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The Value of Emissions Trading

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Abstract

This paper estimates the value of international emissions trading, focusing attention on a here-to-fore neglected component: its value as a hedge against uncertainty. Much analysis has been done of the Kyoto Protocol and other potential international greenhouse gas mitigation policies comparing the costs of achieving greenhouse gas emission targets with and without trading. These studies often show large cost reductions for all Parties under trading compared to a no trading case. We investigate the welfare gains of including emissions trading in the presence of uncertainty in economic growth rates, using both a partial equilibrium model based on marginal abatement cost curves and a computable general equilibrium model that allows consideration of the interaction of emissions trading with existing energy taxes and changes in terms of trade. We find that the hedge value of international trading is small relative to its value in reallocating emissions reductions when, as in the Kyoto Protocol, the burden-sharing scheme does not resemble a least-cost allocation. The Kyoto Protocol also allocated excess allowances to Russia, so-called “hot air,” and much of the value often attributed to emissions trading stems from other Parties having access to these extra allowances, which has the effect of lowering the aggregate emissions target. We also find that the effects of preexisting tax distortions and terms of trade dominate the hedge value of trading. We conclude that the primary value of emissions trading in international agreements is as a burden-sharing or wealth transfer mechanism and should be judged accordingly.

Contents

1. Introduction.....	1
2. Model, Data, and Policy Cases	2
3. The Conventional Case: Emissions Trading Under Certainty.....	5
4. Emissions Trading under Uncertainty: Partial Equilibrium Estimates.....	6
5. Emissions Trading under Uncertainty: General Equilibrium Estimates	9
6. Conclusions.....	14
7. References.....	16

1. INTRODUCTION

The design and implementation of the Kyoto Protocol includes emissions trading as one of its primary elements (United Nations, 1997). Much analysis has been done of the Protocol and other potential greenhouse gas mitigation policies comparing the costs of achieving greenhouse gas emission targets with and without trading (Babiker *et al.*, 2002; Manne and Richels, 1999; Weyant and Hill, 1999). These studies often show large cost reductions for all Parties under trading compared to a no trading case. Our contention is that emissions trading has “value” in such studies because the targets assigned to different countries either intentionally or accidentally redistributed the cost burden of the reductions among the Parties. In our view, the value estimated in such studies is not the value of emissions trading as a policy instrument per se but is more appropriately thought of as the savings from allowing a reallocation from an initial burden sharing agreement to a least cost allocation. This leads to our interest in estimating the additional value of emission trading as a hedge against uncertainty. The “hedge value” results from the fact

that countries are uncertain about their future emissions growth. Thus, even if the negotiated targets were such that the expected level of net trade was zero, one might expect that there would be a positive *expected value* of trade because of uncertainty.

The logic for positive expected value when the expected net trade is zero is straightforward: partial equilibrium analysis of emissions trading shows that all parties benefit from trade, whether they are a buyer or a seller. The worst outcome from having the trading option available is that *ex post* it has a zero value. Thus, the *ex ante* expected value of trade across uncertain outcomes is necessarily positive. This value of international emissions trading more closely corresponds to the equivalent domestic case for emissions trading, where the regulator has poor information on the relative abatement opportunities among different firms. Trading allows the market to correct an initial misallocation by the regulator of reduction targets among firms. The conventional analyses of the Kyoto Protocol, conducted under certainty, do not capture this value of emissions trading at all.

Our goal is to estimate the hedge value of international emissions trading for greenhouse gas abatement. We develop a stochastic model of emissions growth (and thus abatement cost). We assign Parties a target so that net trade is zero in the case where all parameter values of the abatement model are at their expected value levels. We then simulate the model for hundreds of different parameter sets drawn from probability density functions that drive emissions growth. For each parameter set we simulate the policy with and without emissions trading. Comparing the welfare cost of the trading and no trading case for each parameter set provides an estimate of the value of trade for each realization of the world. The expected value of trade is the mean of this distribution of benefits.

The paper is structured as follows: In Section 2, we describe the model, the data on uncertain parameters, and the policy cases we investigate. We use Section 3 to provide a benchmark with the conventional literature on the value of emissions trading, by comparing aggregate costs with and without trading when parameters of the model we use are simulated as if known with certainty. In Section 4, we develop a Marginal Abatement Curve (MAC) model to examine the value of trading under uncertainty in this simple framework. Section 5 then provides a stochastic analysis using a global CGE model where we investigate the value of emissions trading when mitigation policy interacts with existing energy taxes and also affects the terms of trade. Section 6 summarizes the results and discusses the policy relevance of them.

2. MODEL, DATA, AND POLICY CASES

The Emissions Prediction and Policy Analysis (EPPA) model (Paltsev *et al.*, 2005), a computable general equilibrium model of the world economy, is used both to estimate a marginal abatement curve model, and for simulations where we use it directly. EPPA Version 4 is a component of the MIT Integrated Global Systems Model (IGSM), developed to enable detailed studies of the effects of climate policies (Prinn *et al.*, 1999; Sokolov *et al.*, 2005). The main advantage of CGE models is their ability to capture the influence of a sector-specific (*e.g.*, energy, fiscal, or agricultural) policy on other industry sectors, on consumption, and also on

international trade. EPPA is a recursive-dynamic and multi-regional model covering the entire world economy. It is built on the economic and energy data from the GTAP dataset (Dimaranan and McDougall, 2002; Hertel, 1997). It has been used extensively for the study of climate policy (Babiker *et al.*, 2002; Jacoby *et al.*, 1997; McFarland *et al.*, 2004; Paltsev *et al.*, 2003; Reilly *et al.*, 2002; Viguiet *et al.*, 2003), climate/multi-gas interactions (Felzer *et al.*, 2004; Hyman *et al.*, 2003; Reilly *et al.*, 1999), and to study uncertainty in emissions and climate projections for climate models (Webster *et al.*, 2002; Webster *et al.*, 2003). **Table 1** provides an overview of the basic elements of the model, with greater details in Paltsev *et al.* (2005).

