# *MIT Joint Program on the Science and Policy of Global Change*

## Russia's Role in the Kyoto Protocol

*Alain Bernard, Sergey Paltsev, John M. Reilly, Marc Vielle and Laurent Viguier*

**Report No. 98**
***June 2003***

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

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

This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives. Titles in the Report Series to date are listed on the inside back cover.

Henry D. Jacoby and Ronald G. Prinn,
*Program Co-Directors*


For more information, please contact the Joint Program Office

Postal Address: Joint Program on the Science and Policy of Global Change
MIT E40-428
77 Massachusetts Avenue
Cambridge MA 02139-4307 (USA)

Location: One Amherst Street, Cambridge
Building E40, Room 428
Massachusetts Institute of Technology

Access: Phone: (617) 253-7492
Fax: (617) 253-9845
E-mail: globalchange@mit.edu
Web site: http://mit.edu/globalchange/



*Printed on recycled paper*

# Russia's Role in the Kyoto Protocol

A. Bernard[a], S. Paltsev[b], J. Reilly[b], M. Vielle[c], L. Viguier[d]

[a]Ministère de l'Equipement, des Transports et du Logement, France
[b]MIT Joint Program on the Science and Policy of Global Change, USA
[c]CEA – IDEI – LEERNA, Université des Sciences Sociales, France
[d]Faculty of Economics and Social Sciences, University of Geneva, Switzerland

**Abstract**

As a result of the allocation of emissions reductions, and the differential willingness of countries to ratify, it turns out that Russia is a central player in the Kyoto Protocol. With the U.S. out and Japan and the EU ratifying, the Protocol cannot enter into force without Russian ratification. In part, U.S. rejection of the Kyoto Protocol resulted from the fact that, had the U.S. been in, its least costly road to implementation would have involved large purchases of emissions credits from Russia. With the U.S. out, Russian credits are worth much less but Russia may be able to exploit monopoly power to increase the value of those permits, or Russia could bank permits on the expectation that prices will rise in the future, perhaps as a result of the U.S. reentry into the Protocol in later periods. The Russian decision is more complex, however, in that it is also a major fossil fuel exporter. To the extent it withholds permits from the market, fossil energy prices are depressed further, and the value of its exports of energy are reduced. Thus, Russia faces a tradeoff between maximizing its permit revenue and its revenue from fossil energy exports. We develop this problem as a simple dynamic optimization problem and calibrate the model to the results of two CGE models (EPPA and GEMINI-E3) that fully capture interactions of energy trade, permit trade, and permit and energy prices. We show that carbon prices are relatively insensitive to Russia's behaviors when the U.S. is assumed to participate. It also shows that, in the absence of U.S. participation, the impact of market power by Russia and Ukraine is largely dependent on the elasticity of demand for permits. Finally, we focus on the uncertainty about the supply of CDM by developing countries. It is shown that permit prices are relatively insensitive to CDM supply in the short run but not in the long run.

JEL Classification: Q4, Q3, C68, D58.

Keywords: Climate Change; Kyoto Protocol; Russia; Computable General Equilibrium Model; Emission Trading.

# 1 Introduction

Russia has become a central player in international climate policy. For the Kyoto Protocol to enter into force, Annex B Parties accounting for 55% of 1990 carbon emissions must ratify. The Russian Federation accounted for 16.4% of 1990 carbon emissions. Thus, with U.S. indicating it will not ratify, and alone responsible for almost 34% of 1990 emissions, Russian ratification is necessary for entry into force. With the EC, Japan, and other smaller countries having already ratified, Russian ratification is sufficient. Other countries where ratification may not succeed, can neither assure nor block entry into force. The Russian allocation of greenhouse gas (GHG) emissions under the Kyoto Protocol also seems to have figured in the U.S. rejection of the Kyoto Protocol. The U.S. President Bush rejected the Protocol as "fatally flawed." One concern expressed by the U.S. Administration was that the U.S. would need to rely on untested flexibility mechanisms, like permit trading and CDM, to make the U.S. costs of meeting the Protocol acceptable. Studies of the Kyoto Protocol show that the availability of Russian "hot air", as well as further low cost real reductions there, and in other transition economies like Poland, greatly reduce the price of carbon and welfare impacts in the U.S. compared with a no trading case. Depending on whether the Kyoto Parties use trading flexibility and whether the U.S. joins or not, Russia's gains from permit sales could range from billions of dollars to almost nothing.

In this context, the Russian Federation, perhaps acting with other potential sellers such as Ukraine, has a heightened incentive to adopt monopolistic behavior, and sell only a share of available permits from the "hot air" in order to maximize revenues from permits sales. The incentive for monopoly behavior by the Russian Federation and Ukraine has been analyzed elsewhere, both before (Burniaux, 1998; Bernstein, et al, 1999) and after the withdrawal of the U.S. from the Kyoto Protocol[1]. With the U.S. in the Protocol, estimates of the international trading price with optimal monopolistic behavior by Russia and Ukraine increases on the order of 38% (Burniaux, 1998) to 43% (Bernstein et al, 1999). The trading price in these studies is, in turn, nearly three times the domestic marginal cost in the Russia, reflecting the fact that Russia would then undertake much less real domestic reduction. Recent studies (Babiker et al, 2002; Bernard and Vielle, 2001; Blanchard and Criqui, 2002; Bohringer, 2001; Ciorna et al, 2001; den Elzen and de Moor, 2001; Manne and Richels, 2001) have also considered Russian monopoly power with the withdrawal of the U.S. The studies generally find that it is optimal for Russia and Ukraine to sell only about 50% of the "hot air" available, with the equilibrium price of permits ranging from $20 to $57 per ton of carbon.

Three key issues arise in considering Russia's strategy on permit sales should it ratify the Kyoto Protocol. First, one of the key findings of CGE modeling of greenhouse gas mitigation is that climate policy can have strong effect on welfare for some countries through a terms of trade effect. The main effect occurs through international fossil energy prices. As oil and gas are a major source of export revenue for the Russia, this effect is potentially important in evaluating an optimal strategic response by them. Essentially, by restricting carbon permits sales, Russia would force greater reductions of energy use in the other Annex B countries. This, in turn, would cause a greater reduction in the international producer price of fossil fuels than without the permit sales restrictions. Russia would thus face a loss of export revenue due both to declining quantity and price of oil and gas exports. The optimal decision is thus a tradeoff between increasing gains from permits sales and reductions in oil and gas revenue.

Second, it may be in the interest of Parties to bank permits for use in future periods, and such banking is allowed under the terms of the Kyoto Protocol. In the simplest case, banking would be desirable if, absent banking, the permit price was expected to rise at greater than the discount rate. It would then make sense to hold back sales of permits (reduce emissions further in earlier periods) to slow the rate of permit rise to the discount rate. In this regard emissions permits are a scarce resource

[1]Due to lack of data needed to disaggregate the Former Soviet Union (FSU) nearly all studies investigate the behavior of FSU.

and the problem is to optimally allocate them over time. Thus, similar to the oil market, observed prices for permits may include both "Hotelling" scarcity rents, reflecting Parties' interests in allocating permits over time, and monopoly rents reflecting the exercise of monopoly power by some Parties. That is, the failure of Russia to sell all of its permits, would not by itself be evidence of the exercise of monopoly power but could reflect a decision to bank based on its expectations of future demand.

Third, even if Russia has some monopoly power in the markets for tradable emissions permits, this power might be weakened by competition with other flexibility mechanisms such as the Clean Development Mechanism (CDM). Annex B countries will make trade-offs between the two options, according to their comparative costs. If the net cost of Certified Emission Reductions (CERs) generated through CDM projects is less expensive than emissions permits available in the international emissions trading market, Annex B regions will prefer to buy CERs. At the equilibrium, the marginal costs will be equalized, and the "supply" of CDM will be determined.

To the extent previous studies have found similar or different results, the reasons for these similarities or differences are not immediately obvious. In some cases, the focus has been on banking and in others on monopoly rents. Several have looked at the purely static, one period problem of maximizing rents whereas others have considered the problem in a dynamic CGE context[2]. Not all analyses to date have included the terms of trade effects, and different models can give rise to different results solely because of different assumptions about abatement opportunities. In this paper, we seek to clarify the source of differences in results. We develop a simplified dynamic model whose parameters can be set to reflect the underlying structure of more complex models. In so doing, we can better explain the conditions under which there is, or is not, room for substantial monopoly and Hotelling rents to be earned by permit sellers. Moreover, we explicitly consider the tradeoff between oil and gas revenue and permit revenue.

We simulate an international trading regime characterized by a monopolistic behavior by Russia and Ukraine. Two profit-maximization schemes are successively assessed, a static one and an inter-temporal one. The latter considers the time horizon through 2040. Following a previous study by Bernard and Vielle (2002), the simulations are implemented through a recursive dynamic inter-temporal optimization calibrated on two Computable General Equilibrium (CGE) models (EPPA and GEMINI-E3). Beside the working of the carbon market – including the competition from other flexibility mechanisms, in particular the CDM, – the optimization program simulates the behavior of the other Annex B regions in the emissions markets, and the effects on their income and terms of trade.

In section 2, we present the Russian position in the context of climate change mitigation. In section 3, we present the general formulation of the inter-temporal optimization model. Section 4 deals with the calibration of the model to the outcomes of the two CGE models. Numerical results are discussed and compared in section 5. Section 6 presents the sensitivity of numerical results to the amount of CDM available. Section 7 concludes.

## 2 Russia's position on Kyoto Protocol ratification

As of May 2003, to enter into force the Kyoto Protocol requires only the ratification of the Russian Federation. Russian Premier Minister Mikhail Kasyanov announced at the 2002 Earth Summit in Johannesburg that Russia hoped to ratify the Kyoto Protocol "in the very near future." However, since then the issue of Russian ratification has become less clear. What is clear is that the decision about ratification (or not) will be based on economic and foreign policy considerations. Environmental reasons will have little impact on the Russian position.

