The Effect of Trade Liberalization on Carbon Leakage under the Kyoto Protocol: Experiments with GTAP-E

Paper prepared for the 4th Annual Conference on Global Economic Analysis, June 27-29, 2001, Purdue University, West Lafayette, Indiana, U.S.A.

Onno Kuik*

Institute for Environmental Studies, Vrije Universiteit, Amsterdam

Abstract

A group of industrialised countries and countries with economies in transition have agreed to reduce their emissions of greenhouse gases under the Kyoto Protocol of the United Nations Framework Convention on Climate Change. Because of impacts on international trade and investments, the emission reduction policies of these countries - the so-called Annex I countries - could lead to loss of competitiveness and carbon leakage. In the context CO2 reduction policies, changes in import tariffs and other trade barriers have received little attention in the literature. This paper presents quantitative estimations of the impacts of the implementation of the Kyoto agreements on carbon leakage with and without freer trade. The calculations are made with a static, multisector, multiregion applied general equilibrium model (GTAP-E) that allows for inter-fuel and inter-factor substitutions. We find that under a plausible range of assumptions, the implementation of the Uruguay Round reductions of import tariffs a) increases the rate of carbon leakage by around 3 percent-points, but b) does not reduce the competitiveness of energy-intensive industries in Annex 1 countries.

Keywords: Kyoto; Leakage; CO2 reduction policies; Uruguay; Trade liberalization

---

* E-mail address: onno.kuik@ivm.vu.nl

1. Introduction

A group of industrialised countries and countries with economies in transition have agreed to reduce their emissions of greenhouse gases under the Kyoto Protocol of the United Nations Framework Convention on Climate Change. Because of impacts on international trade and investments, the emission reduction policies of these countries - the so-called Annex I countries - could lead to increases of emissions in countries without emission reduction commitments, the non-Annex I countries. This effect is called carbon leakage. Energy- en carbon-intensive industries in the Annex I countries fear that unilateral carbon abatement measures will harm their competitiveness, endanger employment and will not improve the environment because of carbon leakage. There have been a number of studies that analysed the mechanisms of changes in competitiveness and carbon leakage and that have provided quantitative estimates of their extent. Of the many factors that potentially affect competitiveness of energy-intensive industries and the rate of carbon leakage, changes in import tariffs and other trade barriers have received little attention in the literature. Yet we know that, at least until 2005, tariffs and other trade barriers will be subject to the gradual implementation of the Uruguay Round of multilateral trade negotiations. After that and up to the first commitment period of the Kyoto Protocol (2008-2012), further trade liberalization may be envisaged. This paper presents quantitative estimations of the impacts of the implementation of the Kyoto agreements on carbon leakage with and without the full implementation of the import tariff reductions that were agreed in the Uruguay Round. We find that under a plausible range of assumptions, the implementation of the Uruguay Round reductions of import tariffs a) increases the rate of carbon leakage by around 3 percent-points, but b) does not reduce the competitiveness of energy-intensive industries in Annex 1 countries. The estimations are made with a static, multisector, multiregion applied general equilibrium model (GTAP-E) that allows for inter-fuel and inter-factor substitutions. The model employs a special-purpose database that combines comprehensive input-output data by region, bilateral trade and protection data, and energy price, quantity and tax data that were collected from the International Energy Agency and other sources.

Section 2 of this paper briefly describes the political context of the Kyoto regime and the issues of international competitiveness and carbon leakage. Section 3 surveys literature on carbon reduction policies, trade and carbon leakage. Section 4 presents the design of the experiments carried out with GTAP-E, while section 5 presents the results. Section 6 concludes.

2. Background, key concepts and research problem

2.1 Political context

In the debate on climate change policies, the issue of “competitiveness”, and especially the fear of losing it, remains high on the political agenda. Only recently, President Bush criticized the Protocol as being unfair to the United States because it exempts many countries from making reductions, and he worried it will cost jobs (CBS, 2001). This concern on the impacts of the protocol on the competitiveness of US industry was also clearly expressed in the Byrd-Hagel resolution in the U.S. Senate in 1997, which opposed the ratification of the Kyoto protocol in its present form (U.S. Senate, 1997). In a speech to the Senate, Senator Hagel (co-sponsor of the Byrd-Hagel resolution) explained: “The main effect of the assumed policy [a Kyoto-like agreement] would be to redistribute output, employment, and emissions from participating to nonparticipating countries” (Hagel, 1997). This statement suggests that unilateral emission reduction would not only harm industries in participating countries, but would also harm the environmental integrity of the agreement by shifting emissions to non-participating countries. Moreover, it suggests that competitiveness and carbon leakage are two sides of the same coin.