One of the primary drivers of uncertainty in emissions and abatement costs is the uncertainty in economic growth rates (Webster *et al.*, 2002). In EPPA, different rates of economic growth can be simulated by assuming different rates of labor productivity growth. A historical analysis of variability in GDP growth rates between 1960 and 2000 (Webster and Cho, 2006), provides a basis for constructing probability distributions for the labor productivity growth parameters. They fit probability distributions to the historical data for individual countries and for aggregate model regions, in annual and 5-year time steps. We used the variability of average annual growth

Table 1. Countries, Regions, and Sectors in the EPPA Model.

Country or Region	Sectors	Factors
Developed	Non-Energy	Capital
United States (USA)	Services (SERV)	Labor
Canada (CAN)	Energy-Intensive Products (EIT)	Land
Japan (JPN)	Other Industries Products (OTHR)	Crude Oil Resources
European Union+ ^a (EUR)	Transportation (TRAN)	Natural Gas Resources
Australia & New Zealand (ANZ)	Agriculture (AGRI)	Coal Resources
Former Soviet Union ^b (FSU)	Energy	Hydro Resources
Eastern Europe (EET)	Coal (COAL)	Shale Oil Resources
Developing	Crude Oil (OIL)	Nuclear Resources
India (IND)	Refined Oil (ROIL)	Wind/Solar Resources
China (CHN)	Natural Gas (GAS)	
Indonesia (IDZ)	Electric: Fossil (ELEC)	
Higher Income East Asia ^c (ASI)	Electric: Hydro (HYDR)	
Mexico (MEX)	Electric: Nuclear (NUCL)	
Central & South America (LAM)	Electric: Solar and Wind (SOLW)	
Middle East (MES)	Electric: Biomass (BIOM)	
Africa (AFR)	Electric: Natural Gas Combined Cycle (NGCC)	
Rest of World ^d (ROW)	Electric: NGCC with Sequestration (GGCAP)	
	Electric: Integrated Gasification with Combined Cycle and Sequestration (IGCAP)	
	Oil from Shale (SYNO)	
	Synthetic Gas (SYNG)	
Emissions of Climate Relevant Substances		
Substances	Sources	
CO ₂ , CH ₄ , N ₂ O, HFCs, SF ₆ , PFCs, CFCs, CO, NOx, SOx, VOCs, black carbon (BC), organic carbon (OC), NH ₃	Combustion of refined oil, coal, gas, biofuels and biomass burning, manure, soils, paddy rice, cement, land fills, and industrial production.	

^a The European Union (EU-15) plus countries of the European Free Trade Area (Norway, Switzerland, Iceland).

^b Russia, Ukraine, Belarus, Latvia, Lithuania, Estonia, Azerbaijan, Armenia, Georgia, Kyrgyzstan, Kazakhstan, Moldova, Tajikistan, Turkmenistan, and Uzbekistan.

^c South Korea, Malaysia, Phillipines, Singapore, Taiwan, Thailand.

^d All countries not included elsewhere: Turkey, and mostly Asian countries.

rates over 5-year periods, the time step of the EPPA model. Because projected growth rates differ from average growth rates of the past, for the stochastic simulations, the distributions of GDP growth were normalized for each region such that their median is equal to 1.0. Sample values drawn from these normalized distributions are multiplied times the projected reference labor productivity growth rate between the present (2005) and 2010. **Table 2** shows the statistics of the distribution of simulated annualized GDP growth. As shown, GDP growth rates in Canada and the EUR region composed mostly of the EU-15 countries have been less variable than Japan. GDP growth in the transition economies of Eastern Europe (EET) now part of the EU-25, and the FSU has been most variable. Webster and Cho (2006) also estimated the correlations in growth rates observed historically (**Table 3**), which we impose in the base runs.

We simulate three carbon mitigation policy cases to identify the separate effects of the Russian allocation, the effect of differential allocation of allowances among the remaining Parties, and the value of emissions trading as a hedge against uncertainty. In each, we focus on CO₂-only cases. The first case, *Kyoto with (w/) FSU*, approximates idealized implementation of the Kyoto Protocol as it has currently gone into force, with participation by Canada (CAN), the EU (EUR), Japan (JPN), Eastern European Countries (EET), and Russia and the other former Soviet Republics (FSU).¹ The United States (USA) and Australia (ANZ) are not constrained in this policy since they have not ratified the Protocol. The emissions constraints have been modified to account for credits for Article 3.4 carbon sinks negotiated at Bonn and Marrakech (United Nations, 1997). The second case, *Kyoto no FSU*, excludes the FSU from emissions trading. Many European countries have expressed a desire to meet caps without the Russian “hot air” and realistically Russia may not succeed in setting up a domestic trading system in a timely manner. This may be a more realistic, albeit, still relatively idealized implementation of the Protocol.

The third case, which we refer to as *Cost-Effective*, is constructed by reallocating allowances in the *Kyoto no FSU* case such that there is no incentive to trade when simulating policy under

Table 2. Uncertainty in GDP Growth Rates: Projected Annual Growth Rate 2005-2010 (percentage).

	CAN	JPN	EUR	EET	FSU
Lower 95%	1.4	0.9	1.4	-7.8	-6.0
Median	3.8	2.8	2.8	4.1	4.0
Mean	3.8	3.0	3.0	3.5	3.9
Upper 95%	6.2	6.5	6.4	11.2	12.0

Table 3. Historical Correlations in GDP Growth Rates.

	CAN	EUR	EET	FSU	JPN
CAN	1.00				
EUR	0.66	1.00			
EET	0.68	0.27	1.00		
FSU	0.71	0.64	0.47	1.00	
JPN	0.54	0.76	0.14	0.60	1.00

¹ Russia, Ukraine, and Baltic states are part of the Kyoto Parties accepting caps. The other former republics are not among the capped Parties, but they are not separately identifiable in the current version of the EPPA model.

reference assumptions of the model; *i.e.*, the autarkic carbon price is equal across regions. Once uncertainty is introduced, emission growth deviates from the reference, marginal costs of abatement differ, and regions have an incentive to trade. We are not claiming this expected-equal-marginal-cost allocation to be necessarily a goal or a desirable outcome of political negotiations. It is simply designed so that we can separately measure the hedge value of trading.