The main attraction for Russia is a potential for sales of "hot air", a situation when emission quotas appear to be in excess of Russian anticipated emissions due to economic downturn of the 90s (Victor

[2]See the analysis done by Manne and Richels (2001) with MERGE that considers banking explicitly.

et al, 1998; Paltsev, 2000; Bohringer, 2000). In the post-Kyoto negotiations, the European Union opposed the sale of "hot air" because of a stated preference for higher domestic abatement activities, even submitting a proposal (UNFCCC, 1999) for limits on the share of emissions reductions a country might obtain through use of emission trading. With the U.S. withdrawal from the Kyoto, the EU has toned down the opposition to the "hot air" sales. However, there are some indications that the EU, Canada, and Japan may decide not to buy "hot air" permits.

Even if "hot air" is for sale, the exact amount is not certain and depends on the pace of Russian economic recovery. The expected reduction of the world carbon emissions due to the Kyoto activities is around 300-350 MtC, while the "hot air" estimates range from 150 to 500 MtC (Paltsev, 2000). Russian national estimates can be found in the Second National Communication (UNFCCC, 1998), which projects 2010 emissions at 90-92% of the 1990 level. Also, Kotov (2002) reports that in the official forecast by Russian Ministry of Fuel and Energy, emissions from the energy sector are forecasted at 85% of the 1990 level. He notes that this forecast is based on an assumption of an extremely high growth in energy efficiency rates. However, the U.S. DOE (2002) is substantially less optimistic about Russian economic recovery and projects the 2010 emissions from the former Soviet Union at only 72% of the 1990 level.

It should be noted that Russia is a major but not the sole potential seller of "hot air". Emissions in 1990 from the economies of transition were as follows: Russia 650 MtC, Ukraine 190 MtC, Eastern Europe 300 MtC. Most of the projections show that in 2010 these emissions will reach 470-600 MtC for Russia, 140-170 MtC for Ukraine, and 230-260 for Eastern Europe. It leaves an estimated 50-180 MtC of Russian, 20-70 MtC of Ukrainian, and 40-70 MtC of Eastern European "hot air". Each of these players have different political and economic agendas regarding their excess permits. Eastern European countries, for the most part, are likely to be absorbed into the system through their accession to the EU. Russia and Ukraine are then left as the most likely sellers of "hot air".

Inside Russia environmental concerns are not among the top priorities. People are rather worried about unemployment, poverty, a sharp decrease in the standards of living, and day-to-day survival. The public perception of climate policy is that global warming is not so bad for cold Russia and that the economic compensation from the West for the years of transition from communism is justified. The Russian government also did not put climate policy at the top of its list. The Interdepartmental Commission on Climate Change (ICCC) originally was headed by Hydromet (Meteorological Committee), a government body which does not have a status of a ministry. There also has been a clear lack of financing of climate policy research and institutional capacity building. For example, in 1996-2000 the federal program on climate change was funded only for 3-4% of required resources (Kotov and Nikitina, 2002).

However, with the prospects of a windfall from "hot air" sales, much more important players entered the arena. In 1999, the Ministry of Fuel and Energy proposed an institutional structure for climate policy (Kotov, 2002). According to this proposal, the rank of the ICCC would be raised, the carbon permits market managed at the federal level with individual enterprises excluded from the direct access to the international permit market, and bi-lateral cooperation with other countries would be emphasized. In 2000 the ICCC was shifted from the hands of Hydromet to the Ministry of Economic Development and Trade, a move which shows an increased importance of climate policy in the bureaucratic hierarchy. Russian development so far is based on a reliable fuel and energy sector. The energy lobby is very powerful in Russian politics and the Kyoto ratification depends on their support. There is a clear conflict between climate policy goals and energy exporters' goals because of a potential negative impact on the world prices of oil, gas, and coal. It should be noted that the Russian energy lobby has expressed an interest in joint implementation projects only if such projects would lead to investment in the energy sector, rather than payments for "hot air" made to the Russian government. It is clear that if Russia cannot secure buyers of "hot air" or investors to the energy sector, then Russia is unlikely to hurry to ratify the Kyoto.

Even if the economic interests of energy groups are satisfied and Russia decides to ratify the Kyoto Protocol, that process is time consuming. To bring the law into force, the Russian government must first prepare a draft of the National Report on Climate Change and send it to the State Duma. The Duma must then approve ratification of the Protocol. The Federation Council, the upper Chamber of the Russian Parliament, then must also approve ratification. Finally, the law is passed to the President, who can sign it or decline it. Depending on political will, this process may take several months.

Given the reality of the Russian political system and the diverse interests of its constituencies, Russia may or may not ratify, use monopoly power or choose to optimally bank permits. Moreover, the underlying structure of the CGE models we use, require us to assume that Russia and Ukraine cooperate, and this may be unrealistic. Nevertheless, the model and calculations that follow are illustrative of the potential gains that could accrue if these strategic behaviors are followed.

## 3 The model

In this section we present a model for the general case of inter-temporal optimization, and derive from it the case of myopic behavior. Our notation is given below, with index $t$ representing time, from 0 to $T$.

**Notations**

| | | |
|---|---|---|
| $\bar{HA}_t$ | : | available "hot air" (tC) |
| $q_t$ | : | emissions abatement by Russia and Ukraine (tC) |
| $d_t$ | : | demand for flexible instruments by other Annex B countries (tC) |
| $s_t$ | : | abatement realized through the CDM mechanism (tC) |
| $v_t$ | : | permits sold by Russia and Ukraine ( $= d_t - s_t$ ) |
| $p_t$ | : | price of permits ($/tC) |
| $r_t$ | : | revenues from the sales of permits ( $= p_t v_t$ ) |
| $c_t$ | : | abatement cost in Russia and Ukraine ($) |
| $g_t$ | : | gains from Terms of Trade (or change from a reference situation) ($) |
| $\pi_t$ | : | social value of the held over stock of permits |
| $S_t$ | : | stock of permits of Russia and Ukraine available at the beginning of year t |
| $S_{T+1}$ | : | residual stock of permits of Russia and Ukraine at the end of year T |
| $p_{T+1}$ | : | unit value of permits at the end of year T |
| $i$ | : | discount rate (assumed constant over time) |

The inter-temporal optimization program for Russia and Ukraine can then be written in the form:

$$\max \left[ \sum_{t=1,T} e^{-it} \Big[ r_t + g_t(p_t) - c_t(q_t) \Big] + e^{-i\ T+1} p_{T+1} S_{T+1} \right] \tag{1}$$

where the $r_t$ term represents revenues from permit trade, the $g_t$ term captures the welfare effects on Russia through the terms of trade (mainly fossil energy price) effects[3], and $c_t$ is an abatement cost in

[3]The gains from terms of trade are directly computed in the CGE model using the following definition:

$$g_t = \sum (x_j^1 - x_j^0) X_j - \sum (m_j^1 - m_j^0) M_j$$

where $x_j^0$, $x_j^1$, $m_j^0$, and $m_j^1$ are respectively the exports and imports prices of good $j$ in the baseline and policy case, and where $X_j$ and $M_j$ are respectively the volume of exports and imports in the baseline scenario. Gains from Terms of Trade is thus the change in net revenues of foreign trade resulting from the change in the prices of imports and exports (ex-ante, Russia and Ukraine. The last term, $e^{-i(T+1)}p_{T+1}S_{T+1}$, represents the value of the stock of permits carried into $T+1$.

The following constraints are applied in the optimization program:

$$
\begin{array}{llrcl}
(\pi_t) & & S_{t+1} - S_t - q_t - \bar{HA}(r_t) + d_t(p_t) - s_t(p_t) & = & 0 \\
 & & \text{with} \quad S_1 & = & 0 \\
(\mu_t) & & S_t & \geq & 0 \\
(\mu_{T+1}) & & S_{T+1} & \geq & 0 \\
(\theta_t) & & q_t & \geq & 0
\end{array}
$$

where $\pi_t$, $\mu_t$ , $\mu_{t+1}$, $\theta_t$ are the Lagrangian multipliers associated each of the constraints. The first constraint describes the accumulation of permits over time, that is the stock of permits in $t+1$ is equal to the stock in period $t$ plus abatement, "hot air", and CDM, less purchases of permits from Russia and Ukraine by other Annex B countries. The other constraints represent initial stock of permits and non-negativity conditions. Resolution of the optimization program yields the Kuhn & Tucker conditions for optimality:

$$
\begin{array}{llrcl}
(p_t) & & \pi_t \left[ \frac{\partial d_t}{\partial p_t} - \frac{\partial s_t}{\partial p_t} - \frac{\partial \bar{HA}_t}{\partial r_t} \frac{\partial r_t}{\partial p_t} \right] & = & e^{-it} \left[ \frac{\partial r_t}{\partial p_t} + \frac{\partial g_t}{\partial p_t} \right] \\
 & & \text{with} \quad \frac{\partial r_t}{\partial p_t} & = & p_t \left( \frac{\partial d_t}{\partial p_t} - \frac{\partial s_t}{\partial p_t} \right) + d_t(p_t) - s_t(p_t) \\
(S_t) & & -\pi_t + \pi_{t-1} + \mu_t & = & 0 \\
 & & \text{with} \quad \mu_t & \in & \begin{cases} \{0\} & \text{if } S_t > 0 \\ ]-\infty, 0] & \text{if } S_t = 0 \end{cases} \\
(S_{T+1}) & & \pi_{T+1} + \mu_{T+1} & = & e^{-i(T+1)} p_{T+1} \\
 & & \text{with} \quad \mu_{T+1} & \in & \begin{cases} \{0\} & \text{if } S_{T+1} > 0 \\ ]-\infty, 0] & \text{if } S_{T+1} = 0 \end{cases} \\
(q_t) & & \pi_t & = & e^{-it} \frac{\partial c_t}{\partial q_t} + \theta_t \\
 & & \text{with} \quad \theta_t & \in & \begin{cases} \{0\} & \text{if } q_t > 0 \\ ]-\infty, 0] & \text{if } q_t = 0 \end{cases}
\end{array}
$$

If the non-negativity constraint on the stock of permits is not binding, the discounted social value $\pi_t$ is constant over time[4]. The supply of permits and the level of emissions abatement are determined by the two decision variables: $(p_t)$ and $(q_t)$. The relationship describing the optimal level of $p_t$ may be written in the form:

before domestic demand for imports and exports to other countries adjust to the new prices). Note that this simplified formula applies because both CGE models used here close their foreign sector by assuming a fixed (across cases) capital flow. For more on computation of the gains from terms of trade see Bernard and Vielle (2003).

