MIT Joint Program on the Science and Policy of Global Change

Is International Emissions Trading Always Beneficial?

Mustafa H. Babiker, John M. Reilly and Laurent L. Viguier

Report No. 93
December 2002

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Abstract

Economic efficiency is a major argument for the inclusion of an international emission permit trading system under the Kyoto Protocol. Using a partial equilibrium framework, energy system models have shown that implementing tradable permits for greenhouse gases internationally could reduce compliance costs associated with the emission targets. However, we show that international emission trading could be welfare decreasing under a general equilibrium framework. We describe a case of immiserizing growth in the sense of Bhagwati where the negative terms of trade and tax-interaction effects wipe out the primary income gains from emission trading. Immiserizing emission trading occurs only when there are pre-existing distortions in the economy. Simulation results based on a CGE model developed at MIT, the EPPA model, show that under an EU-wide emission trading regime the introduction of a permit trading system cause welfare losses for some of the trading countries.

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1 Introduction

There is an extensive literature in climate change economics assessing the potential economic gains from emission trading under the Kyoto Protocol (Weyant, 1999). This literature emphasizes that the aggregate economic cost of achieving the Kyoto target might be reduced if marginal abatement costs are equalized across countries. This result is consistent with textbooks in environmental economics insisting on the cost-effectiveness of transferable emission permit system and explaining that polluters have an incentive to use the flexibility created by the system to achieve a given target at the lowest possible cost (e.g. Tietenberg, 2000). Indeed, all pollutors are supposed to gain from emission trading, whether sellers or buyers of permits, compared to the case where permits are not freely transferable. The logic appears irrefutable: why would parties freely enter a trade if they did not gain? Indeed, the gains to all parties can be demonstrated graphically in a simple partial equilibrium framework. And, empirically the economic benefits of carbon emission trading have been verified with model-based analysis using energy system models (e.g. Criqui *et al.*, 1999; Gielen and Kram, 2000).

The conditions under which international permit trading would be introduced, however, diverges from the standard environmental economics textbook analysis in several important ways. In particular, in the case of international permit trading we are interested in the impacts on a nation or region whose economies may be subject to various economic distortions. And, while not always clearly specified, the idea is that the traders are private firms within the countries, rather than the countries themselves. Thus, what may be beneficial to individual trading entities may not result in a net benefit for the country. We draw on the general theory of second best (Lipsey and Lancaster, 1956), and the international trade literature on "immiserizing growth" started by Bhagwati (1958) to explain why, in the more general case, all countries may not benefit from the introduction of a permit trading system. Trade economists will immediately recognize that immiserizing growth can occur only when there are pre-existing distortions and others will see this as an extension or application of the theory of the second best. However, the possibility that emission permits trade might be welfare decreasing in some cases seems not to have been generally appreciated in the environmental economics literature, nor has its empirical importance been explored for the case of carbon permit trading.

In section 2, we briefly present the general theories of second best and immiserizing growth, and their relevance to international emissions trading. Then, in section 3, we explain geometrically why international emission trading might be a suboptimal policy in second best setting. Finally, we present in section 4 simulation results based on a version of the MIT Emissions Prediction and Policy Analysis (EPPA) model that disaggregates nine European countries. We focus the empirical analysis on introduction of a permit trading system limited to trading within the European Union.

2 International emissions trading in a second best setting

Different fuels are taxed at very different rates within almost all European countries, and the same fuel is taxed at very different rates from one country to another (Newbery 2001). Are energy taxes completely justified by the internalization of environmental damages and the charge for road use? According to Newbery (2001), in most cases the taxes predate environmental concerns, are not related in any systematic way to environmental damage, and do not meet minimal criteria for so doing. Coal is almost invariably the most environmentally damaging fuel, but it is usually the least heavily taxed, and in many countries its production is heavily subsidized. If road fuel taxes can to a considerable extent be justified as road user charges, there is little evidence that road taxes are set on the basis of charging the long-run marginal cost of expanding roads (Newbery, 1992).

Since climate policy will be implemented under imperfections and distortions in the energy markets, one might expect the general propositions of the second best theory and the theory of trade policies to be valid for the analysis of markets for tradable emissions permits. Our general proposition is that international emissions trading (IET) may be welfare decreasing when primary gains from trading are outweighed by "secondary costs" associated with pre-existing distortions and market imperfections. In this section, we will focus on the efficiency costs of IET due to the "tax-interaction effect" and the terms of trade effect.

2.1 The tax-interaction effect of IET

Lipsey and Lancaster (1956) have shown that, generally, when one optimal equilibrium condition is not satisfied, for whatever reason, all of the other equilibrium conditions will change. Thus if one market does not clear, it would no longer be optimal for firms to set price equal to marginal cost or for consumers to set the price ratio equal to the marginal rate of substitution.[1]

When imperfections or distortions are present, the standard policy prescriptions to maximize national welfare in a first-best or non-distorted economy will no longer hold true. Also the implementation of what would be a detrimental policy in a first-best world can become a beneficial policy when implemented within a second-best world.

Applying the theory of the second-best in international trade theory, Bhagwati (1971) provides a framework for understanding the welfare implications of trade policies in the presence of market distortions. He demonstrates the result that trade policies can improve national welfare if they occur in the presence of a market distortion and if they act to correct the detrimental effects caused by the distortion. Bhagwati also shows that for each distortion, it is possible to analyze the welfare ranking of all alternative policies, from the first best optimal to the second best.

Recent studies have focused on the ranking of alternative environmental policy instruments in a second best setting. It is shown that the presence of distortionary taxes raises the costs of pollution abatement under each policy instrument relative to its costs in a first-best world (e.g. Fullerton and Metcalf, 1997; Goulder *et al.* 1998; Parry and Williams, 1999). In a first best setting, the relative cost-effectiveness of different policies can be explained fully in terms of the difference in primary costs, including the cost from the "abatement effect" and the cost from the "output-substitution effect". In a second best setting, the gross efficiency cost of various environmental policies comprise the primary costs and the cost impact of pre-existing taxes, including the "tax-interaction effect"[2] and the "revenue-recycling effect"[3]. Usually, pre-existing distortionary taxes raise the costs of a given tax since the tax interaction effect dominates the revenue-recycling effect.

[1] The general theorem for the second best optimum is formulated by Lipsey and Lancaster (1956) as below:

> "[If] there is introduced into a general equilibrium system a constraint which prevent the attainment of one of the Paretian conditions, the other Paretian conditions, although still attainable, are, in general, no longer desirable."

[2] The tax-interaction effect has two components (Goulder *et al.*, 1998): the policy instrument increases the price of goods, implying an increase in the cost of consumption and thus a reduction in the real wage. This reduces labor supply and produces a marginal efficiency loss which equals the tax wedge between the gross and net wage multiplied by the reduction in labor supply. In addition, the reduction in labor supply contributes to a reduction in tax revenues.