Each of these policy cases is simulated with and without emissions trading, which we designate with *tr* (trading) and *ntr* (no trading). For the uncertainty analysis, we focus on the cases without the FSU, stochastically simulating them using both the partial equilibrium and general equilibrium model. We then investigate the interactions of climate policy with tax distortions, by developing a case where we remove existing fuel tax distortions. Recent work (Babiker *et al.*, 2004; Paltsev *et al.*, 2004) has shown that trading may not be beneficial to Parties in the presence of tax distortions, a result we find here as well, and this case helps to resolve differences between the partial and general equilibrium results. Finally, we consider cases that test the sensitivity of results to the correlation of growth among countries. While we have an estimate of correlation from Webster and Cho (2006) the statistical significance of it is weak, and with changing international relations (*e.g.*, integration of the EET states into the EU) the historical correlation is likely a poor guide to the future.

3. THE CONVENTIONAL CASE: EMISSIONS TRADING UNDER CERTAINTY

We simulate an EPPA reference and the three policy cases, with and without international emissions trading using the EPPA model. Resulting carbon prices and consumption changes are reported in **Table 4**. We show total consumption for each case and the change in consumption between each trading and respective no-trade case. Much of the gain from emissions trading under Case 1, *Kyoto with FSU*, is the hot air itself. By lowering the aggregate abatement by nearly 230 MtC of carbon, the total costs of abatement across participating nations are necessarily lower. Russia also undertakes real abatement of 83 MtC from its reference emissions. The welfare gain from allowing emissions trading aggregated across all participating regions is \$106 billion when the FSU is included, while the welfare gain from emissions trading under *Kyoto without the FSU* is \$26 billion.² Much of this \$80 billion difference is the savings from lowering the aggregate emissions target. The carbon price in the *Kyoto with FSU-tr* case is \$25/tC, compared with \$142/tC in the *Kyoto no FSU-tr* case, the difference reflecting the hot air and addition of low cost abatement options in the FSU. We verify that the *Cost-Effective-tr* and *Cost-Effective-ntr* are identical, producing the same carbon price in each region without trading as with, and with no impact on consumption. The autarkic cases show CAN with the highest carbon price at \$225/tC, JPN and EUR both somewhat below \$200/tC, and the EET with an \$18/tC price.

² EPPA is based on the GTAP-E data base, and all regional economies are denominated in US \$ at base year (1997) exchange rates, and all commodities, including emissions permits, are traded at these exchange rates. Aggregate benefits are summed across regions in US dollar as denominated in the model. A further issue, not explored here, is the aggregation of welfare measures across regions using exchange rates. In principle, a real purchasing power index, such as the Purchasing Power Parity (PPP) index should be used to make such cross country comparisons. We abstract from that issue here but these PPP differentials represent another violation of the perfectly competitive and idealized market conditions of this simple case, part of which we take up in the next section.

Table 4. Welfare Impacts of Kyoto Policy under Certainty.

	Case	CAN	JPN	EUR	EET	FSU	TOTAL
Welfare (Consumption) (\$Billion)	Reference	641	3372	7654	293	636	12597
	Kyoto w/FSU-ntr	634	3357	7559	293	634	12476
	Kyoto w/FSU-tr	639	3370	7637	293	643	12582
	Kyoto no FSU-ntr	634	3357	7559	293	634	12476
	Kyoto no FSU-tr	635	3361	7575	298	634	12502
	Cost-effective-ntr	637	3362	7581	289	634	12502
	Cost-effective-tr	637	3362	7581	289	634	12502
Gain from Emissions Trading (tr-ntr) (\$B)	Kyoto w/FSU	5.8	12.7	77.9	0.4	9.1	106
	Kyoto no FSU	1.2	3.5	15.8	5.4	0.0	26
	Cost-effective	0.0	0.0	0.0	0.0	0.0	0
Carbon Price (\$/ton)	Kyoto w/FSU-ntr	225	199	183	18	0	
	Kyoto w/FSU-tr	25	25	25	25	25	
	Kyoto no FSU-ntr	225	199	183	18	0	
	Kyoto no FSU-tr	142	142	142	142	0	
	Cost-effective-ntr	142	142	142	142	0	
	Cost-effective-tr	142	142	142	142	0	

4. EMISSIONS TRADING UNDER UNCERTAINTY: PARTIAL EQUILIBRIUM ESTIMATES

Figure 1 offers a simple diagrammatic analysis of the standard partial equilibrium analysis that underlies the expectation that the hedge value of emissions trading should be positive. As shown, Country A has a marginal abatement cost of P_A and Country B has a marginal abatement cost of P_B . When emission trading is introduced, the international carbon price is P_W . At this price, A will buy ΔQ_A permits in order to reduce its abatement level and B will sell ΔQ_B permits and increase its abatement by that amount. The total abatement cost to A falls by a_1+a_2 , and the cost of buying permits is a_2 , resulting in a net gain of area a_1 . The total abatement cost to B increases by b_2 , but since revenue from the permit sales is b_1+b_2 there is a net gain of b_1 . The worst possible outcome of trading in this situation is no gain when a Country's autarkic price is the same as the world price with trading, and the country thus is neither a net buyer nor seller.

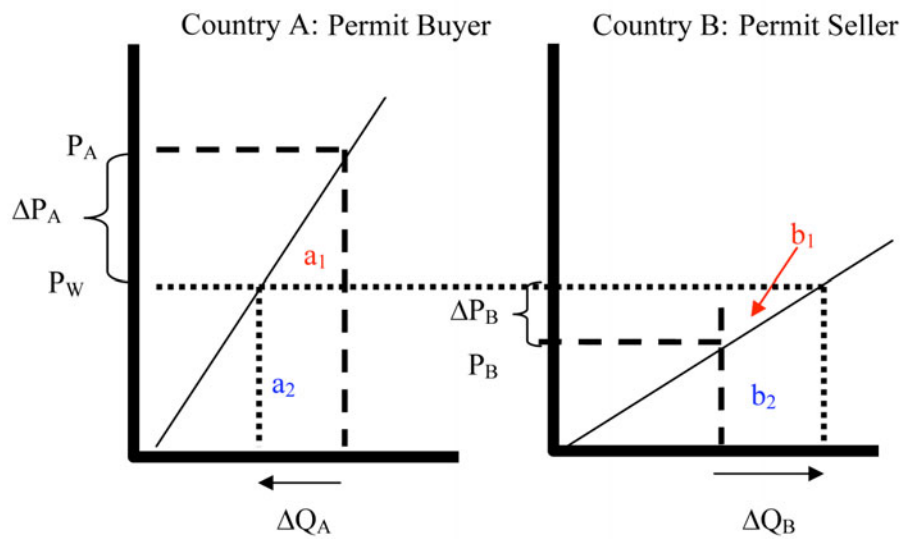


Figure 1. Graphical Description of Partial Equilibrium Gain from Emissions Trading.