[4]Equivalent, in the present case, to the Hotelling law.

$$\pi_t e^{it} = p_t \frac{1+\eta_t}{1-\zeta_t-\frac{1}{1+\varepsilon_t}} \tag{2}$$

with

$$\varepsilon_t = \frac{p_t}{v_t}\frac{\partial v_t}{\partial p_t} \quad \text{(price elasticity of permits demand)}$$

$$\eta_t = \frac{\partial g_t}{\partial r_t} \quad \text{(effect of permits revenues on the gains from terms of trade)}$$

$$\zeta_t = p_t \frac{\partial HA_t}{\partial r_t} \quad \text{(effect of permits revenues on "hot air")}$$

Relationship (2) is the general case for intertemporal monopoly. The optimality condition for the myopic monopolistic behavior can be seen by noting that in such a case the social value of permits held over for next period is zero by definition, i.e., the value of banking is not considered. One can further see that if we were to neglect the macroeconomic effects of permit revenue on emissions (and thus “hot air”), $\eta_t = 0$, and the effects on the terms of trade, $\zeta_t = 0$, then relationship (2) reduces to the condition that the price elasticity of demand equals minus one, the familiar partial equilibrium condition for a monopoly. Elasticity of demand seen by Russia takes into account the competition by CDM supply. Greater competition from the CDM mechanism means a decrease of the monopolistic power of Russia.

The relationship describing the optimal abatement level, $q_t$ is

$$(q_t) \quad \frac{\partial c_t}{\partial q_t} \geq \pi_t e^{it} \quad \text{with equality if} \quad q_t > 0 \tag{3}$$

which sets the marginal abatement cost equal to the social value of permits.

## 4 Calibration of the model with two CGEs

Estimation of the functions appearing in the optimization model is carried out using simulation results of the two CGE models, EPPA (Babiker et al, 2001) and GEMINI-E3 (Bernard and Vielle, 2000). Specifically, we simulated each of these models across a wide range of carbon constraints so that the resultant fitted response functions capture model behavior over the full range of results we later evaluate with our dynamic simulation model.

The Emissions Prediction and Policy Analysis (EPPA) model is a recursive dynamic multi-regional general equilibrium model of the world economy that has been developed for analysis of climate change policy. Previous versions of the model have been used extensively for this purpose (e.g., Ellerman and Decaux, 1998; Jacoby and Sue Wing, 1999; Reilly et al, 1999; Babiker et al, 2000; Ellerman and Wing, 2000). A specific version of the model (EPPA-EU) including a detailed breakdown of the European Union and incorporating an industry and a household transport sectors for each region has been developed (Viguier et al, 2001; Babiker et al, 2001). EPPA is built on a comprehensive energy-economy data set (GTAP-E[5]) that accommodates a consistent representation of energy markets in physical units as well as detailed accounts of regional production and bilateral trade flows. The base year for the model is 1995 and it is solved recursively at 5-year intervals. The version of EPPA used here includes some recent updates beyond that described in Babiker et al (2002). For example, it includes

[5]For description of the GTAP database see Hertel (1997).

endogenous estimation of the cost of abatement of non-$CO_2$ greenhouse gas emissions $CH_4$, $N_2O$, HFCs, PFCs and $SF_6$. For comparability with GEMINI-E3, however, we considered only a constraint on carbon emissions to develop the response functions estimated here. Other revised features of this model include greater detail in the electricity sector so that fossil, nuclear, hydro, biomass, solar, and wind electric generation are explicitly treated; reevaluation of fossil energy resources, improved representation of recent developments in Chinese energy use, and reevaluation of trends in energy efficiency improvements. Among the developed countries and Russia, the focus of analysis here, the energy efficiency of the electric sector is modeled as improving at a rate of 0.40 to 0.45 percent per year while non-electric sectors increase in energy efficiency by 1.2 to 1.3 percent per year.

GEMINI-E3 is a multi-country, multi-sector, dynamic General Equilibrium Model incorporating a highly detailed representation of indirect taxation (Bernard and Vielle, 2000; Bernard and Vielle, 2003). For assessment of energy policies directly involving the electric sector, e.g., implementation of nuclear programs, the model can incorporate a technological sub-model of power generation better suited for comparing investments in different types of plants. We use the third version of the model that has been especially designed to calculate the social marginal abatement costs (MAC), i.e., the welfare loss of a unit increase in pollution abatement. Beside a comprehensive description of indirect taxation (mainly for France), the model simulates all relevant markets: markets for commodities (through relative prices), for labor (through wages), for domestic and international savings (through rates of interest and exchange rates). Terms of trade (i.e., transfers of real income between countries resulting from variations of relative prices of imports and exports), and "real" exchange rates, can then be measured[6].

The functions we estimate based on the CGE models are:

- the *demand for flexible instruments* by non Annex B countries (other than Russia and Ukraine, and including or not the U.S. according to the case), i.e., what these countries are globally willing to purchase at a given price (or, symmetrically, what they are willing to pay for a given amount of flexible instruments, either emission permits or CDM);

- the *supply of CDM*, i.e., the amount of CDM projects (measured in terms of yearly emission abatement) which are profitable, for both contracting Annex B and non-Annex B countries, as a function of the price of permits;

- the *marginal abatement costs curves* in Russia and Ukraine, as a function of the price of permits;

- the relationship between the *gains from terms of trade (GTT)* for Russia and Ukraine and *the price of permits* or the revenues from permits sales by Russia and Ukraine. This relationship summarizes the spillover macro-economic impacts on Russia of the climate change policies implemented in the rest of the world. Much of this effect is due to revenue loss from energy sales because of reduced demand for fossil fuels as deeper cuts in $CO_2$ are required if less "hot air" is available.

## 4.1 The demand for flexible instruments

Figure 1 represents the demand curves for flexible instruments in 2010 and 2040 computed with EPPA and GEMINI-E3 with and without the U.S. participation to the Kyoto Protocol. An important difference between these two models is that GEMINI-E3 does not include Eastern European countries whereas the EPPA model includes all of these countries in its EET region and as part of Annex B. The estimated demands used in the simulations reported in the following sections of the paper reflect

[6]The real exchange rate between two countries is the relative price of the "numéraires" chosen in each country (and usually based on a basket of goods representative of GDP). It is not identical to the monetary exchange rate of the currencies of the two countries: in particular, the real exchange rate can evolve between countries belonging to the same monetary union.

this different country coverage, and are shown as solid lines in Figure 1. Also shown for the "without the US" case is a separate line showing the demand from the EPPA model excluding the Eastern European countries from the Annex B trading block. It shows that this difference in country coverage is one reason for the differences between the models. Specifically, EPPA simulates "hot air" from these countries in 2010 of about 20 million tons of carbon. With this "hot air" removed, Annex B demand based on EPPA is shifted horizontally to the right which has the effect of raising the demand at any given price. This adjustment makes the EPPA demand generally more similar to that of GEMINI-E3 at quantities less than 150 MtC, although demand from GEMINI-E3 is more steeply sloped.