[3] The revenue recycling effect corresponds to the efficiency gain from the reduction in the rate of pre-existing distortionary tax obtained with the revenues raised from the emissions tax (Goulder, 1995).

Free trade in emission permits is a cost-effective solution in a first best setting. However, in a second best world, one needs to take into account efficiency loss due to pre-existing distortionary taxes. Selling emission permits generates primary income gains but also may cause income losses due to restructuring of production in the selling country. Since the post-trading price of the permit is higher than the pre-trading price in the selling country, emission trading raises the costs of producing output, increases the relative price of consumption goods and reduces the real household wage. The selling country might be worse off compared to the case where a uniform carbon tax is implemented domestically if the efficiency costs from the "tax-interaction effect" outweigh the primary income gains from emissions trading.

2.2 The terms of trade effect of IET

Bhagwati (1958) has underlined the paradoxical possibility of "immiserizing growth", where a country finds that the growth induced deterioration in its terms of trade that implies a sufficiently large loss of welfare to outweigh the primary income gain from growth. In the original Bhagwati case, growth can be welfare decreasing when it occurs in a country with monopoly power in trade, even if the country has an optimal tariff policy in the pre-growth situation.[4] In the Johnson case (1967), immiserizing growth can arise without any monopoly power in trade if the country has a sub-optimal tariff policy in the pre-growth situation. Bhagwati (1968) demonstrates that immiserizing growth can arise under any kind of distortion, whether endogenous (monopoly) or policy-imposed (e.g. distortionary wage differentials), and showed that immiserizing growth is also possible when growth occurs in a country with monopoly power under a distortionary tariff policy. The general theory of immiserizing growth states that growth can be welfare decreasing only if (1) the pre-growth situation departs from full optimality and (2) if the distortion is not removed by a policy intervention (Bhagwati, 1969).[5]

[4] The necessary conditions for export-biased immiserizing growth (Bhagwati and Brecher, 1982, Kindelberger and Lindert, 1978) are: (1) the country's growth must be biased toward the export sector, (2) the country must already be heavily dependent on trade (so that the terms of trade effect is strong enough to offset the gains from higher supply of exportable goods), (3) the rest of the world must have an inelastic offer curve or growth of the export sector must decrease the production of the import sector at the initial product-price ratio.

[5] The possibility of immiserizing growth has been expanded into a whole set of arguments regarding the effect of policymaking in developing countries. For example, it is recognized that trade liberalization, in the presence of foreign capital, may be immiseriz-

The theorem on immiserizing growth applies to the case of international emissions trading as well. One might define the pre-emissions trading situation as a state where countries reach their emissions targets through domestic actions, i.e. economy-wide emissions trading systems. In the no distortion case, this situation is a suboptimal situation compared to the case where emissions permits can be freely traded internationally. Since markets for emission permits are imperfect, some countries will have higher marginal abatement costs than the others. Competitiveness effects are expected in that policy case. Countries with low abatement costs will gain a cost advantage (term of trade gains) compared to countries with high abatement costs. This cost advantage disappears when emissions permits are freely traded across countries. IET may be immiserizing for a selling country if the primary gains from permits selling are outweighed by the negative terms of trade effect.[6]

3 Economic Impacts of IET

3.1 Gains from Trading - The no Distortion Case

Many economists favor transferable emission permits because they rely on market forces to seek out the least cost reductions, and require no knowledge on the part of the control authority with respect to where these least costly abatement opportunities exist (Tietenberg, 2000). Rather, the main task of the control authority is to issue the appropriate number of emission permits. A cost-effective outcome can be achieved in the market regardless of the initial distribution of permits (Knight, 1924; Coase, 1960; Dales, 1968). In fact, a tradable permit system allows the policy maker to effectively separate efficiency and equity issues, allocating permits on the basis of equity, or

ing (Bhagwati 1973; Bhagwati and Tironi, 1980). Based on this logic, it is also affirmed that foreign aid and domestic capital should be channeled away from the exporting sectors (e.g. agricultural or mineral productions) into industry (Bhagwati and Brecher, 1982).

[6] This adverse terms of trade effect of permits trading has been emphasized elsewhere. Using a CGE model of the world economy featuring 7 sectors and 23 regions (15 of which are EU member states), Böhringer (2002) finds that some countries (i.e. Austria, Germany and France) may suffer from a terms-of-trade loss as compared to the no trading case. According to the author, "their gains in competitiveness with respect to energy-intensive production vanishes with equalized marginal abatement costs across EU countries, which is not offset by permit sales". According to him, "the transition from purely domestic action to a comprehensive trading system does not provide a Pareto-improvement because countries with low marginal abatement costs may lose initial cost advantages (terms-of-trade gains) under the no-trade case that are not offset by additional income from permits sales" (p. 530).

perhaps as an incentive for political support of the control policy, and letting the permit market seek out where the most cost-effective reductions can be achieved.

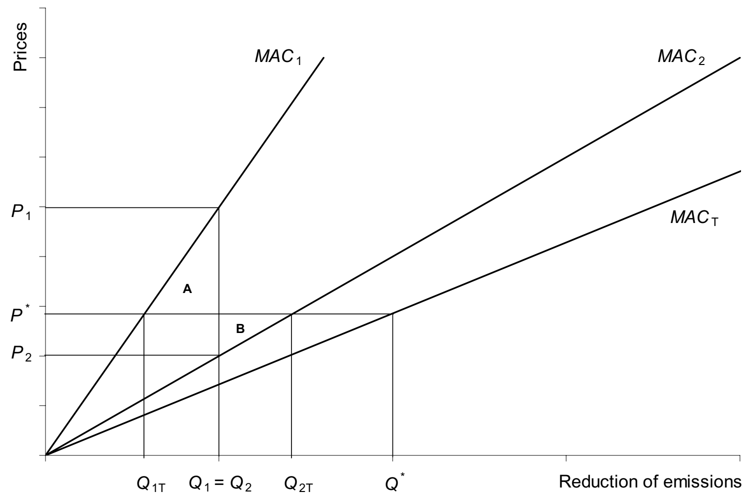

Figure 1: Cost-effectiveness of international emissions trading

It is easy to demonstrate graphically the cost-effectiveness of international emission trading when there are no distortions. **Figure 1** is drawn by measuring the marginal cost of emission reduction for country 1 (MAC_1) and country 2 (MAC_2). In the initial situation, we assume that carbon emissions are constrained in the two countries, so that emissions have to be reduced (without emission trading) by Q,where Q is a paired reduction target for the two countries (Q_1, Q_2) such that $Q_1 + Q_2 = Q$, and where $Q_1 = Q_2$. As shown, the marginal abatement cost of emission reductions at Q are higher in country 1 than in country 2 ($P_1 > P_2$).