The next two sections briefly examine the concepts of competitiveness and carbon leakage. After that, Section 2.4 introduces a specific method to decompose emission changes due to trade and environmental policies. Finally, Section 2.5 presents the research problem.

2.2 International competitiveness

A common definition of competitiveness is the degree to which a country can, under free and fair market conditions, produce goods and services which meet the test of international markets, while simultaneously maintaining and expanding the real income of its people over the longer term (OECD, 1992). This would suggest that it is the relative competitive position vis-à-vis other countries that determines the economic success of a country. Not so, says trade economist Krugman: predominantly it is the absolute, domestic growth of productivity that matters. And although deteriorating terms of trade could, in theory, reduce the “buying power” of domestic production, there is no empirical evidence that this is a serious issue for large countries such as the USA, the EU or Japan. The focus on international competitiveness is a “dangerous obsession”, as it diverts attention away from domestic impediments to growth, may result in a misallocation of resources and may give rise to protectionist’ sentiments with respect to international trade (Krugman, 1994).

Nevertheless, the concern for competitiveness effects on specific industries is understandable and legitimate. Most vulnerable are those industries that are energy-intensive and exposed to international trade. They include iron and steel, chemicals, non-ferrous metals and mineral products.

The effects of climate change and trade policies on these individual industries are measured by changes in net trade and changes in output. In addition, in order to measure the overall effect of these policies on industrial structure, use is made of the so-called “composition effect” that is discussed in Section 2.4 below.

2.3 Carbon leakage

Carbon reduction policies in the Annex I region can have effects on developing countries through price and volume changes in the world markets of energy commodities and other goods and services.

First, as the import demand for fossil fuels in Annex I declines, fuel prices on the world market, and consequently in the non-Annex I region may fall. This gives rise to income and substitution effects. If we assume that the prices of the fuels with the highest carbon content fall most, economic agents in developing countries will find it profitable to substitute higher-carbon fuels for lower-carbon fuels. Moreover, they may substitute fuels for other factors of production. The sign of the substitution effect is unambiguous: it increases the demand for carbon-intensive fuels and thus raises carbon emissions. The income effect differs between net exporters and net importers of energy. Net importers see their terms of trade improve and the induced income gain will, all things equal, increase carbon emissions. Net exporters see their terms of trade decline, and this will reduce the growth of their economies and hence carbon emissions.

Second, due to the typical specialization pattern of developing countries (net exporter of primary commodities such as fossil fuels and net importer of advanced industrial products, including energy-intensive goods and services), its terms of trade vis-à-vis the industrialized countries will decline. The resulting income losses will, all other things equal, reduce carbon emissions.

Third, lower fuel prices reduce the cost of production of energy-intensive industries in the non-Annex I region. These industries experience an improvement in their domestic competitiveness as well as an improvement of their competitiveness over Annex I competitors. The relative expansion of output of energy-intensive industries in non-Annex I will cause, all other things equal, a rise in carbon emissions.

The net effect of these forces on carbon emissions and carbon leakage is an empirical question. Note, that there are several causes of carbon leakage of which industrial relocation is only one. There is no one-to-one relationship between carbon leakage and industrial relocation.

2.4 Scale, composition and technique effects

Since Grossman and Krueger's influential paper on the environmental impacts of NAFTA (Grossman & Krueger, 1991), the environmental impacts of trade liberalization are often decomposed into a scale effect, a composition effect and a technique effect. In this paper this decomposition is used to analyse the effects of carbon reduction policies, as well as trade policies. The scale effect measures the environmental impact of the expansion (contraction) of economic activity following a policy change, assuming that the nature (composition and technique) of that activity remains unchanged. But, of course, the sector structure, the composition of industry, may change as well. The effect of the change of composition of industry on pollution is called the composition effect. Given the scale of economic activity and the technique of production, the composition effect is positive (more CO2 emissions) if the economy specializes in the direction of pollution-intensive industries; it is negative (less CO2 emissions) if the specialization is in the opposite direction. Finally, there is the technique effect. Industries may not produce their output in the same way as before the policy change. For example, the levying of a carbon tax on fuels may cause profit-maximising firms to substitute away from fuels with a high level of CO_2 per energy-unit or to substitute fuels for other factors of production.

