit by trade, however, importantly including a massive trade in oil and other fossil fuels. Thus if restrictions on carbon emissions are adopted by a sub-set of nations, the effects will be felt throughout the world economy. In the countries accepting greenhouse restrictions the cost of using carbon-emitting fossil fuels will rise, simultaneously lowering the demand for these fuels (thereby reducing their international prices) and raising the cost of goods that require them as inputs. Also, the total level of economic activity in these countries may fall somewhat relative to the output levels that otherwise would be achieved, lowering their demand for imports of all kinds. These changes will ripple through the international trade system, impacting countries who may have made no agreement to participate in the control regime or to share its burdens.

To explore this set of interactions, we use the Kyoto Protocol as a case example, even though some have argued that it is unlikely to go into force as written (Portney, 1999). The Kyoto Protocol calls for reductions in Annex B country emissions, below 1990 levels, which average around 5% for the 2008-12 commitment period (United Nations, 1997). The number of country ratifications needed to put the Protocol into force now seems unlikely to be achieved, even under the most optimistic assumptions, until some years after the year 2000. By then it will be too late to design, legislate and implement the needed policy changes, and to allow time for them to have their effect (Jacoby and Sue Wing, 1999). In any case, it is likely that at some point in the next few years a process will begin to re-negotiate the agreement. When that time does come, however, it also seems likely that any new agreement will follow the general lines of Kyoto, with national targets and timetables as the key instrument, and with the control burden (at least in the early years) falling on a group of richer countries similar to the current Annex B (Jacoby, Schmalensee and Sue Wing, 1999).

Thus in the implementation of the Kyoto Protocol, or whatever revised agreement succeeds it, questions will inevitably arise concerning the economic implications that a program of emission restrictions, applied to only a subset of countries, has for countries who have assumed no controls of their own. Stated in the context of the Kyoto Protocol, several questions deserve particular attention. When Annex B emissions restrictions are applied, what is the distribution of welfare loss among the regions of Annex B and Non-Annex B? What are the mechanisms by which actions taken within one country come to hurt or help another? And what difference does it make how the Annex B countries choose to impose the restrictions? Finally, can countries that are harmed do anything to prevent it?

* For crucial contributions to the preparation of the EPPA-GTAP model used here, and helpful criticism of the paper, thanks are due to R. S. Eckaus, A.D. Ellerman, J. M. Reilly, I. Sue Wing, and D. Reiner.

To study these questions, we use a general equilibrium model of the world economy, and we begin in Section 2 with a brief description of the model and a definition of the policy scenarios that will serve as the basis for the analysis. Then in Section 3 we look to the distribution of burdens from the Kyoto Protocol, and the mechanisms that lead to it, taking the year 2010 as representative of the first commitment period under the Protocol. As shown by others (Babiker, Maskus and Rutherford, 1997; Montgomery, Bernstein, and Rutherford, 1998) the welfare loss attributable to Kyoto can be larger for some Non-Annex B countries than for the ones taking restrictions, where the vulnerability of nations is roughly related to the weight of oil exports in their economies.

We further explore the shift in a country's terms of trade (i.e., the ratio of the prices of a country's exports, suitably weighted, to the prices of its imports which is a key mechanism influencing the distribution of losses and gains). For example, cost penalties on carbon emissions will cause the costs of energy-intensive goods (if manufactured in a country under restriction) to rise, even if the international price of oil itself falls. In this circumstance, an oil exporting country will be able to pay for fewer energy-intensive imports with its oil revenue, and will be hurt as a result. Other Non-Annex B countries, with a different mix of imports and exports, may be made better off by the same set of Annex B restrictions.

Sections 4 and 5 consider the implications for Non-Annex B countries of different generic approaches to imposition of the Kyoto targets. First, many countries already have fiscal systems that are heavily based on indirect taxation of energy goods, particularly gasoline. If countries impose carbon taxes or carbon cap-and-trade systems, or portfolios of regulatory instruments, it matters whether these existing taxes are left in place (what we call a "distortion" case) or if they are removed, to be replaced by a system impacting fuel prices only through the carbon penalty (our "harmonized" case). Second, the details of potential carbon permit trading among countries are important component of a Kyoto-style approach. The cost-reducing advantages of such trading have been much studied for developed countries, but it is important to recognize that trading also has important implications for the burdens imposed on Non-Annex B countries.

Finally, in Section 6 we draw some conclusions from these sample calculations, about both the nature and magnitude of the process and the ways these impacts might be ameliorated.

2. Design of the Analysis

2.1. The EPPA-GTAP Model

For analysis of these burden sharing issues we apply the MIT Emissions Prediction and Policy Analysis (EPPA) Model (Babiker *et al*., 1999; Yang *et al*., 1996).[1] EPPA is a recursive dynamic, multi-regional general equilibrium model of the world economy. The current version of EPPA is built on a comprehensive energy-economy dataset (GTAP-E)[2] that accommodates a consistent representation of energy markets in physical units as well as detailed accounts of regional

[1] This component of the MIT modeling system has been developed with the support of a government-industry partnership including the U.S. Department of Energy (901214-HAR; DE-FG02-94ER61937; DE-FG0293ER61713) and the U.S. Environmental Protection Agency (CR-820662002), the Royal Norwegian Ministries of Energy and Industry and Foreign Affairs, and a group of corporate sponsors from the United States and other countries.

[2] This special database is provided by the Global Trade Analysis Project (GTAP) along with release 4 of their economy-trade database. For further information on GTAP see Hertel (1997).

Table 1 Dimensions of the EPPA-GTAP Model

Production Sectors	*Annex B*
Non-Energy	USA United States
1. Agriculture	JPN Japan
2. Energy-Intensive Industries	EEC Europe[1]
3. Other Industries and Services	OOE Other OECD
Energy	FSU Former Soviet Union
4. Crude Oil	EET Central European Associates
5. Natural Gas	*Non-Annex B*
6. Refined Oil	KOR Korea
7. Coal	IDN Indonesia
8. Electricity	CNN China
Future Energy Supply	IND India
10. Carbon Liquids	MEX Mexico
11. Carbon-Free Electric	VEN Venezuela
Primary Factors	BRA Brazil
1. Labor	RME Rest of Middle East[2]
2. Capital	RNF Rest of North Africa[3]
3. Fixed Factors for Fuel and Agriculture	SAF South Africa
untries and Regions	

Notes:
1. Includes European Union (15).
2. Includes the Arabian Peninsula, Iran and Iraq.
3. Includes Algeria, Libya and Egypt.

production and bilateral trade flows. The base year for the model is 1995 and the model is solved recursively through 2100 in 5-year time intervals.

The GTAP-E database identifies 22 sectors and 45 nations or regions, which allows EPPA the flexibility to tailor the level of aggregation suited to different analysis tasks. For the studies carried out here, the model was aggregated to eight sectors, plus energy backstops, and 25 regions. As shown in Table 1, non-energy goods are aggregated to only three sectors, whereas the energy sector is represented in some detail by fuel type and electricity. Regarding regional definition, Annex B is aggregated into six regions, as the table shows. Non-Annex B is modeled in greater detail, to allow for the study of impacts of Kyoto-style restrictions on developing countries. Within the calculations, Non-Annex B is modeled as 19 separate countries or multi-country aggregates. For ease of presentation, however, only the 10 regions listed in Table 1 are shown in the tables and figures reported in the paper.

The model's equilibrium framework is based on final demands for goods and services in each region arising from a representative agent. Final demands are subject to an income balance constraint with fixed marginal propensity to save. Investment is savings- driven, and capital is accumulated subject to vintaging and depreciation. Consumption within each region is financed from factor income and taxes. Taxes apply to energy demand, factor income and international trade, and are used to finance an exogenously grown level of public provision. International capital flows in base year accounts are phased out gradually, and the government budget is balanced each period through lump-sum taxes.

Along the baseline, fossil energy resources are calibrated to an exogenous price path for fuels based on DOE/EIA statistics (DOE/EIA, 1998) through 2010. Afterwards they are driven by a long run resource depletion model. Energy goods and other commodities are traded in world markets. Crude oil is imported and exported as a homogeneous product, subject to tariffs and export taxes. All other goods, including energy products such as coal and natural gas, are characterized by product differentiation with an explicit representation of bilateral trade flows calibrated to the reference year, 1995. Energy products (refined oil, coal, natural gas, and electricity) are sold at different prices to industrial customers and final consumers. All existing energy subsidies are phased out gradually along the baseline.

Results from the EPPA-GTAP model differ in important ways from those of the previous versions of the EPPA model (e.g., Jacoby *et al.,* 1997; Ellerman, Jacoby and Decaux, 1998), which were based on the OECD GREEN database (Burniaux *et al*., 1992; Yang *et al*., 1996). Aside from the move to greater sectoral and regional detail, the shift from the GREEN to the GTAP dataset updates the model benchmark from 1985 to 1995. This last change allows consideration of recent growth performance of key nations (e.g., China and India) and the inclusion of the former East Germany in the modern German state (and thus in the EEC within our regional definition). Also, along with the change in dataset a number of other improvements have been made in the model's structure, importantly including the handling of fossil resources and nuclear power and the modeling of consumption (Babiker *et al*., 1999).

2.2. Specification of Cases for Analysis

The implications of the Kyoto Protocol differ depending on the treatment of carbon sinks and the six non-CO_2 gases included in the agreement. The inclusion of sinks and all gases in the baseline, and in the control regime, yields a total cost of control for Annex B countries that is 10% to 20% lower than the cost that emerges from a carbon-only analysis (Reilly *et al*., 1999). To simplify the analysis, however, we calculate the Kyoto reductions from a carbon-only baseline, and consider only the emissions reductions that would result from lowered burning of fossil fuels. Were the analysis extended to all gases and carbon sinks, the welfare effects would be reduced somewhat, because the needed carbon price is lower, but the basic patterns of burden distribution, and the mechanisms that produce them, would remain essentially the same.

We base our analysis on five cases: a reference case and four versions of the way Kyoto-type restrictions might be applied. The cases and the shorthand notation used in figures and tables are shown in Table 2. The carbon emissions under the reference conditions are shown in Figure 1, for the Annex B and Non-Annex B aggregates. Also shown in the figure is the trajectory of Annex B emissions under the Kyoto emissions restraint, assuming the agreement stays in place at the 2008-12 level for succeeding decades. Under Kyoto-type constraints, the emissions of Non-Annex B countries may vary from the reference levels, because of carbon leakage, but that difference is not shown here because it varies from case to case.

The crude oil price trajectory for the reference case is shown in Figure 2 (along with results from the other cases, about which we will say more later). Note that the exogenous projection of oil price has it falling steadily over the period 1995 to 2010, when the restrictions are imposed.[3] This is a smoothed approximation of price behavior in the period 1995 to 1999, when the market was highly

[3] For an analysis of the effects of beginning policy implementation with different degrees of lead-time, see Jacoby and Sue Wing (1999).

Table 2 Reference and Policy Cases

Case	Notation
Reference	REF
Kyoto, No Permit Trade	
With Tax Distortions	NT-D
Harmonized Carbon Tax NT-H	
Kyoto, With Permit Trade	
Annex B Only	T-AB
Annex B plus China	T-ABC

volatile. At the time of this analysis, in early 1999, the oil price was about 17% below the 1995 level (which is imbedded in the GTAP database) in real terms. The turn up in the price level after 2010 under the baseline is due to the long run resource depletion model, which governs the price behavior after 2010.

Within the no emissions-trading regime, we distinguish between two potential implementations of the Kyoto protocol. The bulk of the results are derived under the assumption that carbon policies are applied on top of existing fuels taxes, an assumed policy approach we call the "no trade with distortions" case and is denoted NT-D in the figures. The effect of this assumption on world oil prices can be seen in Figure 2; between the reference case and this no-trade case, oil price in 2010 is reduced by about 15%. The other no-trade case assumes that all other fuel taxes are abandoned in favor of a carbon policy, so that the distortions of existing taxation are removed. This "no trade, harmonized" case is denoted NT-H. For this case the effect of Kyoto Protocol on oil price is reduced from the case with distortions: the 2010 world oil price is only 9% below the level under reference conditions.

Figure 1 Reference and Kyoto Carbon Emissions

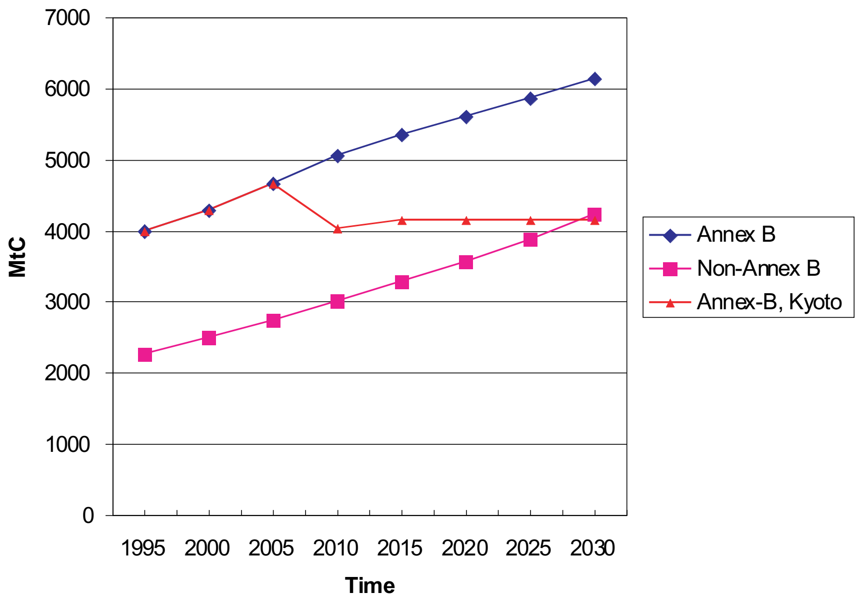
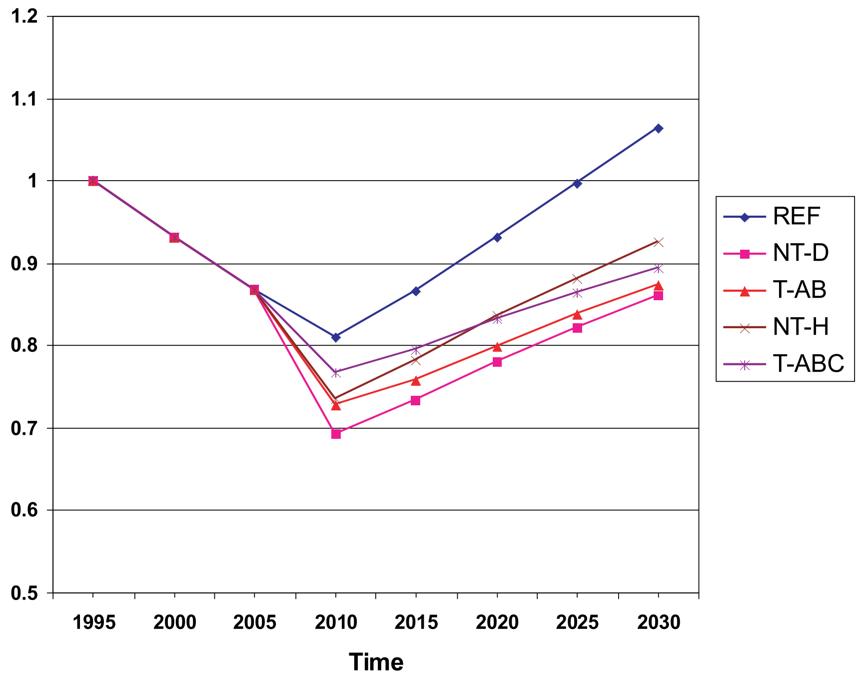


Figure 2 International Crude Oil Price (relative to its 1995 level)



Two additional cases are studied which allow trading of emissions permits. One assumes trading among Annex B countries only, and is denoted T-AB. The other tests the implications of inclusion of a large developing country in the trading regime, China in this analysis, and this case is denoted T-ABC.[4] Both the trading cases yield a roughly equal or smaller impact on oil price than do the cases without trading. The "Annex B only" assumptions yield an oil price in 2010 that is 10% below reference; the addition of China would lower this effect to only 5%. As will be discussed later, these differences in oil prices (and related prices for other fossil fuels) are an important component of the welfare effects of these assumed policies.

2.3. Interpretation of the Results

Our purpose in these numerical exercises is to explore the mechanisms by which policies adopted by Annex B countries might influence the economies in Non-Annex B, and to develop a rough impression of the relative magnitudes of the effects. The absolute magnitudes of these effects are, of course, subject to considerable uncertainty (Webster, 1997; Webster and Sokolov, 1998). For example, the cost of attaining any fixed emissions target is highly sensitive to growth rates in the period of forecast from 2000 to 2010, as a glance at Figure 1 might suggest. The experience of the last decade in the United States, Japan, and several Asian developing countries has indicated the possibility of large errors in growth forecasts. It is worth pointing out, on the other hand, that the mechanisms of burden transfer would remain the same (though the magnitude of effect might change) across the wide range of possible estimates of growth and ease of economic adjustment to

[4] The participation of China is accommodated through an early entry arrangement, in which China gets a quota equivalent to 95% of its 2020 projected emissions under the baseline of no control. The motivation for this assumption is the notion of common but differentiated responsibilities imbedded in the Climate Convention, which would imply that Non-Annex B countries would enter the regime only with some provision for post-1990 growth.

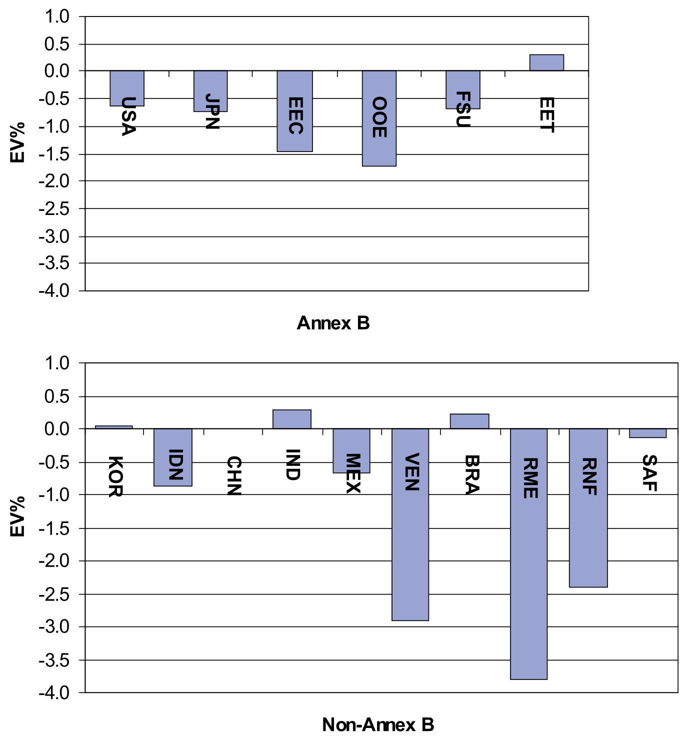
changed relative prices. A further caveat regarding the results presented in this paper is the fact that they are computed under an environment that assumes the absence of other shocks, and that the policy is implemented efficiently. Yet in reality, though it may be possible to identify and roughly quantify these policy effects *ex ante*, their influence would not likely be separable from the general variability in the economic system *ex post*.

3. The Effects of Kyoto Protocol on Developing Countries

3.1 The Distribution of Welfare Effects

Figure 3 shows the welfare losses expressed as percentage changes in the equivalent variation index for year 2010.[5] As seen in previous analyses (Jacoby *et al., 1997;* Jacoby and Sue Wing, 1999; Kolstad, Light and Rutherford, 1999), across Annex B countries Kyoto yields welfare losses in the range 0.5 to 2.0%, except East Europe (EET) which realizes short term welfare gains from its improved comparative advantage in relation to the rest of Annex B. For Non-Annex B, the results show welfare losses in excess of those in Annex B for some regions, e.g., RME, and net welfare gains for others, e.g., IND. Overall, the results suggest that energy importers would be likely to gain from Kyoto, whereas all energy exporters would lose from implementation of the Protocol. Among the oil exporting regions, Figure 3 shows that those who depend heavily on oil proceeds are the most adversely affected by Annex B emissions control.

Fig 3 Welfare Effects of Kyoto Protocol: EV% (NT-D,2010)



[5] EV is the Equivalent Variation measure of welfare expressed in percentage form, and it roughly shows by how much regional well-being (level of consumption) changes as a result of the policy.

Table 3 Decomposition of Impacts of the Kyoto Protocol (2010)

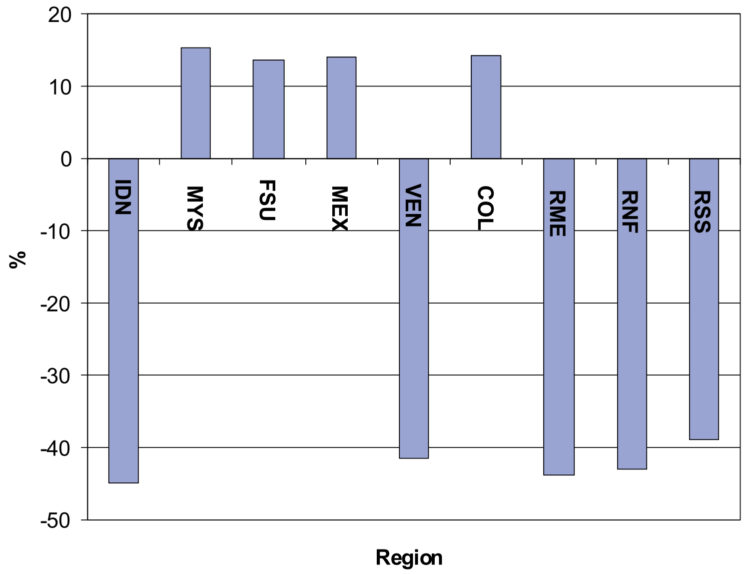
Region	Percent Change with Kyoto		
	EV	GNP	Terms of Trade
Annex B			
USA	-0.64	-1.18	1.31
JPN	-0.75	-1.84	1.41
EEC	-1.45	-3.68	1.07
OOE	-1.73	-3.70	-0.62
FSU	-0.68	-0.38	-2.27
EET	0.30	0.42	0.27
Non-Annex B			
KOR	0.04	0.19	0.48
IDN	-0.86	-0.71	-2.13
CHN	-0.01	0.06	-0.30
IND	0.29	0.55	1.12
MEX	-0.67	-0.58	-1.98
VEN	-2.92	-2.56	-8.82
BRA	0.22	0.23	0.72
RME	-3.81	-3.12	-8.65
RNF	-2.40	-2.77	-6.79
SAF	-0.13	0.06	-0.26

The mechanism by which Annex B emissions controls are translated into welfare gains or losses in non-Annex B regions is as follows. The imposition of controls in Annex B reduces the demand for domestic and imported energy and raises the prices of exports from Annex B. The GTAP database shows that 1995 oil imports by Annex B countries amount to more than 65% of international energy trade, so the world oil price is directly affected by the control policy. Hence, energy exporters face adverse movements in their terms of trade, while some non-Annex B energy importers may achieve improvements in their terms of trade. These terms-of-trade effects are carried through the rest of the non-Annex B economies through income and price effects, yielding welfare gains for some and losses for others.

To illustrate this transmission process, we report the impact on welfare, GNP, and the terms of trade in Table 3. First, focusing on terms of trade, it is clear that not all Annex B countries have favorable movements in their terms of trade, and neither do all non-Annex B countries have adverse movements. Indeed, the general feature reflected by the numbers is favorable movements in terms of trade for energy importers and adverse movements for energy exporters. Second, the results for welfare change based on equivalent variation (EV) indicate how misleading GNP can be as a measure of the burdens of an emissions control program. In particular, the higher GNP losses of Annex B are mitigated by the favorable movements in their terms of trade, whereas the relatively lower GNP losses for oil exporting countries are aggravated by the unfavorable movements in their terms of trade. Further, an interesting contrast is that both China and South Africa suffer welfare losses from Kyoto due to the adverse movements in their terms of trade, even though they experience positive gains in terms of GNP.

Considering the substantial welfare impacts that would result from emissions restrictions by Annex B, it is interesting to see whether the oil exporters could shield their economies from these loses by

Figure 4 OPEC Cartel and Kyoto: Change in Oil Production Profiles from Reference (NT-D, 2010)



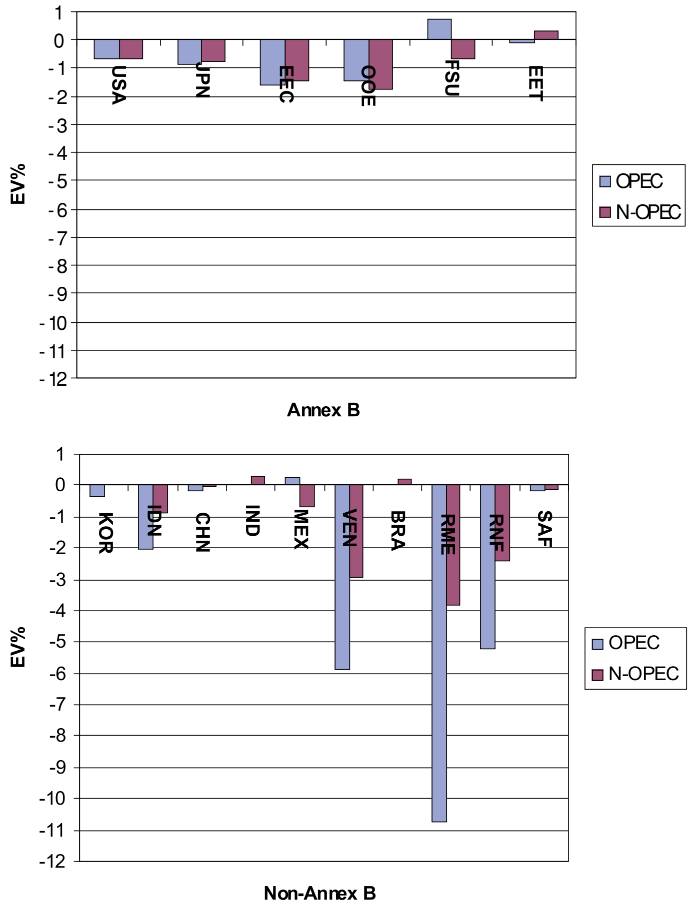
controlling oil price, by restricting oil production. To explore this question we simulate a case in which OPEC countries restrict output in order to maintain the baseline oil price trajectory. The resulting oil production profiles are shown on Figure 4, and the welfare consequences relative to the Kyoto Protocol without such an action are shown in Figure 5. Figure 4 shows that OPEC regions would have to cut their production by 40% to prevent the international price of oil from falling, given the reduced demand in Annex B in response to the carbon constraint, and the increased output by non-OPEC oil exporters. The net welfare result, shown in Figure 5, reveals large welfare losses for OPEC members, additional welfare costs for Annex B and the oil importing non-Annex B regions, and, of course, welfare gains for non-OPEC oil exporters. Relative to Kyoto with no OPEC response, the welfare repercussions suggested by Figure 5 amount to an average 6-15% increase in cost for the oil-importing Annex B, but a more than doubling of the welfare loss for the OPEC regions[6]. With such significant potential welfare losses in OPEC, it seems the chances for such a response to Kyoto are small.

3.2 Carbon Leakage

Carbon leakage is the increase in carbon emissions in the non-abating regions resulting from the relative price and income effects generated by carbon restrictions in the abating regions. Leakage is usually stated as a percentage of the total cutback in emissions by countries under restriction. In particular, the abatement action in Annex B raises the production costs of energy intensive goods and encourages the offshore production of these goods. Also, the fall in Annex B demand for imported oil puts downward pressure on the international price of oil and encourages its use in Non-Annex B regions. The combination of the shift in non-Annex B comparative advantage in energy-intensive production, together with the fall in energy prices, is likely to increase carbon emissions

[6] These results are sensitive to the details of the EPPA-GTAP model structure, including the assumed structure of the energy markets and the sub-model of resource supply.

Figure 5 Welfare Effects of OPEC Price Control Relation to Kyoto Protocol with no OPEC Response (NT-D, 2010)



in non-Annex B above their baseline trajectories. This phenomenon is illustrated in Figure 6, which shows the net exports of energy-intensive goods for the Annex B regions and for those Non-Annex B regions that we highlight here. Exports from the OECD fall with the imposition of the Kyoto restrictions (with the USA becoming a net importer). The FSU and EET (whose Kyoto restrictions do not bind in 2010) increase exports, as do a number of Non-Annex B countries, while all the others lower their net imports.