Now, let's assume that an international emission trading regime is implemented, so that marginal abatement costs can be equalized across the two countries. As shown in **Figure 1**, the optimal reduction levels in the two countries are given by quantity pair labeled Q^* and the marginal abatement costs (or carbon prices) P^* in both regions. In that trading regime, country 1 reduces emissions by Q_{1T} and buy emission permits whereas country 2 reduces emissions by Q_{2T} and sell permits. As shown in **Figure 1**, the two countries are necessarily better off with international emission trading compared to the no trading case. The net income gains are equal to area A for country 1 and to area B for country 2.

3.2 Emissions Trading - The Pre-existing Distortion Case

A recent literature in public finance is devoted to the analysis and measure of the incremental welfare costs of raising extra revenues from an already existing distorting tax (e.g. Browning, 1976; Ballard *et al.*, 1985; Browning, 1987; Fullerton, 1991). The basic concepts of that literature can be used to analyze IET in a second best setting.

According to Browning (1976), the marginal cost of public funds is defined as the direct tax burden plus the marginal welfare cost produced in acquiring the tax revenue. The marginal welfare cost is the ratio of the change in total welfare cost to the change in tax revenue produced when tax rates are varied in some specific way (Browning, 1985). The direct tax burden is the direct cost per dollar of tax revenue. It corresponds to the marginal cost of public funds with no distortions.[7]

In order to measure the welfare impact of international emission trading in a second-best world, one might distinguish between the marginal abatement cost in the first best setting (MAC_n), the marginal welfare cost of emission reduction (MWC), and the marginal abatement cost in the presence of pre-existing distortions (MAC). Representing only the primary costs of the carbon policy (direct tax burden), MAC_n is defined as $\partial T/\partial C$, where T is the total abatement cost in the no distortion case and C represents the abatement level. The marginal welfare cost (MWC) of emissions reduction is the ratio of the change in total welfare cost to the change in carbon abatement; $\partial W/\partial C$ where W is the total welfare cost of abatement. MWC measures the secondary costs of pre-existing distortions, including the tax-interaction effect and the terms of trade effect. MAC is equal to the direct cost of abatement plus the marginal welfare cost of abatement ($(\partial T + \partial W)/\partial C$).[8]

[7] The marginal welfare cost per dollar of revenue is equal to $\partial W/\partial R$ where W is the marginal welfare cost produced by a change in the tax rate and where R is the additional revenue. The marginal cost of public funds is simply equal to $(\partial W/\partial R)+1$ when we assume that the tax base did not change in response to a change in the tax rate (Browning, 1976). The "marginal excess burden" (MEB) of taxation that measures the incremental welfare costs of raising extra revenues from an already existing distorting tax is $(\partial W - \partial R)/\partial R$. According to Fullerton (1991), no measure of MEB is really necessary. The "marginal cost of funds" (MCF) is enough information to compare the distorting effects of different tax changes.

[8] A comparable approach can be found in Bernard and Vielle (2001). The authors break down the income effect into two components: (1) the pure cost of carbon taxation and (2) the "distortion" cost of carbon taxation. The pure cost of carbon taxation is the income

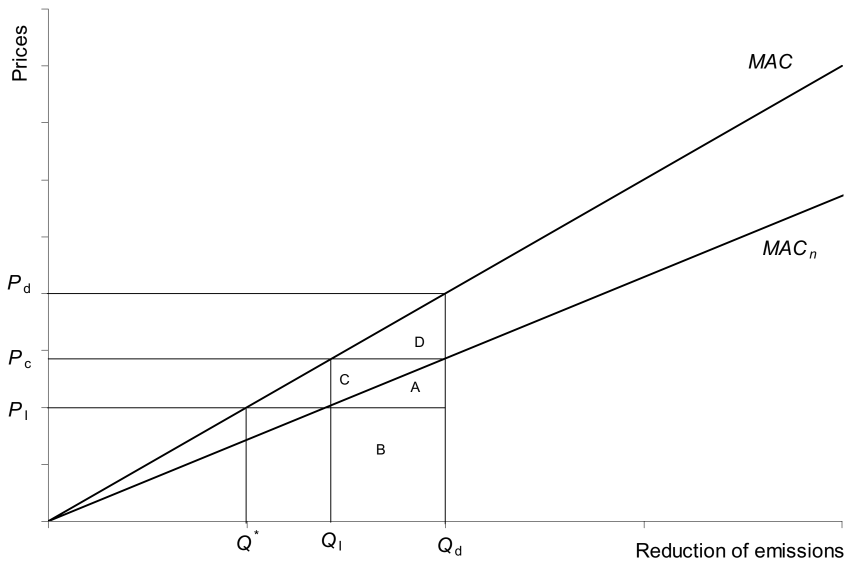

Figure 2: Impact of IET for the net buyer of permits

In **Figure 2**, we draw marginal abatement costs curves in the no distortion case (MAC_n) and in the distortion case (MAC) for a given country. In the reference case, we suppose that the country meets a reduction target Q_d through an economy-wide emission trading scheme but without international emission trading. In that case, the marginal abatement cost associated with this target is P_c. If we suppose the presence of distortionary taxation, the marginal abatement cost of the domestic reduction is equal to P_d, with $P_d > P_c$.

Now, let's assume that emission permits can be traded internationally, and that the international permits price is P_I. In that context, domestic emissions are reduced by Q^* with $Q^* < Q_d$. As a net buyer of emission permits, the firm will reduce its total cost of reduction by area A. At the same time, a lower domestic effort to limit carbon emissions has the effect of reducing secondary effects (tax-interaction effect and terms of trade effect) due to pre-existing taxation (area C+D). If we add add primary and secondary gains, international emission trading is thus welfare improving for the buyer country (area A+C+D).

change (in EV) produced by the carbon policy in a first-best world without distortions, or in a second-best economy based on optimal taxation.

Figure 3 shows that the situation may be very different for the seller country. Lets assume that the country goes beyond its emissions target in order to sell emission permits. In that case, domestic emissions reduction may increase from Q_d to Q^*. The total cost of the extra reduction is then equal to area B and the trading gains for the firm are equal to area A+C. However, this reduction has the effect of increasing secondary costs associated with pre-existing taxes (area A+D), and the net welfare effect of permits selling, λ, is equal to area C minus D. λ can be positive or negative depending on the size of the distortions and the amount of permits traded. When the two curves are close (i.e. the marginal distortion is small) and the international price is such that a lot of permits are exported, λ can be positive. In contrast, when the economy is highly distorted and the size of the emissions trading market is rather limited, λ can be negative.