The decomposition of a change in emissions in scale, composition and technique effects is complicated by interactions between the effects. In this paper we have circumvented these complications by carrying out the decomposition in a specific order. First the composition effect is calculated, keeping scale and technique[1] constant. Total output of industry is kept at the same level, but the shares of individual industries may have changed. Second, the scale effect is calculated given the new composition, but still using the old technique. Third, new emission coefficients (CO2 emissions per dollar of output) are applied to calculate the technique effect. Annex I presents the formulae in detail.

2.5 Research problem

The research problem of this paper is a problem of policy-interaction: What is the effect of increased openness of the world's trading system on the competitiveness and carbon leakage effects of unilateral carbon reduction policies? Or more specific: What would be the effect of the full implementation of the import tariff reductions that were agreed upon in the Uruguay Round Agreement on competitiveness and carbon leakage due to the implementation of the Kyoto Protocol?

The reduction of trade frictions through trade liberalization encourages countries to (further) specialize according to their comparative advantages. But what determines these comparative advantages? Antweiler, Copeland and Taylor (1998) present two opposing views. The Pollution Haven hypothesis, on the one hand, suggests that increased openness will make countries with less stringent environmental regulations dirtier. Unilateral pollution restrictions, as in the Kyoto Protocol, would increase the comparative advantage of non-regulated countries in dirty goods production. Trade liberalization encourages specialization according to comparative advantages and hence encourages the shift of CO2-intensive industries to countries without a CO2 reduction target, i.e. the non-Annex I countries.

On the other hand, the Factor Endowment hypothesis of international trade theory would suggest that when emissions are concentrated in capital-intensive industries, as is the case for CO_2 emissions, then trade liberalization would lead to a further concentration of these industries in relatively capital abundant countries, i.e. the Annex I countries. Non-Annex I countries would be encouraged to specialise according to their traditional comparative advantages, i.e. in labour and natural resource intensive industries.

In the case of CO_2 emissions, the Pollution Haven hypothesis and the Factor Endowment hypothesis work in opposite directions. Neglecting, for the moment, specific effects on the markets for energy carriers, the Pollution Haven effect reduces the competitiveness of industries in regulated countries and increases carbon leakage, while the Factor Endowment effect potentially increases competitiveness of regulated industries and reduces carbon leakage. Which effect is stronger? The net effect is again an empirical matter (Nordström & Vaughan, 1999).

---

[1] Technique is captured by industry-specific emission coefficients, measuring CO2 emissions per dollar of output.

In the absence of empirical evidence, model simulation is the only tool available to gain insight into the sign and order of magnitude of these effects.

3. Survey of the literature

The literature on competitiveness and carbon leakage, both theoretical and empirical, is huge. Therefore, this section only presents a brief and necessarily incomplete survey. Specific attention is given to the literature that links these issues to trade policies.

The economic consequences of carbon reduction policies of industrialised countries have been assessed in a variety of ways. They have been assessed for single countries (e.g., Jorgenson & Wilcoxen (1993) for the USA), for regional entities such as the EU (e.g., Barker, 1999) and for the entire world, in different regional aggregations. Barker and Johnstone (1998) review models that were used in studies before the completion of the Kyoto Protocol. A number of more recent models were presented at the Stanford Energy Modelling Forum in 1999. Weyant and Hill (1999) divide the models according to two dimensions: the representation of the economy and the representation of the energy sector and carbon generation processes. The representation of energy/carbon ranges from the use of simple carbon coefficients (x g carbon per dollar of output of industry y) to very detailed sub-models of the energy sector. The representation of the economy in the models ranges from a very simple aggregate production or cost function (MERGE), to multisector general equilibrium (WorldScan) and multisector macroeconometric (Oxford). The macro-econometric models account for unemployment and financial market effects, while the general equilibrium models tend to ignore those effects (although there are exceptions and intermediate cases; see Weyant and Hill, 1999).