EPPA-GTAP shows a global leakage rate of 6% for 2010, which is in line with that reported for GREEN (OECD, 1992), the G-Cubed model (McKibbin *et al*., 1999), and with results from EPPA-GREEN (Jacoby *et al*., 1997). Nevertheless, compared to other studies (e.g., Babiker *et al*, 1997; Felder and Rutherford, 1993; Kolstad *et al*, 1999), this leakage rate is somewhat lower. One reason why we have lower leakage rate compared to models other than GREEN is the way existing distortions in the energy markets are treated. In particular, both GREEN and EPPA-GTAP phase out energy subsidies and balance of payment deficits along the baseline whereas other models do not. Simulating the model under the existing subsidies, we found global leakage would increase to 8% in 2010. The contributions of a selection of developing countries to the global leakage rate is shown in Figure 7. The two main features from the figure are that 30% of the leakage is contributed

Figure 6 Net Exports of Energy-Intensive Products with Kyoto Protocol (NT-D, 2010)

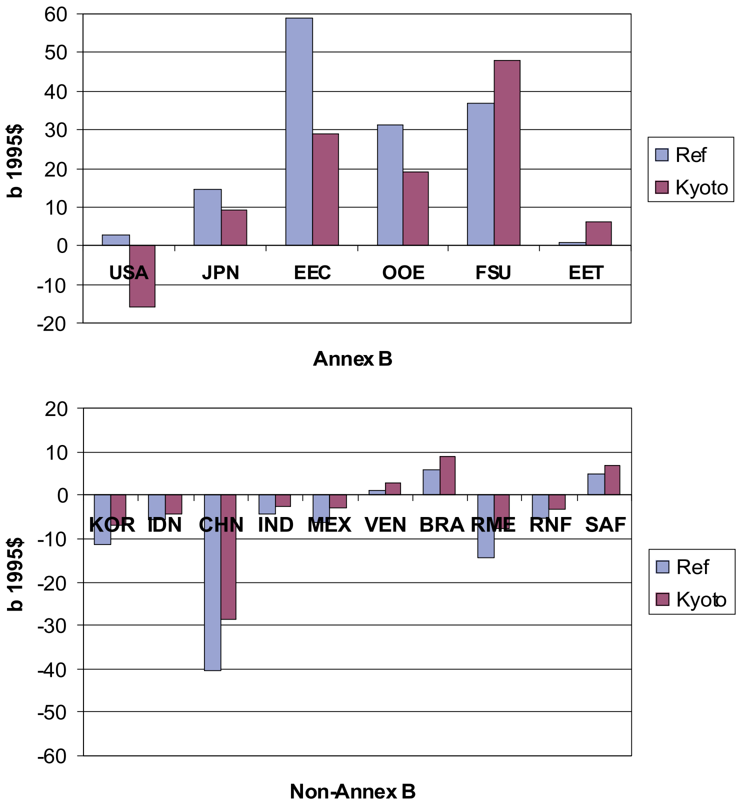
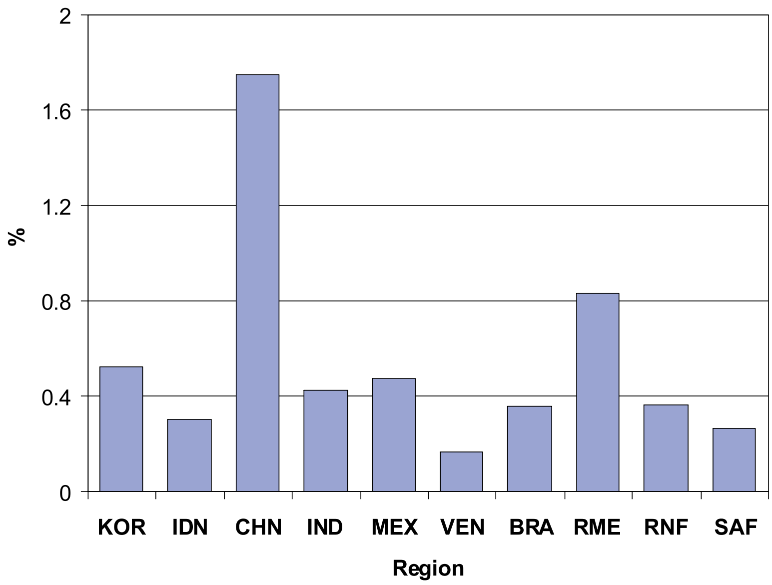


Figure 7 Carbon Leakage Rates Under Kyoto Protocol (NT-D, 2010)



by China alone and that more than 60% of the leakage is contributed by five key countries: China, India, Brazil, South Korea, and Mexico. This would suggest that an effective policy to curtail leakage will have to focus on these countries.

4. Implications of Alternative Annex B Policy Designs

Most analyses of Kyoto-type emissions agreements assume that the policy is imposed as a uniform tax on fossil fuels, or by means of a cap-and-trade system that results in a common price of carbon emissions across sources. One can even think of such calculations as approximating the results of a system of regulatory measures so calibrated as to yield a common marginal cost of carbon reduction across all sources. But the circumstances, in reality, are more complicated than what such calculations imply, because the fiscal systems of many countries, particularly in Europe, have for many decades used fuel taxes as an important source of revenue. Others, like the United States, have a different fiscal tradition, and use these taxes far less.

The fact that the GTAP database identifies these fiscal distortions provides an opportunity to explore the implications of different ways of imposing the Kyoto restrictions. Countries could harmonize fuel taxes on a common carbon basis, yielding a uniform carbon-equivalent tax across all fuels. On the other hand, and more likely, the existing fiscal measures might be left intact, with any carbon taxes or permit fees simply imposed in a supplemental manner. Though, in practice the result is likely to be some blend of the two, a simple comparison between the two polar cases provides insight as to the implications of the choice for developing countries. In the welfare comparisons we do not compensate for the possible difference in revenue within Annex B countries between the two cases, implicitly assuming that any loss or gain in revenue due to an abandonment of non-carbon fuel taxes is made up with a non-distorting lump-sum levy.[7]

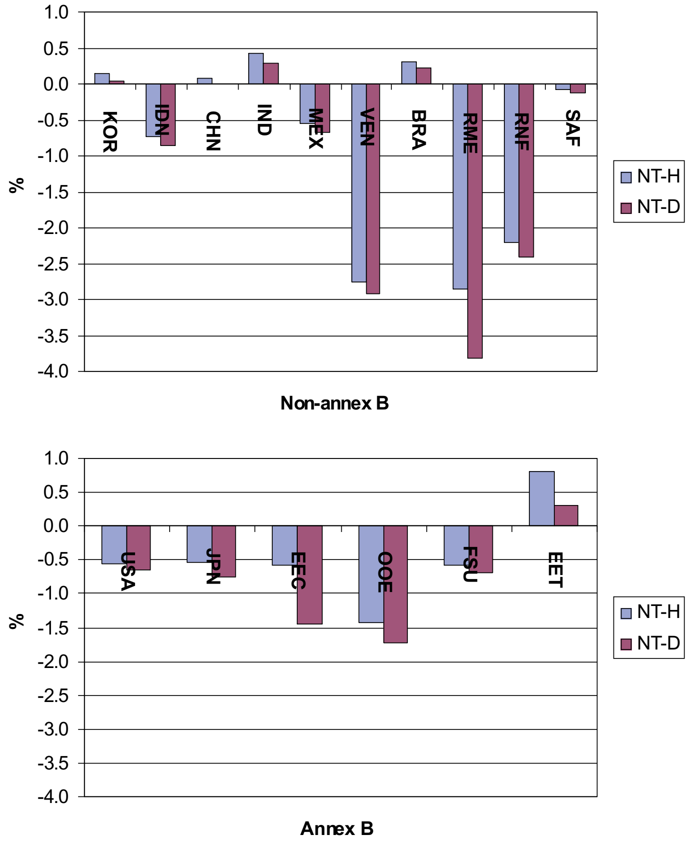
The comparison is shown in Figure 8. Looking first at the Annex B countries, shown in the lower part of the figure, it can be seen that a switch to a harmonized carbon-based increase in fuel prices is favorable to all regions. The gain is greatest in Europe because the distortions are greatest there.

Interestingly, a choice of harmonized as compared to distorted fuel surcharges is beneficial to Non-Annex B countries as well, as seen in the upper part of the figure. For the oil exporting regions the reason for this effect is straightforward to explain.[8] Recall that the increase in world oil price, in relation to the reference, is only 9% if harmonized taxes are applied, whereas the increase is 15% if existing distortions are maintained. Thus with a harmonized system, the deterioration in terms of trade of the oil exporters is reduced, reducing their welfare loss.

[7] Our calculation is not exactly equivalent to the tax treatment in most analyses of the double-dividend issue because we do not impose the condition that the revenue raised from the taxing system remains the same, i.e., it is not revenue neutral for the tax-collecting agent. However, imposition of a revenue-neutrality condition would not likely change the implications for Non-Annex B countries of the removal of these distortions.

[8] Given the complex general equilibrium process involved, the reason why other Non-Annex B regions are better off requires further analysis. One possible explanation is the removal of existing distortions in Annex B increases their demand for oil (compared to the distortion case) and reduces the export price of their energy intensive goods to Non-Annex B.

Figure 8 Kyoto and Welfare: The Implication of Pre-existing Distortions In Annex B's Energy Markets (2010)

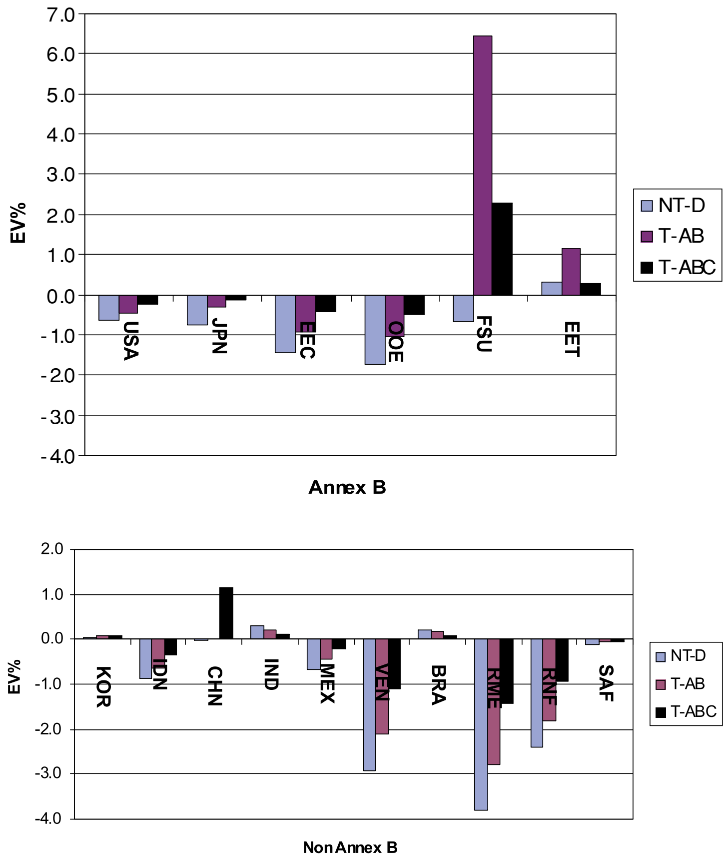


5. Effects of Emissions Trading

The details of international emissions trading, covered under Article 17 of the Kyoto Protocol (United Nations, 1997) are the subject of continuing debate within the Conference of Parties. Although the complexities of alternative implementation schemes may prevent attainment of the cost savings of an ideal trading regime (Hahn and Stavins, 1999), many studies have shown that the potential for cost reductions is great (*e.g*., Montgomery *et al*., 1998; Jacoby *et al*., 1997; OECD, 1992). The analysis conducted here shows the same result. The gains from emissions trading are substantial not only for those engaging in the trade, but often for others as well. We consider two such cases: (1) trading within Annex B alone, and (2) Annex B trading with participation by China, to illustrate the implications of extending the regime to include developing countries.

The results are shown in Figure 9. Consider first the Annex B countries, and the case where only they can trade emissions permits. Given our reference forecast, the FSU and the EET together have 165 MtC of "hot air" in 2010. They benefit from selling it, and the four OECD regions benefit from the lowered cost of carbon control. In the United States, for example, the carbon price in 2010 drops from $205 per ton under autarchy to $92 with Annex B trading. In welfare terms, the cost is lowered most in Japan (by 58%), and in the rest of OECD regions as well (by 28% to 40%) compared to the case of no emissions trading.

Figure 9 Kyoto Protocol: The Welfare Implication of Alternative Emissions Trading Schemes (2010)



As shown in Figure 2, the presence of Annex B trading means that the oil price should fall from the Reference by less than in the no-trading case (10% as compared to 15%). The reduced impact on energy prices tends to mediate the effects that are transmitted through the mechanisms of international trade discussed earlier. So, for example, the oil exporters (*e.g.*, IDN, MEX, RME and RNF) suffer lower welfare loss than they do in a world without trading. On the other hand, those regions that benefited under the no-trade conditions (*e.g.,* KOR and IND) are somewhat less advantaged by Kyoto if trading is in effect.

These effects are only enhanced if a large developing country joins the trading regime. Acceding to the trading regime with 95% of its projected 2020 emissions as a quota, China gets a total hot air to sell of about 200 MtC in 2010[9]. The results from this trading scenario are also shown in Figure 9. Oil prices are only 5% below those under Reference assumptions, and so oil exporters are even better off than under Annex B-only trading. Oil importers among the Annex B nations benefit still less than under trading among Annex B only, and, not surprisingly, the OECD countries also benefit from being able to buy permits from a larger set of suppliers. China benefits most, of course,

[9] Expanding the Annex B coalition in this way results in a global emission reduction of about 75% of the Kyoto reductions to be achieved by the Annex B-only coalition in 2010. But with China in the agreement as assumed, the global reduction is 108% of the Annex B only case in 2020, and 125% in 2030.

because of its hot air and because of having low-cost opportunities for reducing its carbon emissions below the baseline level. The big loser is the FSU. It is better of than with no trading at all, but it would much prefer not to have to sell its hot air in competition with China.[10]

6. Summary and Conclusions

It is no surprise that emissions control actions by the large developing countries, who dominate world trade flows, can have ripple effects on the global economy, influencing countries who have not volunteered to share any burdens of the regime of emissions control. The magnitudes of these impacts are highly uncertain, but the analysis above does give an idea of what these impacts might be, as well as how they are transmitted through the international trade system. Clearly, the greatest loss is imposed on energy exporters, and the more dependent a country is on these exports the greater the percentage effect on its economic welfare. So a country like Mexico, with a large and diversified economy is much less influenced than the nations of the Persian Gulf (RME), for whom oil revenues constitute a large faction of GNP. Moreover, according to our analysis there is not much that the exporters can do about it, say through coordinated efforts by OPEC. The elasticities of demand by importing countries, and of supply by the non-OPEC exporters, combine to produce a market condition where efforts to resist the fall in oil price resulting from Kyoto restrictions lead to still lower overall OPEC revenue. Attempts to do the same by a smaller group within OPEC would lead to even worse results for those taking action to support the price. Recall, of course, that these results are for 2010, and in the longer term the relevant elasticities could change, influencing this result.

Moreover, details of the process of implementation of Kyoto-type agreements matter to the Non-Annex B countries. The distribution of burdens differs depending on the treatment of existing fuels taxes in the enacting of carbon policies; and the presence or absence of emissions trading is even more significant. One troublesome result of these studies, however, is the observation that Non-Annex B countries do not necessarily have a common interest in these details. Within the bounds of uncertainty in this issue the lists of winners and losers among Non-Annex B could shift somewhat, but the fact would remain that interests conflict within the group. In general, those importing energy will benefit from more stringent the policies, and the energy exporters will lose. Moreover, emissions trading and tax harmonization will look different depending on a nation's position on this scale. The intensity of the response will be approximately in proportion to the weight of the energy sector in the national economy.

[10] For further exploration of trading scenarios, see Ellerman, Jacoby and Decaux (1998).

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The IPCC-SRES Stabilisation Scenarios

Johannes Bollen[1], Ton Manders[2], Hans Timmer[2]

We analyse both the macro economic impacts and the effects on energy markets of imposing global constraints of CO_2 emissions, given that on the medium term the Annex-1 region (OECD regions and Economies in Transition) will undertake the abatement effort and comply with the Kyoto protocol, and for the longer term some all NA-1 countries gradually, based on a welfare trigger, will join the A-1 group of countries. The aim of the global CO_2 constraint is stabilize concentrations at 550 ppmv. Starting point is the calibration of the new A1 scenario, which is used as the 'Business-As-Usual' scenario[1] and developed with the Applied General Equilibrium model WorldScan. We show how a specific burden sharing rule yields different regional target profiles, depending on whether the global policy calls for an early action or a delayed response. It is shown that by applying a system of tradable permits to achieve a global constraint, new partners can be attracted to join the abatement coalition. But it is also shown that some countries within the abatement coalition might be against entry of any new partners. Also we will illustrate that the evolution of permit markets will be less stable in a situation of early action than with a delayed response.

1 Introduction

The Kyoto protocol states that countries belonging to Annex-1 (A-1) will take the lead in limiting greenhouse gas emissions. Other members of the Framework on the Convention of Climate Change (FCCC), the Non-Annex-1 (NA-1) countries, do not have to sign up to targets. The negotiations under the FCCC have proven to be very difficult. Why so? The answer can be found in the different interests of the countries around the negotiation table, originating from differing contributions to the cumulation of greenhouse gases in the atmosphere, and diverging economic interests in doing so.

The Parties to the FCCC have introduced three new instruments under the Protocol, allowing Parties (or entities) with emission limits to achieve emission reductions outside their national borders. There are three mechanisms for transferring the emissions internationally under the protocol: Joint Implementation (JI), International Emission Trading (IET) and Clean Development Mechanism (CDM) .

- Joint Implementation (JI) concerns project-level credits, labeled Emission Reduction Units (ERU's) as defined in Article 6, transferable among Annex I Parties.

[1] National Institute of Public health and the Environment (RIVM), P.O. Box 2, 3720 BA Bilthoven, the Netherlands

[2] CPB Netherlands Bureau for Economic Policy Analysis (CPB), van Stolkweg 14, P.O. Box 80510, The Hague, the Netherlands

[3] Please note that the we participated in collaboration with the RIVM IMAGE team in the development of the scenarios for the IPCC Special Report on Emissions Scenarios (SRES). Calculations in this report are based on input from the modeling teams participating in SRES and explore how SRES-type scenarios could be used for mitigation analysis. They are necessarily preliminary, since the SRES scenarios have not been approved by IPCC and are therefore subject to changes.

- International Emission Trading (IET), as defined in Article 17 of the Protocol, concerns transfer of the Assigned Amounts (AA's) among Annex-1 Parties, which are applicable in the first budget period, running from 2008 till 2012. The AA's are corrected for Certified Emission Reductions (CER) obtained from CDM projects.
- Clean Development Mechanism (CDM) concerns CER's, as defined in Article 12, transferable from non Annex I Parties to Annex I Parties

The first two instruments can reduce the total costs of emission reductions within the Annex I region, because they create the option to realize reductions in those countries where marginal abatement costs are lowest. From an Annex I perspective, the third instrument can be seen as an extension of this flexibility to the global level. Since costs of emission reduction are relatively low outside the Annex I area, this global flexibility should further reduce costs for Annex I Parties.

This report focuses on the application of the first flexible instrument only. This instrument is assumed to be applied both within the time frame of the Kyoto protocol, but also beyond 2010. This report is also an attempt to address the some of the issues related to the economics of when-flexibility (see Nature, 1996). We will use prescribed global pathways of emissions (aiming at stabilization of atmospheric concentrations by the year 2100) as the starting point of our analysis.

This report does not address legal issues of enlargement of the abatement coalition nor the topic of implementation of a tradable permit market. This report attempts to highlight some of the macro-economic impacts of implementing targets as described in the Kyoto protocol, based on simulations with WorldScan.

The organization of the report is as follows. First a short description of the model will be presented. Second, a short description of the A1 baseline scenario will be given. Also the feasible policy strategy will be described within the context of the A1 baseline scenario. This strategy aims for a significant reduction of CO_2 emissions due to fuel combustion, and hence a lower CO_2 concentration in the atmosphere. Third, since the feasible policy strategies leads to a gradual extension of the current abatement group of countries, some theoretical notions will be presented on the impacts of enlarging the abatement coalition. The report will finalize with an overview of the main findings of the results and conclusions of the model simulations.

2 Overview of the model

WorldScan has been developed to construct scenarios. To avoid extrapolation of current trends or mere reproduction of the current situation, WorldScan relies on the neoclassical theories of growth and international trade. Changes in economic growth and international specialization patterns evolve from changes in (relative) endowments. The emphasis on the long run also manifests itself in the broad definition of sectors. The WorldScan Core model distinguishes 11 sectors. This is a relatively small number compared to other AGE models. Over a long period of two decades or more the character of products and branches of industry change drastically. Current statistical definitions of products and branches of industry are likely to become irrelevant at the end of scenario period. For this reason, WorldScan uses broad aggregates.

The WorldScan Core model

Compared to the standard neoclassical theories of economic growth and international trade, worldScan is extended to add realism to scenarios. In doing so, we aim at bridging the gap between academic and policy discussions. The extensions include:

- an Armington trade specification, explaining two-way trade and allowing market power to determine trade patterns in the medium run, while allowing Heckscher-Ohlin mechanisms in the long run;
- imperfect financial capital mobility;
- consumption patterns depending upon per capita income, and developing towards a universal pattern;
- a Lewis-type low-productivity sector in developing regions, from which the high-productivity sector can draw labour, enabling high growth for a long period.

The model distinguishes the following regions, sectors and productive:

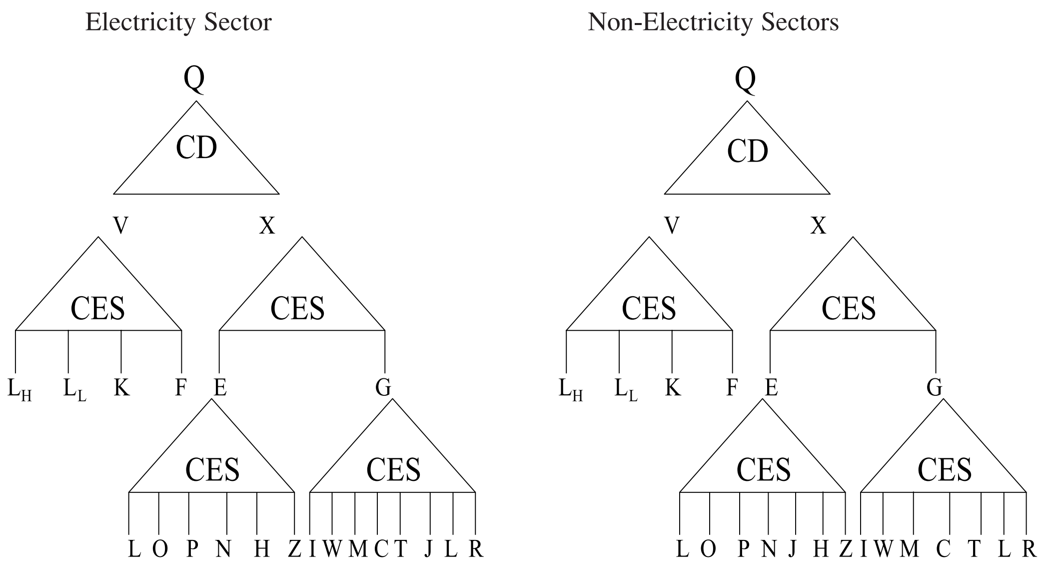
Regions		*Sectors*		*Productive factors*
United States	U	Agriculture	L	Primary inputs
Western Europe	W	Services	W	Low-skilled labour
Japan	J	Trade and Transport	D	High-skilled labour
Rest of the OECD	P	Electricity	J	Capital
Eastern Europe	E	Intermediate goods	I	Fixed factor
Former Soviet Union	F	Consumer goods	C	
Middle East and North Africa	M	Capital goods	M	*Intermediate inputs*
Sub-Saharan Africa	S	Other Raw Materials	R	from all sectors
Latin America	L			
China	C			
South-East Asia	N			
South Asia & Rest	O			

The standard neoclassical theory of growth distinguishes three factors to explain changes in production: the accumulation of physical capital, labor, and a fixed technology trend. WorldScan augments the simple growth model in three ways. First, WorldScan allows overall technology to differ across countries. It also takes up the related idea that developing countries can catch up quickly by adopting foreign state-of-the-art technologies. Second, the model distinguishes two types of labor: high-skilled and low-skilled labor. Sectors differ according to the intensity with which they use high-skilled and low-skilled labor. Countries can raise per capita growth by schooling and training the labor force. Third, in developing countries part of the labor force works in low-productivity sectors. In these sectors workers do not have access to capital and technology. Reallocation of labor from the low-productivity sectors to the high-productivity sectors enables countries to raise per capita growth as well. In principle, all these three factors affect the performance of a region only temporarily. Catching-up, training of low-skilled workers and reallocating labor to the high-productivity sector do not raise the growth rate indefinitely. Nevertheless, they are important. Adjustments in the economies of developing regions take a great deal of time and will surely show up in the growth rates of these regions in the period under consideration.

The Carbon extension of the WorldScan core model has more sectors. The model also distinguishes coal, gas, and oil, and raw materials (which all four were included in 'raw materials' in the core model version). Moreover, the carbon extension includes an electricity producing sector (which is part of the utilities sector in the core model version). Desaggregation allows for better reproduction of the empirical relations between energy use, sectoral structure of output, employment and trade, and macroeconomic development. However, more desaggregation also fixes the I-O system at the specific situation of the baseyear (i.c. 1992). Furthermore, it leads to a more complex system, which takes up more time to find solutions. This is because the share parameters can be very small in some sectors for some inputs. We therefore chose to take a desaggregation which allows analysis of interfuel substitution between fossil energy sectors, the emergence of alternative energy, and a focus on international differences in technology. The resulting desaggregation of some sectors is mentioned below in Figure 1, which also presents an overview of the adjusted production structure as assumed in this model version. Sectoral concordance with GTAP can be found in CPB (2000).

The production functions are specified in such a way that long run technical convergence can be steered by adjusting factor-specific input efficiency factors. This long run convergence has to coincide with a long run tendency towards the law of one price, because only in such a situation can price levels be converged and can technology indices be interpreted as comparable productivity levels. At the moment of writing, the long run law of one price is not included in the model's specification. It has been used in a previous version (see Gielen and van Leeuwen, 1996, and Geurts et al, 1995).

Figure 1 Production input structure



With:
Q = Sectoral output, V = Value added, X = Non-Value Added inputs, E = CES aggregate of all Energy Inputs, CD = Cobb Douglass, CES = Constant Elasticity Substitution Function
G= CES aggregate of all Intermediate Inputs,
O = Coal, N = Natural Gas, P = Oil, H = Biomass, Z = Non-thermal Electricity

The model is benchmarked to the GTAP4E data set, see Mc Dougall et all. (1998). The calibration year is 1995. From this data base we derive not only demand, production and trade patterns, but also labour and capital intensity of the various sectors. The sectoral classification according to skill intensity is broadly correct, but the precise differences could very well change, when better data become available.

Population trajectories follow those of the A1 Narrative. The ILO (1996) provides participation rates for the base year, and for the years up to 2100 they follow the trend of the share of the 15-60 year cohorts. The data for the supply of low-skilled and high-skilled workers at a regional level have been taken from Ahuja and Filmer (1995). Workers are labelled high-skilled when they have completed secondary education or a higher level. Ahuja and Filmer provide projections for many developing countries. We lack projections for the OECD, Eastern Europe and the Former Soviet Union. Therefore we use the Barro and Lee (1996) data on education. We derive a trend between OECD and non-OECD regions between 1960 and 1990 and extrapolate this trend until 2100. The data on the size of the informal sector are obtained from the WorldBank (1995) and the ILO (1998).

Energy data in GTAP4E is an improvement over previous data like in GTAP4. This improvement is due to the incorporation of data on energy volumes prices provided by IEA (1997). Implicit prices result from the confrontation of the value of output and trade per region in GTAP4 with volume data of output and trade. The difference between domestic prices and internationally traded prices is matched by energy subsidies.

Data on the input of biofuels and renewables is drawn from IMAGE. From IMAGE we derive the volume data on the use of biofuels and renewables (as a percentage of fossil fuels). We assume prices to equal prices of agriculture and services, respectively.

3 Feasible Policy Strategies in the A1 Narrative

This scenario is dominated by moderate high economic growth with the emphasis on global technological convergence, and strongly intensified trade linkages. The population growth is relatively low, with a decline of the global population after 2050. The energy intensive sectors develop technologies which lead to relatively low energy demand, with a sharp decarbonization after 2050. The emphasis of the people in this scenario is to maximize income, rather than to pursue any environmental objectives.

In order to analyze the potential impacts of additional climate policies within this narrative, two sets of different global emission profiles are used. Both these profiles only refer to the fossil energy related emissions, and are assumed to stabilize CO2 emissions at 550ppmv[4]. The first is one of immediate action and the second is a delayed version of the first. This approximately means that the cumulative emissions over the 1995-2100 period are the same. We start with the Kyoto protocol, followed by the entrance of some non Annex I regions. In the A1 scenario climate agreements are assumed to be feasible, but only as an extension of the Kyoto protocol. The A1 narrative tells us that although regions pursue market-oriented policies, it does not exclude incentives for governments to agree on a significant carbon abatement effort. The wealthy nations take the responsibility of

[4] Unfortunately, the global emission profiles presented in this paper lie below 550 ppmv, but will be adjusted in a next version of this exercise to make the calculations comparable with other models.

matching the global reduction profile and thus implement an international environmental agreement. The creation of a international Annex I permit market with gradual extensions is consistent with the narrative characteristics of the A1 baseline scenario. The establishment of an international permit market is believed to be the minimal required policy instrument to combat climate change. Governments under the FCCC have the power to agree on protocols which will extend the Kyoto protocol and introduce new members to the Annex I group of countries by creating advantageous circumstances for these new members. The danger of assigning permits to regions that lead to hot-air trade is present, but this is still regarded as a long term restriction of the emissions of these new members countries. But the speed at which governments are actually capable to attract new members to the agreement differs. Welfare triggers are used to force entrance of new members to the Annex I group of countries. The welfare trigger is set at 10000 US$ p.c. for both the delayed response as well as the early action scenario.

The regional Assigned Amount (AA) share distribution of the Kyoto protocol remains applicable for the current Annex-1 group, up to the moment of entrance of new partners. After the entrance of a new partner, the residual for the old A-I group is calculated as the remainder of the global emission profile and the AA of the new partner. The AA amount of the new partner is defined to be constant for a fixed period[5]. After this "grace period" the regional AA share distribution is upgraded, based on the prevailing share distribution. The global constraint is always achieved, since the abatement group accounts for any carbon leakages to non-abating countries.