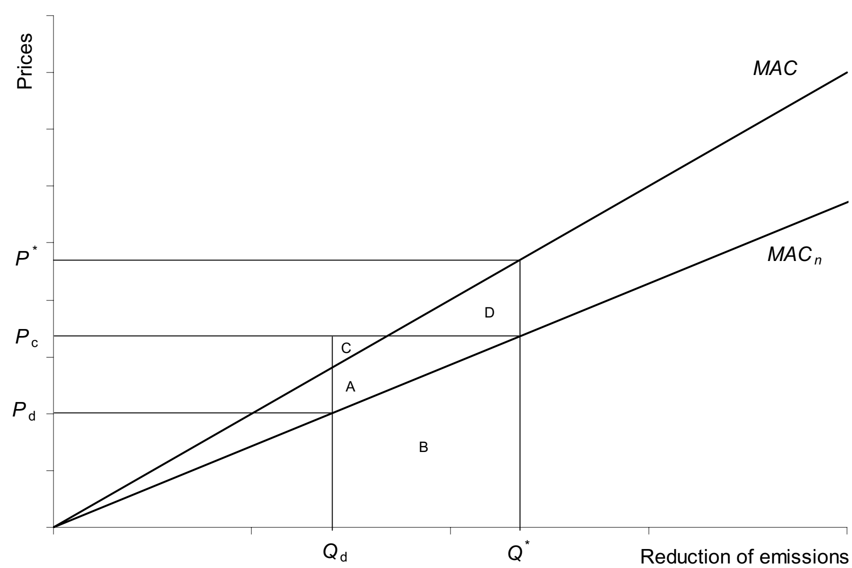

Figure 3: Impact of IET for the net seller of permits

The institutional architecture of domestic and international emissions trading regimes should be defined in the light of these results. The way domestic trading systems and international markets will interact is not neutral. Two institutional structures can be compared: 1) national governments allocate permits to legal entities and permits are freely tradable domestically and internationally (option 1); 2) legal entities trade permits domestically and national governments trade internationally to establish compliance (option 2) (Kerr, 2000).

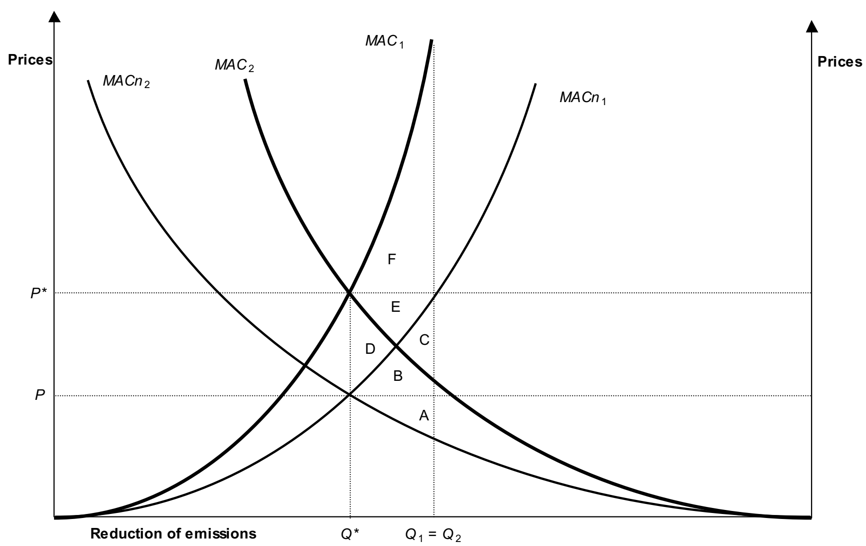

Figure 4: Public versus private trading

Figure 4 is drawn by comparing the two institutional options. $MACn$ and MAC are depicted for two countries. The curves are plotted from the left-hand axis for country 1 ($MACn_1$ and MAC_1) and from the right-hand axis for country 2 ($MACn_2$ and MAC_2). In the initial situation, we assume that carbon emissions are constrained in the two countries, so that emissions have to be reduced by Q in each country (with $Q_1 = Q_2$), and that $MACn$ and MAC are lower in country 2 than in country 1.

When option 1 is implemented, trading units recognize only the primary costs and so $MACn$ are equalized across the two countries. As shown in **Figure 4**, the optimal reduction is $Q*$ and the permits price is P. In that trading regime, trading gains are equal to area B+C for legal entities in country 1 and to area A for legal entities in country 2. If we assume distorted economies, the welfare impact of international trading would be positive for country 1 (area B+C+D+E+F) and negative for country 2 (area B+D).

When option 2 is implemented, and if we assume governments can evaluate the social cost and all of them will trade to optimize domestic welfare, then as constructed in **Figure 4**, the optimal reduction of emission will remain Q^* in the two countries but the international permits price will be at P^* (with $P^* > P$). In that institutional framework, both countries will be better off compared to the no-trade case. In our example, the welfare gains will be equal to area F for country 1 and area E+C for country 2.

4 A General equilibrium analysis based on the EPPA-EU model

4.1 The EPPA-EU 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 (see, for example, Babiker *et al.*, 2000a; Ellerman and Wing, 2000). Previous versions of the model have been used extensively for this purpose (e.g., Jacoby *et al.*, 1997; Ellerman and Decaux, 1998; Jacoby and Sue Wing, 1999; Reilly *et al.*, 1999). The current version of EPPA is built on a comprehensive energy-economy data set (GTAP4-E)[9] 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. A full documentation of EPPA is provided in Babiker *et al.* (2001).

In this paper, we use a new version of the model (EPPA-EU) including a breakdown for the European Union. The reference case for Europe in EPPA-EU is presented and compared with other economic models in Viguier *et al.* (2001). The EPPA-EU model has also been used to analyze welfare impacts of hybrid carbon policies in the European Union (Babiker *et al.*, 2001). EPPA-EU extends the current version of EPPA by bringing in a detailed breakdown of the EU and incorporating industry and household transport sectors for each region. The regional, sectoral, and factor aggregation shown in **Table 1**, together with the substitution elasticities in **Table 2**, completely specify the benchmark equilibrium.

The European Union is disaggregated into 9 countries and 1 region representing the Rest of Europe (ROE). Four out of the 9 EU countries (France, Spain, Italy, and the Netherlands) were aggregated together with ROE in the GTAP4-E database. We disaggregated this region using data from the

[9]For description of the GTAP database see Hertel, 1997.

GTAP-5 Pre-release that provides a complete disaggregation of the EU.[10] To accomplish this task we developed an optimization algorithm that uses the economic structure of these 4 countries in GTAP-5 Pre-release while imposing the output, demand, and trade balances for their corresponding aggregate region in GTAP4-E. This allowed us to leave unchanged all other regions of the standard EPPA based on GTAP4-E.