The assessments of the consequences of Kyoto on the rate of leakage vary considerably (see Table 1). Weyant and Hill (1999) compared the models with respect to a number of variables such as baseline emission projections and carbon taxes under various trading regimes. Böhringer et al. (2000), Bollen et al. (2000) Burniaux and Oliveira-Martins (1999) specifically consider the reasons for varying predictions of carbon leakage.

According to Burniaux and Oliveira-Martins (1999), the impacts of carbon reduction policies on energy and non-energy markets depend on the rate of reduction required and the efficiency of the policies employed to achieve the required reduction. Thus, carbon leakage would be less the lower the reduction required and the more efficient the policies employed. In Table 1, the rate of carbon leakage predicted by the GREEN model is indeed lower if emission trading among Annex I countries is assumed.

In addition, assumptions on three sets of elasticities have been identified as having major impacts on carbon leakage: trade elasticities, fuel substitution elasticities, and the elasticity of supply of fossil fuels. [2]

---

[2] More potential sources of differences are identified by Barker and Johnstone (1998). They include: assumptions on the exchange rate and monetary policies, international factor mobility, market power in the oil sector, expectations and adjustment, revenue recycling, the level of aggregation of regions, sectors and fuels, technological change and strategic behaviour.

Experiments with GTAP-E

Böhringer et al. (2000) pay specific attention to the representation of international trade. Most general equilibrium analyses employ the Armington assumption on trade, i.e. goods from different countries are treated as different goods or varieties. This has the advantage that intra-industry trade can be accounted for and that unrealistically strong specialization effects due to changes in trade policy are avoided. Under the competing Ricardo-Viner assumption, traded goods are homogeneous (and trade elasticities are very large). Böhringer et al. (2000) show that the choice of assumption has a severe impact on the rate of leakage: the larger the trade elasticities (the more homogeneous the goods), the larger the rate of leakage.

Bollen et al. (2000) perform sensitivity analysis on trade and substitution elasticities. Lower trade elasticities lead to lower leakage, confirming the results of Böhringer et al. (2000). Changing substitution elasticities among fuels and other inputs in production gives ambiguous results. In the case of lower substitution elasticities in production, a larger carbon tax is necessary to achieve a certain reduction in emissions. This will shift production to non-regulated countries and increase leakage. However, there is also less downward pressure on fuel prices, thus reducing leakage.

Burniaux and Oliveira-Martins (1999) argue that the key parameter to explain carbon leakage is the inferred supply elasticity of fossil fuels, and especially that of coal. In the extreme case of zero supply elasticity all adjustment would be through prices and there would be no adjustment in quantities. In that case, any unilateral reduction in carbon emissions would be completely offset by increases of carbon emissions elsewhere, i.e. a leakage rate of 100 per cent. With a large elasticity of supply, most adjustment goes through quantities and leakage is modest. The GREEN model employs large supply elasticities for fossil fuels (around 20), which may explain its relatively low rate of carbon leakage (see Table 1). The problems are that empirical estimates of supply elasticities are conflicting and that there are large opportunities for strategic behaviour on the supply side, especially in the oil market.

Table 1 Some model estimates of the rate of carbon leakage.

Carbon leakage rates in a number of models	
Model	Carbon leakage (%)
Light et al. 1999	21 %
WorldScan	20 %
Merge	20 %
GTAP-E (this paper)*	**14%**
EPPA-MIT	6 %
G-Cubed	6 %
GREEN (no trade)	5 %
GREEN (Annex I trade)	2 %

*) including the full implementation of Uruguay Round tariff reductions.
Source: Burniaux and Oliveira Martins, 1999, and this paper.

One would expect that the emission restrictions of Kyoto would affect international capital mobility. Jeppesen et al. (1998) discuss the impacts of environmental policy on international capital mobility at a general level. They do not exclude the possibility that strict environmental policies could lead to capital flight, although little empirical evidence exists as yet. For the case of the Kyoto Protocol, Burniaux and Oliveira-Martins (1999) argue that the degree of international capital mobility does not affect leakages significantly. Their argument is that unilateral abatement in the Annex I region reduces energy imports, increasing its current account surplus and thus resulting in the appreciation of its real exchange rate. This increases the rate of return on capital measured in foreign currency. This appreciation effect would attract international capital, offsetting, to a certain extent, a reduction in the rate of return on capital (measured in domestic currency) induced by the unilateral abatement costs. McKibbin et al. (1999), using a model that explicitly incorporates capital markets, reach similar conclusions. In a recent paper, Babiker (2001) also asserts that carbon leakage is largely unaffected by the extent of capital flows. Because of the fact that carbon constraints in Annex I reduce the relative prices of fossil fuels in non-Annex I, leakage is largely a self-financed process that does not require any capital flows.