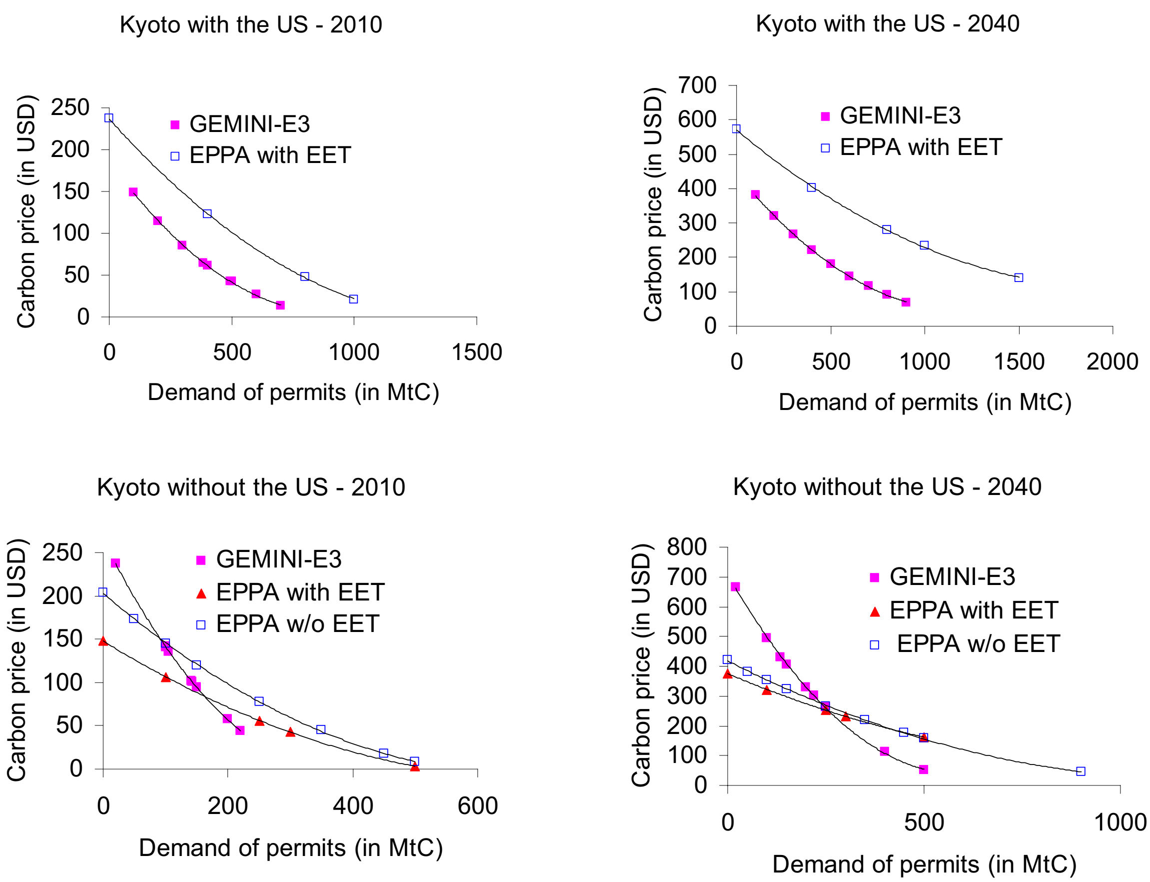


Figure 1: Demand for flexible instruments by Annex B except Russia and Ukraine (with and without U.S.)

With the US included in the Kyoto Protocol, Annex B demand as estimated from EPPA is greater than GEMINI-E3 demand by more than 200 MtC at any price, even with the EET's "hot air" included in the EPPA demand. This reflects more rapid baseline growth of emissions in EPPA. Removing the EET from the "with US" estimated demands from EPPA would have the same effect as removing it from the "without US" demand, shifting the demand horizontally to the right by the approximately the same quantity. It would thus increase the EPPA demand by another 50 to 100 MtC. The relative magnitude of the shift is much less, however, because the quantity demanded when the US is included in Annex B demand is greater by about by 300 to 400 MtC then when the US is not part of Kyoto. It is also important to recognize that these estimates do not include forest and agricultural sinks, which if included would reduce these demands[7].

### 4.2 MAC curves for Russia and Ukraine

Marginal abatement curves are derived by setting progressively tighter abatement levels and recording the resulting shadow price of carbon or by introducing progressively higher carbon taxes and recording the quantity of abated emissions. As explained by Ellerman and Decaux (1998), a computable general equilibrium (CGE) model can produce a "shadow price" for any constraint on carbon emissions for a given region R at time T. A MAC curve plots the shadow prices corresponding to a different level of emissions reduction.

Figure 2 shows MAC curves for Russia and Ukraine estimated in EPPA and GEMINI-E3. They have been plotted as a function of the amount of reduction below reference emissions. We can see that the marginal costs of reducing carbon emissions by a given level are very similar in the two models.

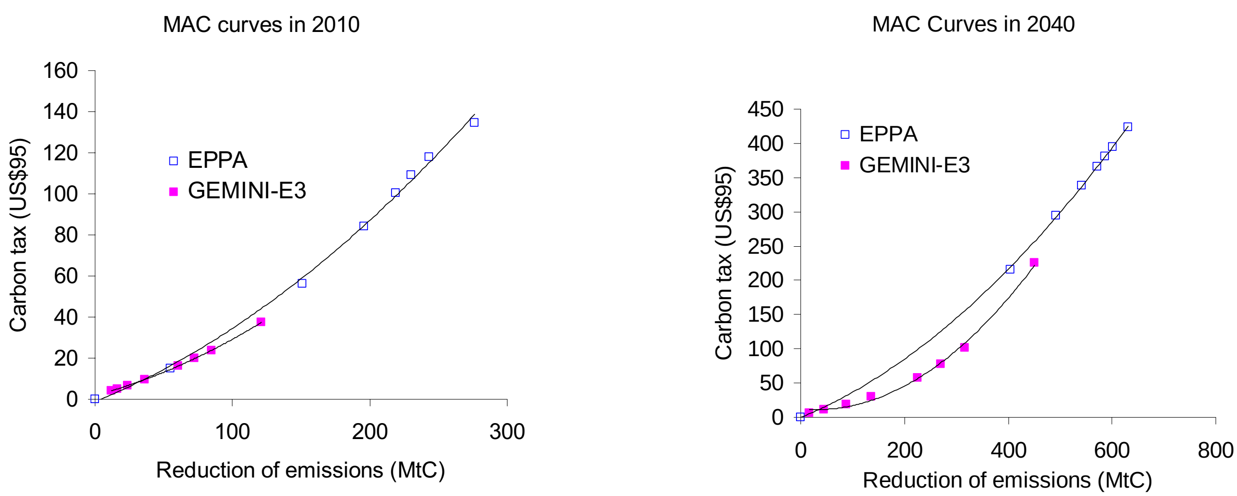


Figure 2: MAC curves in Russia & Ukraine

These curves leave out the amount of "hot air" available to Russia and Ukraine in the 2010-2040 period. The amount of Russian "hot air" is far from being certainly established as it depends on, among other things, how GDP rapidly recovers. In the EPPA model, the "hot air" is projected to decline from 186 MtC in 2010 to 41 MtC in 2020 whereas it goes from 300 MtC in 2010 to 136 MtC in 2030 in GEMINI-E3. We base our results on the EPPA estimates of the Russian "hot air".

### 4.3 Curves of CDM supply

The last component of the model is the supply of CDM credits. Very few studies have assessed the potential of this flexibility mechanism. The ultimate potential of CDM is the total amount of GHG abatement in non Annex B countries at a cost less than or equal to the equilibrium price of permits. Few analysts expect this full potential will be realized.

With the rules yet still incomplete, estimates of CDM supply are highly speculative. If fairly strict conditions of eligibility exist, and (as anticipated) case-by-case evaluation is required to certify them,

[7] In the final Marrakech agreement, the Annex B parties (excluding Russia) were allowed a total of about 35 MtC of sinks, and this would reduce their demands by this amount at all prices, and Russia was allocated 33 MtC of sinks. Due to its withdrawal from the negotiations there is no such agreed sink allowance for the US but prior to withdrawal the sinks allowance being discussed was 50 to 75 MtC.

high transaction costs are likely, and the actual supply may be a small share of the total "hot air"; i.e., 5 to 10% or even less. We parameterize supply using a convenient "yardstick": *the amount of CDM (in terms of carbon emissions abated) profitable in 2010 at 100 dollars*[8]. The central estimate we used for this benchmark was 100 MtC. Sensitivity scenarios were performed with the assumptions of 0, 50, and 150 millions tons of carbon. The equation used in the model is the following:

$$S_t = (1+\delta)^{t-2010} \alpha \sqrt{\frac{p_t}{100}} \tag{4}$$

where $\alpha$ represents the CDM parameter, and $\delta$ the annual growth of the CDM per year parameterized in this paper to 2.5%/year.

# 5 Scenarios and numerical results

We consider the "Kyoto forever" case where the Kyoto targets for 2008-2012 are retained through the end of the simulation period. We consider only abatement of fossil $CO_2$ emissions (excluding sinks and non $CO_2$ GHGs) for the following scenarios: (1) the U.S. in the Protocol, (2) the situation as it now exists with the U.S. out, and (3) cases where the potential of CDM is modified. For each of these, we first consider the competitive case where Russia and Ukraine do not restrict their supply of "hot air". Then, we assess the case where Russia and Ukraine act as a "myopic" monopoly, and maximize their revenues at each period of time. Finally, the case of inter-temporal monopolistic behavior is evaluated. We assume a discount rate of 5% and a final stock of permits of zero[9].

## 5.1 Russia's strategy in the market for tradable emissions permits

As shown in Figure 3, in the case when the U.S is in the Kyoto Protocol, the competitive price in 2010 is $80/tC for the EPPA model results. This rises to $97/tC under the myopic monopoly results, and to $117/tC when Russia and Ukraine intertemporally optimize. The corresponding prices for GEMINI-E3 are $53/tC, $69/tC, and $83/tC. The myopic monopolistic prices are lower than the inter-temporal monopolistic prices in the short term (2010-2015), and higher in the long term (2030-2040).

Not surprisingly, carbon prices tend to be higher with EPPA than with GEMINI-E3. Since the amount of "hot air" is exogenously set and MAC curves for Russia and Ukraine are very similar in the two models, this result is explained by the demand for flexible instruments derived from the models. Indeed, we saw that EPPA gives higher demand than GEMINI-E3 for the whole period of time (see Figure 1).

In Figure 4, we can see that the amount of permits supplied by Russia and Ukraine depends on the behavioral assumption. When Russia and Ukraine are allowed to behave strategically, they have an interest in restricting their supply of permits and to bank them. The sales of permits by Russia are always higher in the competitive case compared to the monopolistic scenarios. In the competitive and myopic monopolistic cases, the supply of permits by Russia is fairly stable other time. This is not true in the inter-temporal monopolistic case where Russia banks some permits in order to maximize its trading gains. This result is observed with the two models, although Russia banks more permits with EPPA since carbon prices increase more rapidly in the long run than in GEMINI-E3.

The most immediately noticeable effect of the U.S. withdrawal from the Kyoto Protocol is that it has a depressing impact on the price of carbon permits (Figure 5). Both models show this negative effect of demand reduction on the trading market, although the detailed results coming from the two

[8]The curve is then completed assuming a function of power 1/2. For latter period, it is assumed than the potential at 100$ increases at the rate of world growth, 2.5 % a year.

[9]The results may be sensitive to how the terminal conditions are specified. In tests, not reported here, the results were not sensitive to reasonable assumptions regarding these conditions.