We develop a partial equilibrium model based on Marginal Abatement Curves (MACs), following the approach of (Ellerman and Decaux, 1998) and others, to examine the hedge value of emissions trading in this simple case. The MACs are third-order polynomial fits of 40 simulations of abatement ranging from 1% to 40% reduction below the reference in 2010 (**Figure 2**). To simulate uncertainty in emissions, we sample from the uncertainty in growth rates for all regions based on the historical variability described in Section 2. Latin Hypercube sampling (Iman and Helton, 1988; Iman and Conover, 1982), a stratified sampling method shown to be more efficient than random sampling, was used to construct 250 simulations. EPPA is used to project the 250 growth samples under the *Kyoto no FSU* case with and without trading and the *Cost-Effective* case with and without trading. Differences in growth rates result different reference emissions, which therefore changes the amount of abatement required to achieve the fixed target and the cost of that abatement. With shifts in abatement costs of all regions, the number of permits bought/sold will vary correspondingly. The resulting changes in CO₂ for each region as calculated by EPPA between the no-trade and the trading cases are used in conjunction with the MAC curves to calculate the net gain from emissions trading.

The partial equilibrium estimates of the gains from emissions trading are calculated for these four regions and summed (**Table 5**). The gain from trade under the *Cost-Effective* case is a measure of the hedge value of emissions trading, which under this case we find to be about \$2.4

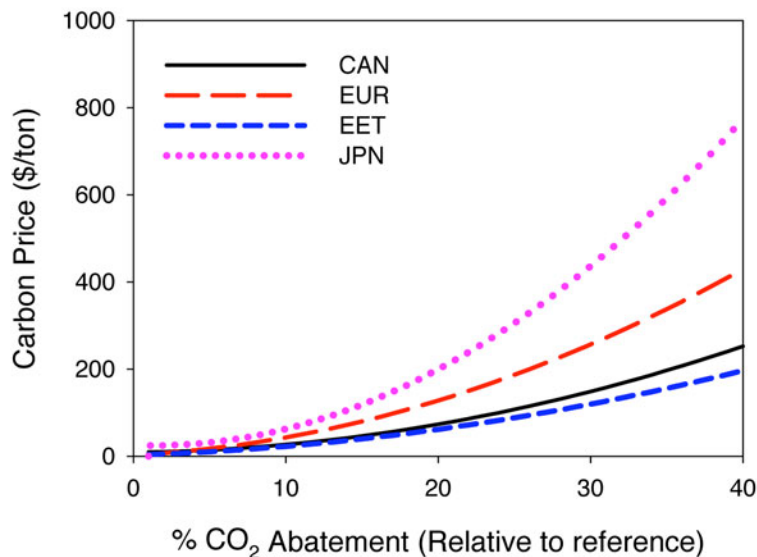


Figure 2. Marginal Abatement Cost Curves Derived from EPPA Model.

Table 5. Uncertainty Estimates of Gains from Trading: Partial Equilibrium Results (\$ Billion 1997 US).

Case		EUR	JPN	EET	CAN	TOTAL
Kyoto no FSU	Lower 95%	0.0	0.0	0.7	0.1	1.8
	Mean	1.0	0.7	4.6	0.7	7.0
	Upper 95%	2.9	3.3	10.4	1.5	15.3
Cost-Effective	Lower 95%	0.0	0.0	0.0	0.0	0.1
	Mean	0.3	0.4	1.5	0.1	2.4
	Upper 95%	1.3	1.3	7.0	0.4	8.9

billion, the mean estimate. The 95% probability range is from \$0.1 to \$8.9 billion. The *Kyoto no FSU* case has mean gains from trade of \$7.0 billion (95% range of \$1.8 to \$15.3 billion). As expected no region is ever worse off with trading. The hedge value of trading is a relatively small component of the total value of trading in this case, at the mean value it is about one-third. The hedge value that we derive from the MAC model reflects the uncertainty distribution. The more uncertain the emissions, the greater the hedge value of trading. The range is fairly wide because there are some cases in the sample where some regions have very high growth while others have low, and thus trading is particularly valuable. However, these results suggest that it is the redistribution goals implicit in the Kyoto Protocol that give greater value to trading than uncertainty in growth of emissions. This is true even in comparison with the *Kyoto no FSU* case. *Kyoto with FSU* has even stronger implicit redistribution goals.

The value of trading estimated with the partial equilibrium model is much smaller than the value of trading simulated with the CGE model under certainty. In those we found the value of trade to be \$26 billion (\$106 billion under *Kyoto with FSU*), and these did not include a hedge value. The MAC costs, derived from integrating under the marginal abatement curves, and the welfare cost computed from the CGE model would not be expected to be identical because the CGE results include feedback effects. As shown elsewhere, pre-existing tax distortions can lead to a large difference between the direct cost, the area under a MAC, and the estimated welfare cost (Paltsev *et al.*, 2004). We investigate this difference further in the Section 5.