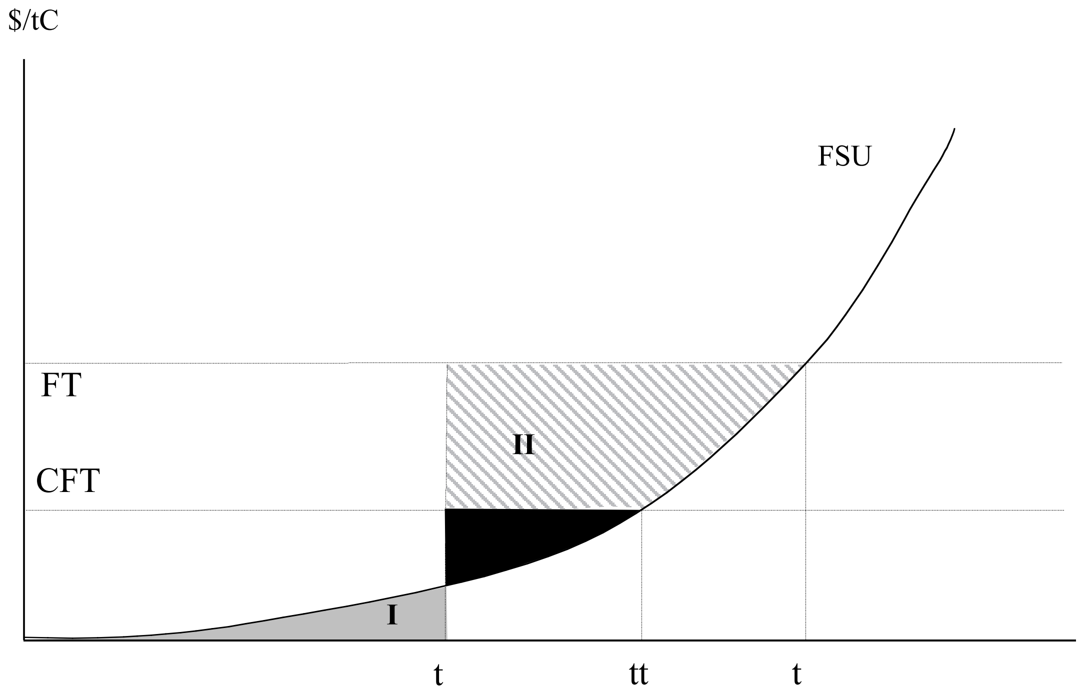
4 Permit Market Dynamics

Suppose that a country is acting on a permit market, e.g. in this case the former Soviet Union. An illustration is given below in Figure 2, which shows some familiar marginal CO2 abatement cost curve: with on the y-axis the marginal costs of abatement and on the x-axis the level of abatement. Let us assume an agreed abatement level for the Former Soviet Union, being equal to t, at a given equilibrium trade price level (FT). Total costs of abatement equals the surface labeled I. But since the equilibrium price level equals FT, the actual emission reduction exceeds the target level. The actual reduction will equal tt. This implies that the total costs for the FSU equals the surface I minus II. This implies that the total costs are negative, and hence if a permit market is established the FSU will surely gain from acting on this Annex I permit market, given the rules laid out in the protocol.

But, suppose now that other countries such as China enter the abatement coalition. There are several reasons for joining the abatement group. First, A-1 countries could force them to do so, because it is cheaper to them to have more countries supply abatement technologies on the permit market. In this way the increasing burden of abatement is shared, but also it might lead to a tighter restriction on the total allowed emission level. Secondly, as time evolves, NA-1 countries must increasingly feel the responsibility to reduce CO_2 emissions, because in the end they also will become a significant contributor to the built-up of greenhouse gas concentrations in the atmosphere. Finally, the regional external effects from global warming might actually persuade countries to join the Annex I group of countries.

[3] The Kyoto protocol states for the current A-1 group of countries that by the end of the first commitment period emissions will equal the AA's. These AA's are defined in terms of 1990 emission levels. An exception will be made for non-feasible reduction pathways once the necessary global emission reduction rate is too high).

Figure 2 Costs of abatement for EEFSU when another country enters the abatement group



How does this relate to Figure 2? Let us assume that there will be an additional player in the abatement group, and suppose that the required reduction effort in absolute terms for the new abatement group is the same as for the old one. Let us focus only on the former Soviet Union. First there will be a reduction of the permit price, simply because the number of abatement technologies for the new abatement group is lager than for the old group. This means that the reduction effort of the FSU reduces to tt, at price equal to CFT. Hence the EEFSU costs of reduction reduces, but at the same time the gains from trade reduces even stronger, and therefor the advantageous position of the former Soviet Union within the Annex I group in the Annex I trading case might not be sustained for the long run.

In general, expanding the abatement coalition, and setting less stringent restrictions on CO_2 emissions on countries in the "old" abatement coalition, may reduce the net costs of abatement of countries which are net-importers of permits and lower the benefits to net-exporters of permits. These benefits may even turn negative, at the expense of benefits or lower net costs to counties which join the abatement coalition. Hence, the reason to create a carbon coalition - and achieve a reduction of potential welfare losses from abatement or increase the willingness to pursue any abatement - and even bribe countries outside the coalition to join and experience income gains from permit trade, at the same time reduces the incentive for the winners in the "old" coalition to remain within the coalition and agree with new entries. This will be illustrated with simulations with the WorldScan (WS) model.

However, we ignored in this example important macro-economic feedbacks that might significantly affect welfare of all countries, either within or outside the abatement coalition. Within the coalition, costs of abatement lead to welfare losses, although for some countries permit trade might have a positive effect on welfare. Generally, countries and regions not only are linked to each other via permit trade, but also by trade of goods on other international markets (energy goods, and high and low energy-intensive-non-energy goods). The welfare of countries outside the abatement coalition is influenced by three factors. First, abatement by countries within the abatement coalition implies costs, and hence leads to decreased expenditures to imports from countries outside the abatement coalition and therefor depresses welfare. Secondly, countries within the abatement coalition will experience terms of trade gains due to abatement (see Martin *et.al.*, 1992), i.e. a relative increase of prices of exported energy-intensive goods (and to a lesser extend also the other goods) compared to their imported goods from countries outside the abatement coalition. The abatement coalition has market power, and will partly pass on these higher prices to the countries outside the abatement coalition. Finally, carbon leakage will occur, but it remains to be seen whether export flows in value terms from NA-1 will be positively influenced. For net-energy exporters this will be offset by the reduction of energy prices. Countries, primarily exporting non-energy goods, might experience a positive influence from lower unit costs of exports due to lower prevailing energy prices. In the WS model all these elements are at work, and it enables us to analyze the impacts of these different elements on welfare.

5 Results & Conclusion

Figure 3 shows the emission profiles of the A1 baseline scenario. It can be seen that emissions peak around 2060 at 17 Gt C and go down again to 12 Gt C by 2100. This is caused by a combination of ongoing technological progress and a global decline of the population. But also the stabilization scenarios are presented. In the 2010-2065 period global emissions of the delayed case lie above those of the early response case. Also it can be seen that WG1 emission profiles by the end of scenario period lie well above the delayed response and the early action scenarios. In that sense the WG1 emission profiles can be interpreted as early action variants of the other two stabilization scenarios.

Not shown in Figure 3, but important to realize is that the rate of change of the global emissions are mainly determined by the entrance of Non Annex I regions to the carbon abatement group. Be aware

Figure 3 Emissions of the A1 Scenario and the 550 ppmv Stabilization cases

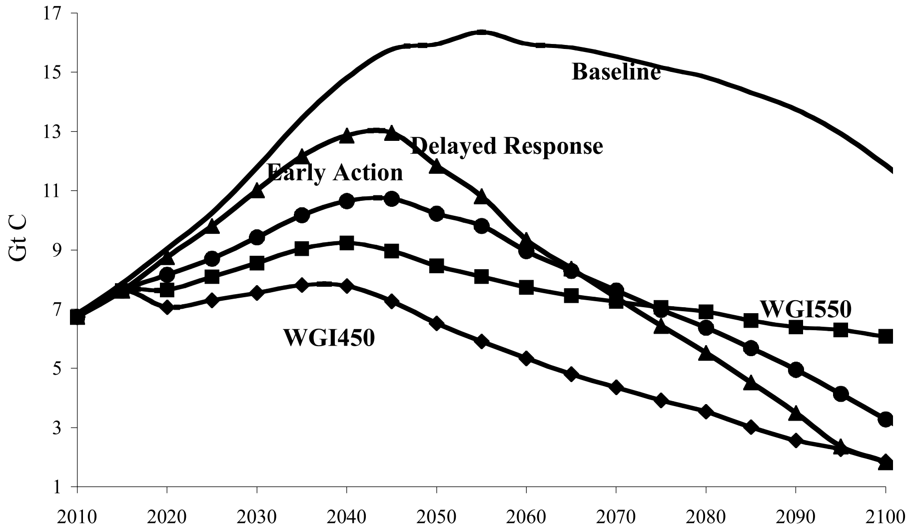
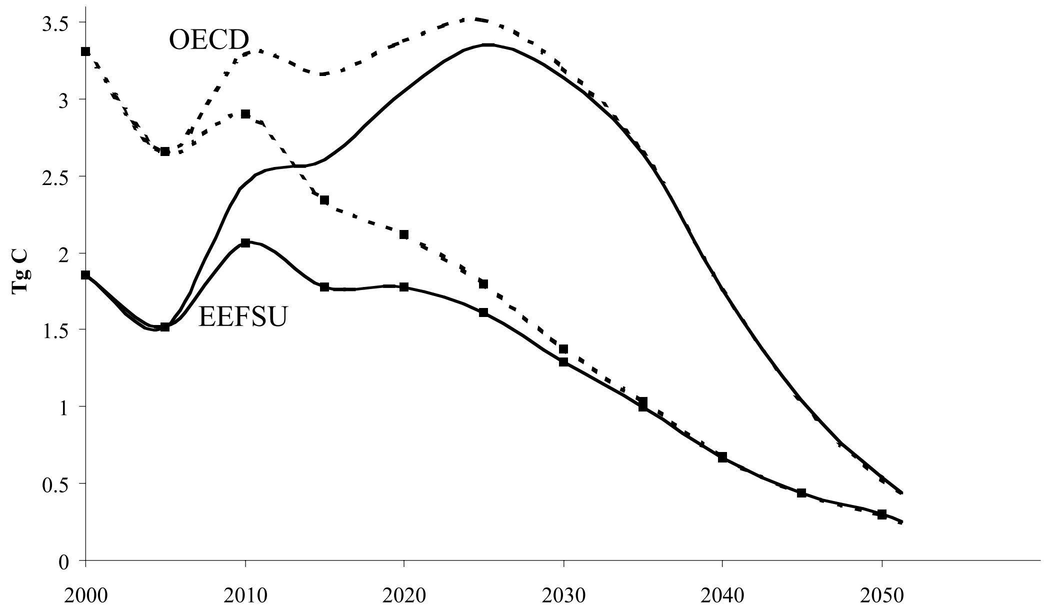


Figure 4 Permits pc of the Stabilization Scenarios of the OECD and EEFSU regions for 2000-2050



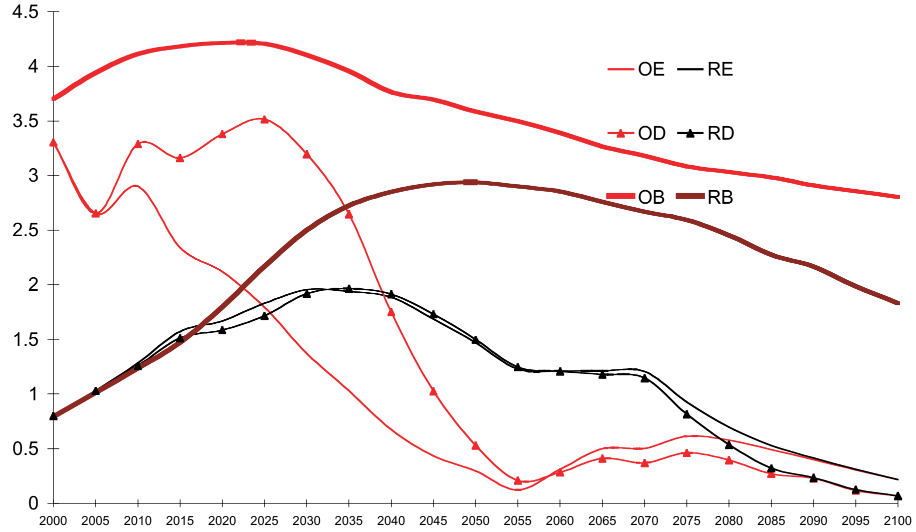
that the endogenously calculated carbon leakage from the abatement group to the non abatement group translates to sharper emission reductions of Annex I region. In the delayed case the Annex I group is allowed to increase its emissions, but mainly due to increased carbon imports by Annex I regions from Latin America and the Dynamic Asian Economies entering the carbon abatement group in 2020 respectively 2025. Delayed action leads to much higher Annex I emissions by 2040 (40% compared to early action), equalize by 2070, and are much lower by 2100 (35%) for all 550 ppmv stabilization scenarios.

It should be pointed out here that the global cumulative emissions are equal for both stabilization scenarios. As time evolves and more non Annex I countries join the carbon abatement, their emissions start to stabilize and decline even after 2045. Carbon leakage rates are not presented here, but increase in the beginning of the scenario period, stabilize as well, and start to decrease as more countries join the carbon abatement group. By 2100 Annex 1 emissions and Non Annex I emissions are more or less of the same order.

But how does this relate to the actual assigned amounts? In Figure 4 the Permits p.c. are presented for both the OECD and the aggregate of Eastern Europe and the former Soviet Union (EEFSU). First focus on the period up to 2060. Here the differences are much more pronounced in terms of the two stabilization scenarios. In 2020, the OECD and EEFSU permits in the delayed case are almost 100% higher than in the early action scenario, but they converge to it by 2055 and remain below afterwards. This implies that the burden of carbon abatement on Annex I economies is very different in the delayed response scenario from the early action case, at least in the medium term. It may be expected that a world aiming for a stabilization of greenhouse gases in the atmosphere will show the tendency of the initial abaters to start moderately with abatement and favor the delayed response scenario. After 2060 the regional permits p.c. are more or less the same for all Annex-1 countries.

If we, however, take a closer look at the regional p.c. permits of the OECD in the long run (up to 2100), it can be seen from Figure 5 that convergence of the p.c. permits of the OECD versus the

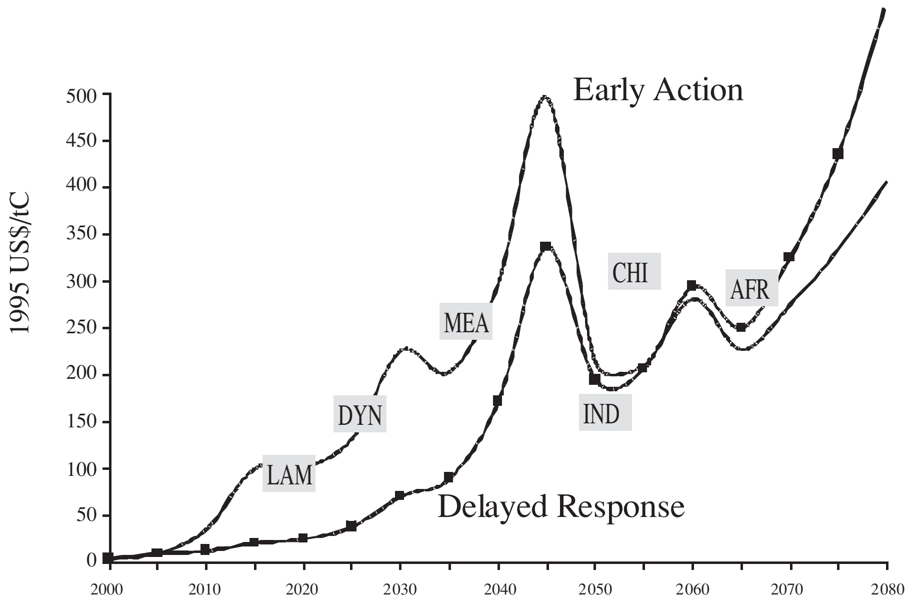
Figure 5 Permits pc of the Stabilization Scenarios of the OECD ROW regions for 2000-2100



Rest of the World (Africa, Middle East, and Latin America) occurs by 2085. In the delayed response scenario, all regions will experience a lower permit level than in the "early action" stabilization scenario.

Below, Figure 6 presents the trade permit price level for the two scenarios for the 2000 – 2080 period. After 2080, the difference between the price level of the two scenarios diverge so strongly, that the differences at the start of the next century do not show up anymore.

Figure 6 Permit prices of the Stabilization scenarios for the 2000-2080 period

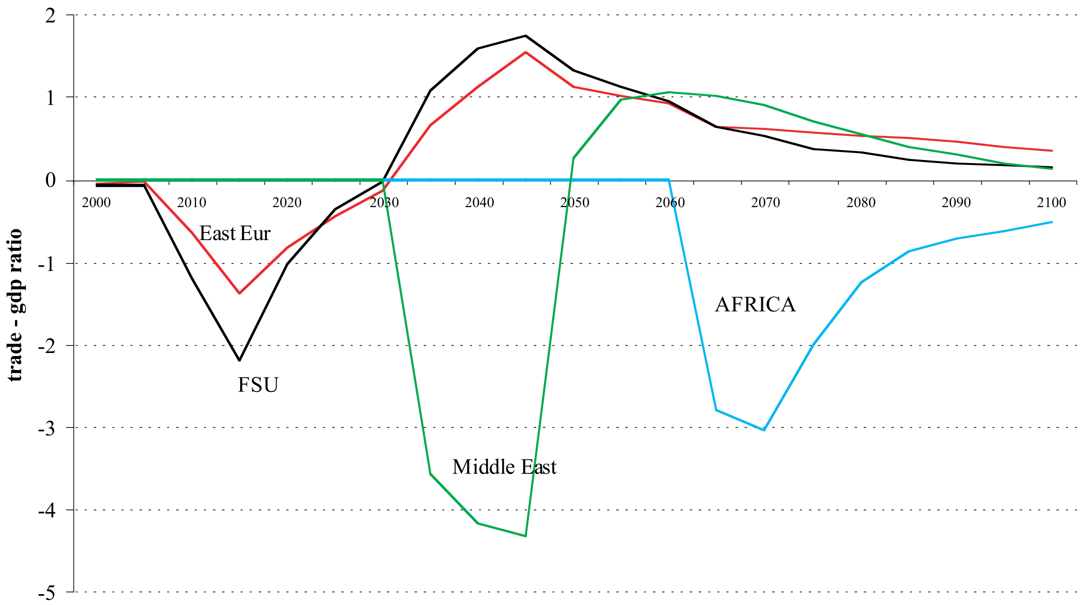


First, Figure 6 shows the moment of entrance of new members to the carbon coalition. E.g. it can be seen that the countries from Latin America are the first NAI countries to enter the abatement club, followed by the Dynamic Asean Economies which will join by the year 2025. Also it can be seen that around the middle of the next century, in both scenarios, China and India enter the abatement group. Although China grows very rapidly in this scenario, in 1995 they also have one of the lowest income levels (per capita) of the world. Moreover, in the A1 scenario, growth rates of the Chinese economy declines over time.

By the time that China and India join the abatement group, the permit price drops sharper in the early action scenario compared to the delayed response (from 400 US$ / t C down to 210 US$ / t C and 330 to 190 respectively). The general picture that emerges is that the evolving permit market is much more unstable in the early action case than in the delayed response scenario. This means that in the delayed response scenario, one may expect that the losers in the abatement group loose more and the winners win more, but generally the non abating group will loose. Recall from Figure 2 on permit dynamics, that the position of permit exporters might change (becoming a net importer) once a new or more than one country joins the abatement group. But generally, delaying the global response will reduce the chance of resistance or non-compliance of the "loosing" members within the old abatement club.

Figure 7 shows the permit trade imports as a share of National Income. Here we remind the reader to Figure 2 and see that the entrance of new members, e.g. the Middle East, has a negative impact on the position of some of the Annex I countries (EEFSU). The gradual extension of the abatement club can have a positive impact on the new members. We see that EEFSU will become a net importer of permits after entrance of Latin America and the Dynamic Asean economies. There are two reasons. First, the entrance of a new member to the abatement club will increase the supply of permits, which is also reflected by the fluctuating profile of the permit price in Figure 6. Secondly, and more important, as time evolves the regional permits p.c. converge within the abatement club.

Figure 7 Trade in the Permit Market of the Early Action Scenario



Therefore, EEFSU now experiencing a relatively low p.c. emission level, is faced as the OECD economies with new NAI members which have a much lower p.c. emission level. The EEFSU graduates within the Annex I group of countries, and therefor turn into net exporter. Figure 7 also shows that by the end of the next century, the scope for trade in terms of National Income declines. This is due to convergence of regional marginal cost curves.

Concluding, within the A1 scenario, it seems that stabilization of greenhouse gases in the atmosphere at 550 ppmv can be achieved at moderate costs. Still, within the context of stabilization scenarios at 550 ppmv, a delayed response is negative for Non Annex I countries, since it relaxes the overall constraint on Annex I countries. At the other end, the early response is negative for Annex I countries. The gradual approach of the entrance of new members to the Annex I group of countries may lead to favorable effects to these countries. The permit allocation can reverse the negative income effects. In the end, it seems that in the A1 world a delayed response aiming for 550 ppmv is globally beneficial. At the same time the price distortion in the end may be too large. In other words, delaying the global response is beneficial for the world because there is less chance to overshooting in the medium run, less overall free riders behaviour, and potential negative impacts at the end of the century may diminish due to discounting. At the other end, the model simulations show that there might be conflicting interests due to income transfers from permit trade.

Further research will focus on other stabilization goals. But also other IPCC marker scenarios will be implemented in the WSCAN model to assess other stabilization scenarios and test the robustness of the conclusions presented in this paper.

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Discussion

Steve Lennon

This discussion is based on an assessment of an electronic copy of the presentation delivered by J Bollen. It was delivered to the author on the morning of the presentation. As such it is qualitative and non-rigorous.

- Assumptions re Non-Annex I entrance - leakage countered by Annex1?, $10 000 entrance level?
- Is convergence to a global per capita allocation equitable at a national level?
- Methodology seems rigorous - but limited opportunity for assessment
- Role of technological development over a period of one century - especially under the A1scenario?
- Early action may promote higher levels of innovation, hence greater rate of change after an initial period - not applicable to delayed response and feedback loops are required
- If ancillary benefits are included then do net costs change to net profits?
- Choice of A1 scenario
    - A1 rapid growth, technologically optimistic, major reductions in per capita income
    - Optimistic and may present a best case for stabilisation
- A2 results would be very different!
- Evaluate for a range of scenarios and then define those common and robust parameters which:
    - Constrain stabilisation
    - Enable stabilisation
- Evaluate robust parameters with a view to develop strategies to overcome constraints and maximise enablers

The modelling exercise is based upon several assumptions, some of which may be challenged. In particular the assumption that carbon leakage will be countered by Annex 1 countries is queried as being idealistic. The $10 000 entrance level is high and difficult for developing nations to relate to. If relevant, it would take longer than anticipated in the model to reach. For example it would require a fivefold increase in many developing country per capita incomes - and this in an environment of decreasing per capita incomes in recent years. If the negative impacts of AIDS are added over the next 20 years then it could be assumed that a minor contribution can be made by Non-Annex 1 countries over the next 20 - 40 years. It is however accepted that the economic development of Non-Annex 1 countries is a function of the scenario selected.

The assumptions assume a convergence by Non Annex 1 countries to Annex 1 per capita Carbon emissions by the end of the modelled period. Whilst this is a valid assumption at a global level, at a national level the use of standardised per capita entitlements is not necessarily equitable. This is primarily due to the unequal allocation of resources globally as well as varying environmental and climatic conditions.

The validity of assuming a particular rate of technology change is questioned - although it is accepted that this is primarily defined by the scenario selected.

The inclusion of a “lessons learnt” feedback loop in the early action case could give it an incremental boost over the delayed response case

Would the inclusion of ancillary benefits in the model change net costs to net benefits? Clearly this would require the quantification of these ancillary benefits which is extremely difficult - especially where local costs may have global ancillary benefits. It is also extremely difficult to internalise these benefits using conventional systems and models.

The main concern relating to the work reported lies in the selection of the scenario to model. A1 is an optimistic scenario which lends itself to the stabilisation situation. It is clear that the use of any other scenario, particularly A2, would produce considerably different results.

The primary question to ask of this work is, what is the ultimate application for its results? To maximise the value of this useful work to the climate change debate and strategy, it is recommended that all scenarios be modelled and then evaluated for common parameters which either constrain stabilisation initiatives, or which enable stabilisation initiatives.

The robust parameters defined above can then be evaluated with a view to develop strategies to negate constraints and to maximise enabling activities.

Analysis of Advantages and Disadvantages of Implementation of AIJ for China

Ruqiu Ye, Yunhui Jin and Xue Liu

1. About the Arguments on AIJ

1.1 The Connotation of AIJ

The concept of Joint Implementation (JI) was first put forward by the Norwegian delegation at the negotiation on the Framework Convention on Climate Change in 1992. It had been written into Article 4.2 of UNFCCC in which: the developed countries Parties and other Parties included in Annex 1 "may implement policies and measures jointly with other parties and assist other parties in contributing to the achievement of the objective of the convention"

The concept of Joint Implementation was complemented by Activities Implemented Jointly (AIJ) at the UNFCCC COP1 in March of 1995, which endorsed a pilot phase for AIJ. The pilot phase allows Activities Implemented Jointly among Annex 1 Parties and, on a voluntary basis, with non-Annex 1 Parties. The major decision made by this conference can be summarized as follows:

- AIJ should be compatible with development priorities of the host countries;
- All the Activities Implemented Jointly in the pilot phase require prior approval, agreement, or confirmation from the governments of the contracting parties involved in these activities;
- AIJ must lead to actual measurable, long-term environmental benefits with respect to the mitigation of climate change;
- The financing of AIJ must take place in addition to the obligations of the developed countries within the context of the financial mechanism of the FCCC, as well as in addition to the current official development aid;
- During the pilot phase, no contracting party may offset emission reductions achieved by AIJ against its own GHG emissions.

1.2 Different Understanding of AIJ

Since the environmental benefits from GHG reduction are not directly related to the reduction location, the large differences of marginal cost of emission reduction between developed and developing countries and the complement of their resources and technology provide the possibility of achieving emission reduction objectives on a cost effective basis. The international cooperation

[1] The discussion in this paper is preliminary

in AIJ has been developed gradually after the COP1 though the progress is limited. The reasons lie not only in the scientific uncertainties about climate change, but also in that in the implementation process of AIJ the determination of base line for emission reduction, its monitoring and checking and other technical problems have not been effectively solved. But the most important reason is the wide differences of understanding of the concept of AIJ, and the basis and preconditions for their implementing. The major differences can be summarized as:

1) Sharing the emission reduction responsibility
Considering the externality of the GHG as a public good and preventing free riders, most of the developed countries emphasize that the responsibilities should be shared by all parties of FCCC. Most developing countries think that the obligation should be undertaken according to the environmental responsibility on the basis of historical responsibility of GHG emission.

2) Starting point for establishing the AIJ mechanism
The objective of developed countries is to establish a market for emission reduction credits or transfer of tradable emission permits via AIJ. As there are markets of equipment, technology and capital for emission reduction behind the markets of emission reduction credits, it is obvious that the developed countries not only want to reduce the costs of emission reduction through AIJ, but also want to gain trade benefits by exporting equipment and technology via AIJ.

Many developing countries would like to set up such a mechanism for AIJ under which they can achieve their development objectives by obtaining the modern clean and sustainable production technology with the use of their advantage of marginal costs of emission reduction.

3) The supply of financial resources and technology for implementing AIJ
Developed countries insist on a distinction between AIJ and grants or aid. Based on the fact that private enterprises own the emission reduction technologies, some of the developed countries consider AIJ should follow the commercial rule of profit as the priority since the private sector should be the principal actor.

The developing countries hold that the financial resources supply for AIJ should be made distinctive from the commercial investment. They emphasize that the lower marginal emission reduction cost of developing countries should have returns.

Obviously, there is different understanding on the environmental equity issue, and big differences exist concerning the responsibility sharing for resource conservation and pollution control and cost sharing for pollution prevention and environmental damages. The atmosphere is a public good, and GHG emission reduction is a collective action. In order to make this collective action more successful, it is necessary to help all parties to find the win-win strategy. Other than solving the technical problems in the AIJ implementation process, the current focus should be on the information exchange and the identification of interests of every party. This will help to narrow down the differences and to reach a common understanding of the basic preconditions and steps for implementing AIJ, so that more countries can be involved in the international cooperation in AIJ.

2. The Disadvantages AIJ for China

Many developing countries are skeptical of the concept of AIJ. The major concerns can be summarized as:

- International society can not allocate emission rights fairly, which will make the developing countries assume obligations which are not commensurate with their responsibility and capability and will constrain their social and economic development;
- The best opportunities for AIJ in developing countries will be taken up by firms from developed countries, thereby increasing the eventual cost of emission reduction for developing countries themselves;
- International monitoring on the emission reduction effects of AIJ may affect the sovereignty of the host country;
- The developing countries may be in a disadvantageous situation in the allocation of benefits from AIJ;
- The host countries are required to provide necessary funding, but opportunity cost of the investments for the host country is too high.

China is a big developing country and has many in common with other developing countries as well as its own special conditions.

2.1 Impact on Social and Economic Development

Social and economic development will be affected if China adopts AIJ which make it commit to emission reduction obligation not commensurate with its present environmental responsibility and capability. It is for this reason that China holds the same attitude as other developing countries.

Zhongxiang Zhang estimated the impacts on China's economy by CO2 emission mitigation using the CGE approach. The annual growth rate of GNP of China was assumed to be 7.92% from 1987 to 2000 and 7.55% from 2000 to 2010. Based on this assumption, the energy demand and the CO2 emission during these two periods were predicted. Whit the predicted emission amount in 2010 as the base line which is 2.46 times that of 1990, it was estimated that China's GNP growth rate will be reduced by 1.5% and 2.8% and the growth rate of welfare measured by Hicksian equivalent variation will be reduced by 1.1% and 1.8%, if China reduces the CO2 emission by 20% and 30% respectively. The data and information show that China's GNP and national welfare is very sensitive to the amount of CO2 emission reduction. If the reduction obligation undertaken by China increases, China will suffer more losses. On the other hand, even if most of the industrialized countries implement stricter emission controls than China, their losses will still be lower or corresponding to that of China (Zhongxiang Zhang, 1996). Therefore, China is one of the countries that is affected most seriously by carbon emission reduction.

In developing countries, most of the environmental problems are related to lack of development. There are 58 million people who still lack basic living conditions in China. If they make efforts to change their lives in an improper way of exploitation of natural resources, it is hardly possible to avoid the occurrence of various environmental and ecological problems, such as increased pollution, deforestation and soil erosion. Obviously, if China undertakes emission reduction obligation too early while making efforts to solve environmental problems, its economic development will be affected. Such a situation does not contribute to the solution of environmental problems in China, it only weakens its capability for solving these problems.