We followed the methodology developed by Babiker *et al.* (2000b) for the United States to break out transportation from EPPA's OTHERIND sector and to create a household supplied transportation sector (i.e. private automobiles) in the EU. The basic approach for the TRANS sectors is to use GTAP's trade and transport sector that combines transport with trade margins in combination with data from Input-Output tables produced by the European statistical office (Eurostat). These tables provide the data to disaggregate trade margins from transportation for each European country. For the other regions in the model, we used the US input-output coefficients from Babiker *et al.* (2000b) study. We have also made adjustments directly to the Household (H) sector to represent own-supplied transportation services, primarily those provided by personal automobiles. We used consumption expenditure of private households reported by Eurostat (1999) and energy prices and taxes from the International Energy Agency (IEA, 1998a; IEA, 1998b; IEA, 2000) along with the coefficients reported in the Babiker *et al.* (2000b) study were used to separate the household purchases that are part of household production of transportation from other household purchases. The new breakout yields a sector of own-supplied personal transportation (private automobiles) separate from other household activities, and a separate transportation sector in industry that supplies transport services to both industry (i.e., freight transportation and any passenger transportation purchased by business) and households (purchased transportation service, mainly passenger transportation services such as air and rail service).

[10] Though GTAP-5 Pre-release has all 9 of these countries broken out we chose to focus on disaggregating only the 4 largest of these countries.

Production Sectors	Name	Countries and Regions	Name
Non-Energy		***Annex B***	
1. Agriculture	AGRI	United States	USA
2. Energy-Intensive Industries	EINT	Japan	JPN
3. Other Industries and Services	OIND	Europe	EEC
4. Transportation	TRAN	Denmark	DNK
Energy		Finland	FIN
5. Crude Oil	OIL	France	FR
6. Natural Gas	GAS	Germany	DEU
7. Refined Oil	REFOIL	Italy	ITA
8. Coal	COAL	Netherlands	NLD
9. Electricity	ELEC	Spain	ESP
Future Energy Supply		Sweden	SWE
10. Carbon Liquids		United Kingdom	GBR
11. Carbon-Free Electric		Rest of EU[a]	ROE
		Other OECD	OOE
Households (Consumers) Sector	H	Former Soviet Union	FSU
		Central European Associates	EET
Primary Factors		***Non-Annex B***	
1. Labor	L	Brazil	BRA
2. Capital	K	China	CHN
3. Fixed Factors for Fuel and Agriculture		India	IND
		Energy Exporting Countries	EEX
		Dynamic Asian Economies	DAE
		Rest of World	ROW

[a] Includes Austria, Belgium, Greece, Ireland, Luxemburg, and Portugal.

Table 1: Dimensions of the EPPA-EU model

Parameter	Description	Value
σ_{ERVA}	Elasticity of substitution between energy resource composite & value-added (agriculture only)	0.6
σ_{ER}	Substitution between land and energy-material bundle (agriculture only)	0.6
σ_{AE}	Substitution between energy and material composite (agriculture only)	0.3
σ_{VA}	Substitution between labor & capital[a]	1
σ_{ENOE}	Substitution between electric and non electric energy	0.5
σ_{EN}	Substitution among non-electric energy[b]	1
σ_{GR}	Substitution between fixed factor and the rest of inputs	0.6
σ_{EVA}	Substitution between energy and value added composite[c]	0.4
σ_{DM}	Armington substitution between domestic and imports[d]	3
σ_{MM}	Armington substitution across imports: Non energy goods:	5.0
	Energy goods:[e]	4.0
σ_{CS}	Temporal substitution between consumption and saving	1
σ_{C}	Substitution across consumption goods[f]	
G0	Labor supply annual growth rate in efficiency units: Developed countries:	1-3%
	Developing countries:	2.5-6%

[a] Except nuclear in which it is 0.5.
[b] Except for electricity where coal and oil generation substitute at 0.3 among themselves and at 1.0 with gas.
[c] Except energy intensive and other industry where it is 0.5.
[d] Except Electricity where it is 0.3.
[e] Except refined oil (6) and electricity (0.5).
[f] Varies across countries and is updated with income recursively to reflect income elasticities based on an econometrically estimated equation. See Babiker *et al.* (2001) for details.

Table 2: Model parameters

4.2 A Simple Approach to Welfare Decomposition

Building on the conventional Hicks and Slutsky partial equilibrium decomposition analysis of a price change into income and substitution effects, we extend the approach to the carbon policy and the general equilibrium context. Under general equilibrium the welfare effect of a carbon constraint is channelled through income and prices. The imposition of a carbon policy raises production costs and consumer prices (depending on the carbon intensities of the produced and/or consumed goods), and thereby induces changes in welfare. Also, by raising production costs, carbon policy causes output and income losses, which affect consumption and thereby welfare. Emission trading is thought, by equating marginal costs, to reduce the welfare costs of any given carbon policy. Whether this is always true, however, depends on the effects of equating marginal costs on incomes and consumer relative prices. Thus a welfare decomposition of these effects helps to explain when and why a country may benefit or lose from emission trading, and to trace back the sources of these benefits or losses.

Ignoring the environmental benefits from emission reductions, we define the indirect welfare function as:

$$W = W(P(carbon), M(carbon)) \tag{1}$$

where P is the consumer price vector and M is income, and where we use "carbon" to indicate the carbon policy regime. The effect of an infinitesimal change in the carbon policy regime on welfare at values $\overline{M}$ and $\overline{P}$ is then:

$$\frac{dW}{dcarbon} = \sum_i \frac{\partial W}{\partial p_i} \frac{\partial p_i}{\partial carbon} |\overline{M} + \frac{\partial W}{\partial M} \frac{\partial M}{\partial carbon} |\overline{P} \tag{2}$$

where i refers to the consumption goods. The first term on the right hand side is then the price effect and the second term is the income effect. For a large change in the carbon policy regime such as moving from national caps to international permit trading the decomposition may be approximated as:

$$\triangle W \approx \sum_i \frac{\partial W}{\partial p_i} \triangle p_i |\overline{M} + \frac{\partial W}{\partial M} \triangle M |\overline{P} \tag{3}$$

where we have assumed linearity in the welfare response to prices and income. In addition to linearity, two further problems with the above formulation in the general equilibrium context are the interdependence among prices (i.e. , substitutability and complementarities) and the joint determination of incomes and prices. The numerical method we develop allows us to test whether these assumptions are quantitatively important. We apply this technique to decompose the welfare impacts of emission trading among the EU member countries using the EPPA-EU model.

The method proceeds as follows. Utilizing the price-quantity duality in the model, we use the unit expenditure function, which defines the consumer price index (CPI), to summarize the price effect on welfare. Yet the challenge is how to disentangle numerically the joint determination of income and prices in the general equilibrium model. We do this by using simultaneously two instruments, one to control the consumer price index and the other to control income. The more general form of the welfare decomposition that we use is thus:

$$\triangle W \approx \triangle W|\overline{M} + \triangle W|\overline{P} \quad (4)$$

where P here is the CPI or the unit expenditure index and where $\triangle W$ is the welfare after trading minus the welfare before trading. According to this expression the change in welfare due to the introduction of emission trading is approximately equal to the welfare change due to changes in relative prices only (the price effect) plus the welfare change due to change in income only (the income effect). Numerically we compute one effect and obtain the other by subtraction. To assess our handling of the non-linearity in the price income relationship, we reverse the order and compute the other effect first and then compare the results from the two procedures. After ensuring a satisfactorily agreement in results, we use the procedure that fixes income to do a further decomposition of the price effect into a pure domestic price effect and a terms-of-trade effect. The extent to which the two estimates differ indicates the accuracy of the decomposition approach; that is much the empirical modeling diverges from the assumptions of linearity and independence of the two effects. The results from applying the decomposition technique are presented and explained in the results section.