Not surprisingly, the pattern of who buys and who sells emissions permits differs significantly between these two policies (**Figure 3**). Under *Kyoto no FSU*, the probability of being a permit seller for EUR, JPN, EET, and CAN are, respectively, 5%, 18%, 99%, 2%. The fact that the EET is a permit seller in nearly all cases and JPN, EUR, and CAN are buyers in nearly all cases reflects the burden redistribution aspects of the Kyoto Protocol that favored the EET. Under the *Cost-Effective* case, the probability of being a net permit seller for EUR, JPN, EET,

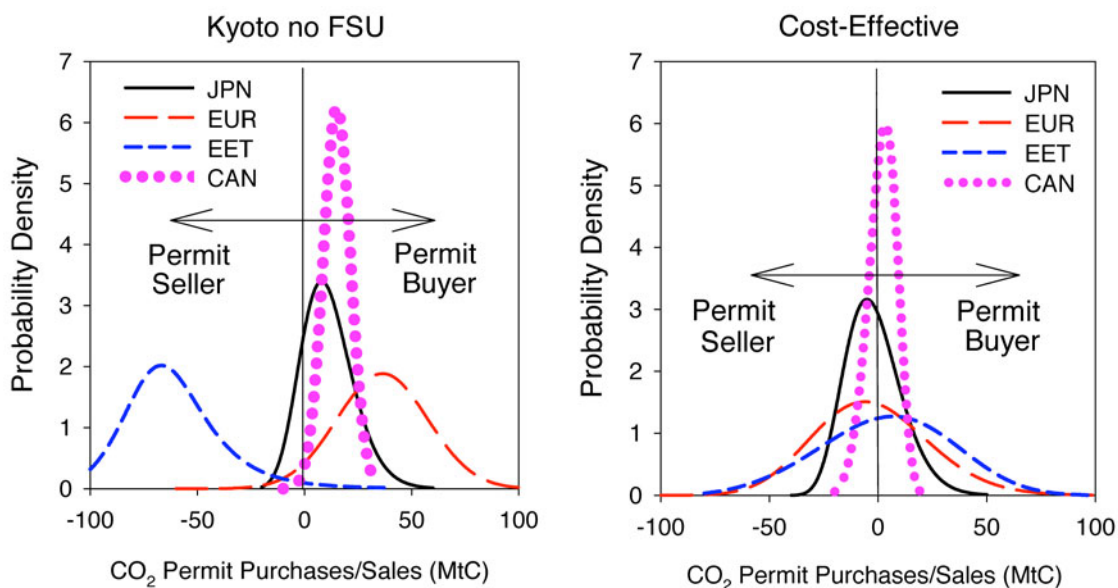


Figure 3. Buyers and Sellers of Permits: Partial Equilibrium Results.

and CAN are, respectively, 59%, 60%, 42%, 35%, much closer to even odds of being either a buyer or a seller. This reflects the allocation design where reference growth rates in all regions will result in no trading.

5. EMISSIONS TRADING UNDER UNCERTAINTY: GENERAL EQUILIBRIUM ESTIMATES

The partial equilibrium analysis provided a numerical test of the simple case made for emissions trading—that it reduces the cost for both buyers and sellers of permits. As already noted, the CGE estimates of trading gains in the certain case were much larger than the median (or even the 95% upper limit) from the partial equilibrium analysis. Previous studies have shown in simulations under reference conditions (*i.e.*, certainty) that the economy-wide implications of trading can differ from that for the individual firms that would be the direct buyers and sellers due to the presence of tax distortions and terms-of-trade effects (Babiker *et al.*, 2004; Paltsev *et al.*, 2004).

We turn now to results of stochastically simulating the CGE model to investigate emissions trading where these distortions and other feedbacks exist. We again use Latin Hypercube sampling from the distributions on GDP growth provided in Section 2. We translate these into changes in the growth of labor productivity such that we reproduce the historical variability in GDP in the forward forecasts. As noted in Section 2, we normalize the historical distributions around the reference forecasts of the EPPA model. We again focus on the *Kyoto no FSU* and *Cost-Effective* cases. In addition we include a case with the cost-effective allocation where we remove all fuel taxes, which we label *Cost-Effective-n.f.t.* (no fuel tax).

Table 6 provides the key results. Here we see that the median gains from trade in *Kyoto no FSU* are much closer to the estimate under certainty than with the partial equilibrium results. Because of non-linearities, skewness of the distributions, and the imposed correlation structure we would not expect the median or mean from this stochastic simulation of the CGE to be exactly the same as when simulated under certainty with reference growth assumptions. The 95% range for the aggregate gain is from about \$0 to \$60 billion. Even in this *Kyoto no FSU* case, however, we see that in some cases EUR and JPN lose from emissions trading. In the *Cost-*

Table 6. Uncertainty Estimates of Effects of Trading: General Equilibrium Results (\$Billion 1997 US).

Case		CAN	EUR	JPN	EET	TOTAL
Kyoto no FSU	Lower 95%	0.3	-2.0	-1.7	0.1	0.2
	Median	1.3	12.7	2.3	4.3	21.5
	Mean	1.3	13.7	3.6	4.8	23.3
	Upper 95%	2.5	37.0	16.3	13.1	59.3
Cost-Effective	Lower 95%	-0.1	-14.9	-3.9	-0.1	-12.1
	Median	0.1	-2.1	-0.7	0.6	-1.9
	Mean	0.1	-0.5	0.2	1.2	1.1
	Upper 95%	0.6	20.2	10.0	6.0	26.8
Cost-Effective n.f.t.	Lower 95%	-0.6	-4.4	-0.3	-0.6	-1.8
	Median	-0.1	0.6	0.1	0.0	0.7
	Mean	0.0	0.6	0.2	0.4	1.3
	Upper 95%	1.0	6.0	1.2	3.9	8.0

Effective case the likelihood of losses from emission trading occurs frequently enough in all regions such that at the median there are net losses summing across the regions from emissions trading with the 95% range from a loss of \$12 billion to a gain of \$27 billion. In the *Cost-Effective-n.f.t.* case much of this strong tendency for emissions trading to cause welfare losses for regions is eliminated. The median and mean effect is a small gain, \$0.7 and \$1.3 billion respectively. At the same time, the distribution is much narrower. The 95% high end estimate falls from \$27 billion to \$8 billion. Fuel taxes are particular high in EUR and JPN, and a main benefit of emissions trading is to avoid those circumstances where EUR or JPN grow rapid relative to other regions, forcing a high autarkic carbon price that greatly exacerbates the tax interactions effect. Fitted probability density functions for the aggregated welfare impacts across the four participating regions are shown in **Figure 4**.