2.2 Emission Reduction Cost

China's participation in AIJ will increase the marginal cost of its emission reduction and make its future emission reduction more difficult. But this situation may not produce significant impacts for a relatively long period.

In the pilot phase of AIJ in order to gain more significant economic and environmental benefits, the relevant participating parties will certainly choose as pilot projects those with low marginal cost of emission reduction. Therefore, the low-hanging fruit will be picked first. This situation will increase the difficulty of future emission reduction. However, there is no need to worry too much about this problem because of the following:

- There are large untapped potentials for emission reduction and increase of sinks of GHGs;

Although the per capita emission level of GHGs is low in China, the total emission is among the highest. China has been maintaining its economic growth rate by high input and high consumption of resources. The total energy utilization efficiency is only about 35%, the utilization efficiency of mineral resources is only 45-50%, and the energy consumption of unit of GNP is 3.5 times that of the world average level (Zhenhua Xie, 1996). China has paid much attention to industrial dust, waste water, solid wastes and others. The CO2 emission has not received enough attention, and the indicators regarding CO2 emissions have not been listed in the environmental statistics. There is a large gap between China's technology on energy utilization and GHG emission control with the international advanced level. In the field of sinks, China has large potential with 85.39 million ha. of barren mountains which are appropriate for afforestation, and about 17.2 million ha. of sparse woodland (Honghui Zhang, 1996). The distribution of marginal emission reduction cost within and between industries still need further study. But from the information available, there are many fields with low marginal emission reduction cost.

- The scale of China's participation in international cooperation in AIJ is hardly increased quickly;

If the scale of international cooperation in AIJ is big or increases quickly, the marginal reduction cost may increase quickly. But from the current information about the supply of financial resources and the technology for the implementation of AIJ, the "additional" capital that developed countries committed has not been fulfilled. Even if it will increase in the future, the technologies that China can obtain are limited, because there exist many demanders. It is therefore unlikely the AIJ international cooperation will be expanded soon.

In addition, if the emission right is allocated unfairly and developed countries do not undertake their environmental obligation corresponding to their responsibility, the supply of financial resources and technology of AIJ as well as the scale of international cooperation will be limited.

- The initial emission right allocation for GHG under future control mechanism of the Convention has not been determined.

The burden of emission reduction on a country will depend on the allocation of initial emission right to the country. Accordingly, the sensitivity to the rise of marginal cost of emission reduction will differ. If the future emission right for China is allocated on the basis of the emission amount at the time when China begins to undertake emission reduction obligation, China will assume more obligations because of its large total emission amount and will be more sensitive to the rise of marginal cost of emission reduction. If the emission right is allocated in accordance with per capita emission level or per capita GNP, China will obtain a more favorable initial emission right and will be less sensitive to the rise of marginal cost of emission reduction.

The analysis above shows that the implementation of AIJ in China will increase the marginal reduction cost and increase the difficulties of emission reduction in the future. But on the other hand, because of the large total emission amount and low energy efficiency in China, limited supply of financial resources and technology of AIJ as well as the uncertainty of initial emission allocation approaches, it is estimated that the marginal reduction cost of China will not increase rapidly. If the relatively low marginal cost of emission reduction of China can have a favorable return, the increase of marginal reduction cost should not be a major obstacle for China's involvement in the international cooperation in AIJ.

2.3 The impacts on the sovereignty of China by international monitoring of the emission reduction effects of AIJ

As there might be the case of "collusion" between the investing country and host country on the calculation of emission reduction, an international mechanism is needed for the checking and monitoring of the emissions reductions reported by the countries. However, if the international monitoring mechanism on the reduction effects of AIJ is not established on the basis of equity and respect to the host country's sovereignty, it will result in the host country's non cooperation, and therefore increase the monitoring cost greatly, and hardly makes AIJ cost effective. Therefore, the design and establishment of any AIJ mechanism in the future must take account of the compatibility of the monitoring and the host country's sovereignty.

2.4 Distribution of AIJ Benefits

The imbalance between the supply and demand structure of AIJ financial resources and technology may cause an unfavorable distribution of AIJ benefits to China. However, if China and other developing countries can urge the Annex 1 parties to undertake their emission reduction obligations and if a certain level of financial resources and technology supplies can be ensured, the position of China and other developing countries in the distribution of benefits from AIJ may be changed

The benefits from AIJ include economic benefits and environmental benefits of AIJ projects. The distribution of AIJ benefits depends upon the supply/demand structure of AIJ financial resources and technology, the amount of supply and demand, and the differences in marginal reduction cost between suppliers and demanders.

Firstly, from the market structure's point of view, the distribution of AIJ benefits is unfavorable to China and other developing countries. The reasons are as follows:

1) Since the AIJ financial resources and technology are in a few countries of Annex 1, the supply is small and the demand is huge, and he suppliers are centralized and the demanders are scattered. In addition, the information asymmetry as well as the difficulty of pricing the technology will definitely favor the suppliers.

2) A completely market bound trade system does not exist in the traditional products market, not to say in the market of emission reduction credits. Because of the local environmental benefit and other economic and political factors, some of the developed countries may focus on cooperation

with their traditional partners which will result in a market structure more unfavorable to China and other developing countries.

Secondly, another major factor determining the position of China in the AIJ benefit distribution is the supply of AIJ financial resources and technology. For China, the supply of financial resources and technology depends upon the degree of the reduction obligations undertaken by developed countries, the difference in marginal reduction costs between developed and developing countries, as well as the difference of the reduction costs between China and other developing countries. If developed countries commit more GHGs emission reduction obligations when determining the initial emission rights or emission reduction obligations, the supply and demand of AIJ financial resources and technology can reach the balance favorable to developing countries. If the reduction amount that developed countries commit is limited, then the developing countries, including China, will be in an unfavorable position. Furthermore, to a certain degree, the relative difference of reduction cost between China and other developing countries may decide the flow of AIJ financial resources and technology. In general, China's marginal reduction cost is relatively low for it is a big GHG emission country with lower energy efficiency.

Figures 1 and 2 can be used to illustrate the benefit distribution between developed countries and developing countries in implementing AIJ. The abscissa represents the amount of emission reduction, while the ordinate represents the price or unit cost of emission reduction, SS refers to the supply curve of emission reduction of developing countries, DD refers to the demand curve of emission reduction of developed countries. For the reasons stated above, the impacts on the supply of GHG emission reduction are weak, while they are more significant on demand. Thus, the SS curve in Figure 1 is relatively smooth, while DD is relatively steep. Under this situation, most of the surplus benefit from AIJ (area of ACE) will flow to demanding countries (area APE), and very few to developing countries (area PEC).

Figure 1 Benefit Distribution

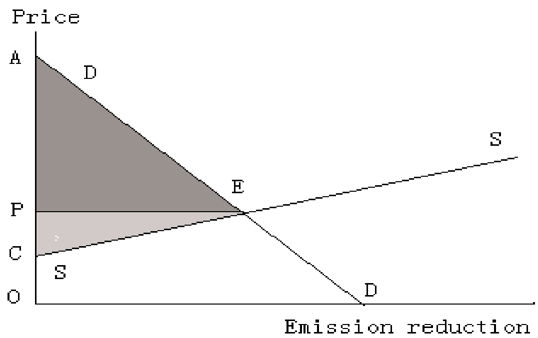
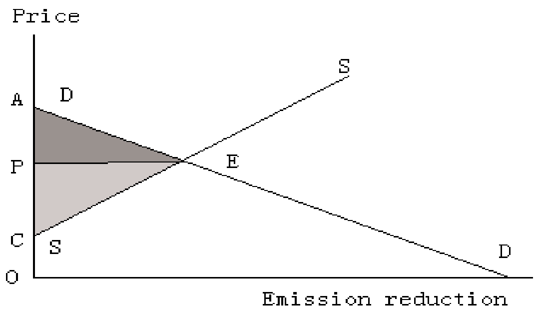


Figure 2 Change in Emission Reduction and Distribution of AIJ Benefits



If developed countries undertake more emission reduction obligation and there exist larger difference in marginal cost in developed and developing countries, then as figure 2 shows, curve DD becomes relatively more smooth and curve SS more steep. This means the distribution of surplus benefits is more reasonable.

2.5 Oppurtunity Cost of Capital

As China's economy is experiencing high speed growth, with huge capital demands, the investment in the necessary capital requirements of AIJ projects is bound to be accompanied by higher opportunity costs. However, if the AIJ projects are selected carefully and are consistent with the priorities of China's economic development, the opportunity cost can be reduced to a manageable level.

The capital provided by foreign countries alone can not meet the demand for emission reduction in China because of its great amount of GHG emission and great potential of emission reduction. In order to achieve more reduction effects through AIJ cooperation, China should provide a definite amount of necessary or starting funds. This may be one of the most important preconditions for attracting AIJ financial resources and technology when AIJ enter the post pilot period and period of large scale dissemination. The areas with great potential of GHG emission reduction such as technological renovation in energy, metallurgy, building material, paper making and chemical industries and technological renovation of industrial boilers are just the strategic areas for China for achieving the transformation of patterns of economic growth. Therefore, in a definite period of time the opportunity cost can generally be reduced by careful selection of projects.

It can be seen from the analysis above, the cost of implementation of AIJ for China depends mainly on whether China undertakes the obligation of emission reduction, when it takes the obligation, and how big the obligation is. It depends also on the degree of emission reduction obligations taken by developed countries. If the participation of China in international AIJ cooperation will result in unduly early undertaking of emission reduction obligation or to its undertaking of obligation not commensurate with its responsibility, there will be disadvantageous consequences for China from the participation. If the participation in AIJ cooperation does not lead to this kind of result, the cost of participation in AIJ experiment will not be high. The purpose of developed countries in the implementation of AIJ is to establish a market of emission reduction credits. Behind the market, there are market of funding for emission reduction and market for technology and equipment for emission reduction. The position of the participating parties in the markets of funding, technology and equipment for emission reduction and the scope of benefit distribution among them are determined by the distribution of initial emission rights. Through international negotiation and thorough consultation, it is possible to turn these factors to a direction of development favorable to China and other participating parties.

3. Analysis of the potential Benefit for China's Involvement in the AIJ International Cooperation

International cooperation in AIJ can bring to China direct as well as indirect benefits.

3.1 Direct Benefits from Participation in International Cooperation in AIJ

1) China can obtain advanced and appropriate environmental technology

At present, China is making great efforts to realize the goals of environmental protection, energy conservation and economic growth. Sometimes, there are conflicts between the goals of economic growth and environmental protection and energy conservation. Introduction of environmental technologies , especially cleaner production technologies can play an important role in harmonizing these goals. Participation in international cooperation in AIJ with careful selection of cooperation partners can help China to obtain advanced and appropriate environmental technologies and to promote sustainable development in China.

2) China can obtain funds necessary for pollution control and GHGs emission reduction.

China is still a developing country conducting at present large scale environmental investment. .However, it is faced with constraints of economic capability and high opportunity costs. Through participation in international cooperation in AIJ, China can obtain additional funds. This will help to mitigate the insufficiency of domestic capital and promote the harmonization of economic development and environmental protection.

It should be noted, that the amount of funds which can be brought to China through international cooperation in AIJ depends on the number and scale of AIJ projects. However, the amount of technologies which China can obtain depends not only on the number of projects, but more on whether it is possible to set up a mechanism under the framework of AIJ favorable to the diffusion of environmental technology. In fact, whether AIJ can become an effective mechanism for solving global environmental problems depends in a large extent on whether it is possible to solve the problem of intellectual property right under the framework of AIJ. This is because the number of AIJ projects is limited no matter in the pilot phase or in the phase of implementation. However, the influence of diffusion of environmental technology is hardly possible to estimate. The following analysis of indirect benefits from international cooperation in AIJ for China was based in a great extent on the assumption of existence of a mechanism favorable for the diffusion environmental technology.

3.2 Indirect Benefits from International Cooperation in AIJ

1) China can obtain benefits from the improvement of global environment

In the sense of total amount of emission, China is one of the countries in the world emitting great amount of GHGs. If China can take part in AIJ international cooperation in a large scale and gain significant effects of emission reduction, it will help to prevent the tendency of degradation and to promote the improvement of the global environment. At the same time, China is naturally the beneficiary of global environmental improvement. According to the estimate of Samuel Frankhauser (see Table 1), when the CO_2 concentration reaches the level of double of that in 1988, the greenhouse effect might cause China great loss accounting for 4.7% of its GNP (the world average level is 1.4%). The estimated loss of China ranks among the top of major countries or group of countries. China will obviously be the major victimized country of global environmental degradation. China will gain great benefits if the global environment is improved.

Table 1 Estimated Loss in Percentage of GNP Caused by Greenhouse Effect (CO_2 concentration = 2x CO_2 concentration in 1988)

Region	% of GNP
EU	1.4
USA	1.3
Other OECD	1.4
Former USSR	0.7
China	4.7
Rest of the world	2.0
OECD	1.3
Non OECD	1.6
World	1.4

Source: Samuel Fankhauser: Valuing Climate Change: The Economics of The Greenhouse Effect (London Earthscan 1995) p55, Table 3.16

Table 2 The Emission and Index of Increase of Industrial Waste Gas, Waste Water, Dust and SO_2 (1985 - 1994)

Year	Waste gas Billion cubic meters		SO_2 10,000 TONS		Industrial waste water 10,000 tons		Industrial dust 10,000 tons	
	Amount	Index	Amount	Index	Amount	Index	Amount	Index
1985	93,970	1.00	1,325	1.00	2,574,009	1.00	1,305	1.00
1986	69,679	0.74	1,250	1.01	2,602,380	1.01	1,075	0.82
1987	77,275	0.82	1,412	1.07	2,637,531	1.02	1,004	0.77
1988	82,380	0.88	1,523	1.15	2,683,886	1.04	1,125	0.86
1989	83,065	0.88	1,565	1.18	2,520,945	0.98	840	0.64
1990	85,380	0.91	1,494	1.13	2,486,861	0.97	781	0.60
1991	101,416	1.08	1,622	1.22	2,356,608	0.92	579	0.44
1992	104,787	1.12	1,685	1.27	2,338,534	0.91	576	0.44
1993	109,604	1.18	1,795	1.35	2,194,919	0.85	617	0.47
1994	11363	1.21	1,825	1.38	2,155,111	0.84	583	0.45

Source: China's Statistics Year Book, from 1986-1995

2) China can get the benefits of improvements of local environment in China.
The local environmental pollution has been becoming more serious as China's economy has grown quickly in recent years. Table 2 lists the emission and index of increase of major pollutants in China from 1985-1994.

Table 2 shows the amount of waste gas emission increased by 21% from 1985-1994. If 1986 is taken as the base year, the increase will be 63%. The total amount of SO_2 emission is great and increased by 38% in ten years.. Although the discharge of industrial waste water decreased in certain extent and the emission of industrial dust decreased by about 50%, the total amount of waste is still large. This has caused environmental problems in some areas. It is estimated that by adopting cleaner production technologies, the current wastes emission can be reduced by about 50%. Therefore, the involvement of China in international cooperation in AIJ can not only reduce GHG emission bringing about global environmental benefits, but also can be helpful to mitigate and solve the local environmental problems in China.

3) It helps China to promote the strategic transformation of economic growth mode
China had been maintaining its economic growth by extensive production. This traditional mode of economic growth had played a role in eradication of poverty and improving living standard of the people. However, it also brought about a series of problems such as:

- the vicious circle of high input, high energy consumption, high speed, low output, low benefits

- waste of capital, raw materials and energy, resulting in the shortage of them

- putting emphasis on expansion of scale, ignoring technological innovation and development, which resulted in slow progress of technology, outdated production equipment, weak international competitiveness of the Chinese industries

- Unreasonable economic structure

The inflation of investment and inflation of consumption occurring in the time of economic growth often disturbed the process of optimization of the industrial structure and the structure of enterprise organization.

Obviously, such growth pattern is not a sustainable one. Therefore, the Chinese government has decided to set the transformation of growth pattern as a strategic priority. The central point of transformation is to improve the efficiency of resource utilization, which is consistent with the strategic objective of GHG emission reduction. International cooperation in AIJ can be an important way for China to introduce efficient and clean technology, to improve the efficiency of resource utilization, and to achieve the goal of transformation of economic growth mode.

4) It helps China to improve energy utilization efficiency
Like other developing countries, China has made economic development the first priority. But the shortage of energy has become the bottleneck constraining China's economic development. It has been predicted that China's energy demand will reach 1600-1700 million tons of standard coal by the year 2000. In recent years, China faced a shortage of 20-30 million tons of coal, 10 million tons of petroleum, and 70 billion kWh of electricity. The gap between the current and potential production capacity of China's industrial manufacturing sectors has widened because of the shortage of energy and transportation capacity and the aggravation of pollution. It was estimated that the loss caused by the shortage of energy is 20-60 times the value of the energy. The shortage of every 100 million tons of coal results in a loss of 100 billion yuan. (Binxian Kui, 1996)

The energy utilization efficiency in China is low. In 1992, the amount of energy consumed on $10,000 of GDP in China was 24,950 tons of standard coal, which was 2.86 times that of India, 5.45 times that of the U.S.A., 14.33 of Japan, and 10.86 of Germany. It was estimated that the energy conservation potential in China is 300 million tons of standard coal (Jingshui Sun, 1996). Although the development of energy conservation technology in China has made good progress, there is still a large gap compared with international levels.

The future economic growth of China will be constrained by the supply of energy. While great energy conservation potentials exist, China lacks the technology for conserving energy. Under such a situation, introducing, digesting, and diffusing clean and efficient technology will be a realistic and favorable choice for China. The implementation of AIJ may be one of the proper ways to introduce foreign advanced energy conservation technologies at reasonable costs.

5) It helps China to promoting the development of hydropower and nuclear power.
The industrial sector accounts for nearly three quarters of China's CO2 emission from energy consumption. Within the five largest energy consuming industries, electricity generation ranks first. Almost 3/4 of the total electricity generated in China come from coal fired power plants. For the purpose reducing GHG emission, more investments in electricity generating facilities of large scale and high efficiency are required. However, the improvement of the structure of electricity generation through the increase of the proportion of hydro and nuclear electricity is also an important way.

It is estimated that China has the largest hydropower resources in the world. It has potential hydropower resources of about 378 GW or an annual electricity generation of 1920 TWh. However, the total installed capacity of hydroelectricity generation accounts only for 9.5% of the total potential capacity in China, which is much lower than that of the developed countries, and lower than that of Brazil, India and other developing countries. (See Table 3)

Currently there are 2 nuclear power plants in commercial operation in China. The development of nuclear power has successfully gone through the initial stage. There is a great potential in the future development of nuclear electricity in China.

The abundant hydropower resources as well as the great potential for developing nuclear power provide the possibility for China to change the energy structure and reduce GHG emission. The introduction of funds and technology through participation in international cooperation in AIJ will help to turn this possibility into reality.

According to the above discussion, we believed the introduction of environmental technology and funds through cooperation in AIJ is consistent with the strategic objectives of China in pursuing sustainable development and the transformation of the mode of economic growth. The gain of potential benefits is definite. If all parties concerned take the common but differentiated

Table 3 The Hydropower Exploitation in Selected Countries

	Capacity			Electricity Generation		
Country	Installed (GW)	Potential (GW)	I/P ratio (%)	Current (TWh)	Potential (TWh)	C/P ratio (%)
USA	90.10	147.25	61.2	279.8	457.1	61.2
Former USSR	64.98	315.73	20.6	223.3	1420.0	15.7
Canada	59.19	163.23	36.3	293.1	593.0	49.4
Brazil	48.75	213.00	22.9	213.4	1194.9	17.9
Japan	37.48			88.0	130.5	67.4
China	36.04	378.53	9.5	126.3	1923.3	6.6
Norway	26.60			121.6	172.0	70.7
France	24.70			69.6	72.0	96.6
Italy	19.00			31.1	60.0	47.8
India	18.34	84.00	21.8	57.8	450.0	12.8
Spain	16.70			25.7	65.6	39.2
Sweden	16.40			71.5	99.0	72.2
Swiss	11.60			30.7	41.0	74.9
Australia	10.90			32.5	53.7	60.5

Source: World Energy Herald, No.13, 1992. (Adjusted, from Zhongxiang Zhang (1996)) responsibilities in accordance with the principles of FCCC and the developing countries are provided with sufficient "ecological space" necessary for their sustainable development, there will be more advantages than disadvantages for China's participation in international cooperation in AIJ.

4. Basic and Prerequisite of China's participation in International Coopreration of AIJ

GHG reduction is not a game with no winners. Obviously, all parties concerned have a basis of common interests. These are global and regional environmental benefits and many other additional benefits brought about by GHG reduction. Therefore, detailed analysis of interests and positions of all parties and the possibilities and constraints of their strategic choices, and on this basis to find ways to mitigate and eliminate conflicts may result in a win-win situation.

4.1 Equity considerations

Sharing of environmental responsibilities and obligations on an equitable basis is the prerequisite of Chinas participation in AIJ cooperation. Equity is the key of success of AIJ. Sources of funds, monitoring of projects, distribution of benefits and other aspects of AIJ should be based on the principles of environmental equity. Environmental equity among countries will play more and more important role in distribution obligations for resources protection and in bearing the costs of prevention of environmental pollution and other environmental hazards. Moreover, while considering environmental equity among countries, not only the issue of equity among the present generation of different countries but also the issue of intergenerational equity should be taken into account.

In order that China plays greater role in international cooperation of AIJ, common understanding in the following aspects is needed.

1) Developed countries are mainly responsible for the degradation of the world environment.

Relevant studies show, the amount of carbon dioxide emitted from burning of fossil fuels from 1860 to 1949 was 187 billion tons and 55.9 billion tons from 1950 to 1989, of which more than 80% were emitted by developed countries. At present, the amount of carbon dioxide emitted from burning of fossil fuels by developed countries account for about 60% of the total emission amount in the world (Ekins 1995). Although we consider, that the result of the study may underestimate the environmental responsibility of developed countries, it still shows that developed countries are mainly responsible for the degradation of the world environment.

2) For the control of degradation of the global environment, countries have common but differentiated responsibilities.

It is the capital and technologies accumulated in the previous generations through high consumption of resources and high emissions of pollutants, that the residents in developed countries can enjoy the present economic achievements and high standard of living. At the same time they should also inherit the corresponding environmental responsibilities. The implication of Intergenerational equity should not be limited only to the equity between the present and future generations, the problems of distribution of historical responsibilities should also be taken into account.

3) China and other developing countries are the major sufferers of the environmental degradation. Firstly, As one of the developing countries, China shares the negative external economic consequence, like the greenhouse effects, of the economic growth of developed countries. This was shown by the study of Samuel Frankhauser. It can be seen from Table 1, the losses suffered by China from the greenhouse effects are higher than the world average by 3.36 times. The percentage of losses in GDP suffered by developing countries is also obviously higher than the world average. Secondly, the development mode of developed countries in the past has resulted in the accumulation of the amounts of GHGs which already exceeded the self-purification capability of the environment. Any new increase of emission will lead to the accelerated increase of environmental costs. Therefore, the choice of development strategy for China and other developing countries is greatly constrained.

4) China should not commit to the obligation of GHGs emission reduction that is not commensurate with its responsibilities and capabilities.

China is one of the countries which emit large amount of GHGs. The amount of carbon dioxide emission of China now accounts for about 11% of the total emission of the world. Nevertheless, the per capita emission of China is very low. For China, sustainable development is the only choice it should make. However, quite a significant number of technologies of sustainable development can be developed only when a countrys integrated economic and technical power reaches a definite stage of development. The replacement of fuels is constrained also by the resource and technological conditions. The transformation of economic structure needs a long time of period and is not feasible in a short time. Therefore, if China takes the obligation of larger emission reduction but could not obtain cleaner technologies from developed countries with reasonable prices, the social and economic development of China will inevitably be affected seriously.

5) The return from environmental investment for developed countries is higher than for developing countries. Therefore, developed countries have the responsibilities to support the environmental control in developing countries.

Countries with different levels of development have different demands for environmental quality and also different rates of return from environmental investments.

Firstly, for people living in different countries and regions, the environment always has the following functions:

- Contribution of good environment to good quality of life. Good environment is a resource of comfort and is enjoyed by human as important constituents of nice scenery and leisure.

- Negative influence of poor environment on quality of life. Poor environment exerts pressure on human and affects human health, and further affects the enjoyment of life and labor capability of human.

- Direct contribution of environmental and related industries to development and economic growth. Investment in environmental protection and provision of resources of comfort can create benefit and increase employment.

- Direct contribution of environmental resources to economic activities. For economic activities, the natural environment not only provides raw materials and energy in the form of petroleum, coal, natural gas, fuel woods, minerals etc., but also assimilate wastes and turns them into resources and regenerate resources.

- Contribution to the maintenance of life support system. The ecological functions of oceans, forest, wetlands and other natural environmental systems are now well understood. They play extremely important role in maintaining the life support systems.

Secondly, The effects of environmental quality for countries of different levels of development are different.

The same environmental quality will bring different effects and values to people at different levels of needs. A. H. Maslow, the American psychologist, divided human needs into five levels: physiological needs, safety needs, social needs including love, belongingness, acceptance and friendship, esteem needs, and self-actualization needs. Only when the needs of lower level are satisfied, human will pursue satisfaction of needs of the next higher level. When the needs of lower level have not been satisfied, there will not be driving force for the needs of higher level, or the driving force will be very weak. Therefore, even if there exist objective conditions for the satisfaction of needs of higher level, there will be no effects brought about.

Although we can not find a place in the Maslows needs levels for the environmental demand of human, but we can assure, that the first two functions of the environment exceed the level of physiological needs and safety needs. In a society where the productivity level is relatively low and the physiological and safety needs are not fully met, these two functions of the environment only have limited value and importance for this society in comparison with a society with highly developed productivity. Also for this reason, the third function of the environment, the contribution of environmental investment for providing resources of comforts to the increase of employment and the growth of GDP is negligible. Only the fourth function of the environment has an essential significance for developing countries. However, overexploitation will bring about negative environmental effects.

Thirdly, the return rates of environmental investments are different for developed and developing countries.

It can be seen from the above discussion, the demand of human for the environmental quality is closely linked with the level of development. For countries wit different levels of development and incomes, the sensitivity of environmental quality to income is different. For countries of low income level, this kind of demand is insensitive to the change of income. Only when incomes reach a relatively higher level, the elasticity of demand for environmental quality to income will be higher than one, i.e. this demand is more sensitive to the change of income. For countries of high income level, when the income level rises, the demand for improvement of environmental quality becomes more urgent, and the improvement of environmental quality will result in more significant effects. This means the return rates of environmental investment will be higher. For countries of low income level, even when there is a rise of the income level, the demand for environmental quality remains not very urgent, and the effects brought about by the improvement of environmental quality are limited. Therefore, the opportunity costs of environmental investment are high, and the return rates of investment are relatively low. For this reason, developed countries have the responsibility to support developing countries for the environmental protection.

In the past, China shared the burdens of the negative external economic effects (like GHG effects and others) in the process of economic development of developed countries. At present, as the result of accumulation of GHGs emitted mainly by developed countries, the space of choice of development strategy of China is limited. In the future, if China takes the obligation of GHG emission reduction, which is not commensurate with its capability, China will have to import expensive emission reduction technologies from developed countries. This will once more put China in an unfavorable position in international trade which China does not like to face.

4.2. The Feasible Strategic Choice of Developed Countries in Face of Climate Change Caused by the Emission of GHGs.

Facing the hazards of different kinds caused by climate change as the result of anthropogenic GHG emissions and other uncertainties, every country has the following two choices:

- Emission reduction— reduction or elimination of major factors leading to climate change. Because of the externality of the greenhouse effect, the effectiveness of emission reduction activities depends on the common efforts of many countries. Besides, an international mechanism is needed to ensure the effectiveness of the cooperation for the protection of the global environment. The costs of emission reduction will depend on the degree of difficulty of the following activities in relevant countries: changing the fuel structure, enhancing energy efficiency, transforming economic structure, etc..

- Adaptation— restructuring the social and economic organization to adapt to the changed climate and taking defensive measures to reduce harms caused by climate change. Adaptation is a kind of regional regulative measures which are relatively easy in implementation. The costs of adaptation include direct costs, for example costs of dams construction to defend from sea level rise, setting more air conditioners to defend from heat wave attack, readjustment of the agricultural structure to adapt to the change of climatic conditions, etc.. Indirect costs should also be included, such as the costs of the spillover of local climatic harms caused by climate change, conflicts caused by fighting for rare and scarce environmental resources, sharp reduction of biological diversity, and long term hazards resulted from other irreversible environmental changes and others.

It is obvious that adaptation investment and emission reduction investment are not mutually complementary, but are mutually independent and irrelevant. In views of capital scarcity, decision makers should make proper choice from the two. Although there exist great uncertainties in estimating the costs of adaptation and the costs of emission reduction, it is certain the costs of emission reduction the developed countries are willing to pay will not exceed the costs of their action of adaptation.

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Discussion

ZhongXiang Zhang[1]

1. Introduction

The paper of Ye et al. (1999) discusses four major issues related to AIJ. The first issue is about the arguments on AIJ. The second issue is about the disadvantages of AIJ for China. The third issue is about the potential benefits, both direct and indirect, of China's involvement in AIJ. The fourth issue is about the prerequisites of China's participation in AIJ. Reading this very interesting paper suggests five questions or issues to me. The first question is about the subject of the paper. The second question is about China's concern about CDM. The third issue is what China has done so far in limiting its carbon emissions. The fourth issue is what can be expected from China at the international climate change negotiations subsequent to Buenos Aires. And the fifth question is whether combating global climate change is in China's interest.