4.3 Scenarios and results

In our simulations, we suppose that each Annex B country implements the necessary policies to meet their Kyoto commitment by 2010.[11] In addition, the reallocation made by the Burden Sharing Agreement (BSA) is applied for European countries (Viguier, 2001). We also assume that Annex B

[11]The analysis examines only CO_2 emissions from fossil fuels. Kyoto includes flexibility to abate other greenhouse gases and to offset emissions with limited forest and land use sinks for carbon, which are not considered here.

countries outside the EU bubble meet their target only by domestic actions (without international flexibility). Finally, no restriction is put on non-Annex B countries.

The cases we construct to investigate the welfare effects of international emission trading (by which we refer to trading among the EU member countries) are:

ETR: **E**conomy-wide **TR**ading where each EU country implement a full domestic emission trading system but without trade across countries (including pre-existing energy market distortions).

IET$_d$: **I**nternational **E**mission **T**rading where emission permits can be traded across sectors within the European Union in the presence of pre-existing **d**istortions.

IET$_{nd}$: **I**nternational **E**mission **T**rading where emission permits can be traded across sectors within the European Union, and where pre-existing distortions (e.g. energy taxations) are removed (**n**o **d**istortion).

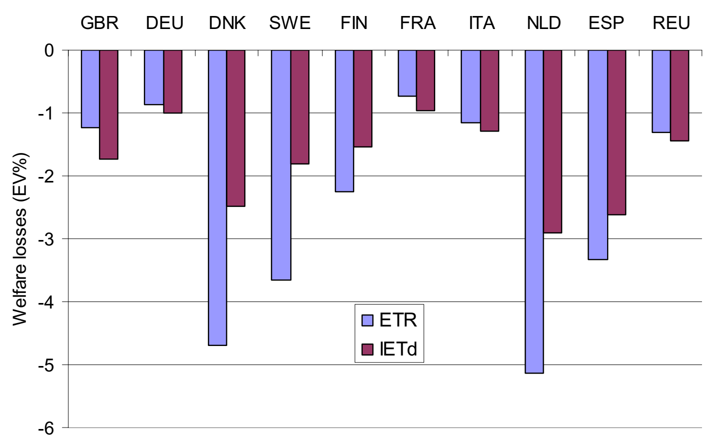

Figure 5: Welfare effects of EU-wide emissions trading (in EV%)

Figure 5 illustrates welfare losses associated with the Kyoto constraint when a uniform carbon tax is applied in each EU country (ETR case). According to the EPPA-EU model, welfare cost of Kyoto range from –0.7% in France to over –5% in Netherlands. **Figure 5** also shows the effect of implementing a EU-wide emission trading in the presence of existing energy taxes. Some countries, like Scandinavian countries or Spain (mainly importers of carbon permits), would be better off with international trading whereas other, like the United Kingdom, Germany or France (mainly exporters of carbon permits) are worse off with trading than without.

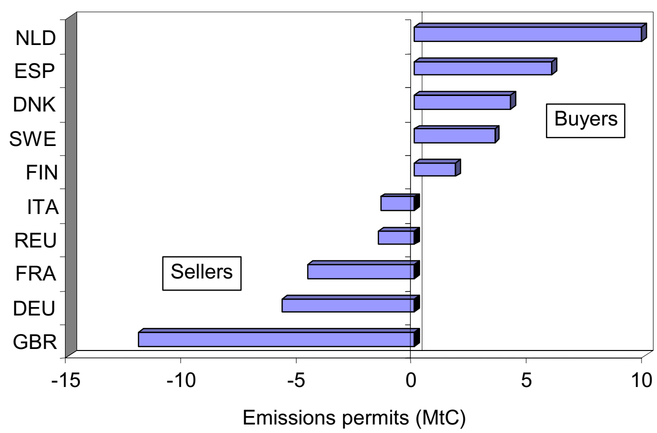

Figure 6: EU-wide emission trading market, IETd case

Figure 6 depicts trade position of EU countries on the carbon market under the IET_d case. According to the EPPA-EU model, 25 MtC are expected to be traded in this carbon market by 2010. The estimated carbon price for the EU bubble is around \$175/tC. The United Kingdom, Germany, France, Italy and the rest of Europe are projected to sell emission permits to Netherlands, Spain, Denmark, Sweden and Finland. If we compare the welfare effects of international emission trading with trade positions, we can see that net sellers of permits are those that are expected to be damaged with international emission trading whereas net buyer of permits correspond to winner countries.

Table 3 and **Table 4** provide the decomposition of the welfare gains from international emission trading in the context of Kyoto Agreement, expressed in EV% points (i.e. EV% for case IET_d minus EV% for case ETR) for year 2010. According to our explanation in section 3.2, international emission trading has a positive income effect and a negative price effect on seller countries. In the presence of existing energy taxes, welfare is reduced in

	Method (A) control for the price effect			Method (B) control for the income effect		
	Income effect	Price effect	Total effect	Income effect	Price effect	Total effect
GBR	0.29	-0.80	-0.51	0.41	-0.92	-0.51
DEU	0.09	-0.23	-0.13	0.11	-0.25	-0.13
DNK	-1.95	4.15	2.20	-2.05	4.25	2.20
SWE	-1.06	2.90	1.84	-0.99	2.83	1.84
FIN	-0.26	0.97	0.71	-0.28	1.00	0.71
FRA	0.09	-0.33	-0.24	0.06	-0.30	-0.24
ITA	-0.02	-0.11	-0.13	-0.04	-0.09	-0.13
NLD	-1.09	3.33	2.23	-1.54	3.77	2.23
ESP	-0.30	1.01	0.71	-0.40	1.12	0.71
REU	-0.01	-0.13	-0.13	0.00	-0.13	-0.13

Table 3: Decomposition of welfare change from emission trading, IETd case (in EV%)

	Domestic price effect	Terms of trade effect	Total price effect
GBR	-0.84	-0.08	-0.51
DEU	-0.18	-0.06	-0.13
DNK	1.86	2.39	2.20
SWE	1.61	1.22	1.84
FIN	-0.01	1.01	0.71
FRA	-0.21	-0.10	-0.24
ITA	-0.09	0.01	-0.13
NLD	3.31	0.46	2.23
ESP	1.24	-0.12	0.71
REU	-0.01	-0.13	-0.13

Table 4: Decomposition of the price effect from emission trading, IETd case (in EV%)

all permit-exporting countries since income gains from international emission trading are outweighed by the negative price effect. Conversely, international emission trading is welfare increasing for permit-importing countries.