The likelihood that trading results in a welfare loss is shown in **Table 7**. In the aggregate there are losses in just 2% of the simulations in the *Kyoto no FSU* case, but the losses occur in 18% of the simulations for JPN and 6% for EUR. However, when we try to estimate just the hedge value of emissions trading we find that in more than one-half (58%) of the simulations in the *Cost-Effective* case there is an aggregate loss from trade. This drops to 32% in the *Cost-Effective n.f.t.* case, a smaller probability but far from a rare anomaly. This indicates that a substantial number of the cases of welfare losses are the result of the tax effects.

Babiker *et al.* (2004) and Paltsev *et al.* (2004) also identify terms-of-trade effects as potentially important. Because the terms-of-trade change endogenously in the model we are not able to simply eliminate them as we did with fuel taxes. We thus examine changes in terms of

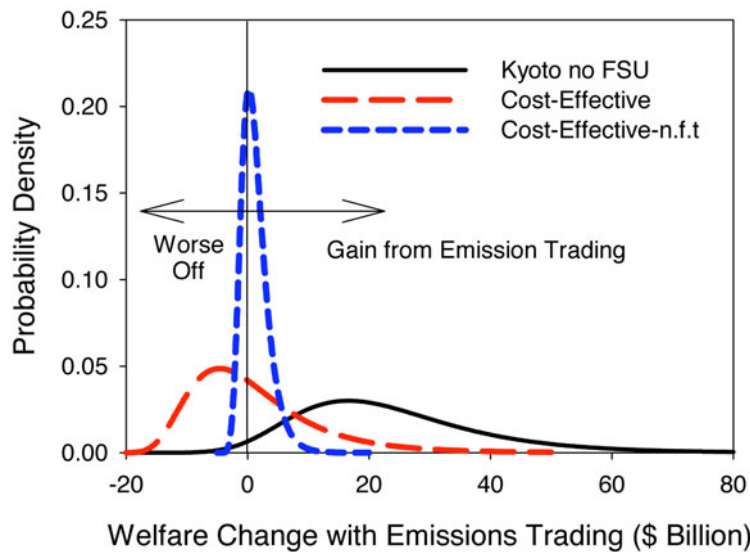


Figure 4. Welfare Impacts of Emissions Trading under Uncertainty (General Equilibrium Estimate).

Table 7. Probability that Trading Reduces Welfare: General Equilibrium Results (percentage).

Case	CAN	EUR	JPN	EET	TOTAL
Kyoto no FSU	0	6	18	1	2
Cost-Effective	30	59	60	11	58
Cost-Effective-n.f.t.	62	38	27	50	32

trade by relating these to losses and gains from emissions trading. **Figure 5** shows the probability distribution of the change in the terms of trade when trading is allowed. Under the *Kyoto no FSU* policy, the permit buyers (EUR, JPN, CAN) experience a decrease in the terms of trade of up to a half of a percent, and the permit seller (EET) experiences an improvement in the terms of trade. Under the *Cost-Effective* case, regions are roughly equally likely to experience a gain or loss in their terms of trade. The size of this effect is relatively small, less than a percent for EUR, JPN, and CAN and up to two or three percent for EET.

We plot the change in welfare measured as the change in consumption against the change in terms of trade in **Figure 6** for each region for the *Cost-Effective-n.f.t.* case. This case eliminates other sources of disparity (*i.e.*, fuel tax interactions) and thus comes closest to isolating the terms of trade as a cause of the welfare change. EUR and CAN show a strong positive relationship: losses (gains) in terms of trade are strongly associated with losses (gains) in consumption. The relationship is very tight suggesting that the terms-of-trade effect strongly dominates any direct benefits of emissions trading. The results for EET and JPN show a more complex relationship. With large shocks in either direction (*i.e.*, large terms-of-trade effects), there is a tendency for consumption gains. Climate policy interactions with the terms-of-trade effect are complex, affecting multiple export and import markets, and dependent on the specific trading relationships and trading partners. Whether the terms-of-trade effect will dominate the direct cost effect of carbon policy will also depend on how important trade is in a region’s economy. Each of the realizations of the future represented in the 250 parameter sets is a unique combination of differential growth rates among the regions.

It is perhaps surprising that the “indirect” terms-of-trade effect can dominate the “direct” effect of emissions trading. A primary reason for this is likely a feedback effect on the domestic economy from terms-of-trade changes caused by emissions trading among other regions. Consider the case where, for example, EET’s autarkic price is exactly at the world trading price.

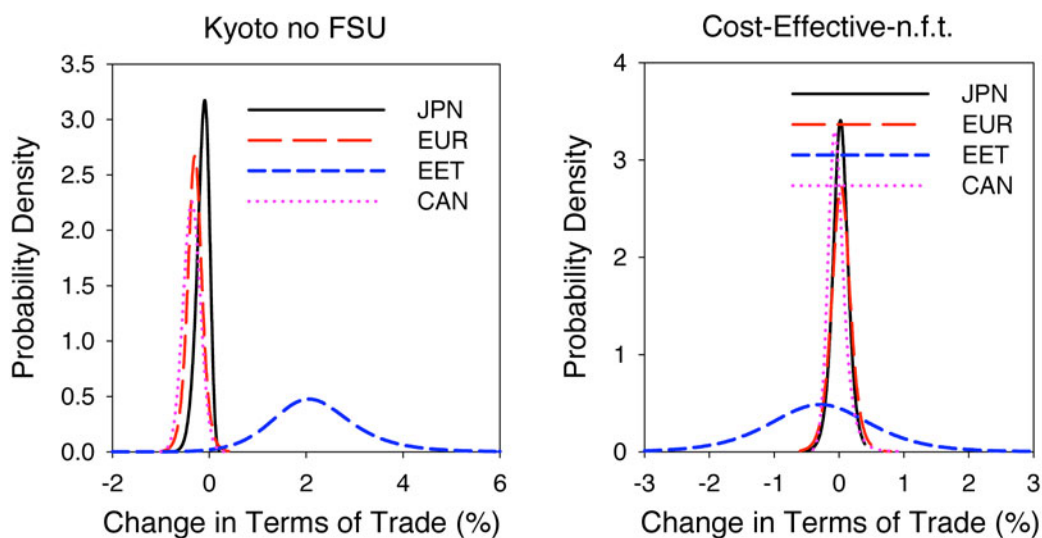


Figure 5. Impacts of Emissions Trading on Terms of Trade Relative: Terms of Trade in the Trading Case Compared with the No Trading Case.