2. The Subject: AIJ or CDM?

Acknowledging the strong opposition to the concept of joint implementation in the developing world, the first Conference of the Parties (COP) to the UNFCCC in Berlin in April 1995 endorsed a pilot phase of joint implementation, referred to as "Activities Implemented Jointly" (AIJ) among Annex I Parties and, on a voluntary basis, with non-Annex I Parties. During the AIJ pilot phase, emission reductions achieved are not allowed to be credited to current national commitments of investor countries under the UNFCCC. By the time of the UNFCCC's second synthesis report on AIJ, 95 projects were listed as AIJ projects (UNFCCC, 1998). These projects are located in 24 host countries, with Africa hosting only one certified AIJ project. The uneven geographical representation means that most non-Annex I countries have not experienced an AIJ project within their own countries and thus provides insufficient details to draw conclusions. This leads to the decision 6/CP.4 at the fourth COP to the UNFCCC held in November 1998, Buenos Aires, to continue the AIJ pilot phase (UNFCCC, 1999). Although more countries might gain experience from a new round of AIJ projects, however, the future of AIJ is likely to be limited. This is partly because of lack of adequate incentives for the private sector participation in AIJ project financing. It is partly because of the adoption of the Buenos Aires Plan of Action, an ambitious two-year work programme intended to make the Kyoto Protocol operative (UNFCCC, 1999). According to the Plan, decisions on rules governing cooperative implementation mechanisms are to be made in the year 2000 at the latest. With the work programme in place, attention has since focused on how clean development mechanism (CDM), JI and emissions trading would work, with priority being given to CDM. Therefore, it is generally acknowledged that the interest of potential investors in project-based cooperative mechanisms is likely to focus on CDM and JI rather than AIJ.

[1] The views expressed here are those of the author. The author bears sole responsibility for any errors and omissions that may remain.

The paper of Ye et al. (1999) addresses a variety of concerns regarding to AIJ. However, mach of the discussion is related to CDM rather than AIJ. Against the above background, I suggest that the title of the paper should indicate that the subject is CDM. Accordingly, the main text should be adjusted to enrich the policy relevance.

3. China's Concerns about CDM

CDM is an innovative mechanism built into the Kyoto Protocol. While many Annex I countries have put and continue to put pressure on developing countries to take on emissions limitation commitments, CDM so far is the only mechanism with an authentic global reach. If designed appropriately, CDM could prove to be a win-win-win mechanism.

- First, CDM could provide an opportunity for developing countries to get increased access to more advanced energy efficiency and pollution control technologies and additional funding and could thus accelerate their future development along a more sustainable path.
- Second, it will help Annex I countries to meet their Kyoto commitments at a lower overall cost than would otherwise have been the case.
- Third, CDM enhances international cooperation in combating global climate change and thus is beneficial to the global environment, as well.

It seems that developing countries prove somewhat more receptive to CDM than to the original concept of joint implementation. However, they have still expressed the fear that:

- They would face possible exploitation due to lack of capacity to negotiate fair contracts with CDM investors from Annex I countries.
- All their low-cost abatement options would be used up, leaving them to face only high-cost options if they would be subsequently required to reduce their own emissions.
- The OECD countries would redefine existing development aid projects as CDM projects, and reduce their aid budgets accordingly. Small developing countries, in Africa in particular, fear that CDM would tend to shift the OECD countries' attention towards those developing countries with large economies and greenhouse gas emissions.
- Developed countries may use CDM to interfere their internal affairs, given that the implementation of CDM projects across national borders would touch on the issue of national sovereignty.

As a developing country, China shares these general views. But, in my view, there are other specific concerns that lead to China having taken a cautious approach to CDM.

First, China and India insist that before CDM commences, the entitlements of both developed and developing countries have to be defined (Sharma, 1998).

Second, CDM could lead to attempts to draw developing countries into unduly early agreeing to something that could be interpreted as new commitments. Closely related to this, there is a particular concern about country-wide baselines that aim to address the leakage problems associated with project baselines, because of their possible links to voluntary or binding commitments. So, in order to protect the longer-term interests of developing countries, it must be absolutely clear from the outset that such baselines, if any, are only for the purpose of reckoning the CDM credits during the agreed periods, without prejudice to future divisions of mitigation responsibilities.

Third, although the sustainable development objective of CDM makes it attractive to developing countries, there is a tendency that CDM would serve the only purpose of assisting Annex I countries in meeting their commitments. Much of the discussion on the CDM to date has focused on technical issues, but its sustainable development objective has not received as much attention. This to a large extent explains why CDM does not trigger much more interests from the developing world than what was thought to be the case. If CDM were only beneficial to Annex I countries, CDM could not be sustained.

In order to facilitate the effective developing country participation in the CDM, the sustainable development objective of the CDM must be addressed. Because the CDM will be eventually implemented through projects, this raises a very important question: how can the objective of sustainable development be explicitly incorporated into individual CDM projects?

One possible option is to develop a set of operational criteria or indicators against which social, economic and environmental dimensions of individual CDM projects can be measured. They could differ per type of CDM projects. If sustainable development indicators could be defined in operational terms and be adopted by the parties to the UNFCCC, they provide useful and user-friendly information to guide decisions about whether a proposed CDM project contributes to sustainable development. Another option would be to require the project developers to demonstrate how the CDM project in question is compatible with development priorities of the host country. It is not enough that CDM projects be not harmful because harmless projects that are unrelated to development priorities divert limited resources away from priority activities and thus involve high opportunity cost for the host country. In my view, no matter what an option to measure sustainable development is adopted, host developing countries retain the right to decide whether a proposed CDM project is likely to contribute to sustainable development.

4. What Has China Done so far in Limiting its Carbon Emissions?

The paper of Ye et al. (1999) mentions several times that China should not commit any greenhouse gas abatement obligations that are not commensurate with its capabilities. But it does not spell out what a level of commitment could be acceptable to China. At present, China contributes 13.5% of global CO_2 emissions. Its share in global CO_2 emissions is expected to exceed that of the US by 2020, if the current trend of economic development in China continues (World Bank, 1994). Therefore, it is not surprising that the role of China is a perennial issue at the international climate change negotiations. Before going into elaborate efforts and commitments that can be expected from China, I like to address what China has done so far in terms of limiting its carbon emissions. The reason why I pay attention to this issue is that significant contribution China has made to reducing global CO_2 emissions has been too little appreciated.

With more than 1.2 billion people, China is home to about 21.5% of the world's population (see Table 1) and has a large and rapidly growing economy, making the country an important player on the world's stage. Since launching its open-door policy and economic reform in late 1978, China has experienced spectacular economic growth, with its gross domestic product (GDP) growing at the average annual rate of about 10% over the period 1978-1997. Along with the rapid economic development, energy consumption rose from 571.4 million tons of coal equivalent (Mtce) in 1978 to 1440.0 Mtce in 1997 (State Statistical Bureau, 1998).

Table 1 Shares of Global CO_2 Emissions and World Population, 1996

	Share of global CO_2 emissions (%)	Share of the world population (%)
USA	25.0	4.7
EU-15	14.7	6.5
China	13.5	21.5
CIS Republics	10.2	5.0
Japan	5.6	2.2
India	3.6	16.3
Canada	2.1	0.5
Australia	1.3	0.3

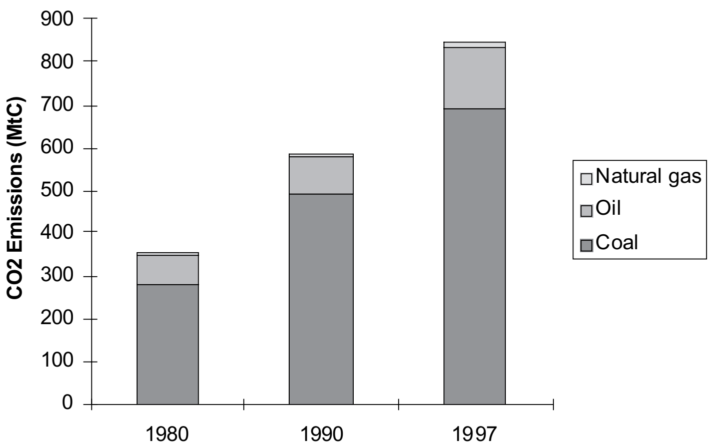
Source: Jefferson (1997).

Accompanying the growth in fossil fuel use, China's CO_2 emissions have grown rapidly. As shown in Figure 1, the total CO_2 emissions in China rose from 358.60 million tons of carbon (MtC) in 1980 to 847.25 MtC in 1997, with an average annual growth rate of 5.2%. This ranks China as the world's second largest CO_2 emitter only behind the US, according to the World Energy Council (see Table 1). But on a per capita basis, China's CO_2 emissions of 0.685 tC in 1997 were very low, only about half the world average (Zhang, 1999).

The breakdown of CO_2 emissions by fuel is shown in Figure 1. Because coal has accounted for about 75% of the total energy consumption over the past years, it is not surprising that coal predominates, accounting for 81.3% of the total emissions in 1997. This share has remained almost unchanged over the past two decades

Table 2 shows the historical contribution of inter-fuel switching, energy conservation, economic growth, and population expansion to CO_2 emissions in China over the period 1980-1997. The data used to obtain the results in Table 2 are plotted in Figure 2, after normalization to the year 1980. The results in Table 2 and Figure 2 clearly indicate the relative importance of each factor in terms of its

Figure 1 China's CO_2 Emissions by Fuel



Source: Zhang (1999).

Table 2 Breakdown of the Contributions to CO_2 Emissions Growth in China, 1980-1997 (MtC)[a]

Due to change in fossil fuel carbon intensity	Due to penetration of carbon free fuel	Due to change in energy intensity	Due to economic growth	Due to population expansion	Total change in CO_2 emissions
+3.93	-10.48	-432.32	+799.13	+128.39	+488.65

[a] A positive sign indicates an increase; A negative sign indicates a decline.
Source: Zhang (1999).

contribution to CO_2 emissions growth in China. Given that China has been the most rapidly expanding economy over the past 17 years, it is not surprising that economic growth measured in per capita GDP was overwhelming. This factor alone resulted in an increase of 799.13 MtC. During the corresponding period, through its strict family planning programmes, China experienced a very low rate of population growth in comparison with other countries at China's income level, which in turn contributed to a smaller increase in China's CO_2 emissions than would otherwise have been the case.[2] As a result, population expansion was responsible for an increase of 128.39 MtC, an increase in emissions considered to be modest given its population size. Also, the change in fossil fuel mix contributed to an increase in emissions (3.93 MtC), but its role was very limited because the share of coal use in total commercial energy consumption increased only slightly during the period.

By contrast, a reduction in energy intensity tended to push CO_2 emissions down. Since the early 1980s, the Chinese government has been placing great emphasis on energy conservation and has formulated and implemented approximately 30 energy conservation laws concerning the administrative, legislative, economic and technological aspects of energy conservation. After years of preparation, China's Energy Conservation Law was enacted on 1 November 1997 and came into force on 1 January 1998. In order to efficiently use energy, China has significantly reduced subsidies for energy consumption, with coal subsidy rates falling from 61% in 1984 to 37% in 1990 and to 29% in 1995, and petroleum subsidy rates falling from 55% in 1990 to 2% in 1995 (Kosmo, 1987; World Bank, 1997a). Currently, coal prices are largely decided by the market and vary significantly depending on the destination of the coal.[3] Energy pricing reforms may have already proceeded to the point where the bottlenecks to more adoption of efficiency measures have less to do with energy prices than other factors (Sinton et al., 1998). Along with the economic reforms that, among other achievements, have spurred investment in more energy efficient production technologies, the Chinese government has also played a crucial role both in promoting a shift of economic structure towards less energy-intensive services (see Table 3) and a shift of product mix towards high value-added products, and in encouraging imports of energy-intensive products.[4] Furthermore, efforts have been made towards implementing nationwide energy conservation programmes. For example, state capital construction loans for efficiency are at an interest rate of 30% lower than commercial loans, and state technological renovation loans for efficiency are with 50% of the interest subsidized

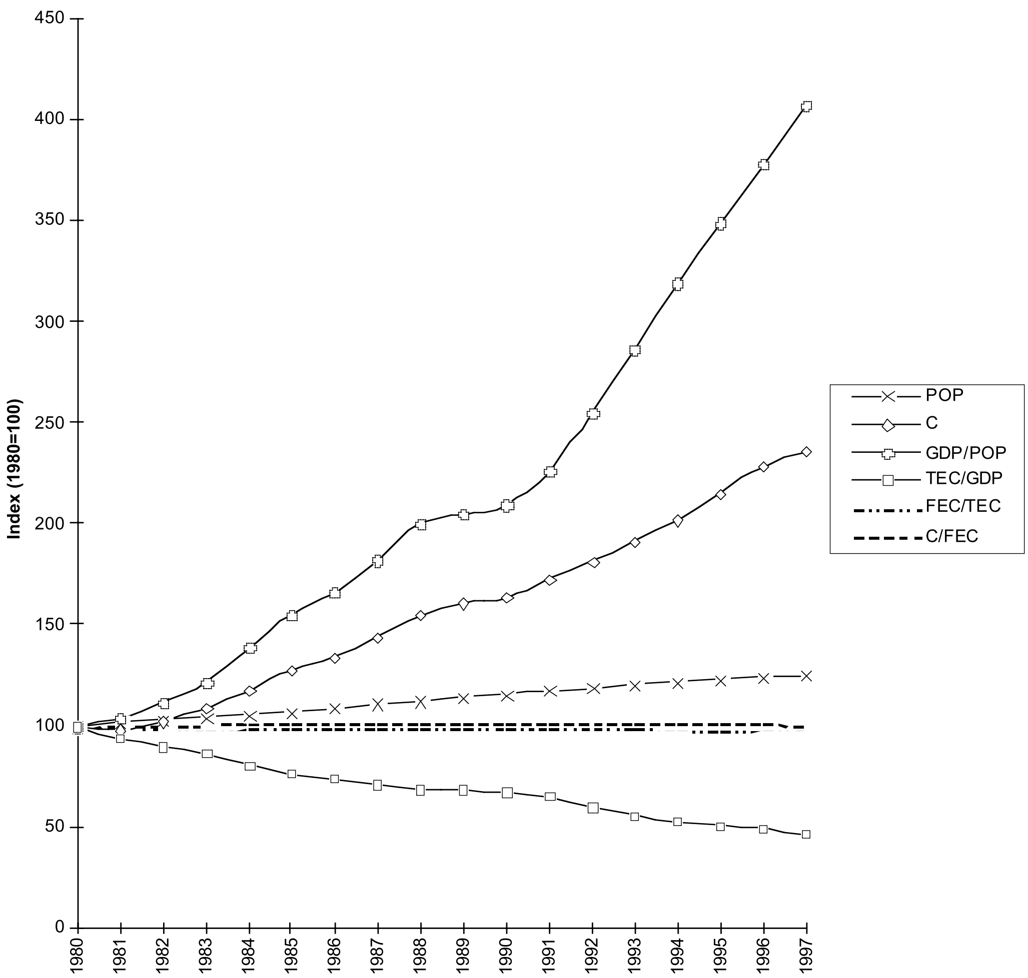
[2] During the period 1980-1997, the annual average growth rate of population in China was 1.33%. In contrast, the corresponding figure for low-income economies (excluding China) between 1980 and 1995 was 2.35%, and the world average was 1.66% (World Bank, 1997c).

[3] For example, the mine-mouth price of Datong mixed coal was 128 yuan per ton in June 1994. The same coal retained for 230 yuan per ton in Shanghai, 262 yuan per ton in Nanjing, 280 yuan per ton in Guangzhou, and 340 yuan per ton in Xiamen (SETC, 1996).

[4] About 10% of the total energy savings during the period 1981-1988 were attributed to imports of energy-intensive products (Zhang, 1997).

(Sinton et al., 1998). The creation of over 200 energy conservation technology service centers throughout the country, which have worked most closely with the end-users of the efficient technologies, devices and practices that the government sought to promote, has been extremely valuable. In power industry, efforts have been made towards developing large-size coal-fired power plants. In 1987, only 11 power stations had an unit capacity of 1 gigawatt (GW) and above. The combined capacity of these power stations was about 15 GW, accounting for one-seventh of the nation's total. By 1994, there were 34 power stations having an unit capacity of 1 GW and above, with a combined capacity of 43 GW, accounting for 21.4% of the nation's total (SETC, 1996). In the meantime, the share of generating units having a capacity of 100 MW and above increased from 32.5% in 1984 to 57.2% in 1994 (MOEP, 1985; SETC, 1996). Along with these large units commissioned into operation, the average generation efficiency of thermal power increased from 28.5% in 1984 to 29.7% in 1994. Given the sheer size of the Chinese power industry, even this small efficiency improvements translate into large coal savings when multiplied by tens of GW of capacity installed.

Figure 2 Contribution to CO_2 Emissions in China, 1980-1997[a]



[a] C = The amount of CO_2 emissions; FEC = Total carbon-based fossil fuel consumption; TEC = Total commercial energy consumption; GDP = Gross Domestic Product; and POP = Population.

Source: Zhang (1999).

Table 3 The Composition of GDP in China, Japan and the US (percentage of GDP)

	China			Japan	United States
	1980	1990	1997	1995	1995
Agriculture	30.1	27.1	18.7	2	2
Industry	48.5	41.6	49.2	38	26
Services	21.4	31.3	32.1	60	72

Sources: State Statistical Bureau (1998); World Bank (1997c).

Table 4 Growth Rates of GDP and Energy Consumption, and the Income Elasticity of Energy Consumption among Different Economies, 1980-1994

	Annual growth of GDP (%)	Annual growth of energy consumption (%)	Income elasticity of energy consumption
Low-income economies *	2.8	4.7	1.66
China	11.0	4.5	0.41
Upper-middle-income economies	2.5	3.9	1.56
High-income economies	2.8	1.1	0.39

* Excluding China.
Source: Calculated based on data from the World Bank (1996).

Clearly, it is by implementing these policies and measures that great progress in decoupling China's GDP growth from energy consumption has been made, with an annual growth of 10.06% for the former but only 5.26% for the latter during the period 1980-1997. This achievement corresponds to an income elasticity of energy consumption of 0.52 and to an annual saving rate of 4.37%.[5] Given the fact that most developing countries at China's income level have the income elasticity of energy consumption well above one (see Table 4), this makes China's achievement unique in the developing world.[6] As a result, a reduction of 432.32 MtC was achieved. In other words, without the above policies and measures towards energy conservation, China's CO_2 emissions in 1997 would have been 432.32 MtC higher, or more than 50% higher, than its actual emissions.

In addition to energy conservation, the penetration of carbon-free fuels contributed to a small reduction in CO_2 emissions (-10.48 MtC). This is mainly due to the underdevelopment of hydropower, and partly because the development of nuclear power in China is still at the initial start-up stage.

[5] The income elasticity of energy consumption is defined as the change in energy consumption divided by the change in economic growth.

[6] As shown in Table 4, the income elasticity of energy consumption in China is quite low by international standards. In addition to energy conservation, there are other two possible explanations for this. First, the growth of energy consumption is underestimated relative to the GDP growth. Second, quantitative restrictions have kept energy consumption from rising as would otherwise have occurred. Drawing on the analysis of rationing by Neary and Roberts (1980), the quantitative restrictions act like an implicit energy tax levied at rates varying with use and fuel. Generally speaking, households face a higher implicit tax than industrial users, and oil and natural gas are taxed at a higher rate than coal.

Table 5 Changes in CO_2 Emissions from Fossil Fuel among Selected Countries and Regions (%)[a]

	1990-1996	1995-1996
OECD[b]	+7.8	+2.6
EU-15	+0.9	+2.3
Denmark	+41.0	+20.6
Germany	-7.8	+2.1
Netherlands	+10.0	+2.6
United Kingdom	-1.0	+2.9
United States	+8.4	+3.3
Canada	+5.5	+1.6
Japan	+14.3	+1.8
Australia	+9.5	+2.2
New Zealand	+10.7	+4.0
Norway	+14.5	+7.3
CIS and C& E Europe	-31.0	-2.6
Developing countries	+32.0	+5.1
World	+6.4	+2.7

[a] A positive sign indicates an increase; A negative sign indicates a decline.
[b] Excluding Mexico, Korea, Hungary and Poland.
Source: Jefferson (1997).

From the preceding analysis, it follows that China has made significant contribution to reducing global CO_2 emissions, although none of these carbon savings have resulted from domestic climate mitigation policies. Unfortunately, China's contribution has been too little appreciated. While China is making such an impressive achievement, we might ask how the OECD countries perform in this regard. They accounted for 50.3% of global CO_2 emissions in 1996 compared with 49.6% in 1990 (Jefferson, 1997) and promised at the Earth Summit in June 1992 to individually or jointly stabilize emissions of CO_2 and other greenhouse gases at their 1990 levels by 2000. As shown in Table 5, the total CO_2 emissions in the OECD countries rose by 7.8% between 1990 and 1996. On their current trends, CO_2 emissions in the US and EU-15 (the fifteen member countries of the European Union) would be 13% and 8% above the promised targets in 2000 respectively (Jefferson, 1997; Reid and Goldemberg, 1997). Therefore, it is fair to say that, with few exceptions, most of the OECD countries are unlikely to meet their voluntary commitments to stablilizing CO_2 emissions at their 1990 levels by 2000.

5. What Can be Expected from China at the Negotiations Subsequent to Buenos Aires?

Of course, the above discussion is not to justify no further action by China. Indeed, faced with both the mounting pressure from the US and the new post-Kyoto negotiating environment, and given the global characteristics of climate change and China's importance as a source of future CO_2 emissions in line with its industrialization and urbanization, China cannot come away without taking due responsibilities.

5.1 The Changed Negotiating Environment

Prior to Kyoto, developing counties' demand for the US to demonstrate the leadership and the EU proposal for a 15% cut in emissions of a basket of three greenhouse gases below 1990 levels by 2010 put collective pressure on the US, which leads the world in greenhouse gas emissions. Now the US has made legally binding commitments at Kyoto. The Kyoto target is seen as not enough but yet not unreasonable given that the US economy would not be disrupted unreasonably (King, 1998).[7] Now the ball is kicked off to China's court. The US has made it clear that bringing key developing countries, including China, on board has been and will continue to be its focus of international climate change negotiations. According to some US Senators, it will be countries like China, India and Mexico that will decide whether the US will ratify the Kyoto Protocol. It is therefore conceivable that the pressure will mount for China to make some kind of commitments at the negotiations subsequent to Buenos Aires. The world's media will undoubtedly bring attention to China's non-participation, which will be seen as holding up the ratification of the Protocol by the US Senate and possibly even be blamed for "blowing up" subsequent negotiations aimed at dealing with developing countries' commitments.

While preparing for greater and greater pressure from the US, China should take the following non-US factors into account in developing its post-Kyoto climate negotiation strategies.

First, although the group of 77 and China[8] managed to block the US proposal for allowing a developing country to voluntarily commit to reductions in greenhouse gas emissions at Kyoto, the US had partial success in weakening the position of the group. As might be expected, the US will continue to apply the "divide and rule" tactic by getting at least a few to accept obligations they are not required to undertake and then putting pressure on the rest of the developing countries to do the same, exploiting the fact that such developing countries as Argentina have already determined to take on voluntary commitments.[9] Given the fact that developing countries are a more diverse and heterogeneous group than the Annex I countries, and that their interests in the climate change debate are heterogeneous and occasionally competing, it might be very difficult to prevent some countries in the group — particularly those countries with a relatively high per capita income and that perceive the greatest potential gain from emissions trading — from being drawn into making commitments of their own at the negotiations subsequent to Buenos Aires.

Second, after the first commitment period 2008-2012, China will soon surpass the US as the world's largest greenhouse gas emitter, due mainly to its sheer size of population and partly to its rapidly growing economy. While it will still take another couple of decades for cumulative greenhouse gas emissions from China to exceed those of the US, Western media and some US Senators could deliberately misguide the general public's attention and then shift the attack on the US to China.

Third, although in accordance with the principle of common but differentiated responsibilities Annex I countries should take the lead in reducing their greenhouse gas emissions and providing

[7] As indicated in Table 5, the US CO2 emissions in 1996 were already 8.4% above 1990 levels. To meet the Kyoto commitments requires the US to cut its greenhouse gas emissions by up to 30% from its business-as-usual levels during the period 2008-2012. This is not tremendous but not trivial either.

[8] As has been the case in the international climate change negotiations, the developing countries express their consensus views as the group of 77 and China's positions. Divergent or dissenting views are then expressed separately, representing either individual countries or smaller groups, such as the Alliance of Small Island States (AOSIS).

[9] At the fourth COP to the UNFCCC held in November 1998, Buenos Aires, the host country, Argentina, proposed the inclusion of voluntary commitments from developing countries on the conference agenda. When delegates considered the agenda, a Chinese delegate saw any discussion on the subject of voluntary commitments from developing countries as a means of destroying the unity of the group of 77 and China, while a Brazilian negotiator said it was a means of helping some countries to avoid existing commitments rather than promoting the UNFCCC (Earth Negotiations Bulletin, 16 November 1998). As a result, the host's proposal was rejected by the group of 77 and China. In the end, during the second week of the fourth COP, Argentina and Kazakstan stepped out from the ranks of the group of 77 and China and declared that they would undertake a voluntary commitment to abate their greenhouse gas emissions at the fifth COP to the UNFCCC in 1999.

adequate technology transfer and financing to non-Annex I countries, broadening commitments to include all countries in the long term is necessary and unavoidable in order to achieve the UNFCCC's ultimate objective of stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Under these circumstances, it would be unwise for China just to sit back and let the US define what is "meaningful participation" from developing countries. It would be also unwise for China simply to distance itself from attempts to draw developing countries into agreeing to something that could be interpreted as new commitments at the negotiations subsequent to Buenos Aires. Doing so would only create negative image and publicity for China, which has been regarded as a "hard liner" at the climate change negotiations. In the meantime, China should keep watch on the negotiating positions of such developing countries as Argentina, Costa Rica and South Korean and should not let the fate of the whole South be left at the hands of these relatively high-per-capita-income countries.

5.2 China's Strategies at the Climate Change Negotiations Subsequent to Buenos Aires

Faced with a different situation from that at Kyoto, China should ponder deeply over its strategies at the international climate change negotiations subsequent to Buenos Aires. On the one hand, China should take much more efforts towards communicating to the industrialized world the substantial contributions it has already made to limiting greenhouse gas emissions. China has cut its energy consumption per unit of output in half since 1980, indicating that if the energy intensity were the same now as that in 1980, China would consume twice as much energy, and produce twice as much CO_2 emissions as it now does. Unfortunately, this achievement is not widely known or appreciated outside of China: outsiders know that the Chinese economy is booming, but they are not as cognizant of China's very impressive improvement in energy efficiency. Therefore, efforts towards effective communication about what has been achieved in China to the outside world will help to correct the distorted picture that had been painted.

On the other hand, while insisting on its legitimate demand for industrialized countries to provide adequate technology transfer and financing, and demanding that emissions targets beyond the first commitment period be set for Annex I countries at the subsequent negotiations over new additional developing countries' commitments, China could propose and direct negotiations, rather than just react and respond. In proposing its voluntary efforts and commitments, China should bear in mind that demanding for the "equal per capita entitlements" is politically unrealistic for the time span we are considering, although it is perfectly justified on grounds that all human beings are born equal and that the atmosphere is a global common. On the other hand, the US demand for imposing a cap on China's future emissions is absolutely unacceptable for China, at least until its per capita income catches up with the level of middle-developed countries. For these reasons, I put aside the proposal for either "equal per capita entitlements" or an absolute cap on national emissions. I envision the following six proposals that could be put on the table as China's plausible negotiation position, which are each described in the order of their stringentness.

First, China could regard its active participation in CDM as "meaningful participation". If appropriate rules and guidelines for CDM are defined, what then are the potential areas in China's interest? It is usually acknowledged that the success of CDM premises an effective understanding of local (host country) development aspirations and the use of CDM to push ahead with efforts to achieve these aspirations. Thus, in order to enhance their possibility of success, there is the need to make due consideration of local objectives and local conditions in designing the CDM projects. Considering that China is more concerned with local pollutants, such as SO_2, NOx and particulates from coal burning, and regards them as its own environmental priorities, it is expected that the most potential areas of interest to China are related to those activities and options aimed at: (1) improving the efficiency of energy use, particularly at energy-intensive energy sectors (for example, iron and steel industry, chemical industry, building materials industry, and power industry) and devices (for example, industrial boilers); (2) pushing efficient use of coal through increasing proportion of raw coal washed; popularizing domestic use of coal briquette; substitution of direct burning of coal by electricity through development of large-size, high-temperature and high-pressure efficient coal-fired power plants; expanding district heating systems and developing co-generation; increased penetration of town gas into urban households; and through development and diffusion of environmentally sound coal technologies; (3) speeding up the development of hydropower and nuclear power; and (4) developing renewables.

Second, just as Article 3.2 of the Kyoto Protocol requires Annex I countries to “have made demonstrable progress” in achieving their commitments by 2005, China could commit to demonstrable efforts towards slowing its greenhouse gas emissions growth at some point between the first commitment period and 2020. Securing the undefined “demonstrable progress” regarding China’s efforts is the best option that China should fight for at the international climate change negotiations subsequent to Buenos Aires.

Third, if the above commitment is not considered “meaningful”, China could go a little further to make voluntary commitments to specific policies and measures to limit greenhouse gas emissions at some point between the first commitment period and 2020. Policies and measures might need to be developed to explicitly demonstrate whether or not China has made adequate efforts. Such policies and measures might include abolishing energy subsidies, improving the efficiency of energy use, promoting renewable energies, and increasing the R&D spending on developing environmentally sound coal technologies.

China should resort to all means of securing either of the above deals. It could even lobby for support from the EU, and therefore put collective pressure on the US.[10] If all the attempts prove unsuccessful, China might resort to the last three options.