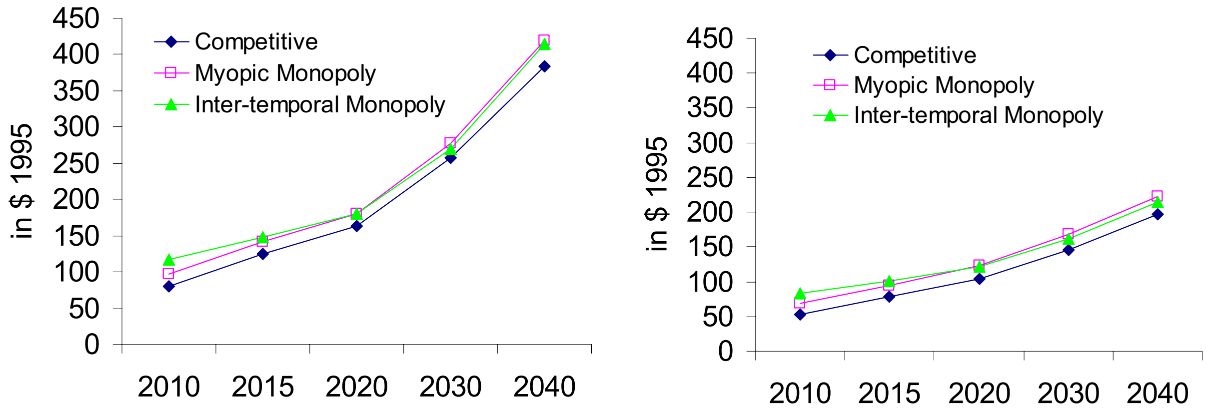


Figure 3: Price of permits depending on Russia's behavior (U.S. in) – EPPA (left) *versus* GEMINI-E3 (right)

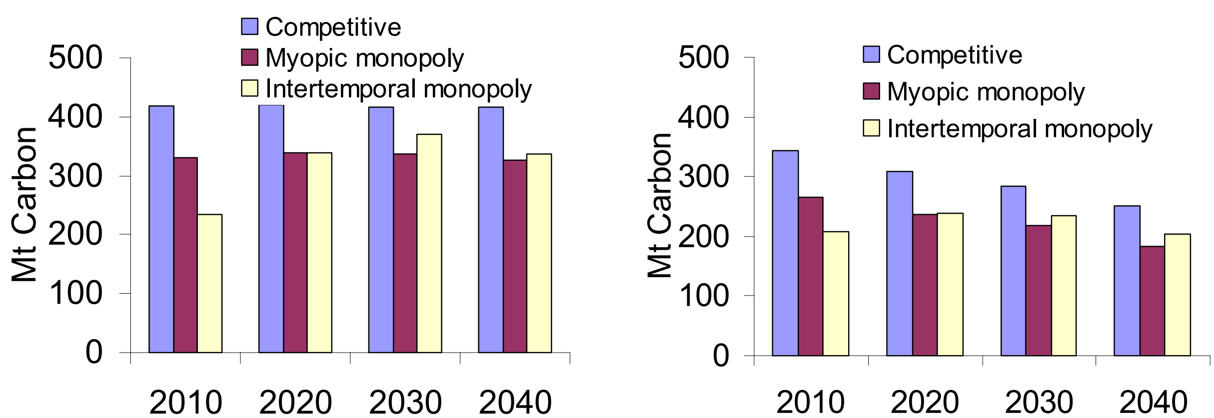


Figure 4: Supply of permits by Russia and Ukraine (U.S. in) – EPPA (left) *versus* GEMINI-E3 (right)

models differ more sharply than in the previous scenario. In the short run, modeling results based on EPPA and GEMINI-E3 are similar when the market is assumed to be perfectly competitive. Carbon prices tend to rise more rapidly in EPPA than in GEMINI-E3 in the different scenarios. Indeed, the quantity of carbon permits demanded is higher in EPPA than in GEMINI-E3 even at this relatively high level of carbon price.

The other noticeable result is that the effects of strategic behavior on the carbon price are much greater in both models with the U.S. out (Figure 5). Permit sales are restricted considerably, in particular in the nearer term (Figure 6).

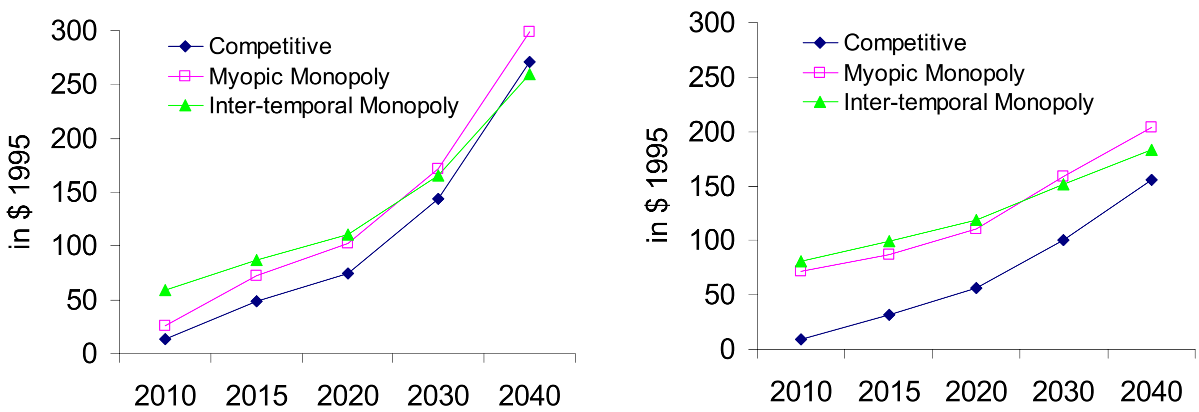


Figure 5: Price of permits depending on Russian behavior (U.S. out) – EPPA (left) *versus* GEMINI-E3 (right)

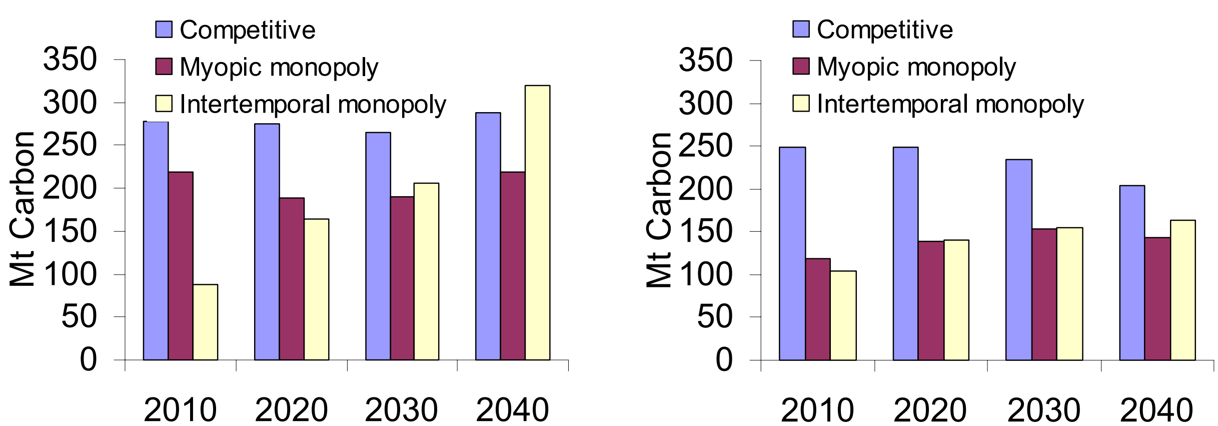


Figure 6: Supply of permits by Russia and Ukraine (U.S. out) – EPPA (left) *versus* GEMINI-E3 (right)

## 5.2 Terms of trade and welfare impacts

Previous studies have emphasized the impact of climate policies on the terms of trade (Babiker et al, 2000; Babiker et al, 2001; Bernard and Vielle, 2002). In this section we focus on the terms of trade effect introduced in Section 3. The carbon constraint has a favorable terms of trade effect for countries importing energy, whose price declines as a result of energy demand contraction. Being a large exporter of energy, Russia may see its terms of trade negatively impacted by the implementation of the Kyoto Protocol. Russia's position may be improved by emissions trading, however. It gains not only from the sale of permits but also from a lower constraint on energy demand in other OECD countries. Thus, Russia faces a trade-off between energy revenues and permits revenues. On one hand, Russia can maximize its trading gains by banking permits. On the other hand, restricting emissions permit sales induces losses from lower energy prices.

Welfare and terms of trade (the weighted price of exports divided by the weighted price of imports) impacts have been computed in GEMINI-E3. For comparison, four scenarios are simulated: 1) Kyoto without trading, 2) Kyoto with competitive trading, 3) Kyoto with myopic behavior on the emission trading market, 4) Kyoto with intertemporal behavior on the emission trading market.

As expected, we can see in Figure 7 that the terms of trade tend to deteriorate in Russia, and that welfare is reduced, when Kyoto is implemented without flexibility. Things are radically different when Russia is allowed to sell emissions permits to other Annex B regions. In that policy case, terms of trade are improved in Russia compared to the baseline scenario. This change is the result of two main effects. First, as suggested before, the depressing impact of the Kyoto Protocol on world energy demand and prices might be reduced by emissions trading in general, and "hot air" trading in particular. Second, domestic prices tend to rise in Russia since emissions abatement is higher. As shown in Figure 8, the same phenomenon occurs when the US is out of the Protocol. But welfare gains from emissions trading are reduced since permit demand and prices are lower. The incentive for Russia to restrict its supply of permits in order to sustain permits prices is thus higher.