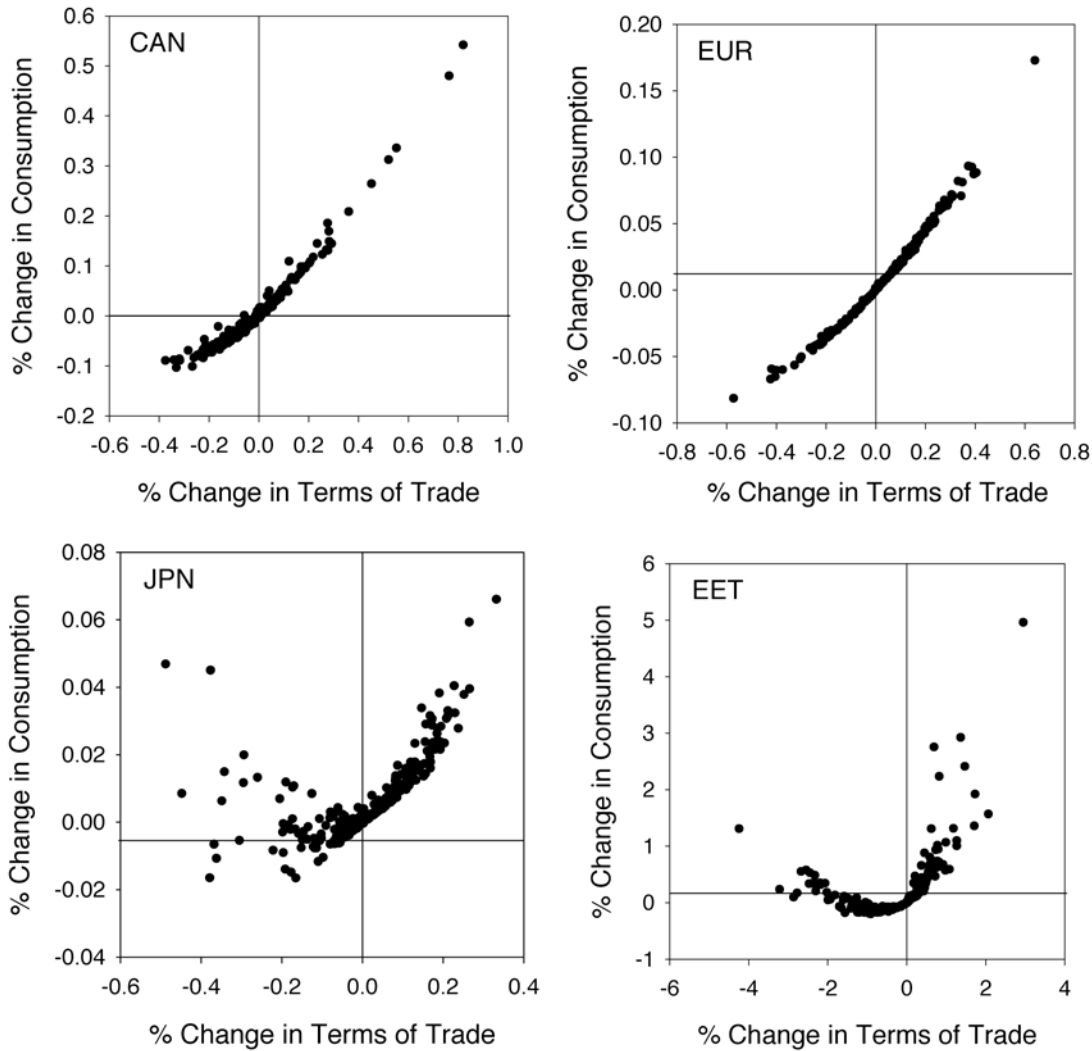


Figure 6. Relationship between Change in Terms of Trade and Change in Welfare from Allowing Emissions Trading (Cost-Effective-n.f.t.)

In this circumstance, the direct benefit from trade is necessarily zero because net trade would be zero. However, suppose other regions have an incentive to trade. Opening emissions trading would thus affect the international prices of goods, including those for EET’s exports and imports even though there was no direct effect of emissions trading on EET’s economy. As this example is constructed, the terms-of-trade change is the only economic change affecting the EET. Any welfare change thus will be completely determined by the change in the terms of trade. The allocation in the *Cost Effective-n.f.t.* case is set so that countries will often have only small incentives to trade. Only in those cases where the region’s autarkic price is far from the world price will there be a big “direct” welfare gain from trading. And, only in these circumstances is it likely that the direct gains from trading can dominate the indirect terms-of-trade effect. The EET and JPN, regions where the relationship between the terms-of-trade change and the consumption loss is more complex, are also those regions where simulated growth is more variable, as discussed in Section 2 and shown in Table 2.

It is useful to compare the general equilibrium results under uncertainty to those from the partial equilibrium analysis. The change in total abatement costs under partial equilibrium for trading in the *Cost-Effective* policy had a mean and 95% lower and upper bounds, respectively, of \$2.4, \$0.1, and \$8.9 billion. The general equilibrium welfare impact has a mean of close to \$1 billion with or without tax distortions, and 95% ranges from -\$12 to \$27 billion with existing fuel taxes and from -\$2 to \$8 when we remove fuel taxes. Distortions and terms-of-trade effects captured in the general equilibrium analysis result in emissions trading producing net welfare losses for individual regions and the sum across regions in many cases. In fact, the median hedge value of trade is negative in the *Cost-Effective* case and nearly zero in the *Cost-Effective-n.f.t.* case, thus for half or more of the cases emissions trading is welfare worsening. The presence of tax distortions also greatly increases the variance. In the *Kyoto no FSU* case, the total value of trade (included the hedge value and the burden redistribution effects) is much larger in the general equilibrium analysis (mean of \$22 billion, 95% range of \$0.2 to \$59 billion) than in the partial equilibrium analysis (mean of \$7 billion, 95% range of \$2 to \$15 billion). This occurs because under the conditions of this policy simulation, trading often means that EUR and JPN are permit buyers, and they thus avoid causing further tax distortion losses.