Fourth, China could make a voluntary commitment to total energy consumption or total greenhouse gas emissions per unit of GDP at some point around or beyond 2020. In my view, carbon intensity of the economy is preferred to energy intensity of the economy (i.e., total energy consumption per unit of GDP) because all the efforts towards shifting away from high-carbon energy are awarded by the former. Such a commitment would still allow China to grow economically while improving the environment. It reflects a basic element of the UNFCCC, which has recongnized the developing countries’ need for further development and economic growth. The industrialized countries, particularly the US, have no reason or right to argue against it. To do so would contradict their claim that asking China’s involvement in combating global climate change is not intended to limit its capacity to industrialize, reduce poverty and raise its standards of living. Even if the Chinese government has claimed that China will continue its efforts towards improving energy efficiency and minimizing further degradation of the environment in any event, it would be wise to propose an explicit value for carbon intensity of the Chinese economy as a starting point for negotiations. In

[10] In the run up to Kyoto, the following two points distinguish the EU from the US. In comparison with the US demand for developing countries to agree to cuts in greenhouse gas emissions in the same timeframe as industrialized countries, the EU has made clear that developing countries need not to promise at Kyoto to make cuts, although they should be persuaded to do so at a later date. Moreover, by permitting a 30-40% increase in emissions to Greece and Portugal, the EU proposal for international community burden-sharing accepts that poorer countries should be treated more leniently, whereas the US has been opposed to differentiated emissions targets until it has to give up its opposition at Kyoto. If Greece and Portugal can have this sort of rise, it would be very difficult for the EU to reject the demand from the really poor, that is, developing countries, for a not unreasonable leeway in emissions.

this regard, there is a pressing need for comprehensive analysis and quantification of the economic implications of climate change for China. For a long time, the Chinese government has claimed that asking for China to take actions would seriously harm China's economic development. However, until now, inside of China there has been no single comprehensive study indicating the economic effects of possible future carbon limits for China, for example, in terms of foregone national income, although along this line there have been some studies done outside of China (e.g., Zhang (1997, 1998)). Findings that show that China would be the region hardest hit by carbon limits can help to convince the world of the Chinese government's claim. Such information can be used to China's advantage in bargaining a possible targeted carbon intensity with other countries, as well.

The fifth option would be for China to voluntarily commit to an emissions cap on a particular sector at some point around or beyond 2020. Taking on such a commitment, although already burdensome for China, could raise the concern about the carbon leakage from the sector to those sectors whose emissions are not capped.

This leads to **the final option** that China could offer: a combination of a targeted carbon intensity level with an emissions cap on a particular sector at some point around or beyond 2020. This is the bottom line: China can not afford to go beyond it until its per capita income catches up with the level of middle-developed countries.

It should be pointed out that before legally binding commitments become applicable to Annex I countries, they have a grace period of 16 years starting from the Earth Summit in June 1992 when Annex I countries promised to individually or jointly stabilize emissions of CO_2 and other greenhouse gases at their 1990 levels by the end of this century to the beginning of the first commitment period in 2008. Therefore, China could demand a grace period before either of the last three commitments becomes legally binding. Even without the precedent for Annex I countries, China's demand is by no means without foundation. For example, the Montreal Protocol on Substances that Deplete the Ozone Layer grants developing countries a grace period of 10 years. Moreover, China could insist that accession of developing countries and burden sharing be based on ability of pay. As such, a country is expected to take on emissions limitation commitments once it exceeds a threshold level of per capita income. On the one hand, this approach would avoid the costing negotiations for accession of developing countries on an individual basis. On the other hand, the approach would bind China and other developing countries, thus giving China more clout in the final bargaining in determining a threshold level.

6. Combating Global Climate Change Is in China's Interest

I fully agree with Ye et al. (1999) that China itself will benefit from international cooperation on combating global climate change. Because economic development remains the priority for China, its climate policy would focus on the so-called win-win strategies. The above efforts and commitments proposed for China reflect that; they do not go beyond the scope of taking no-cost or low-cost "no-regrets" actions. Although the last three commitments are more stringent than the first three, none of them would be likely to severely jeopardize Chinese economic development. Indeed, taking due responsibilities in combating global climate change should be in China's interest on the following grounds.

First, because climate-sensitive sectors such as agriculture still account for a much larger proportion of GDP in China than in the developed countries (see Table 3), China is even more vulnerable to

Table 6 Proved Reserves and Utilization Rates of Fossil Fuels in China, 1997

Resources	Proved reserves	R/P ratio[a] (years)		Per capita proved reserves[b]	
	China	China	World	China	World
Coal	114.5 billion tons	82	219	95	182
% world total	11.1%				
Oil	3.3 billion tons	21	41	3	25
% world total	2.3%				
Natural gas	1.16 trillion cubic meters	52	64	967	25517
% world total	0.8%				

[a] R/P ratio stands for the lifetime of proved reserves at 1997 rates of production.
[b] Measured in tons for coal and oil and in cubic meters for natural gas and based on population in 1995.
Sources: Calculated based on data from the British Petroleum (1998) and World Bank (1997c).

climate change than the developed countries. Therefore, a broad commitment to global efforts towards limiting greenhouse gas emissions would reduce the potential damage from climate change in China itself, since after all it is not only the developed countries whose climate will change if greenhouse gas emissions are not reduced.

Second, China is scarce in energy, with per capita energy endowments far below the world average (see Table 6). Although energy consumption per unit of output in China has been cut in half since 1980, its major industries continue to use energy far more intensively than in industrialized countries (see Table 7). By making the above commitments, China will be pushed for a more efficient use of its scarce energy resources.

Third, driven by the threat of further degradation of the environment[11] and the harmful economic effects of energy shortages, China is already determined to push energy conservation and enhanced energy efficiency in general and more efficient coal usage in particular. Although it is taking such drastic domestic efforts on its own, China badly needs assistance and economic and technical cooperation with the developed countries, because of the huge amounts of capital and technical expertise required. In this regard, CDM, if designed appropriately, could provide an opportunity for China to get increased access to more advanced energy efficiency and pollution control technologies and additional funding.

From the preceding discussion, it follows that the above efforts and commitments proposed for China, though aimed at limiting greenhouse gas emissions, will contribute to the reductions in local pollutants and thus will be beneficial to a more sustainable development of the Chinese economy as well as to the global climate. At the same time, they would give China more leverage at the international climate change negotiations subsequent to Buenos Aires.

11 Existing estimates for the economic costs of China's environmental degradation vary, depending on the comprehensiveness of the estimates. For example, using the measure of willingness to pay, the World Bank (1997b) has estimated that air and water pollution cost China about 8% of its GDP, around $54 billion annually, while Smil (1996) puts China's environmental damages between 5.5% and 9.8% of its GNP.

Table 7 A Comparison of Unit Energy Consumption for Selected Energy-Intensive Users

	1980 China	1994 China	Advanced level abroad
Comparable energy consumption per ton of steel (tce/t)	1.30	1.03[a]	0.6 (Italy)
Energy consumption per ton of synthetic ammonia (tce/t)	1.45	1.34[a]	1.2
Large plants	2.90	2.09	108.4 (Japan)
Small plants	206.5	175.3	327 (ex-USSR)
Energy consumption per ton of cement clinker (kgce/t)	448	413	80-85
Net coal consumption of coal-fired plants (gce/kWh)		60-70	
Thermal efficiency of industrial boilers (%)			

[a] In 1990.
Source: Zhang (1997).

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The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?

Alan S. Manne and Richard G. Richels[1]

1. Introduction

The Kyoto Protocol represents a milestone in climate policy. For the first time, negotiators have attempted to lay out emission reduction targets for the early part of the 21st century. The goal is for Annex 1 (developed countries plus economies in transition) to reduce their aggregate anthropogenic carbon dioxide equivalent emissions by at least 5 percent below 1990 levels in the commitment period 2008 to 2012. The Protocol, however, has yet to enter into force. To do so will require ratification by 55 countries representing 55 percent of total Annex 1 CO_2 emissions in 1990.

As each country considers ratification, important questions will arise. High up on the US list is the issue of economic costs. The Senate, for example, has stated that "any Protocol should be accompanied by a detailed financial analysis of impacts on the economy." Not surprisingly, US negotiators had hardly returned from Kyoto before the first hearings were scheduled on Capitol Hill. Although the issue of costs is but one of many important considerations, policy makers are keenly interested in the economic implications of ratification.

This paper is intended to help clarify our understanding of compliance costs. The focus is on three questions, which we believe to be of particular relevance: What are the near-term costs of implementation? How significant are the so-called "flexibility provisions"? And, perhaps most importantly, is the Protocol cost-effective in the context of the long-term goals of the Framework Convention?

Unfortunately, the answers to these questions will not come easily. It has always been difficult to calculate the economic costs of implementing climate policy. Kyoto has done little to simplify matters. Indeed, it raises at least as many questions as it resolves. These questions fall into two categories: those related to the near-term implementation of the Protocol and those related to the evolution of climate policy over the longer term.

The Protocol is unclear on a number of topics. These include the rules governing emission trading, joint implementation (JI), the Clean Development Mechanism (CDM), and the treatment of carbon sinks. In addition, there is a weak knowledge base regarding the costs of sink enhancement and of controlling several of the relevant trace gases. Until these issues are clarified, analyses will be highly speculative.

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Calculating the costs of Kyoto is also complicated by the issue of “what happens next?” Energy sector investments are typically long-lived. Today’s investment decisions are not only influenced by what happens during the next decade, but also by what happens thereafter. In order to estimate the costs of implementing emission cuts in the first commitment period, assumptions are required concerning the longer-term requirements. Unfortunately, the international negotiation process offers little guidance on this issue. This further complicates the process of analysis.

We do not wish to suggest that economic analysis is premature at the present time. Uncertainty is rarely an excuse for paralysis. It does mean, however, that we must be careful to highlight the tentative nature of the projections and focus, to the extent possible, on the insights for decision making. Here, sensitivity analysis can be particularly useful. For example, in the case of several of the flexibility provisions (emission trading, joint implementation and the Clean Development Mechanism), we explore a variety of scenarios regarding constraints on the purchase of carbon emission rights. While the exact magnitude of the benefits will continue to be debated, the insights, nevertheless, appear to be quite robust.

We also examine the Protocol in the context of the longer-term goal of the Framework Convention, i.e., the stabilization of greenhouse gas concentrations in the earth’s atmosphere. A particular concentration goal can be reached through a variety of emission pathways. Considerable effort has been devoted to trying to understand the characteristics of cost-effective pathways. It is interesting to examine Kyoto in the context of this work. The price tag for moving forward may be formidable. Consistent with the Framework Convention, it is essential that “policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible costs.”

2. The model

This analysis is based on MERGE (a model for evaluating the regional and global effects of greenhouse gas reduction policies). MERGE is an intertemporal market equilibrium model. It combines a bottom-up representation of the energy supply sector together with a top-down perspective on the remainder of the economy. Savings and investment decisions are modeled as though each of the regions maximizes the discounted utility of its consumption subject to an intertemporal wealth constraint. Each region’s wealth includes not only capital, labor and exhaustible resources, but also its negotiated international share in carbon emission rights.

For the present version of the model, known as MERGE 3.0, we have adopted 10-year time intervals through 2050 and 25-year intervals through 2100. Geographically, the world is divided into nine geopolitical regions: 1) the USA, 2) OECDE (Western Europe), 3) Japan, 4) CANZ (Canada, Australia and New Zealand), 5) EEFSU (Eastern Europe and the Former Soviet Union), 6) China, 7) India, 8) MOPEC (Mexico and OPEC) and, 9) ROW (the rest of world). Note that the OECD (regions 1 through 4) together with EEFSU constitute Annex 1 of the Framework Convention.

Particularly relevant for the present analyses, MERGE provides a general equilibrium formulation of the global economy. We model the possibility of international trade in carbon emission rights. This is sometimes known as “where” flexibility. It would allow regions with high marginal abatement costs to purchase emission rights from regions with low marginal abatement costs. In addition, MERGE can be used to examine the related issue of “when” flexibility - intertemporal transfers of carbon emission rights.

We also model international trade in oil, natural gas, and energy-intensive basic materials. We are therefore able to examine issues related to “carbon leakage”. Such leakage can occur through a variety of pathways. For example, Annex 1 emission reductions will result in lower oil demand, which in turn will lead to a decline in the international price of oil. As a result, non-Annex 1 countries may increase their oil imports and emit more than they would otherwise.

The present version of the model includes the notion of endogenous technical diffusion. Specifically, in the electric sector, the near-term adoption of high-cost carbon-free technologies leads to accelerated future introduction of lower cost versions. The model also includes both price-induced and non-price conservation. For most regions and time periods, the AEEI (autonomous energy efficiency improvement) rate is taken to be 40% of the rate of GDP growth. By 2100, this leads to regional energy-GDP ratios that are much closer to each other than they were in 1990.

In calibrating MERGE for the present analysis, several supply- and demand-side parameters were adjusted so that the global emissions baseline would approximate the Intergovernmental Panel on Climate Change (IPCC) central case “no policy” scenario (IS92a).[9] Figure 2.1 shows carbon emissions for each region in the reference case scenario. For more on the model and its key assumptions, see our website:

http://www-leland.stanford.edu/group/MERGE/

3. Treatment of sinks and non-CO_2 greenhouse gases

Few issues have engendered as much confusion as that of carbon sinks. Key questions include their definition, the extent to which they are included in the Protocol, the amount currently being sequestered, their time profile, and the costs of sink enhancement.

The Protocol states that Annex 1 commitments can be met by “the net changes in greenhouse gas emissions from sources and removal by sinks resulting from direct human-induced land use change and forestry activities limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks in each commitment period.” The confusion results from alternative interpretations regarding the treatment of soil carbon, an issue flagged for further study in the Protocol. Their inclusion may result in large increases in the international legal definition of sink potential.

The quality of the data is uneven. The supply curves for sink enhancement are particularly questionable. The degree of confidence concerning current and predicted future levels of carbon sequestration varies enormously across regions of the globe. Not surprisingly, information is most reliable (albeit still poor) for Annex 1 countries. Comparatively little effort has been made to collect such data elsewhere.

As placeholders, we have adopted the values shown in Table 1. To provide some perspective, in order for the US to reduce industrial carbon emissions by 7% below 1990 levels in 2010, it would have to reduce emissions by approximately 550 million tons below its reference trajectory. Sink enhancement would satisfy 9 percent of this obligation. For purposes of the present analysis, we assume that this sink enhancement is costless.

Table 1 Sink Enhancement (million metric tons of carbon annually)

USA	50
OECDE	17
Japan	0
CANZ	50
EEFSU	34

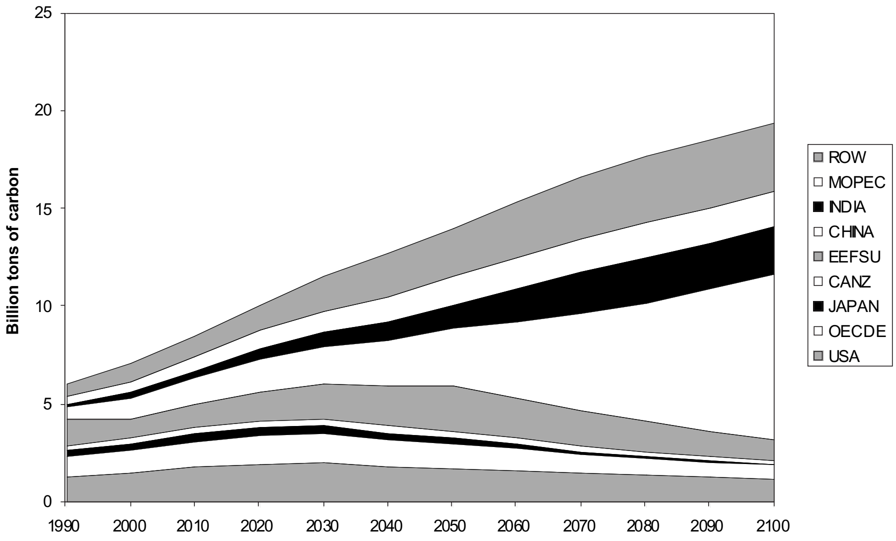
CO_2 is by far the most important of the greenhouse gases. In addition, the Protocol includes five other trace gases (methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride). Given the scarcity of reliable emissions and cost data, the treatment of the non-CO_2 greenhouse gases is also problematic. For purposes of the present analysis, we assume that each gas is reduced proportionately. With this proportionality assumption, the inclusion of the non-CO_2 greenhouse gases does not affect the requirements for CO_2 reductions.

As with our treatment of sinks, we do not include the costs of abating the non-CO_2 greenhouse gases in our estimates of the costs of complying with the Protocol. Clearly, an important next step would be to develop supply curves for the cost of abating non-CO_2 greenhouse gases and for sink enhancement. Neither of these costs is included in the present version of MERGE.

4. "Kyoto Forever"

We begin with an examination of a "Kyoto Forever" scenario. This is a case in which the Kyoto constraints on Annex 1 countries are maintained throughout the 21st century. With regard to non-Annex 1 emissions, we assume they will continue to be bounded by their business-as-usual baseline (Figure 2.1). The latter constraint is imposed in order to prevent carbon leakage. Later on, we will explore the impact of relaxing this constraint.

Figure 2.1 Regional Carbon Emissions--reference case



Numerous studies have shown that global mitigation costs can be reduced substantially by allowing emission reductions to take place wherever it is cheapest to do so - regardless of geographical location.The Kyoto Protocol includes several provisions allowing for a limited amount of “where” flexibility. These include emission trading and joint implementation among Annex 1 countries. They also include provisions for a Clean Development Mechanism (CDM) that is intended to facilitate joint implementation between Annex 1 and non-Annex 1 countries.

As with the definition of sinks, the Protocol leaves many critical details unresolved. For example, it remains unclear whether there will be limits on the extent to which a country can rely upon the purchase of emission rights to satisfy its obligations. The Protocol states that “the Conference of the Parties shall define the relevant principles, modalities, rules and guidelines ...” Similar ambiguity surrounds the Clean Development Mechanism. Again, the elaboration of “modalities and procedures” is left to a future meeting of the Conference of the Parties.

In this section, we explore three scenarios: 1) no trading, 2) Annex 1 trading plus CDM, and 3) full global trading. These three options are representative of alternative implementations of the Kyoto Protocol. Each has its own advocates and opponents, but we do not consider them equally likely. In our opinion, there is little likelihood of enticing all major countries to participate in a global market in emission rights during the initial commitment period (2008-2012). The full global trading scenario places an upper bound on the CDM’s potential to reduce GDP losses. In calculating the potential size of the contribution from a CDM, we therefore calculate this upper bound on the export of emission rights from non-Annex 1 regions. Because of the difficulties in implementation of the CDM, however, we assume that only 15% of the potential would be available for purchase through this mechanism. This is a highly subjective estimate. Given the complexities of the CDM, however, we are not inclined to assign a higher value

Figure 4.1 reports the incremental value of carbon emission rights to the US in 2010 and 2020. We focus first on 2010. In the most constrained scenario, the US must satisfy its emission reduction requirements within its own geographical boundaries. In this case, the value of emission rights approaches $240 per ton. With Annex 1 trading plus CDM, the value drops to slightly less than $100 per ton. As might be expected, the value of emission rights is lowest with full global trading. Here, it falls below $70 per ton.

Figure 4.1 Incremental Value of Carbon Emission Rights in US Under Kyoto Forever

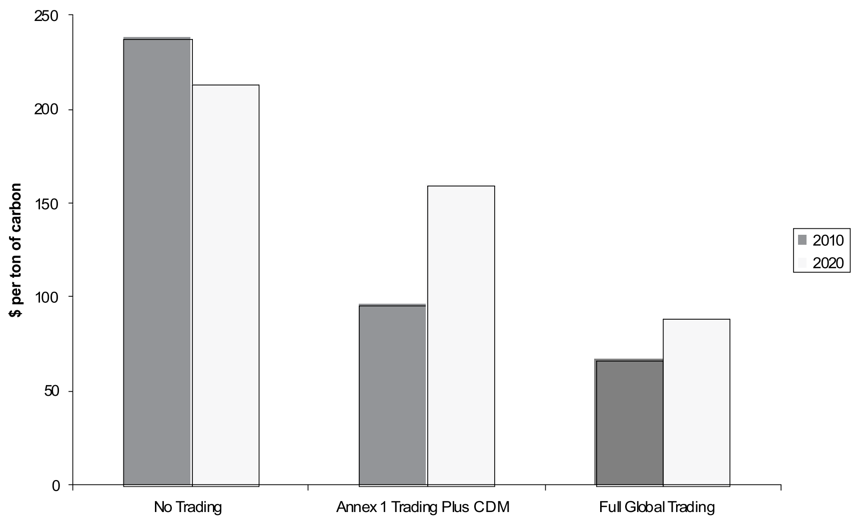
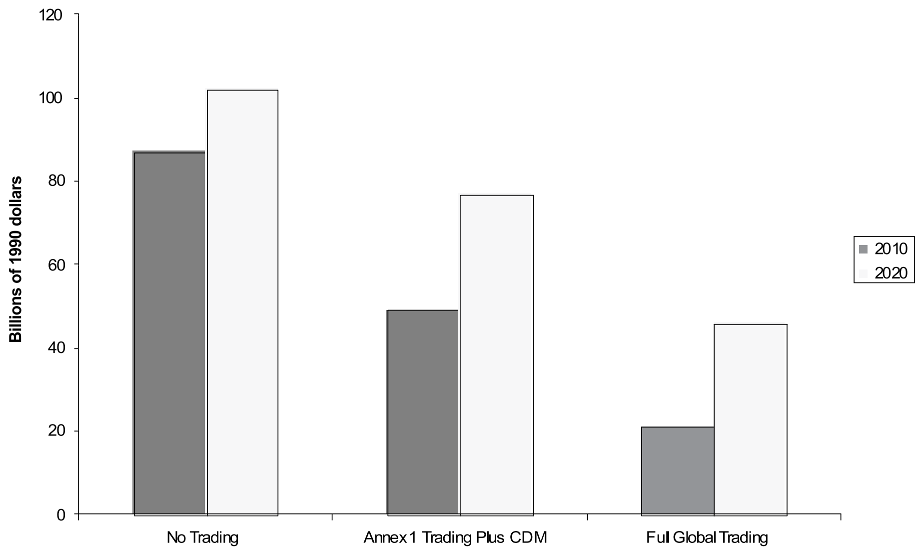


Figure 4.2 Annual US GDP Losses Under Kyoto Forever ($billions)



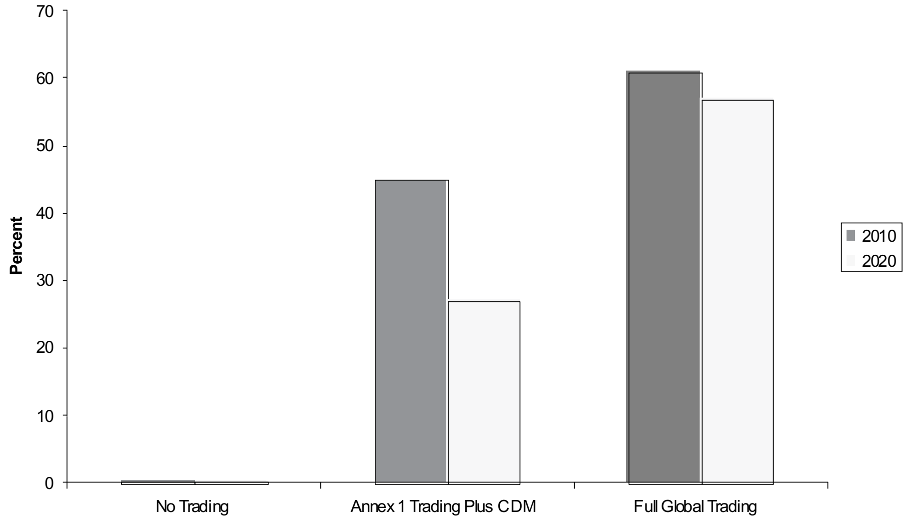
For the two scenarios in which trading is permitted, the value of emission rights increases in 2020. This is because EEFSU's projected emissions lie below its negotiated constraint for 2010. It has been allocated more emission rights than it needs to satisfy its internal obligations. By 2020, however, EEFSU's economic growth is expected to be such that it no longer enjoys an excess of emission rights. As a result, there is more competition for emission rights in the international marketplace, and there is an increase in their price.

Another way to view the costs of abatement is to show the GDP losses. Figure 4.2 contains those for the US. Losses are highest in the absence of trade. Here, they exceed $80 billion dollars in 2010. This is approximately one percent of US GDP. To the extent that trade is introduced, losses decline. In the most optimistic scenario (full global trade), losses are approximately $20 billion or one-quarter of one percent of GDP in 2010.

Of the three scenarios, "Annex 1 trading plus the CDM" is most consistent with the Protocol as it currently stands. However, the US Senate has stated that the US should not be a signatory to the Protocol if it does not mandate specific commitments for developing countries. If this were to result in full global emission trading, we move in the direction of the right-most bar of Figure 4.2.

There is, however, strong sentiment among many parties to the Framework Convention to substantially limit the extent to which Annex 1 countries can meet their obligation through the purchase of emission rights. Several influential developing countries have expressed strong opposition to the concept altogether. Figure 4.2 shows the costs of the no trading scenario. We now turn to the case where trading is permitted, but with limitations on the purchase of emission rights.

Figure 5.1 Percent of US Obligation Satisfied through the Purchage of Emission Rights



5. Limits on the purchase of carbon emission rights

Figure 5.1 shows our estimates of the percentage of the US emission reduction obligation that would be satisfied through the purchase of emission rights under base case assumptions. With full global trading (the least-cost of our three scenarios), trading is used to satisfy more than 50% of the US obligation. But suppose that limits are placed on the purchase of emission rights? For example, suppose that international negotiators agree that Annex 1 buyers can satisfy only one-third of their obligation through this means. What would be the impact on GDP losses?

Figure 5.2 compares three cases. All assume full global participation in an international market for carbon emission rights, but only the first assumes no limits on the amount a country can buy. The second and third case are based upon the one-third limitation. We further make the distinction between a buyers' market and a sellers' market. With the former, sellers of emission rights are price takers. Buyers exert sufficient market power to hold the international price to the marginal cost of abatement in the selling countries. However, since a country is only able to satisfy one-third of its obligation through the purchase of emission rights, it must eventually rely on its own domestic marginal abatement capabilities to meet its obligations. Hence, there is an important distinction between the international price and the domestic price. Conversely, with a sellers' market, buyers face but one price. Here, the rents accrue to the sellers.

Figure 5.3 shows the GDP losses associated with the three scenarios. Note that losses in 2010 are two and one-half to three times higher with the constraint on the purchase of carbon emission rights. That is, the benefits from "where" flexibility are greatly diminished. The message is clear. Developing country participation in the market for carbon emission rights is a necessary, but by no means a sufficient condition for reaping the full benefits of "where" flexibility. To achieve a cost-effective solution, buyers must also be unconstrained in the manner in which they fulfill their obligation.

Figure 5.2 Incremental Value of Carbon Emission Rights with or without Limits on the Purchase of Emission Rights--Kyoto Forever

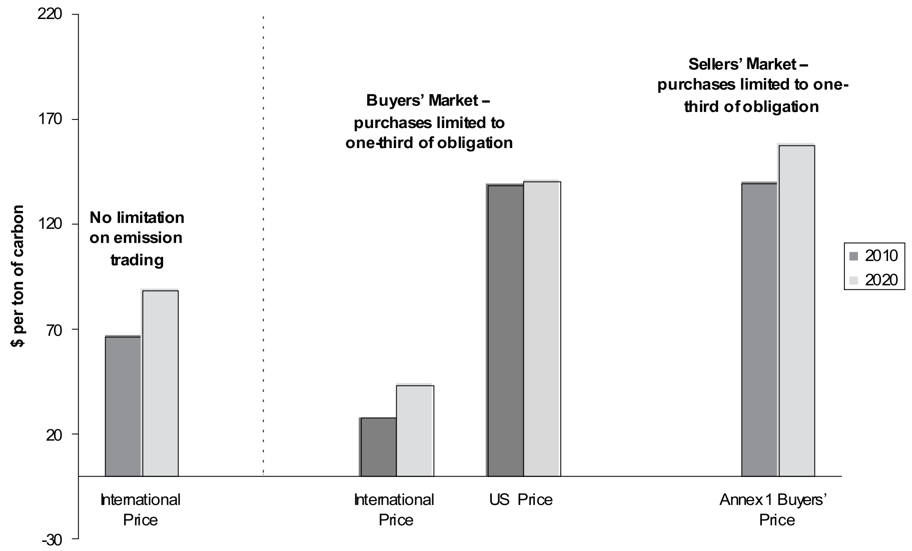
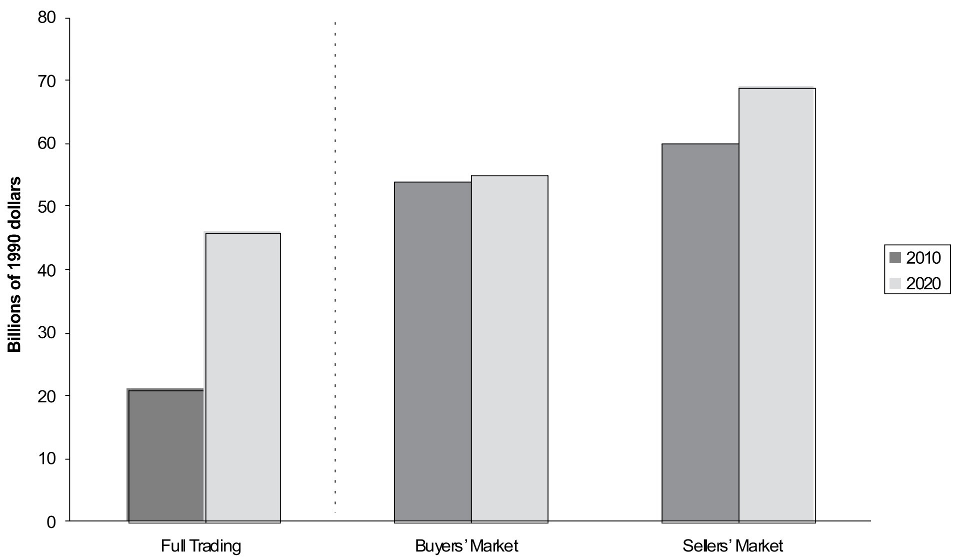


Figure 5.3 Annual US GDP losses with full trading-Annex 1 May Satisfy only one-third of Obligation Through the Purchase of Emission Rights--Kyoto Forever



Also note that the distribution of the rents makes a difference to GDP losses. US losses are 25% higher in 2020 when market power resides with the sellers. The analysis provides an additional message for Annex 1 buyers. If at a given point in time, low-cost sellers are concentrated among a few countries (e.g., EEFSU), they may have considerable potential for extracting monopoly rents.

6. The issue of carbon leakage

The Kyoto Protocol refers specifically to the period centered about 2010. During this period, the onus for emission reductions falls on Annex 1. No specific obligations are imposed on countries outside Annex 1, and there is the possibility of "leakage". That is, the reductions in Annex 1 might be partially offset by increased emissions from China, India, Brazil and other countries that do *not* belong to Annex 1.