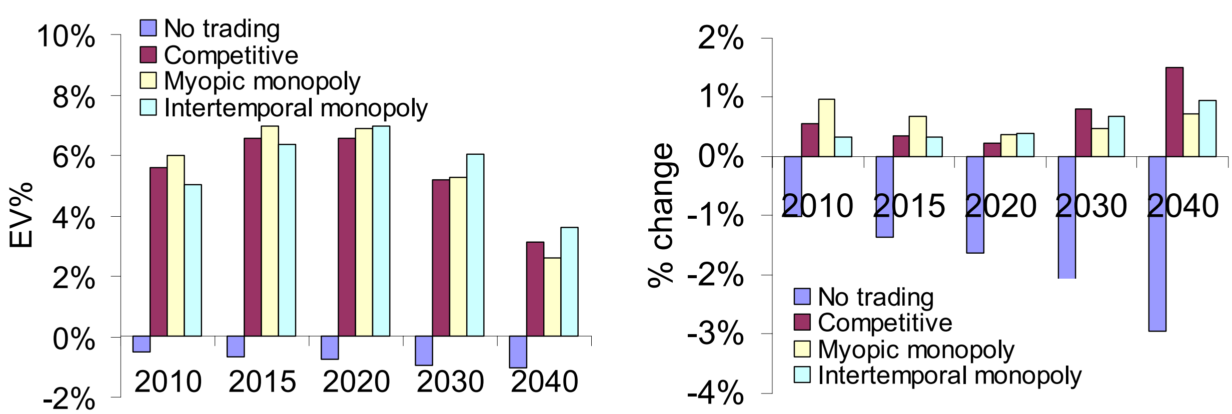


Figure 7: Welfare (Left) and terms of trade (Right) effects with the US in

In general, the Kyoto Protocol has an ambiguous effect on the Russia's terms of trade. The relevant prices that are most affected by the policy variants are energy export prices and the carbon price. Without permit trade the carbon price does not enter Russia's terms of trade calculation. With trading the carbon price represents a major improvement for Russian export sector. Thus, we see that without emission trading the terms of trade deteriorates because of a decrease in fossil-fuel prices and that they improve with trading. Prices of other exports and imports will change as well, but these changes tend to be smaller. Over time the net effect on the terms of trade depends on the relative rise of the carbon price compared to the decline in the world energy prices, with the shareweight varying with exports.

Compared to the no trading case, the welfare gains to Russia are \$389 billion over the entire period in the competitive case, \$406 billion in the myopic case and \$411 billion in the intertemporal monopoly case (with GEMINI-E3). The welfare benefits of strategic behavior by Russia is thus relatively small, at most $22 billion, when the U.S. is in the Protocol. When the U.S. is out, the welfare gains are $147 billion in the competitive case, $239 billion in the myopic monopoly case, and $267 billion in the intertemporal monopoly case (with GEMINI-E3); i.e., the gains from strategic behavior rise to as much as $120 billion. The time path of welfare effects shows somewhat greater benefits for the myopic monopoly case in earlier years than in the intertemporal monopoly case. Banking (intertemporal optimization) results in greater benefits in later years at the expense of benefits in earlier years.

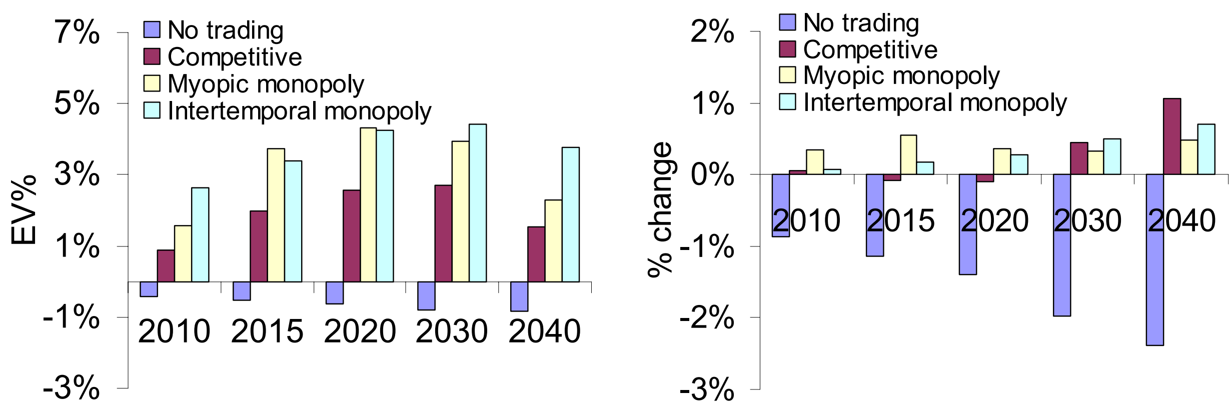


Figure 8: Welfare (Left) and terms of trade (Right) effects with the US out

## 6 The impacts of CDM credit availability

In this section, we assess the sensitivity of our modeling results to assumptions about CDM potential in developing countries. Since we are interested here mainly in its impact in Russia's strategic behavior, we show results only for the "inter-temporal optimization case".

As shown on Figure 9, in the short run the permit prices are relatively insensitive to the quantity of CDM whatever the MAC curves for Russia and Ukraine and the demand curves of the remaining Annex B countries. In the long run, however, the prices of carbon permits tend to go down when more CDM is available. This is particularly true when we use the demand curves generated by GEMINI-E3. Since the demand curves are relatively steep in GEMINI-E3, carbon prices decrease more rapidly when the demand of permits is reduced. When the U.S. is out of the Protocol, the demand estimated with GEMINI-E3 is even more inelastic to prices in the long run. As a result, the assumptions about CDM tend to have an even larger impact on the price of carbon emission permits (Figure 10).

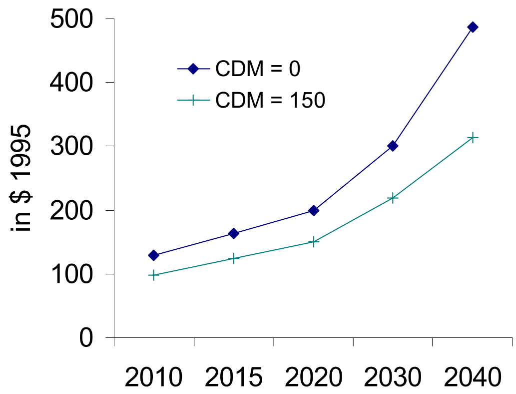


Figure 9: Price of permits with the U.S. in depending on CDM potential – EPPA (left) *versus* GEMINI-E3 (right)

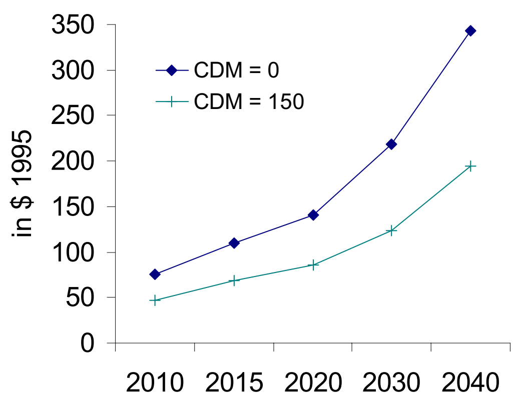


Figure 10: Price of permits without the U.S. depending on CDM Potential – EPPA (left) *versus* GEMINI-E3 (right)

## 7 Conclusion

The emissions allotment under the Kyoto Protocol produced a situation where Russia and Ukraine are likely to have permits in excess of their business-as-usual emissions for decades. This means that these countries are likely to be the dominant suppliers of permits in a trading system. This dominant supplier position gives these countries monopoly power, which can be exercised to increase permits revenues. A proper analysis of the optimal strategic decision requires both an intertemporal model and a representation of the tradeoff faced between permit and energy market revenue, as higher carbon prices in Annex B results in lower world oil prices, a major Russian export. More broadly one needs to consider the overall terms of trade and macroeconomic impacts that result from higher carbon prices in Annex B should Russia behave strategically in the permit market. In this paper, we developed a dynamic model to represent Russia and Ukraine's strategic interest. We parameterized the model using the MIT-EPPA and GEMINI-E3 CGE models that fully capture the trade macroeconomic effects of permit sales restrictions. The main results of our analysis can be summarized as follows:

- With the withdrawal of the U.S. from the Kyoto Protocol, Russia and Ukraine have a much stronger incentive for strategic behavior. The discounted present value of their gains through 2040 from permit sales are multiplied by as much as a factor of six (GEMINI-E3 case) if they intertemporally optimize and strategically limit permit sales compared with myopic competitive market solution.
- The small gains from strategic behavior when the U.S. is in the Protocol are due to two factors. One reason for this small effect is that the growth in emissions is such that there is little benefit from banking of emissions, i.e., the Kyoto forever constraint with the U.S. in the Protocol results in little incentive for temporal reallocation. The other reason is that with the U.S. in the Protocol the energy market effects are that much larger and the lost energy revenue largely offsets the gains in revenue from restricting permits.
- The availability of CDM credits would weaken Russia and Ukraine's market power to some degree. However, the specific impact remains highly speculative. One reason is that the potential supply of CDM credits is uncertain because the rules that will govern admissible credits have not been finalized, and decisions about admissibility are likely to be evaluated on a case-by-case basis. We further found a significant difference in the CDM effects even among the cases we considered that depended on the different elasticities of demand for permits as estimated with the two CGE models. Notably, GEMINI-E3, the model with more inelastic demand, showed a greater effect of CDM credits on reducing Russia and Ukraine's market power, and this effect was greatest in the case where the U.S. is not part of the Protocol. This may partly reflect the fact that it excludes the Eastern European countries, which offer another source of permit credit supply.