The results presented so far are based on imposing correlations among growth as observed over the period 1960-2000. The statistical significance of these correlations were relatively weak, and there are reasons to believe that these correlations may not apply in the future. We thus compare the results with historical correlations to the same policies simulated with growth rates sampled assuming no correlation (probabilistically independent) and with a very strong correlation of 0.90. These correlations are imposed pairwise between every pairing of the four regions where the policy constraints are imposed. We show in **Table 8** the results only for the *Cost-Effective-n.f.t.* case, as the effects of correlation are similar across policies. The effect of different correlations on the mean welfare change is negligible, and the effect on the extremes of the distribution is that weaker correlation causes more uncertainty in welfare change (longer tails). The effect of correlation on other variables is similar to that of welfare. Thus, our overall conclusion is that even with extreme assumptions about correlation the main results of our study are little affected.

Table 8. Sensitivity of General Equilibrium Results to Correlation of GDP Growth Among Regions (*Cost-Effective-n.f.t.*) (\$Billion 1997 US).

		CAN	EUR	JPN	EET
Lower 95%	Uncorrelated	-0.7	-5.7	-0.2	-0.7
	Historical	-0.6	-4.4	-0.3	-0.6
	Correlation = 0.9	-0.5	-2.6	-0.2	-1.2
Mean	Uncorrelated	0.2	1.2	0.8	0.9
	Historical	0.0	0.6	0.2	0.4
	Correlation = 0.9	0.0	0.9	0.1	-0.1
Upper 95%	Uncorrelated	2.6	10.8	3.7	6.2
	Historical	1.0	6.0	1.2	3.9
	Correlation = 0.9	1.7	6.3	0.6	1.4

6. CONCLUSIONS

In this study we have estimated what we refer to as the hedge value of international emissions trading as a greenhouse gas mitigation policy instrument. In our definition, this is the value of trade as a cushion against uncertainty in emissions growth. Previous estimates of the value of trade have estimated its value under certainty, in the context of the Kyoto emissions targets. Much of this value resulted from Russian “hot air” that effectively lowered the aggregate emissions target by, in our reference case, 230 MtC. Trading under certainty with the FSU included has a value, summed across regions, of \$106 billion, much of this due to the fact that it increases the allowances available to all parties by the hot air amount. Removing the FSU reduces the value to \$26 billion. We find the hedge value of emissions trading to be small in comparison. From the partial equilibrium analysis, the mean value was \$2.4 billion with a range of \$0.1 to \$9 billion. When we estimated the hedge value by stochastically simulating a general equilibrium model, we found strong interactions of the climate policy with preexisting fuel taxes and terms-of-trade effects. These interactions meant that emissions trading could often be welfare worsening, and thus the hedge value (the mean value in our stochastic simulation) was even smaller (about \$1 billion) than in the partial equilibrium analysis. With the current levels of fuel taxes left in place, more than half of the cases (58%) resulted in a net welfare loss summed across the regions. With fuel taxes removed, 32% of cases result in a net welfare loss in the aggregate. The distortion and terms-of-trade effect also greatly increase the variance of the value of emissions trading.

The value of international emissions trading and its components identified in this paper (hedge value, burden redistribution, tax interaction, and terms-of-trade effects) obviously strongly depend on the specific circumstances of the trading participants. The hedge value depends on the uncertainty in emissions forecasts, conditions specific to individual regions. We used historical variability in growth rates to estimate likely future variability for these regions. The burden redistribution value of trade obviously depends on the initial allowance allocation. Fuel taxes vary among countries, and terms-of-trade effects depend on particular exports and imports and the geographic patterns of trade. We also emphasize that we would expect much different results for the value of trading in a domestic context, where trading is among individual firms or entities, rather than among countries as we have simulated here. Our suspicion is that the hedge value in the domestic trading context may be much larger because of the scope for large and unexpected changes in emissions for individual entities. Thus, the lessons from domestic trading systems may not necessarily transfer to international trading systems or vice-versa.

We put particular focus on estimating the hedge value of emissions trading, a value that has here-to-fore not been estimated for international greenhouse gas trading. We would argue that the hedge value is most closely related to the pure value of trading as a policy instrument where economic efficiency is the sole objective of policy design, and distributional effects of the policy are ignored as economists would often like to do. Given the importance of the implications of the distributional goals implicit in the Kyoto allocations for the value of trading, at least in the Kyoto

Protocol as we have simulated it, it seems clear that this aspect of a negotiated agreement needs to be a central consideration of economic analysis. From that perspective, the appeal of emissions trading is that it allows equity/burden sharing considerations while allowing the trading system to then re-establish a cost-effective solution—at least from a partial equilibrium perspective that does not include general equilibrium effects where trading can be welfare worsening.

Interestingly, our results suggest that if the redistribution of the burden is large, then we might expect trading to be welfare improving, even if not optimal in the sense that further consideration of tax effects and terms-of-trade effects could further improve the outcome. However, if trading is among countries where each has an allocation that is likely to be close to the trading result (little burden redistribution) then there is a good chance that trade can be welfare worsening. Once recognizing that the primary use of international emissions trading is as a burden sharing or wealth transfer device, concerns for the sustainability or self-reinforcing nature of the agreement may lead one to question whether an emissions trading system is the best method for achieving the redistribution goal.

While countries do what they do for many stated and unstated reasons, the US withdrawal from the Kyoto Protocol likely reflected an unwillingness to go through with the burden sharing agreement in the Protocol that would have involved considerable gain for Russia, to be borne by the US. Europe maintains that it will not use Russian hot air. Whether that position will hold through the end of the Kyoto commitment period is yet to be seen, but again this appears to be an unwillingness to follow through on the burden redistribution agreement in the original deal. The large redistribution implicit in the Kyoto Protocol as originally negotiated is just the situation where trading would have been highly beneficial. From the evidence to date on international implementation of climate policy it is not clear that agreements with large redistribution goals are sustainable. In the end, the value of emissions trading as a policy instrument for international agreements should be judged on its ability to actually accomplish burden-sharing goals (while achieving cost effectiveness), as compared with alternative policy approaches.

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