In this section, we examine the potential for leakage through international fuel markets and through the migration of energy-intensive industries. We therefore drop the assumption that non-Annex I countries are constrained to their reference case emissions. Two variants on the reference scenario are reported. In the first, the only trade impact of the Protocol consists of limiting the ability of the Annex 1 countries to import oil and gas. There is a lower international price of these goods, and there is a modest increase in price-induced demands by non-Annex 1 countries. However, there is no international trade in carbon emission rights, and there is no international migration of production within the energy-intensive sectors (EIS).

The second alternative is the same as the first, except that we now permit EIS trade. For a description of how the model has been modified to account for international trade in the energy-intensive sectors, see Appendix A. Figure 6.1 summarizes the overall results. According to this figure, neither of the two trade alternatives leads to a dramatic increase in carbon emissions outside Annex 1. Apparently there is an international leakage problem, but it appears to be of manageable dimensions.

Figure 6.2 suggests a somewhat different interpretation. Here we report the EIS trade scenario, and we compare the impact upon production-consumption ratios in each region. Under the reference case, these ratios are close to unity (the horizontal line) in most regions. The bars in Figure 6.2 show that the Protocol could lead to serious competitive problems for EIS producers in the USA, Japan and OECD Europe. The Protocol would lead to significant reductions in their output and

Figure 6.1 Carbon Emissions Outside Annex 1-- Alternative Leakge Scenarios

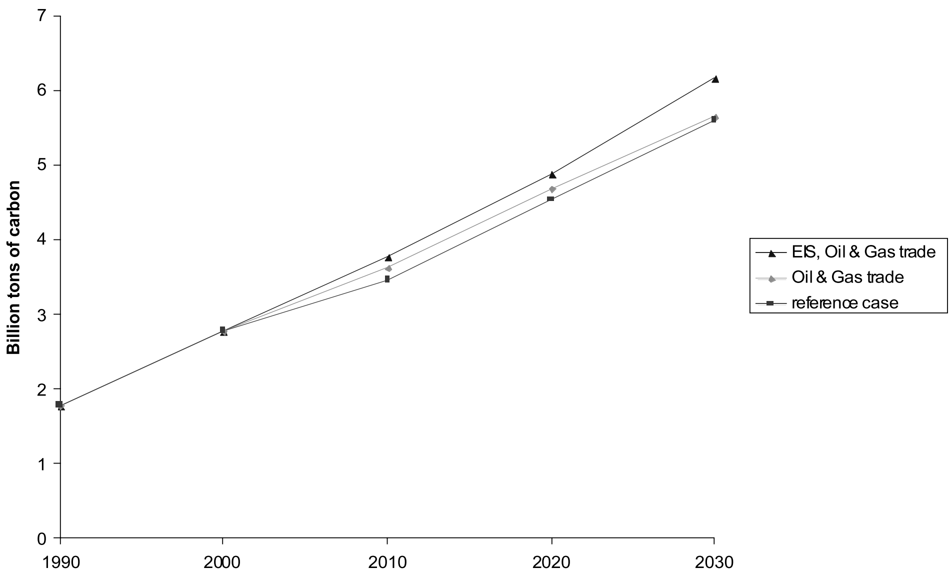
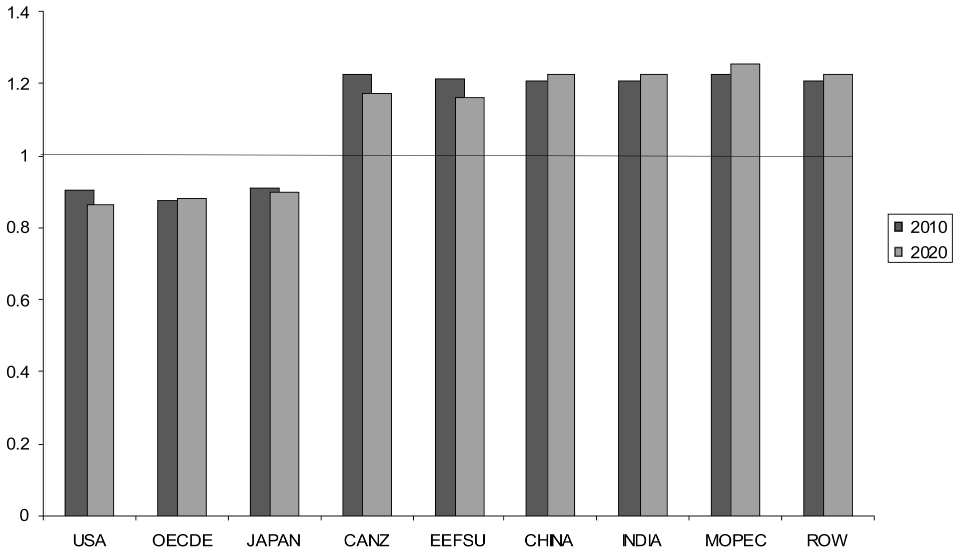


Figure 6.2 Ratios of Domestic EIS Supplies to Demands -- Kyoto Leakage



employment, and there would be offsetting increases in regions with low energy costs. One can easily anticipate calls for protection against "unfair competition". In its present form, the Protocol could lead to acrimonious conflicts between those who advocate free international trade and those who advocate a low-carbon global environment.

7. Evaluating Kyoto in the context of the longer-term goal

The objective of the Framework Convention is "the stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system." The drafters of the Protocol focused exclusively on the initial steps to be taken by Annex 1 countries. Little attention was paid to the ultimate goal. We now examine the Protocol in the context of a long-term stabilization objective.

From Figure 2.1 it is clear that the "Kyoto Forever" scenario will fail to stabilize global emissions and concentrations. A particular concentration target can be achieved through a variety of emission pathways. In this section, we explore three pathways for stabilizing concentrations at 550ppmv (twice preindustrial levels) by 2100. We stress, however, that the issue of what constitutes "dangerous interference" has yet to be determined. Indeed, it is likely to be the subject of intense scientific and political debate for decades to come. Hence, our choice of a target is meant to be purely illustrative.

Our three pathways are intended to illustrate the benefits of "when" flexibility. They are titled: 1) "Kyoto followed by arbitrary reductions"; 2) "Kyoto followed by least-cost"; and, 3) "least-cost". As their names imply, the first two are designed to be consistent with the Protocol during the first commitment period. The third assumes a clean slate in the choice of emissions pathway throughout the 21st century.

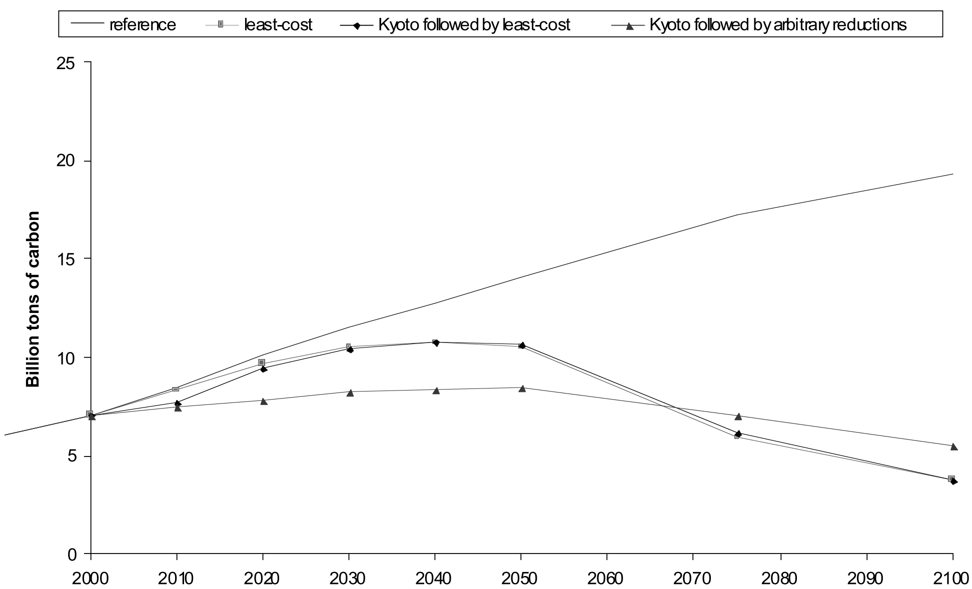
For the first scenario, we assume that Annex 1 countries reduce emissions through 2030 at the same rate as the OECD during the first decade of the 21st century (2% per year). During this period, non Annex-1 countries are permitted to emit up to their reference case levels. By 2020, emissions in the developing nations are larger than those in Annex I. We then choose a pathway to stabilization which represents a relatively smooth transition to the target. As for the post-2030 burden-sharing scheme, we assume that between 2030 and 2050 all regions move to equal per capita emission rights (based on their 1990 population). Equal per capita emission rights have been proposed as one approach to international fairness, but there are others that might also serve to separate the issue of equity from that of economic efficiency.

With "Kyoto followed by least-cost", the Protocol is adopted for the initial commitment period. Thereafter, the most cost-effective pathway is followed for stabilizing concentrations at 550ppmv. With "least-cost", the most cost-effective pathway for stabilizing concentrations at 550ppmv is followed from the outset. The latter two scenarios adopt the same proportionate burden-sharing scheme as the first.

All three scenarios assume Annex 1 trading plus the CDM. However, they differ as to the timing of developing country involvement in the international market for carbon emission rights. By definition, least-cost assumes that emission reductions will be made where it is cheapest to do so, regardless of the geographical location. Hence, in the least-cost scenario, we assume global emission trading from the outset. In the case of "Kyoto followed by least-cost", we assume that global emission trading is delayed until after the first commitment period. With "Kyoto followed by arbitrary reductions", global emission trading does not begin until 2030, the year that developing countries agree to lower their emissions below business-as-usual.

Global carbon emissions. Figure 7.1 shows global carbon emissions for the reference case and the three stabilization scenarios. Following a least-cost strategy from the outset results in an emissions pathway that tracks the reference path through 2010 and then departs at an increasing rate thereafter.

Figure 7.1 Global Carbon Emissions - Reference case and three alternative emission pathways for stabilizing Concentrations at 550 ppmv



There are several reasons why a gradual transition to a less carbon-intensive economy is preferable to one involving sharper near-term reductions.

Concentrations at a given point in time are determined more by cumulative, rather than year-by-year, emissions. Indeed, a concentration target defines an approximate carbon budget, i.e., an amount of carbon that can be emitted between now and the date at which the target is to be reached. At issue is the optimal allocation of the budget. Reasons for relying more heavily on the budget in the early years include: 1) providing more time for the economic turnover of existing plant and equipment, 2) providing more time to develop low-cost substitutes to carbon-intensive technologies, 3) providing more time to remove carbon from the atmosphere via the carbon cycle, and 4) the effect of time discounting on mitigation costs.

We next turn to the two scenarios where we adopt the Protocol for the first commitment period. Notice that the two emission pathways behave quite differently post-2010. “Kyoto followed by least-cost” follows the least-cost pathway once the Protocol’s constraints are relaxed. “Kyoto followed by arbitrary reductions”, on the other hand, bears no resemblance to the least-cost pathway. What is striking about Figure 7.1 is that with a 550ppmv target, the Protocol is inconsistent with the most cost-effective mitigation pathway, i.e. “least-cost”. Indeed, it appears that the ultimate target would have to be considerably lower than 550ppmv for the Protocol to be justified in terms of cost-effectiveness.

Near-term losses. It is instructive to look at the incremental value of emission rights for the three stabilization scenarios (Figure 7.2). With the least-cost path, the value is relatively low in the early years ($11 per ton of carbon in 2010), and it rises gradually over time. With “Kyoto followed by least-cost”, the value is $130 per ton in 2010 and then tracks the least-cost path thereafter. In the case labeled “Kyoto followed by arbitrary reductions”, the incremental value of emission rights starts at about $160 per ton and it remains high.

Figure 7.2 Increment ot Value of Carbon Emission Right under three alternative emission pathways for stabilizing Concentrations at 550 ppmv -- Global Trading

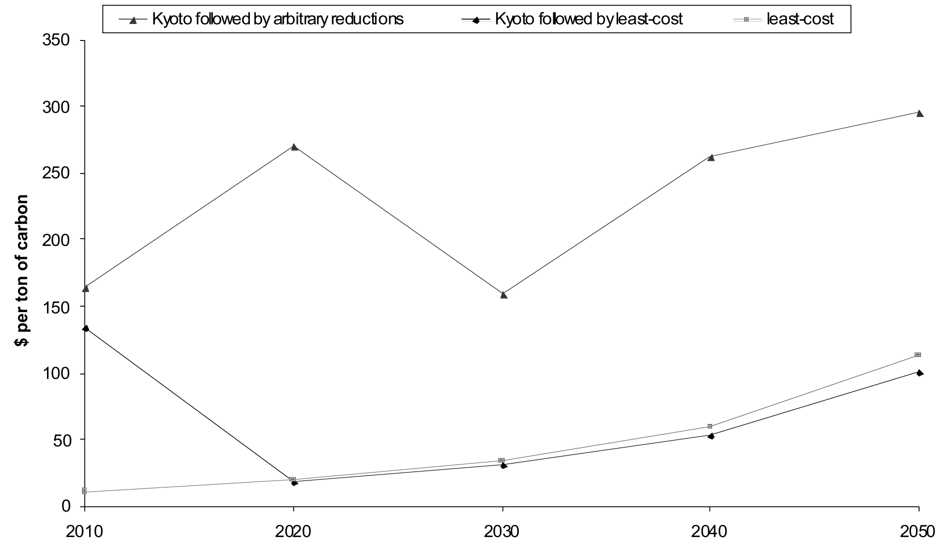


Figure 7.3 US GDP Losses under three alternative 550 ppmvStabilization Scenarios

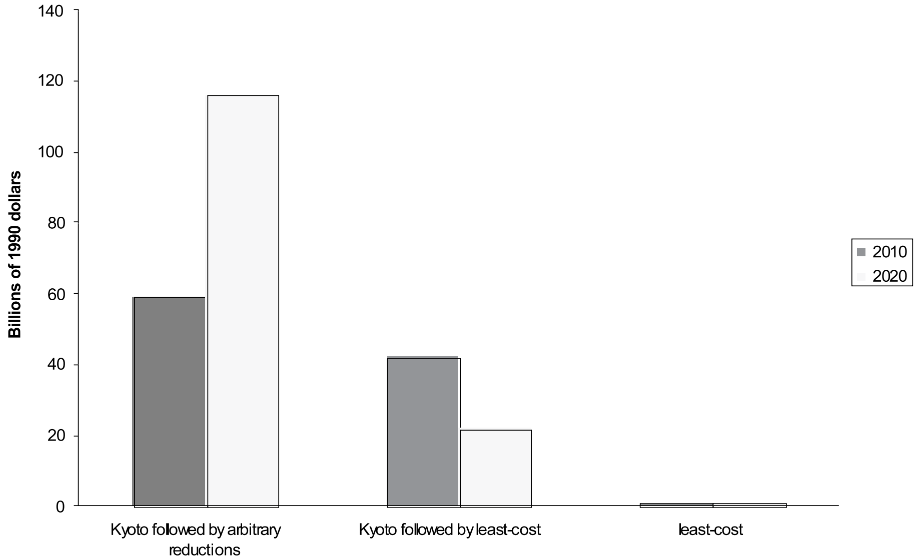


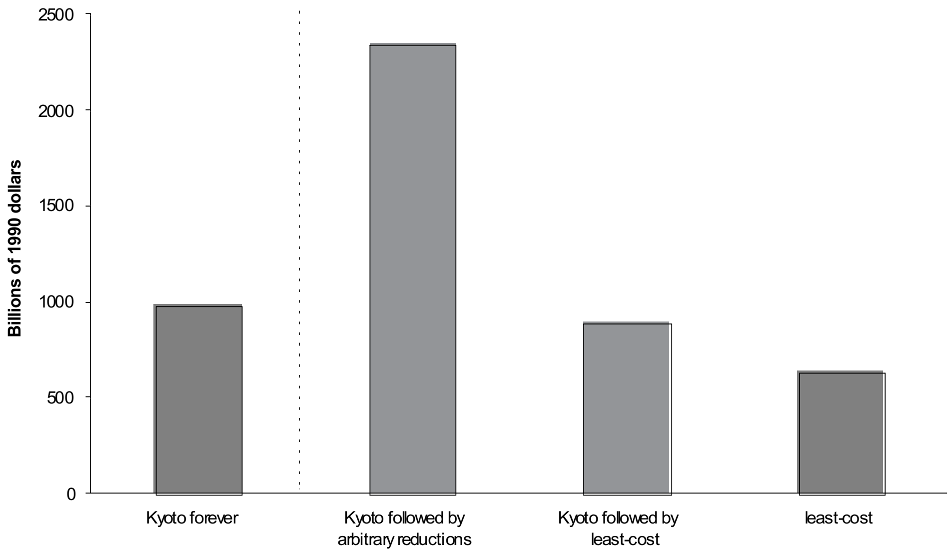
Figure 7.3 shows US GDP losses in 2010 and 2020 under the three stabilization scenarios. Notice that GDP losses in 2010 differ for the two scenarios involving the initial adoption of the Protocol. Because of the long-lived nature of energy investments, investors are concerned both with what happens in the initial commitment period and what happens thereafter. In the case of the more rapid transition away from the baseline ("Kyoto followed by arbitrary reductions"), investors will be forced to invest more heavily in high–cost substitutes in the early years. With "Kyoto followed by least-cost", they will have more flexibility.

It is striking by how much GDP losses can be lowered under the "least-cost" scenario. This strategy involves a more gradual transition away from the baseline in the early years. It relieves much of the pressure for premature retirement of existing plant and equipment and for dependence on high-cost substitutes (both on the supply- and demand-sides of the energy sector). Relative to the reference case, the US also receives some benefits as an oil importer. Recall that a carbon constraint decreases the overall demand for oil and lowers its price on the international market.

Global losses. Finally, it is instructive to examine losses from a global perspective (Figure 7.4). For purposes of the present comparison, we focus on the present value of consumption losses over the 21st century discounted to 1990 at 5 percent. The relative magnitude of the cumulative losses for the three stabilization scenarios comes as no surprise given the previous discussion. "Kyoto followed by arbitrary reductions" is by far the most expensive of the three paths. "Kyoto followed by least-cost" is a considerable
improvement, but is still 40% more expensive than embarking on the most cost-effective mitigation pathway from the outset.

What is surprising is that "Kyoto Forever" turns out to be more expensive than "Kyoto followed by least cost" or "least cost". "Kyoto Forever" results in sharper global emission reductions during the early decades of the 21st century. It does not, however, succeed in stabilizing emissions, much less concentrations. By contrast, the other scenarios all lead to stabilization at 550ppmv. In other words, "Kyoto Forever" ends up costing more, and it buys less long-term protection.

Figure 7.4 Global Consumption Losses through 2100 discounted to 1990 at 5% -- Kyoto Forever vs. Three Scenarios for Stabilizing Concentrations at 550 ppmv



8. Further comments

Some suggest that models such as MERGE tend to *overestimate* the costs of mitigation. They argue that, when prospects for technical progress are incorporated, the costs of a carbon constraint, even a sharp near-term constraint, will be minimal. We, too, are optimistic about the outlook for technical innovation. Indeed, such innovation is embedded both in our reference case and in the policy scenarios. The disagreement is over the rate at which such progress will occur. We do not believe that economically competitive substitutes will become available at such a rate as to trivialize the costs of a Kyoto-like Protocol.

A more valid concern may be that we are *underestimating* the costs of a carbon constraint. There are several reasons why this may be the case. To begin with, optimization models assume that decision makers have perfect foresight. That is, they assume that investors are fully informed about the nature of future constraints, and act accordingly. Given the present state of uncertainty, this is highly unlikely. Models such as MERGE also tend to ignore short-term macro shocks. For example, the higher energy prices brought about by a carbon constraint are likely to be inflationary. If this leads to higher interest rates, investment may be dampened. The result would be a slowdown in economic growth.

In addition, we assume that policies will be efficient. That is, market mechanisms will be chosen over “command and control” approaches to accomplishing environmental objectives. Whereas, in recent years, there has been an increasing trend toward market mechanisms, the approach to be taken with climate policy is by no means assured. Moreover, even if such a commitment were made, we have no assurances that the requisite international institutions will be available when needed.

Although it is easy to quibble over the numbers, the real value of analyses lies more in insights than in numerical values. And, indeed we believe that the current exercise has yielded several insights that may be of value to those charged with interpreting the current proposal. Here, we summarize what we have learned:

- First, it is extremely unlikely that a "Kyoto Forever" scenario will stabilize emissions — much less concentrations. Non-Annex 1 emissions are quickly overtaking those of the OECD and the economies in transition. Hence, meeting the stabilization goal of the Framework Convention will eventually require the participation of developing countries.

- International cooperation through trade in emission rights is essential if we are to reduce mitigation costs. The magnitude of the savings will depend on several factors. These include the number of countries participating in the trading market, the shape of each country's marginal abatement cost curve, and the extent to which buyers can satisfy their obligation through the purchase of emission rights.

- With regard to the latter, limitations on the purchase of emission rights may be especially costly. In the example explored here, limiting purchases to one-third of a country's obligation increased GDP losses by a factor of at least two and one-half in the year 2010. If proponents of such limitations are successful, they may seriously reduce the benefits from "where" flexibility.

- The issue of monopoly power in markets for emission rights may turn out to be important. This is most likely to occur if trading is limited to Annex 1 and the majority of inexpensive emission rights are concentrated in a small number of countries. If these countries were successful in organizing a sellers' cartel, they might be able to extract sizable rents.

- The near-term costs of the Protocol will depend on expectations regarding the future. Energy investments are typically long-lived. Today's investment decisions are not only influenced by what happens during the next decade, but also by what happens thereafter. Hence, analyses which focus solely on 2010 may be underestimating the costs of Kyoto.

- Finally, and perhaps most importantly, unless the concentration target for CO_2 is well below 550ppmv, the Protocol appears to be inconsistent with a cost-effective long-term strategy for stabilizing CO_2 concentrations. Rather than requiring sharp near-term reductions, it appears that a more sensible strategy would be to make the transition at the point of capital stock turnover. This would eliminate the need for premature retirement of existing plant and equipment and would provide the time that is needed to develop low-cost, low-carbon substitutes.

Appendix A. Modeling international trade in the energy-intensive sectors

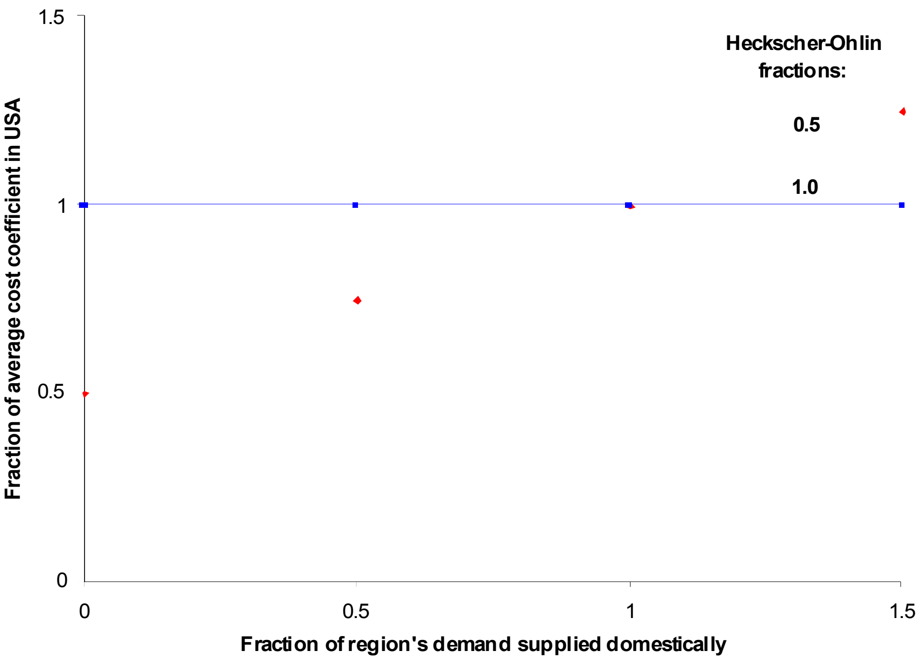
MERGE 3.0 has recently been modified to include the possibility of trade in EIS (energy-intensive sectors). EIS is an aggregate including ferrous and non-ferrous metals, chemicals, nonmetallic minerals, paper, pulp and print. This aggregate does not include the energy-intensive industry of petroleum refining. The model may be run either with or without EIS trade.

The new feature is introduced in a way that preserves the basic simplifying characteristics of the ETA-MACRO submodel. That is, energy, capital and labor are substitutes that enter into an aggregate production function. They produce a numeraire good which may be used for consumption, investment and interindustry payments for energy costs.

It is assumed that trade will continue to represent a relatively small amount of each region's total internal demand for EIS. The GTAP (General Trade Analysis Program, 1992) data base is employed to estimate each region's EIS demands. In all other respects, the model is the same as MERGE 3.0.

For projecting the impact of the Kyoto protocol, each region is taken to be self-sufficient at base year energy prices. Changes in the location of production are attributed primarily to changes in the cost of energy. At base year prices in the USA, 85% of the cost of EIS consisted of non-energy inputs (labor, shipping, capital, iron ore, etc.), and 15% of the cost consisted of energy inputs (half electric and half non-electric). Under these conditions, a doubling of energy prices would imply only a 15% increase in the cost of EIS. This is why it is assumed that the demand for EIS is inelastic with respect to the price of energy. For projecting future demands, the income elasticity is taken to be 0.5.

Figure A.1 EIS Supply Curves -- Marginal Cost of Non-Energy Inputs to EIS



For modeling purposes, we have supposed that the marginal supplies of EIS in all regions are determined by the same international technology that prevails in the USA. Each region has the same energy-EIS production ratio. For non-energy inputs, each supply curve is linear. Its positive slope serves the same purpose as an Armington elasticity describing substitution between foreign and domestic goods. This is the way in which we avoid penny-switching as a characteristic solution mode.

The slope of the non-energy supply curve is described as a Heckscher-Ohlin fraction. If this fraction is unity, EIS is viewed as a perfectly homogeneous commodity. Small changes in energy costs will then lead to large changes in the international location of production. If this fraction is less than unity, the supply function is less elastic, and the changes in location will be less dramatic. (See Figure A.1.)

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Discussion

ZhongXiang Zhang[1]

1. Introduction

Prof. Manne and Dr. Richels have made many valuable contributions in modelling the economic costs of mitigating greenhouse gas emissions, and this paper (Manne and Richels, 1999) is one of these contributions. It first examines a "Kyoto Forever" scenario in which the Kyoto constraints on Annex I countries are maintained throughout the 21st century. Next, the paper calculates what the economic implications of limiting the purchase of carbon emission rights are. It shows that in case Annex I buyers are allowed to meet only one-third of their obligation through trading of carbon rights, the annual GDP losses in 2010 in the US are two and one-half to three times the case in which full global trading is assumed. Then, the paper examines the potential of carbon leakage through international fuel markets and through the migration of energy-intensive industries from Annex I countries to non-Annex I countries. Finally, the paper evaluates the Kyoto Protocol in the context of the longer-term goal of the Framework Convention.

Reading this very interesting paper suggests four issues or questions to me. The first issue is about distributional realities of the international climate change negotiations. The second issue is about correspondence between geopolitical regional aggregates in MERGE and Annex B countries. The third issue is about implications of the autonomous energy efficiency improvement rates assumed in MERGE on the income elasticity of energy consumption. And fourth issue is about market power in an international greenhouse gas emissions trading scheme.

2. Modelling distributional realities of the international climate change negotiations

First of all, I agree with the broad conclusion of the paper (Manne and Richels, 1999) that a long-term climate strategy should be designed to facilitate achieving the Framework Convention's ultimate objective of stabilizing greenhouse gas concentrations in the atmosphere at the lowest possible abatement and transaction costs. One might wonder why keeping down the costs of compliance matters. It is often heard that the high cost of compliance is just what polluters should suffer so that polluters are taught a lesson. From a political perspective, the more costly the compliance, the less likely it is that those who bear the high costs will be willing to commit to stringent emissions targets in the future. Given the fact that no emissions targets beyond 2012 have been set, increasing the overall costs of compliance thus makes it even more difficult to set stringent emissions targets for some Annex B countries, if not all, for the subsequent commitment periods

[1] The views expressed here are those of the author. The author bears sole responsibility for any errors and omissions that may remain.

beyond 2012 in order to achieve the Climate Convention's ultimate objective.[2] It is the lack of the targets of post-2012 that is seen as a threat to the pace of technical innovation needed to make more stringent future emissions targets affordable. The lack of such long-term commitments also restricts the choice of the compliance mechanisms and tools and creates some divergence of views in assigning liability in an international greenhouse gas emissions trading scheme (Zhang, 1999).

There are many paths to a longer-term stabilization concentration target. The path of offering great *when flexibility*, namely, the path that would begin gradually and leave the more drastic cuts in emissions in later periods, receives increased attention in the literature on economic and environmental implications of reaching a specific atmospheric concentration target (see, for example, Richels and Edmonds, 1995; Wigley, Richels and Edmonds, 1996; Manne and Richels, 1998; Yang and Jacoby, 1999). However, as Jacoby *et al*. point out, although these studies are instructive, their emphasis on global cost-effectiveness tends to underplay important distributional realities of the international climate change negotiations, and how they might be worked out over time. With the successful conclusion of the Montreal Protocol that sets percentage reduction targets for CFC emissions, it is not surprising that calls for limiting greenhouse gas emissions have focused on a similar strategy since the June 1988 Toronto Conference, which has recommended a 20% reduction by 2005 and a 50% reduction by 2025 in global CO_2 emissions relative to the 1988 levels (Zhang, 1997). Although it is the accumulated concentration of greenhouse gases in the atmosphere, not the annual emissions, that influences climate change, as at Kyoto, negotiations will continue to be about emissions levels in the near term, not about emission trajectories over several decades. In my review, the main reason is that, in the absence of dramatic and forceful changes from the business-as-usual trends, negotiators, particularly from developing countries, believe that private firms and consumers alike will not change their production and consumption patterns and will not take seriously the need to reduce greenhouse gas emissions.[3] The question then arises: how can one connect negotiations about near-term emissions reductions with a long-term stabilization objective? With the belief that in any fair regime substantial differences in per capita income will translate into substantial differences in emissions control obligations, Jacoby *et al.* (1999), for example, propose that accession of developing countries and burden sharing should be based on ability of pay. Although it is not my intention to recommend the approach as the sole determinant of incremental emissions control obligations, it might be worthwhile pursuing this kind of thought in assuming national commitments in MERGE towards the lowest cost path to the longer-term stabilization concentration target. This would enrich the policy relevance of this study to the ongoing climate change negotiations.