This example based on the EPPA-EU model demonstrates that international emission trading could be welfare decreasing in some countries because of general equilibrium effects. Despite the gains from trading, exporting countries are worse off in this example because of the small size of permit trade and because of the existing price structure, which involves already very high energy taxes. In contrast, permit importing countries are better off mainly because the welfare gains from reducing the carbon tax (through permit trading) in the presence of the pre-existing energy tax system are more than needed to compensate the welfare loss due to giving away money in exchange for permits.

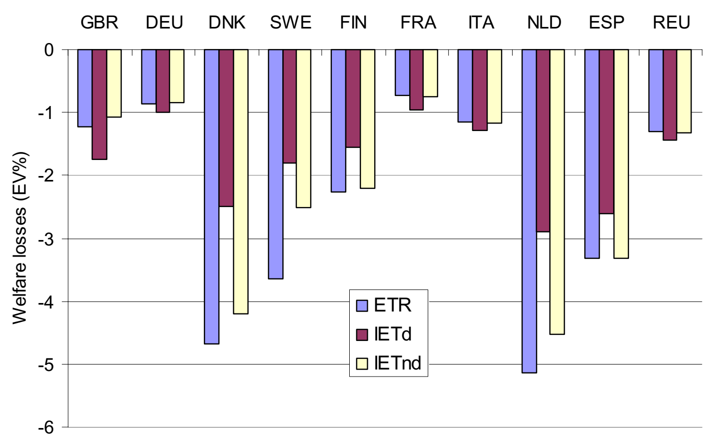

Figure 7: Welfare effects of EU-wide emission trading with and without pre-existing distortions (in EV%)

To further demonstrate that energy taxes are the distortions that lead to losses from trading we conducted additional simulations where we removed existing energy taxes in the EPPA-EU model. As shown in **Figure 7**, the distortionary effect of the carbon constraint is reduced when existing taxations are removed. On one side, welfare gains from emission trading are more limited in importing countries in the IET_{nd} case, compared to the IET_d case. On the other side, most of permit-exporting countries become

	Income Effect	Price effect	Total effect
GBR	0.0350	-0.0324	0.0026
DEU	0.0072	-0.0067	0.0005
DNK	-0.0773	0.0873	0.0100
SWE	-0.0757	0.0987	0.0230
FIN	-0.0115	0.0126	0.0011
FRA	0.0003	-0.0006	-0.0003
ITA	-0.0007	0.0004	-0.0003
NLD	-0.0568	0.0666	0.0098
ESP	-0.0018	0.0020	0.0002
REU	-0.0085	0.0082	-0.0003

Table 5: Decomposition of welfare change from emission trading, IETnd case (in EV%)

better off with international emission trading.

Table 5 presents the decomposition of welfare gains from emission trading when existing taxes are removed, expressed in EV% units for year 2010. In general, the direction of the income and price effects is the same as in the case of distortions shown in Table 3. However, the magnitude of these effects is significantly different. In particular removing existing taxes has greatly alleviated the welfare burden of the incremental carbon tax (caused by trading), and as a result we see the positive income effect offsets the negative price effect leading to a net welfare gain for all exporting countries, except France. In the importing countries, on the other hand, the positive price effect still dominates the negative income effect but net welfare gains are reduced (except in Italy and Rest of Europe).

5 Conclusion

Our analysis shows that international emissions trading can be welfare decreasing because of general equilibrium effects when there are distortions. It occurs in countries exporting emission permits when efficiency costs associated with pre-existing distortionary taxes are larger than the primary gains from emission trading. The case can arise because (1) energy markets are already highly distorted in the European Union, and (2) EU countries are heavily dependent on trade. It means that the tax-interaction effect and the drop in the terms of trade can be great enough to offset the direct income gains from emissions trading. Note that the adverse effect of trading occurs in countries which gained a comparative advantage from the absence of free trade in carbon emission permits.

The adverse effects of emission permits in exporting countries are largely explained by the presence of sub-optimal taxations in the pre-trade situation. When pre-existing distortions are removed, most of European countries exporting permits are better off when an international emission trading regime is implemented. Thus, our analysis highlights the interaction of pre-existing energy taxes and the Kyoto regime. The implementation of Kyoto by economy-wide carbon taxes tend to create high distortions and dead-weight losses in Europe because of existing energy taxation. We find that an EU-wide emissions trading regime in the presence of existing energy taxes is immiserizing for permit-exporting countries.

A critical aspect of our conclusions is that existing energy taxes are viewed as pure distortions. Of course some taxes may be justified if they internalize other externalities, environmental or not. However, can we assume energy taxes in Europe are set at levels that optimally correct externalities? Probably not if we accept the analyses that have found little connection between fuel tax levels and externalities. Thus, a carbon emissions trading system could easily be welfare worsening in the EU. In this respect, the EC proposal to limit the possibility to trade across Europe to energy companies and energy-intensive industries, and by this way to exclude the more distorted sectors from the trading market is probably a good one. Another policy option would be to let legal entities freely trade emission permits domestically while limiting international trade to national governments in hopes that government sponsored trades would reflect social costs.

The first best solution is to remove the existing distortions. In the absence of a willingness to do that, these result show that it is possible for a country to lose as a result of introducing international permit trading. It may therefore be possible for a country to intervene in an international trading system and improve its welfare. Perhaps more importantly, this may help explain the political difficulties of introducing and sustaining an international permit trading system, and the interests expressed in government-to-government trading instead of international firm-to-firm trading. In the case we examined, and with existing distortions, no country had an economic incentive to be a permit seller–clearly a market with no sellers, and only buyers is not feasible. Thus, there does not appear to exist a coalition of countries among those we examined where there is an economic incentive to have a trading system, absent a set of side-payments from those who would gain from trading to those who would lose.

6 Acknowledgments

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 (BER), (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 Richard Baron, Alain Bernard, Denny Ellerman, Alain Haurie, Henry Jacoby, Marc Vielle and anonymous reviewers. The views expressed herein, including any remaining errors, are solely the responsibility of the authors.

7 References

Armington, P., 1969, A Theory of Demand for Products Distinguished be Place of Production, IMF Staff Papers 16: 159-178.

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

Babiker, M., Bautista, M., Jacoby, H., and Reilly, J., 2000b, Effects of Differentiating Climate Policy by Sector: A United States Example, MIT Joint Program on the Science and Policy of Global Change, Report no 61, Cambridge, MA.

Babiker, M., Viguier, L., Reilly J., Ellerman A. D., Criqui, P., 2001, The Welfare Costs of Hybrid Carbon Policies in the European Union, MIT Joint Program on the Science and Policy of Global Change, Report no 74, Cambridge, MA.

Ballard, C.L., Shoven, J.B., Whalley, J., 1985, "General Equilibrium Computations of the Marginal Welfare Costs of Taxes in the United States", *The American Economic Review*, 75(1): 128-138.