There remain uncertainties in any such calculations because they depend on future growth in emissions both in the regions likely to be purchasers of permits as well as in those regions likely to be sellers. These uncertainties stem from our inability to project GDP growth and technological change with great precision. Moreover, the results we generated require cooperation between Russia and Ukraine but we were limited to this case because the underlying CGE models do not disaggregate these countries. We have also looked only at carbon emissions from fossil fuels, and have not considered the potential for carbon sequestration in forests and agricultural soils or the potential effects of including the non-$CO_2$ greenhouse gases. Finally, we considered only the cases of Kyoto forever either with or without the U.S. The strategic decision actually faced by Russia and Ukraine must be made under uncertainty about if and when the U.S. might enter the agreement, whether and by how much the Kyoto target might be changed over time, and whether other countries such as China might enter the agreement. These policy uncertainties are in addition to those in emissions growth and in the structure of demand for permits, which we have tried to capture by parameterizing our dynamic model based on two different economic models.

## 8 Acknowledgements

The authors gratefully acknowledge the support of the Joint Program on the Science and Policy of Global Change, funded through a government-industry partnership including the US Department of Energy's Integrated Assessment Program in the Office of Biological and Environmental Research (DE-FG02-94ER61937), the US Environmental Protection Agency (X-827703-01-0), and a group of corporate sponsors from the United States and other countries. In addition, the work reported here was partially supported by an NCCR-Climate grant. Helpful comments and suggestions have been provided by Alain Haurie, Henry Jacoby, and other anonymous reviewers. The views expressed herein, including any remaining errors, are solely the responsibility of the authors.

## 9 References

Babiker M., H. Jacoby, J. Reilly, and D. Reiner, 2002, The Evolution of a Climate Regime: Kyoto to Marrakech, MIT Joint Program on the Science and Policy of Global Change, Report 82, February.

Babiker, M., J. Reilly, and H. Jacoby, 2000, The Kyoto Protocol and Developing Countries, Energy Policy 28, 525-536.

Babiker, M., J. Reilly, M. Mayer, R. S. Eckaus, I. Sue Wing, and R. Hyman, 2001, The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results, MIT Joint Program on the Science and Policy of Global Change, Report 71, Cambridge, MA, February.

Babiker, M., L. Viguier, J. Reilly, A. D. Ellerman, and P. Criqui, 2001, The Welfare Costs of Hybrid Carbon Policies in the European Union, MIT Joint Program on the Science and Policy of Global Change, Report 74, Cambridge, MA.

Bernard A. L. and M. Vielle, 2000, Comment allouer un coût global d'environnement entre pays: permis négociables versus taxes ou permis négociables et taxes?, Economie Internationale 82, 2ème trimestre.

Bernard A. L. and M. Vielle, 2001, Conséquences de la non ratification du Protocole de Kyoto par les Etats-Unis: une évaluation quantitative préliminaire avec le modèle GEMINI-E3, MELT/CEA

Bernard A. L. and M. Vielle, 2002, Does Non Ratification of the Kyoto Protocol by the U.S. Increase the Likelihood of Monopolistic Behavior by Russia in the Market of Tradable Permits?, Fifth Annual Conference on Global Economic Analysis, June 5-7, 2002 - Taipei, Taiwan

Bernard A. L. and M. Vielle, 2003, Measuring the Welfare Cost of Climate Change Policies: A Comparative Assessment Based on the Computable General Equilibrium Model GEMINI-E3, Environmental Modeling and Assessment, Special Issue on Modeling the economic response to global climate change, to appear.

Bernstein P.M., W.D. Montgomery, T. Rutherford, and G.-F. Yang, 1999, Effect of Restrictions on International Permit Trading: The MS-MRT model, The Energy Journal, Special Issue, 221-256.

Blanchard O., P. Criqui, and A. Kitous, 2002, Après La Haye, Bonn et Marrakech: le futur marché international des permis de droits d'émissions et la question de l'air chaud, IEPE, Working Paper, Janvier

Bohringer C., 2000, Cooling Down Hot Air: a Global CGE Analysis of Post-Kyoto Carbon Abatement Strategies, Energy Policy 28, 779-789.

Bohringer C., 2001, Climate Politics From Kyoto to Bonn: From Little to Nothing? ZEW Discussion Paper 01-49.

Burniaux J-M., 1998, How Important is market power in achieving Kyoto ? : an assessment based on the GREEN model, OECD Experts Workshop on Climate Change and Economic Modeling : Background Analysis for the Kyoto Protocol, Paris, 17-18 September 1998.

Ciorna U., A. Lanza, and F. Pauli, 2001, Kyoto Protocol and Emission Trading: Does the U.S. make a difference? Nota Di Lavoro 90.2001, Fondazione Eni Enrico Mattei.

Den Elzen M.G.J. and de Moor A.P.G., 2001, Evaluating the Bonn Agreement and some key issues, RIVM rapport 728001016/2001.

Ellerman, A. D., and A. Decaux, 1998, Analysis of Post-Kyoto $CO_2$ Emissions Trading Using Marginal Abatement Curves, MIT Joint Program on the Science and Policy of Global Change, Report 40, Cambridge, MA.

Ellerman, A.D., and I. Sue Wing, 2000, Supplementarity: An Invitation for Monopsony?, Energy Journal 21(4), 29-59.

Hertel, T., 1997, Global Trade Analysis: Modeling and Applications (Cambridge University Press, Cambridge, MA).

Jacoby, H. D., and I. Sue Wing, 1999, Adjustment Time, Capital Malleability and Policy Cost, The Energy Journal, Special Issue: The Costs of the Kyoto Protocol: A Multi-Model Evaluation, 73-92.

Kotov, V., 2002, Policy in Transition: New Framework for Russia's Climate Policy. Fondazione Eni Enrico Mattei. Nota Di Lavoro 58.2002.

Kotov V., Nikitina, E., 2002, Reorganization of Environmental Policy in Russia: The Decade of Success and Failures in Implementation and Perspective Quests. Fondazione Eni Enrico Mattei. Nota Di Lavoro 57.2002.

Manne A.S. and R.G. Richels, 2001, U.S. Rejection of the Kyoto Protocol: the impact on compliance cost and $CO_2$ emissions, , Energy Modeling Forum, Meeting on Burden Sharing and the Cost of Mitigation, Snowmass, Colorado, September.

Paltsev, S. V., 2000, The Kyoto Protocol: "Hot air" for Russia?, Department of Economics, University of Colorado, Working Paper No. 00-9, October.

Reilly, J., R. Prinn, J. Harnisch, J. Fitzmaurice, H. Jacoby, D. Kicklighter, P. Stone, A. Sokolov, and C. Wang, 1999, Multi-Gas Assessment of the Kyoto Protocol, Nature 401, 549-555.

Reilly, J., H. Jacoby, and R. Prinn, 2003, Multi-Gas Contributors to Global Climate Change: Climate Impacts and Mitigation Costs of Non-CO2 Gases. Pew Center on Global Climate Change, Arlington, VA. February.

UNFCCC, 1998, Second National Communication of the Russian Federation to the Secretariat of UNFCCC.

UNFCCC, 1999, Submission by Germany on Behalf of the European Community, its Member States, and Croatia, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovak Republic and Slovenia on Emission Trading (Art. 17 KP).

U.S. DOE, 2002, International Energy Outlook (IEO 2002). Energy Information Administration, Washington, DC.

Victor D.G., N. Nakicenovic, and N. Victor, 1998, The Kyoto Protocol Carbon Bubble: Implications for Russia, Ukraine, and Emission Trading. IIASA Interim Report IR-98-094.

Viguier, L., M. Babiker, and J. Reilly, 2001, Carbon Emissions and The Kyoto Commitment in the European Union, MIT Joint Program on the Science and Policy of Global Change, Report 70, Cambridge, MA.