3. Correspondence between geopolitical regional aggregates in MERGE and Annex B countries

It is unclear whether the correspondence between geopolitical regional aggregates in MERGE and Annex B countries is exact. It seems to me that Annex B countries modelled in MERGE constitute all the OECD countries and Eastern Europe and the Former Soviet Union (EEFSU). As such, they

[2] Stavins (1998) points out that the adoption of the US SO_2 allowance trading program is largely attributed to strong support from the Environmental Defense Fund that was able to make powerful arguments for tradeable permits on the grounds that the use of a cost-effective instrument would make it politically feasible to achieve greater reductions in SO_2 emissions than would otherwise be possible. I believe that the arguments also hold for setting the post-2012 greenhouse gas emissions targets.

[3] Negotiating the appropriate size and shape of percentage emissions reductions would be not that easy. On the one hand, whatever a target is agreed on should be large enough to signal a decisive change from the business-as-usual trends. On the other hand, it should not be so large that governments would dismiss it as unrealistic.

include Turkey as an OECD country and the Central Asian Republics as part of the EEFSU. But Turkey and the Central Asian Republics are not Annex B parties to the Kyoto Protocol. Although such a distinction does not have a fundamental impact on the results of the paper, from a climate change negotiator perspective it would be very useful to separate these non-Annex B countries from the Annex B parties aggregates in MERGE.

4. Implications of the choice of autonomous energy efficiency improvement rates on the income elasticity of energy consumption

One of the possibilities of decoupling energy consumption and CO_2 emissions from GDP growth in integrated assessment models, such as MERGE, is represented by the autonomous energy efficiency improvement (AEEI) parameter. The parameter accounts for all but energy price-induced energy conservation. Energy conservation of this type is available at zero or negative net cost, and is taking place regardless of the development of energy prices. It may be brought out by regulations. It may also occur as a result of "good housekeeping" or of a shift in the economic structure away from energy-intensive heavy manufacturing towards services. In the case where the parameter lowers the rate of growth of CO_2 emissions over time and therefore decreases the amount by which CO_2 emissions need to be constrained, the economic impacts of a given carbon constraint will also be lower.

In MERGE, the AEEI value is taken to be 40% of the rate of GDP growth. This implies that energy consumption grows at 60% of the rate of GDP growth. If price-induced energy conservation is taken into account, then energy consumption grows at a rate even lower than 60% of the rate of GDP growth. This leads to an income elasticity of energy consumption of less than 0.6. Comparing the implicitly assumed elasticity with what has been derived from the World Bank (1996), as given in Table 1, we can see that the assumed elasticities are backed from conventional wisdom for the OECD countries and China, but are much lower than what were observed for low-income economie and upper-middle-income economies over the period 1980-1994, which include four geopolitical regions modelled in MERGE, such as, Eastern Europe and the Former Soviet Union (EEFSU), India, Mexico and OPEC (MOPEC), and the rest of world (ROW). Given the implications of the assumed AEEI values, and the fact that the AEEI values have a crucial influence on the estimates of economic costs of a given carbon constraint, what AEEI values are considered reasonable for the countries and regions considered in MERGE are worthy of further investigation.

Table 1 Growth Rates of GDP and Energy Consumption, and the Income Elasticity of Energy Consumption among Different Economies, 1980-1994

	Annual growth of GDP (%)	Annual growth of energy consumption (%)	Income elasticity of energy consumption
Low-income economies *	2.5	3.3	1.32
China	11.0	4.5	0.41
India	5.2	6.3	1.21
Upper-middle-income economies	5.2	3.9	1.56
High-income economies	2.8	1.1	0.39

* Excluding China and India.
Source: Calculated based on data from the World Bank (1996).

5. The issue of market power in an international greenhouse gas emissions trading scheme

The paper investigates the impact of market power. It indicates that the international price of permits depends on who resides in market power. With a buyer's market, buyers exert sufficient market power to hold the international price to the marginal cost of abatement in the selling countries. As such, the international price of permits is much lower than those in the absence of market power. Conversely, when market power resides with the sellers, the international price of permits is much higher than those in the absence of market power. This would lead to high economic losses for the buying countries, such as the US. This raises an important question: is market power a real issue in an international greenhouse gas emissions trading?

In my view, monopoly power in permits market eventually depends on how an international greenhouse gas emissions trading scheme will take shape. Emissions trading modelled in MERGE operates as if governments retain the sole right to trade. As such, emissions trading takes place on a government-to-government basis. Under this trading model, there are few players on the market. So market power could likely be an issue, particularly when the majority of inexpensive emissions permits are concentrated among a few Eastern Europe and the Former Soviet Union countries.

If Annex B governments elect to allocate the assigned amounts to individual sub-national entities, and authorize them to trade on the international emissions permits market, any effectuated trades take place on a source- to-source basis (See Zhang, 1998, 1999) for a detailed discussion on inter-governmental emissions trading and inter-source trading). Incorporating sub-national entities into an international emissions trading scheme would potentially increase the total amount of transactions in the international scheme. Increasing the number of trades would help to improve market liquidity and reduce the potential for abuse of market power. Hargrave (1998) shows that if an upstream trading system, which targets fossil fuel producers and importers as regulated entities,[4] would be implemented in the US, the total number of allowance holders would be restricted to about 1900, as shown in Table 2. Even with such a relatively small number of regulated sources, market power would not be an issue. In the above upstream system for the US, the largest firm has only a 5.6 percent market allowance share. Firms, with each having less than one percent share, would hold the lion's share of allowances (Cramton and Kerr, 1998). Even if market power would not be an issue under the domestic emissions trading scheme, it is hard to imagine a market power problem,

Table 2 Number of Regulated Entities in an Upstream Trading System in the US

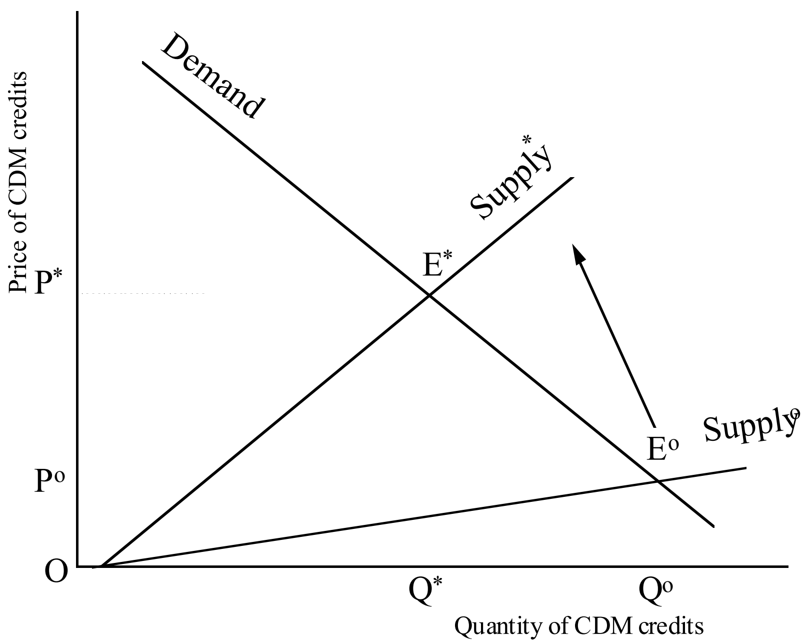
Industry	Point of regulation	Number of regulated entities
Oil	Refinery	175
Oil	Refined product importers	200
Natural gas	Pipeline	150
Natural gas liquids	Processing plant	725
Coal	Preparation plant	550
Coal	Mine	100*
Total		1900

* Although there are approximately 2100 mines in the US, the number of mines actually required to hold allowance probably would be less than 100. This is because mines would be required to hold allowances only for coal not sent to preparation plants. This occurs at a relatively small number of mines, principally located in the West.
Source: Hargrave (1998).

if trading is broadened beyond the national boundary and provided that requisite international institutions supporting trading are available. So, in my review, the results as estimated by MERGE under the assumption of market power should be regarded as an upper bound on the price of carbon permits and the GDP losses.

However, collusive behaviour might occur under the CDM, because both host and investor governments do play the role in approving CDM projects, whereas, under inter-source trading, the governments are limited to setting the rules rather than undertaking emissions trading themselves. This raises the question that how developing countries can limit the supply of CDM credits and maximize the revenues of selling CDM credits. Figure 1 shows an aggregated downward-sloping demand curve of Annex I countries and an aggregated upward-sloping supply curve of non-Annex I countries to supply the total quantity of CDM credits at various price levels (for simplicity, I draw linear demand and supply curves here). The point E^o where the two curves labelled as *Demand* and *Supply*^{o} cross gives the market cleaning price of CDM credits P^o and the total quantity of CDM credits traded Q^o. The area OE^oP^o represents the net gain to non-Annex I countries. Then, how to increase the net gain to non-Annex I countries? As shown in Figure 1, this could be achieved by shifting supply curve upward from *Supply*^{o} to *Supply**. At the new equilibrium E^* where the new supply curve *Supply** crosses the same demand curve *Demand*, although the total quantity of CDM

Figure 1 Aggregated Demand and Supply Curves of CDM Credits



[4] In contrast, a downstream trading system would be applied at the point of emissions. As such, a large number of diverse energy users are included. See Zhang (1998, 1999) for a detailed discussion on upstream, downstream and hybrid emissions trading systems.

[5] When emissions trading were allowed, a country whose legally binding greenhouse gas emissions limits set by the Kyoto Protocol exceed its actual or anticipated emissions requirements would be able to trade these excess emissions, thus creating the hot air that would otherwise have not occurred. The hot air problem would be particularly acute in Russia whose emissions are not expected to rise to its 1990 level until 2010 (UNFCCC, 1997).

credits traded drops to Q^*, the net gain OE^*P^* is greater than OE^oP^o because the market clearing price P^* rises faster than the quantity falls. This has a very important policy implication, as it suggests that if the market clearing price could be held up to the reasonable level, relatively costly CDM projects could be undertaken early with international partners. This would leave low-cost abatement options (the so-called low-hanging fruits) available for later use of their own if developing countries would be subsequently required to reduce their own emissions.

The question then arises: how can the market price of CDM credits could be raised? One *tacit* collusive strategy is that developing countries could insist on restriction on the use of flexibility mechanisms to meet Annex I countries' Kyoto commitments in the name of promoting technical innovation needed to make more stringent future emissions targets affordable and thus kick off the ball to Annex I countries' court. Another way is to prevent trading in hot air, although in practice it is very difficult to distinguish real reduction from hot air.[5] Because hot air is available at zero abatement cost, allowing hot air to be traded tends to push down the overall market clearing price because it reduces Annex I countries' demand for CDM credits. It has dawned on many developing countries and environmental NGOs that the US is counting on breathing Russian hot air to comply with its reduction target set in the Kyoto Protocol, rather than taking abatement actions at home. In this regard, it would be very helpful to clear up the doubt about this, if MERGE could provide the estimated amount of hot air and estimate the economic implications of excluding trading in hot air on the US economy.

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Wrap-up session

Hans Timmer

During the two days of overviews and discussions many areas were bridged and many analyses were linked. One of the very useful bridges was the one between the Kyoto Protocol and the architecture of future agreements. It became clear that a rigid distinction between the two was unsatisfactory. First of all, proposals that are discussed as successor to the Kyoto agreement may well become an alternative for Kyoto. Jonathan Pershing, the negotiator for the US in Kyoto, emphasized that the odds are still against ratification of the Protocol by the US Senate. As a result, more countries may refuse to comply with the agreement and an alternative for Kyoto is needed. Secondly, it is important to realize that Kyoto is just the first step towards a long-run goal. As Jae Edmonds from Pacific Northwest National Laboratory put it, climate change is not about emissions of greenhouse gasses by a group of countries, but about stable global concentrations of those gasses in the atmosphere.

The allocation of emission rights among countries that signed the Kyoto agreement is only a first step in a long process towards those stable concentrations. In fact it is an attempt to internalise a negative externality in the global economy. The primary problem of that attempt is that the market for emission rights is still not complete. While for some countries emissions rights become a scarce good, for others they are still unlimitedly available. That makes this endeavour potentially ineffective and inefficient. Inefficiency may also be introduced because intertemporal trade in emission rights is not possible. That means that the agreed path of emission reductions may not be optimal. These problems touch upon a difficult dilemma. A first, incomplete step towards the introduction of a new market may introduce undesirable distortions and may be even counterproductive. On the other hand, a final step is not possible without a first step.

The conclusion of the discussions was that a rapid introduction of a global market for emission rights is probably more dangerous than a first incomplete move towards that ultimate goal. A true global agreement would enable the efficient use of available low-cost options for emission reductions. It also would provide developing countries with emission rights as a perfectly homogeneous export good, like Tom Rutherford from the University of Colorado indicated. But at the same time it could introduce new financial instabilities in the global economy, a point stressed by Warwick McKibbin from the Brookings Institution and the Australian National University. Equity principles require that developing countries, once they enter an agreement, receive a surplus of emission rights that they can sell to developed economies. An allocation of emission rights based on equity would imply enormous financial transfers across borders, which may destabilise other markets. The transfers are even larger if countries receive permanent emission rights, which value manifolds exceeding the yearly marginal costs of emission reductions.

Intertemporal trade in emission rights may be efficient from the point of view of the current generation, but may lead to unequal intergenerational burden sharing. That could give an argument for fixed reduction targets during given periods instead of a concentration target at some moment in the far future. These considerations resulted in the conclusion that a first step with a limited number of countries and no intertemporal trade options was preferable, but that such agreements should never become a goal in itself. The ultimate goal of a global agreement with a concentration target should be kept in mind.

A topic that was discussed many times and from different angles was the so-called carbon leakage. Mitigation of CO_2 emissions in countries that comply with the Kyoto Protocol or a similar agreement, will probably lead to increased emissions in countries that do not comply and are therefore not restricted in their emissions. Ton Manders presented results with CPB's model WorldScan that showed that the leakage rate heavily depends on the so-called business-as-usual baseline. If non-complying countries become larger and more integrated to the world economy, the leakage rate will become larger too. His discussant Jean Marc Burniaux from the OECD, who developed the GREEN model, emphasized the role of the energy market, and especially the price elasticity of energy supply as a determanant of leakage. Terry Barker from the University of Cambridge pointed at the asymmetries and path dependencies in energy supply. A coal mine that is closed cannot be reopened so easily. Leena Srivastava from India discussed the role of transnational corporations in the reallocation of energy intensive production. Because of the importance and still the huge uncertainties, leakage appeared to remain on the research agenda of many organisations in the coming years.

Another frequently discussed topic was the so-called clean development mechanism (CDM). That mechanism was introduced in the Kyoto Protocol as a way to use low-cost reduction options in countries that do not comply with a reduction target. Countries that impose emission targets may 'buy' emission rights if they subsidize energy efficient technologies in countries that do not impose targets. Thomas Heller from Stanford Law School, one of the leading jurists in the climate change debate saw many institutional problems in the implementation of CDM. Apart from the monitoring problem and the assessment of developments in absence of subsidies, he pointed at the institutional complications that already exist in e.g. foreign direct investments, like severe barriers and restrictions, complicated finance structures and the inability to enforce contracts. CDM projects will probably focus on sectors, like electricity generation, where markets are not very well developed and where institutional problems are huge. The conclusion of the meeting was that CDM could be an undesirable first step, because of the implementation problems and the negative side-effects.

Throughout the discussion the importance of assumptions about future scenarios and long-term dynamics was stressed. Globalisation, the international division of labour and the relative growth rates of emerging economies have a huge impact on the effectiveness of climate change policies. The same is true about the way models describe international trade and international capital flows. The confrontation of many global models at the meeting was very productive in this respect. It resulted in an overview of crucial assumptions which automatically led to a future research agenda.

At the end of meeting policy oriented participants in a panel discussion analysed the current state of the policy issues. Although developed countries still hesitate to commit themselves and developing countries still fear negative side-effects for their growth potential, that discussion showed that already major steps have been made forward to internalise a major negative externality into the global economy. All discussants recognized that emissions can be seen as a scarce good and that it ultimately should have a price to ensure efficient use of that scarce good. Given the need for efficiency the discussion now focusses on practical applications and equity issues.

Part IV

Appendix

Appendix A Meeting Programme

26 May 1999
20.00-22.00 **Welcome Reception**

27 May 1999 ISSUES OF THE ECONOMIC CONSEQUENCES OF KYOTO

Chair: Casper van Ewijk

9.00-9.15 **Opening address:** Annemarie Jorritsma, Minster of Economic Affairs (Netherlands)

9.15-9.45 **Overview of issues:** Hans Timmer (Netherlands)

9.45-10.15 **Overview of modelling results/issues:** John Weyant (USA)

10.15-10.40 **Coffee / tea break**

10.40-11.20 **Global impact of the Kyoto Protocol:** Thomas Rutherford (USA)
Discussant: Snorre Kverndokk (Norway)

11.20-12.00 **Emissions trading, capital flows and the Kyoto Protocol:** Warwick McKibbin (Australia)
Discussant: Ben Geurts (Netherlands)

12.30-13.30 **Lunch**

Chair: Richard Richels

13.30-14.10 **Energy exporters vs. importers:** Tsuneyuki Morita (Japan).
Discussant: Jan Willem Velthuijsen (Netherlands)

14.10-14.50 **Kyoto and carbon leakage:** Ton Manders (Netherlands)
Discussant: Jean-Marc Burniaux (France)

15.00-15.30 **Coffee / tea break**

15.30-16.10 **Clean Development Mechanism:** Thomas Heller (USA)
Discussant: Robert McDougall (USA)

16.10-16.50 **Clean Development Mechanism:** Priyadarsi Shukla (India)
Discussant: Terry Barker (UK)

19.00-01.00am **Social event:** Barbecue at the beach (transport by bus, extra bus at 23.00)

28 May 1999 BEYOND KYOTO

Chair: Mohan Munasinghe

9.00-9.30 **Overview on the EMF-17 model comparison**
options for future research: John Weyant (USA)

9.30-10.10 **Developing economies, capital shortages and transnational corporations:**
Leena Srivastava (India)
Discussant: Thomas Heller (USA)

10.10-10.40 **Coffee / tea break**

10.40-11.20 **Future agreements**: James Edmonds (USA)
Discussant: Thomas Rutherford (USA)

11.20-12.00 **Developing country effects of Kyoto-type emissions reductions:** Mustafa Babiker (USA)
Discussant: Mohan Munasinghe (Sri Lanka)

12.00-13.00 **Lunch**

Chair: Bert Metz

13.00-13.40 **The IPCC SRES stabilisation scenarios:** Johannes Bollen (Netherlands)
Discussant: Stephen Lennon (South Africa)

13.40-14.20 **Analysis of advantages and disadvantages of implementation of AIJ for China:** Ye Ruqiu (China)
Discussant: ZhongXiang Zhang (Netherlands)

14.20-15.00 **The Kyoto Protocol: a cost-effective strategy for meeting environmental objectives?** Richard Richels (USA)
Discussant: Joe Francois (Netherlands)

15.00-15.30 **Coffee / tea break**

15.30-17.00 **Panel discussion on climate policies beyond Kyoto**
Yve de Boer (Netherlands), Bill Hare (Greenpeace), Mohammad Al Sabban (Saudi Arabia), Priyadarsi Shukla (India), Jonathan Pershing (IEA/France)

17.00-17.30 **Wrap-up session and discussion of follow-up work:** Hans Timmer (Netherlands)

17.30-19.00 **Drinks**

Appendix B List of Participants

Mohamad Al Sabban
Ministry of Petroleum
P.O. Box 247
11191 RYADH
Saudi Arabia
Tel: 966 2 667 4044
Fax: 966 2 667 5685
Email: lasabbanms@usa.net

Khalid Al-Hajri
Qater General Petroleum Corp.
P. O. Box
DOHA
Tel: 974 402 662
Fax: 974 402 885
Email: k_alhajri@qgpc.com.qa

Mustafa Babiker
Joint Programme on the Science and Policy of Global Change
Massachusetts Institute of Technology
77 Massachusetts Avenue
Bldg. E40-267
CAMBRIDGE MA
USA
Tel: 1 617 253 0514
Fax: 1 617 253 9845
Email: babiker@mit.edu

Terry Barker
University of Cambridge
Department of Applied Economics
Sidgwick Avenue
CAMBRIDGE CB3 9DE
United Kingdom
Tel: 44 1 223 335 298
Fax: 44 1 223 335 299
Email: terry.barker@econ.cam.ac.uk

Leonard Bernstein
Mobil/IPIECA/USA
105 Lynbrooke Ave.
1007 Auckland
New Zealand
Tel: 64 9 626 7399
Fax: 64 6 626 4197
Email: lsberns@worldnet.att.net

Yve de Boer
Ministerie van VROM
Postbus 20951
2500 EZ THE HAGUE
The Netherlands

Johannes Bollen
National Institute of Public Health and the Environment
P.O. Box 1
BILTHOVEN
The Netherlands
Tel: 31 30 274 36 10
Fax: 31 30 274 44 35
Email: JC.BOLLEN@RIVM.NL

Jean Marc Burniaux
OECD
2 Rue Andre Pascal
75016 PARIS
France
Tel: 33 1 4524 7918
Fax: 33 1 4524 9050
Email: jean-marc.burniaux@oecd.org

Patrick Criqui
Institute of Energy Policy and Economics
BP 47
GRENOBLE 38040 CEDEX 09
France
Tel: 33 4 7651 4881
Fax: 33 4 7651 4527
Email: criqui@iepe.upmf-grenoble.fr

Devra Davis
World Resources Institute
10 G Street N. E.
WASHINGTON DC 20002
United Stated of America
Tel: 1 202 729 7600
Fax: 1 202 729 7798
Email: devra@wri.org

James Edmonds
Pacific Northwest Laboratory
901 D Street SW
WASHINGTON DC 20024-2115
United States of America
Tel: 1 202 646 5200
Fax: 1 202 646 5233
Email: jae@pnl.gov

Casper van Ewijk
Neth. Bureau for Economic Policy Analysis (CPB)
Van Stolkweg 14 2585 JR THE HAGUE
The Netherlands
Tel:	31	70 338 3400
Fax:	31	70 338 3350
Email:	cve@cpb.nl

Ben Geurts
Ministry of Housing, Regional Development and the Environment
P. O. Box 20951
2500 EZ THE HAGUE
The Netherlands

Arjen Gielen
DG Energy Policy
Ministry of Economic Affairs
ALP E 238
P.O. Box 20101   THE HAGUE
The Netherlands
Tel:	31 70 379 79 78
Fax:	31 70 379 74 23
Email:	a.m.gielen@minez.nl

Bill Hare
Greenpeace International
Keizersgracht 176
1016 DW AMSTERDAM
The Netherlands
Tel:	31 20 523 6268
Fax:	31 20 523 6200
Email:	bill.hare@ams.greenpeace.org

Thomas Heller
Stanford Law School
Crown Quad, Room 329
94305-8610 STANFORD, CA
United States of America
Tel:	1 650 723 7650
Fax:	1 650 725 0253
Email:	theller@leland.Stanford.edu

Snorre Kverndokk
The Frisch Centre for Economic Research
Gaustadalléen	21
0371 OSLO Norway
Tel:	47 229 588 11
Fax:	47 229 588 25
Email:	snorre.kverndokk@frisch.uio.no

Nico van Leeuwen
Neth. Bureau for Economic Policy Analysis (CPB)
Van Stolkweg 14
2585 JR THE HAGUE
The Netherlands
Tel:	31 70 338 3300
Fax:	31 70 338 3350
Email:	n.i.m.van.leeuwen@cpb.nl

Steve Lennon
ESKOM Technology Group
Technology Research & Investigations
Private Bag 40175
Cleveland
2022 JOHANNESBURG
South Africa
Tel:	27 11 629 5051/2
Fax:	27 11 629 5500
Email:	steve.lennon@eskom.co.za

Junfeng Li
State Development Planning Commission
Energy Research Institute
Zhan Si Men Road
Shahe, Changping
102206 BEIJING
China
Tel:	86 10 6973 7074
Fax:	86 10 6973 3110
Email:	lijf@public.bta.net.cn

Ton Manders
Neth. Bureau for Economic Policy Analysis (CPB)
Van Stolkweg 14
2585 JR THE HAGUE
The Netherlands
Tel:	31 70 338 3452
Fax:	31 70 338 3350
Email:	ajgur@cpb.nl

Robert McDougall
GTAP
Purdue University
Department of Agricultural Economics
1145 Krannert Building
WEST-LAFAYETTE, IN 47907 - 1145
United States of America
Tel:	1 765 496 2798
Fax:	1 765 496 1224
Email:	mcdougall@agecon.purdue.edu

Warwick McKibbin
Australian National University/Brookings
84 Domnion Circuit
2600 DEAKIN, ACT
Australia
Tel:	61 2 6249 0301
Fax:	61 2 6273 5575
Email:	wmckibbin@msgpl.com.au

Bert Metz
National Institute of Public Health and the Environment
P. O. Box 1
3720 BA BILTHOVEN
Tel:	31 30 274 3990
Fax:	31 30 274 4464
Email:	bert.metz@rivm.nl

Shunsuke Mori
Science University of Tokyo
Faculty of Science and Technology
Yamasaki 2641
278-8510 NODA-SHI, CHIBA
Japan
Tel: 81 471 241 501
Fax: 81 471 224 556
Email: mori@shun-sea.ia.noda.sut.ac.jo

Tsuneyuki Morita
National Institute for Environmental St. Global
Warming Response Team
16-2 Onogawa TSUKUBA, IBARAKI 305-0053
Japan
Tel: 81 298 502 541
Fax: 81 298 502 524
Email: t-morita@nies.go.jp

Mohan Munasinghe
University of Colombo
Dept. of Management
10, De Fonseka Place
COLOMBO 5 Sri Lanka
Tel: 94 1 400 289
Fax: 94 1 580 822
Email: Munasinghe@Eureka.Lk

Youssef Nassef
UN Framework convention on Climate Change
P. O. Box 260 124
53153 BONN
Germany
Tel: 49 228 815 1416
Fax: 49 228 815 1999
Email: ynassef@unfccc.de

Jiahua Pan
IPCC Working Group III
Technical Support Unit
P. O. Box 1
3720 BA BILTHOVEN
Tel: 31 30 274 4310
Fax: 31 30 274 4464
Email: jiahua.pan@rivm.nl

Jonathan Pershing
International Energy Agency
Energy and Environment Div.
9 Rue de la Federation
75739 PARIS, CEDEX 15
Tel: 33 1 405 767 20
Fax: 33 1 405 767 39
Email: jonathan.pershing@iea.org

Richard Richels
Electric Power Research Institute
3412 Hillview Ave
PACO ALTO, CA 94303
United States of America
Tel: 1 650 855 2602
Fax: 1 650 855 2950
Email: rrichels@epri.com

Thomas Rutherford
University of Colorado
Dept. of Economics
Campus Boc 256
BOULDER, CO 80309
United States of America
Tel: 1 303 492 5169
Fax: 1 303 492 5169
Email: rutherford@colorado.edu

Roberto Schaeffer
PPE/COPPE/UFRJ
Av. Ataulfo de Paiva, 1241/Co 1-Leblon
22440-031 RIO DE JANEIRO
Brazil
Tel: 55 21 560 8995
Fax: 55 21 540 5557
Email: roberto@ppe.ufri.br

Priyadarsi Shukla
Indian Institute of Management
310 Vastrapur 380015
AHMEDABAD
India
Tel: 91 79 640 72 41
Fax: 91 79 642 78 96
Email: shukla@iimahd.ernet.in

Leena Srivastava
TERI
Darbari Seth Block
Habitat Place, Lodhi Road
110 003 NEW DELHI
India
Tel: 11 462 2246
Fax: 11 462 1770
Email: leena@teri.res.in

Rob Swart
IPCC Working Group III
Technical Support Unit
P. O. Box 1
3720 BA BILTHOVEN
Tel: 31 30 274 3026
Fax: 31 30 274 4464
Email: jiahua.pan@rivm.nl

Hans Timmer
Neth. Bureau for Economic Policy Analysis (CPB)
Van Stolkweg 14
2585 JR THE HAGUE
The Netherlands
Tel: 31 70 338 3300
Fax: 31 70 33 83 306
Email: h.r.timmer@cpb.nl

Matti Vainio
European CommissionDG XI
XI B.1-Economic Analysis and Environmental Studies
Avenue de Beaulieu 5
1160 BRUSSELS
Belgium
Tel: 32 2 299 6138
Fax: 32 2 296 9559
Email: matti.vainio@dg11.cec.be

Jan Willem Velthuijsen
University of Amsterdam
Foundation for Economic Research
Roetersstraat 11
AMSTERDAM
Tel: 31 20 624 24 12
Fax: 31 20 625 89 93
Email: jwvelthu@seo.fee.uva.nl

John Weyant
Stanford University’
Dept. of Engin.Ec. Systems & Oper. Res.
Terman Engineering Building, Room 406
94305-4023 STANFORD, CA
USA
Tel: 1 650 723 3506
Fax: 1 650 723 4107
Email: weyant@leland.stanford.edu

Ruqiu Ye
State Environmental Prot. Adm.
115 Xizhimennei Nanxiaojie 100035
BEIJING
China
Tel: 86 10 661 517 54
Fax: 86 10 661 517 62
Email: yeruqiu@cenpok.net

ZhongXiang Zhang
University of Groningen
Dept. of Economics & Public Finance
P.O. Box 716
GRONINGEN
Tel: 31 50 363 68 82
Fax: 31 50 363 71 01
Email: Z.X.Zhang@Rechten.RUG.NL