Bernard, A.L., Vielle, M., 2001, Toward a Future for the Kyoto Protocol: Some Simulations With GEMINI-E3, unpublished paper, first version presented at the Annual Congress of the French Association of Economic Science (AFSE) in Paris, September.

Bhagwati, J.N., 1958, "Immiserizing Growth: A Geometrical Note", *The Review of Economic Studies*, 25(3): 201-205.

Bhagwati, J.N., 1968, "Distortions and Immiserizing Growth: A Generization", *The Review of Economic Studies*, 35(4): 481-485.

Bhagwati, J.N., 1969, "Optimal Policies and Immiserizing Growth", *The American Economic Review*, 59(5): 967-970.

Bhagwati, J.N., 1971, "The Generalized Theory of Distortions and Welfare", in: J.N. Bhagwati, R.W. Jones, R.A. Mundell, J. Vanek, eds., *Trade, Balance of Payments, and Growth: Papers in International Economics in Honor of Charles P. Kindelberger*, North Holland Publishing Company.

Bhagwati, J.N., 1973, "The Theory of Immiserizing Growth: Further Applications", in: M. Connolly and A. Swoboda, eds., *International Trade and Money*, Allen and Unwin, London, 45-54.

Bhagwati, J.N., Brecher, R.A., 1981, "Foreign Ownership and the Theory of Trade and Welfare", *Journal of Political Economy*, 89(3): 497-511.

Bhagwati, J.N., Brecher, R.A., 1982, "Immiserizing Transfers from Abroad", *Journal of International Economics*, 13: 353-364.

Bhagwati, J.N., Srinivasan T.N., 1983, "Immiserizing Growth", in: J. N. Bhagwati and T. N. Srinivasan, eds., *Lectures on International Trade*, The MIT Press, Cambridge Massachusetts, 249-259.

Bhagwati, J.N., Tironi, E., 1980, "Tariff Change, Foreign Capital and Immiserization: A Theoretical Analysis", *Journal of Development Economics*, 7:71-83.

Böhringer, C., 2002, "Industry-level emission trading between power producers in the EU", *Applied Economics*, 34: 523-33.

Browning, E.K., 1976, "The Marginal Cost of Public Funds", *Journal of Political Economy*, 84: 282-298.

Browning, E.K., 1987, "On the Marginal Welfare Cost of Taxation", *The American Economic Review*, 77(1): 11-23.

Coase, R. H., 1960, "The Problem of Social Cost", *Journal of Law and Economics*, 3: 1-44.

Criqui, P., Mima, S., Viguier L., 1999, "Marginal Abatement Costs of CO_2 Emission Reductions, Geographical Flexibility and Concrete Ceilings: an Assessment Using the POLES Model", *Energy Policy*, 27: 585-601.

Dales, J.H., 1968, "Land, Water and Ownership", *Canadian Journal of Economics*, 1:791-804.

Ellerman, A.D., Decaux, A., 1998, Analysis of Post-Kyoto CO2 Emissions Trading Using Marginal Abatement Curves, MIT Joint Program on the Science and Policy of Global Change, Report no 40, Cambridge, MA.

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

Eurostat, 1999, *Consumption Expenditures of Private Households in the European Union*, Luxemburg.

Fullerton, D., "Reconliling Recent estimates of the Marginal Welfare Cost of Taxation", *The American Economic Review*, 81(1): 302-308.

Fullerton, D., Metcalf, G., 1997, Environmental Controls, Scarcity Rents, and Pre-Existing Distortions, NBER Working Paper 6091, Cambridge, Mass., July.

Gielen, D., Kram, T., 2000, The role of Kyoto mechanisms: results from MARKAL analysis, ECN-Policy Studies, Amsterdam.

Goulder, L.H., 1995, "Effects of Carbon Taxes in an Economy with prior Tax Distortions: An Intertemporal General Equilibrium Analysis", *Journal of Environmental economics and Management*, 29:271-97.

Goulder, L.H., Parry, I.W.H., Williams III, R.C., Burtraw, D., 1998, The Cost-Effectiveness of Alternative Instruments for Environmental Protection in a Second-Best Setting, NBER Working Paper 6464, Cambridge, Mass., March.

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

International Energy Agency (IEA), 1998a, *Energy Statistics of OECD Countries 1995-1996*, Paris, France.

IEA, 1998b, *Energy Balances of OECD Countries 1995-1996*, Paris, France.

IEA, 2000, *Energy Prices and Taxes*, third quarter 1999, Paris, France.

Jacoby, H.D., Eckaus, R., Ellerman, A., Prinn, R., Reiner, D., Yang, Z., 1997, "CO_2 Emissions Limits: Economic Adjustments and the Distribution of Burdens", *The Energy Journal*, 18(3): 31-58.

Jacoby, H.D., Sue Wing I., 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.

Johnson, H.G., 1967, "The Possibility of Income Losses from Increasing efficiency or Factor Accumulation in the Presence of Tariffs", *Economic Journal*, 77: 151-154.

Kerr, S., 2000, "An International Tracking System for Greenhouse Gas Trading", in: S. Kerr, eds., *Global Emissions Trading. Key Issues for Industrialized Countries*, Edward Elgar, Cheltenham, UK, 27-41.

Kindelberger, C. P., Lindert, P. H., 1978, *International Economics*, sixth edition, Richard D. Irwin, Inc., Homewood, Illinois.

Knight, F.H., 1924, "Some Fallacies in the Interpretation of Social Cost", *Quarterly Journal of Economics*, 38:582-606.

Lipsey, R.G., Lancaster, K. 1956, "The General Theory of Second Best", *The Review of Economic Studies*, 24(1):11-32.

Newbery, D.M., "Should carbon taxes be additional to other transport fuel taxes?", *Energy Journal*, 13(2):49-60.

Newbery, D.M., 2001, Harmonizing energy Taxes in the EU, paper prepared for conference *Tax Policy in the European Union* held in OCFEB, Erasmus University, 17-19 October.

Parry, I.W.H., Williams II, R.C., 1999, "A Second-Best Evaluation of eight Policy Instruments to Reduce Carbon Emissions", *Resource and Energy Economics*, 21: 347-373.

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

Tietenberg, T., 2000, *Environmental and Natural Resource Economics*, Fifth Edition, Addison Wesley Longman, Inc., Reading, Massachusetts.

Viguier, L., 2001, "Fair Trade and Harmonization of Climate Change Policies in Europe", *Energy Policy*, 29(10): 749-753.

Viguier, L., Babiker M., Reilly J., 2001, Carbon Emissions and The Kyoto Commitment in the European Union, MIT Joint Program on the Science and Policy of Global Change, Report no 70, Cambridge, MA.

Weyant, J.P. (Ed.), 1999, "The Costs of the Kyoto Protocol: A Multi-Model Evaluation", *The Energy Journal*, Special Issue.

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