## **REPORT SERIES** of the **MIT** *Joint Program on the Science and Policy of Global Change*

1. **Uncertainty in Climate Change Policy Analysis** *Jacoby & Prinn* December 1994
2. **Description and Validation of the MIT Version of the GISS 2D Model** *Sokolov & Stone* June 1995
3. **Responses of Primary Production and Carbon Storage to Changes in Climate and Atmospheric $CO_2$ Concentration** *Xiao et al.* October 1995
4. **Application of the Probabilistic Collocation Method for an Uncertainty Analysis** *Webster et al.* January 1996
5. **World Energy Consumption and $CO_2$ Emissions: 1950-2050** *Schmalensee et al.* April 1996
6. **The MIT Emission Prediction and Policy Analysis (EPPA) Model** *Yang et al.* May 1996
7. **Integrated Global System Model for Climate Policy Analysis** *Prinn et al.* June 1996 (*superseded by No. 36*)
8. **Relative Roles of Changes in $CO_2$ and Climate to Equilibrium Responses of Net Primary Production and Carbon Storage** *Xiao et al.* June 1996
9. **$CO_2$ Emissions Limits: *Economic Adjustments and the Distribution of Burdens*** *Jacoby et al.* July 1997
10. **Modeling the Emissions of $N_2O$ & $CH_4$ from the Terrestrial Biosphere to the Atmosphere** *Liu* August 1996
11. **Global Warming Projections: *Sensitivity to Deep Ocean Mixing*** *Sokolov & Stone* September 1996
12. **Net Primary Production of Ecosystems in China and its Equilibrium Responses to Climate Changes** *Xiao et al.* Nov 1996
13. **Greenhouse Policy Architectures and Institutions** *Schmalensee* November 1996
14. **What Does Stabilizing Greenhouse Gas Concentrations Mean?** *Jacoby et al.* November 1996
15. **Economic Assessment of $CO_2$ Capture and Disposal** *Eckaus et al.* December 1996
16. **What Drives Deforestation in the Brazilian Amazon?** *Pfaff* December 1996
17. **A Flexible Climate Model For Use In Integrated Assessments** *Sokolov & Stone* March 1997
18. **Transient Climate Change & Potential Croplands of the World in the 21st Century** *Xiao et al.* May 1997
19. **Joint Implementation: *Lessons from Title IV's Voluntary Compliance Programs*** *Atkeson* June 1997
20. **Parameterization of Urban Sub-grid Scale Processes in Global Atmospheric Chemistry Models** *Calbo et al.* July 1997
21. **Needed: A Realistic Strategy for Global Warming** *Jacoby, Prinn & Schmalensee* August 1997
22. **Same Science, Differing Policies; *The Saga of Global Climate Change*** *Skolnikoff* August 1997
23. **Uncertainty in the Oceanic Heat and Carbon Uptake & their Impact on Climate Projections** *Sokolov et al.* Sept 1997
24. **A Global Interactive Chemistry and Climate Model** *Wang, Prinn & Sokolov* September 1997
25. **Interactions Among Emissions, Atmospheric Chemistry and Climate Change** *Wang & Prinn* September 1997
26. **Necessary Conditions for Stabilization Agreements** *Yang & Jacoby* October 1997
27. **Annex I Differentiation Proposals: *Implications for Welfare, Equity and Policy*** *Reiner & Jacoby* October 1997
28. **Transient Climate Change & Net Ecosystem Production of the Terrestrial Biosphere** *Xiao et al.* November 1997
29. **Analysis of $CO_2$ Emissions from Fossil Fuel in Korea: 1961–1994** *Choi* November 1997
30. **Uncertainty in Future Carbon Emissions: *A Preliminary Exploration*** *Webster* November 1997
31. **Beyond Emissions Paths: *Rethinking the Climate Impacts of Emissions Protocols*** *Webster & Reiner* November 1997
32. **Kyoto's Unfinished Business** *Jacoby, Prinn & Schmalensee* June 1998
33. **Economic Development and the Structure of the Demand for Commercial Energy** *Judson et al.* April 1998
34. **Combined Effects of Anthropogenic Emissions & Resultant Climatic Changes on Atmosph. OH** *Wang & Prinn* April 1998
35. **Impact of Emissions, Chemistry, and Climate on Atmospheric Carbon Monoxide** *Wang & Prinn* April 1998
36. **Integrated Global System Model for Climate Policy Assessment: *Feedbacks and Sensitivity Studies*** *Prinn et al.* June 1998
37. **Quantifying the Uncertainty in Climate Predictions** *Webster & Sokolov* July 1998
38. **Sequential Climate Decisions Under Uncertainty: *An Integrated Framework*** *Valverde et al.* September 1998
39. **Uncertainty in Atmospheric $CO_2$ (Ocean Carbon Cycle Model Analysis)** *Holian* October 1998 (*superseded by No. 80*)
40. **Analysis of Post-Kyoto $CO_2$ Emissions Trading Using Marginal Abatement Curves** *Ellerman & Decaux* October 1998
41. **The Effects on Developing Countries of the Kyoto Protocol & $CO_2$ Emissions Trading** *Ellerman et al.* November 1998
42. **Obstacles to Global $CO_2$ Trading: *A Familiar Problem*** *Ellerman* November 1998
43. **The Uses and Misuses of Technology Development as a Component of Climate Policy** *Jacoby* November 1998
44. **Primary Aluminum Production: *Climate Policy, Emissions and Costs*** *Harnisch et al.* December 1998
45. **Multi-Gas Assessment of the Kyoto Protocol** *Reilly et al.* January 1999
46. **From Science to Policy: *The Science-Related Politics of Climate Change Policy in the U.S.*** *Skolnikoff* January 1999
47. **Constraining Uncertainties in Climate Models Using Climate Change Detection Techniques** *Forest et al.* April 1999
48. **Adjusting to Policy Expectations in Climate Change Modeling** *Shackley et al.* May 1999
49. **Toward a Useful Architecture for Climate Change Negotiations** *Jacoby et al.* May 1999
50. **A Study of the Effects of Natural Fertility, Weather & Productive Inputs in Chinese Agriculture** *Eckaus & Tso* July 1999
51. **Japanese Nuclear Power and the Kyoto Agreement** *Babiker, Reilly & Ellerman* August 1999
52. **Interactive Chemistry and Climate Models in Global Change Studies** *Wang & Prinn* September 1999

***Contact the Joint Program Office to request a copy. The Report Series is distributed at no charge.***

53. **Developing Country Effects of Kyoto-Type Emissions Restrictions** *Babiker & Jacoby* October 1999
54. **Model Estimates of the Mass Balance of the Greenland and Antarctic Ice Sheets** *Bugnion* October 1999
55. **Changes in Sea-Level Associated with Modifications of Ice Sheets over 21st Century** *Bugnion* October 1999
56. **The Kyoto Protocol and Developing Countries** *Babiker, Reilly & Jacoby* October 1999
57. **Can EPA Regulate GHGs Before the Senate Ratifies the Kyoto Protocol?** *Bugnion & Reiner* November 1999
58. **Multiple Gas Control Under the Kyoto Agreement** *Reilly, Mayer & Harnisch* March 2000
59. **Supplementarity: *An Invitation for Monopsony?*** *Ellerman & Sue Wing* April 2000
60. **A Coupled Atmosphere-Ocean Model of Intermediate Complexity** *Kamenkovich et al.* May 2000
61. **Effects of Differentiating Climate Policy by Sector: *A U.S. Example*** *Babiker et al.* May 2000
62. **Constraining Climate Model Properties Using Optimal Fingerprint Detection Methods** *Forest et al.* May 2000
63. **Linking Local Air Pollution to Global Chemistry and Climate** *Mayer et al.* June 2000
64. **The Effects of Changing Consumption Patterns on the Costs of Emission Restrictions** *Lahiri et al.* August 2000
65. **Rethinking the Kyoto Emissions Targets** *Babiker & Eckaus* August 2000
66. **Fair Trade and Harmonization of Climate Change Policies in Europe** *Viguier* September 2000
67. **The Curious Role of "Learning" in Climate Policy: *Should We Wait for More Data?*** *Webster* October 2000
68. **How to Think About Human Influence on Climate** *Forest, Stone & Jacoby* October 2000
69. **Tradable Permits for GHG Emissions: *A primer with reference to Europe*** *Ellerman* November 2000
70. **Carbon Emissions and The Kyoto Commitment in the European Union** *Viguier et al.* February 2001
71. **The MIT Emissions Prediction and Policy Analysis (EPPA) Model: *Revisions, Sensitivities, and Comparisons of Results*** *Babiker et al.* February 2001
72. **Cap and Trade Policies in the Presence of Monopoly and Distortionary Taxation** *Fullerton & Metcalf* March 2001
73. **Uncertainty Analysis of Global Climate Change Projections** *Webster et al.* March 2001
74. **The Welfare Costs of Hybrid Carbon Policies in the European Union** *Babiker et al.* June 2001
75. **Feedbacks Affecting the Response of the Thermohaline Circulation to Increasing $CO_2$** *Kamenkovich et al.* July 2001
76. **$CO_2$ Abatement by Multi-fueled Electric Utilities: *An Analysis Based on Japanese Data*** *Ellerman & Tsukada* July 2001
77. **Comparing Greenhouse Gases** *Reilly, Babiker & Mayer* July 2001
78. **Quantifying Uncertainties in Climate System Properties using Recent Climate Observations** *Forest et al.* July 2001
79. **Uncertainty in Emissions Projections for Climate Models** *Webster et al.* August 2001
80. **Uncertainty in Atmospheric $CO_2$ Predictions from a Parametric Uncertainty Analysis of a Global Ocean Carbon Cycle Model** *Holian, Sokolov & Prinn* September 2001
81. **A Comparison of the Behavior of Different Atmosphere-Ocean GCMs in Transient Climate Change Experiments** *Sokolov, Forest & Stone* December 2001
82. **The Evolution of a Climate Regime: *Kyoto to Marrakech*** *Babiker, Jacoby & Reiner* February 2002
83. **The "Safety Valve" and Climate Policy** *Jacoby & Ellerman* February 2002
84. **A Modeling Study on the Climate Impacts of Black Carbon Aerosols** *Wang* March 2002
85. **Tax Distortions and Global Climate Policy** *Babiker, Metcalf & Reilly* May 2002
86. **Incentive-based Approaches for Mitigating GHG Emissions: *Issues and Prospects for India*** *Gupta* June 2002
87. **Sensitivities of Deep-Ocean Heat Uptake and Heat Content to Surface Fluxes and Subgrid-Scale Parameters in an Ocean GCM with Idealized Geometry** *Huang, Stone & Hill* September 2002
88. **The Deep-Ocean Heat Uptake in Transient Climate Change** *Huang et al.* September 2002
89. **Representing Energy Technologies in Top-down Economic Models using Bottom-up Information** *McFarland, Reilly & Herzog* October 2002
90. **Ozone Effects on Net Primary Production and Carbon Sequestration in the Conterminous United States Using a Biogeochemistry Model** *Felzer et al.* November 2002
91. **Exclusionary Manipulation of Carbon Permit Markets: A Laboratory Test** *Carlén* November 2002
92. **An Issue of Permanence: Assessing the Effectiveness of Temporary Carbon Storage** *Herzog et al.* December 2002
93. **Is International Emissions Trading Always Beneficial?** *Babiker et al.* December 2002
94. **Modeling Non-$CO_2$ Greenhouse Gas Abatement** *Hyman et al.* December 2002
95. **Uncertainty Analysis of Climate Change and Policy Response** *Webster et al.* December 2002
96. **Market Power in International Carbon Emissions Trading: A Laboratory Test** *Carlén* January 2003
97. **Emissions Trading to Reduce Greenhouse Gas Emissions in the United States: The McCain-Lieberman Proposal** *Paltsev et al.* June 2003
98. **Russia's Role in the Kyoto Protocol** *Bernard et al.* June 2003

***Contact the Joint Program Office to request a copy. The Report Series is distributed at no charge.***