The following two studies relate carbon leakage to trade policies, i.e. trade liberalization. Cole et al. (1998) assessed the global impacts on certain environmental variables of the trade policy changes that were agreed upon in the Uruguay Round. The impacts of the Uruguay Round on the regional output of various industries and on per capita incomes are derived from Francois et al. (1995). Cole et al. first estimate the effect on emissions of the predicted shifts in regional industrial structure (the composition effect), and then use econometrically estimated relationships between per capita income and emissions to estimate a combined scale and technique effect.[i] They find that the composition effect increases the emissions of four traditional air pollutants (nitrogen dioxide, sulphur dioxide, carbon monoxide, and suspended particular matter) in industrialised countries. In contrast, in most developing countries (except Latin America), the composition effect reduces emissions. Trade liberalization encourages the expansion of energy-intensive industries in industrialised countries, while developing countries specialise in labour-intensive manufactures, such as textiles.

Babiker, Maskus and Rutherford (1997) assessed, before the conclusion of the Kyoto Protocol, the mutual effects that trade policies and carbon reduction policies can have on each other. They used a static 26-region, 13-sector CGE model of the global economy that was originally constructed for the analysis of the economic impacts of changes in trade policies (the Uruguay Round), but that was extended with a representation of energy markets and carbon flows. They find that global trade liberalization as agreed in the Uruguay Round, in isolation (without carbon reduction policies), would increase global carbon emissions. However, in combination with unilateral carbon emission reduction of Annex I countries, trade liberalization would reduce global emissions and carbon leakage. Unfortunately, the authors do not explain this result in great detail.

The very small body of literature on the interactions between trade policy and carbon leakage would thus suggest that trade liberalization reduces carbon leakage through the composition effect. This suggests that the Factor Endowment hypothesis dominates the Pollution Haven hypothesis. In the experiments below, we will test this suggestion and also try to establish the magnitude of the composition effect, relative to the scale and technique effects of trade liberalization.

4. Design of experiments

The experiments described in this paper provide a numerical illustration of the effects of trade liberalization on carbon reduction policies, competitiveness and carbon leakage.

4.1 The model

The model we use is the GTAP-E model. This model belongs to the Global Trade Analysis Project (GTAP) family of models. GTAP is a widely used, static, multisector, multiregion applied general equilibrium model. A full description of its features is given by Hertel (1997). Among the most notable features are its detailed database with a broad coverage of (trade) distortions, the explicit modelling of transport margins, a global bank to mediate between world savings and investment, and a specification of consumer demand that allows for differential responses to price and income changes across regions. This latter feature is important when the model is used for projections. GTAP-E has the same structure as GTAP, but its production structure includes a more detailed description of substitution possibilities among different sources of energy. The E of GTAP-E stands for Energy.

4.2 Aggregation strategy

The full GTAP4E database consists of 45 regions, 50 traded commodities/sectors and five factors of production (land, unskilled labour, skilled labour, capital and natural resources), We have aggregated the regions into twelve countries and regions. Annex I regions include: USA, Japan, EU, Other OECD, Central and Eastern Europe, and the Former Soviet Union. Non-Annex I regions include: China (including Hong Kong), Dynamic Asian Economies (Taiwan, Korea, Singapore, Thailand), the Middle East, Brazil, and the rest of the world, divided between Net Energy Exporters and Net Energy Importers. There are fifteen traded commodities, including five energy commodities (coal; crude oil; gas; petroleum and coal products; and electricity), and seven other goods and services, including various energy-intensive ones. Table 2 presents an overview of the regions and commodities/sectors that are distinguished in the aggregation.

Table 2 Aggregation of regions and sectors/commodities.

Aggregation of regions and sectors/commodities				
Annex I	USA	USA	Coal	COL
	Japan	JPN	Crude oil	OIL
	EU	E_U	Gas	GAS
	Other OECD	O_O	Petroleum and coal products	P_C
	Central and Eastern Europe	CEE	Electricity	ELY
	Former Soviet Union	FSU	Ferrous metals	I_S
Non-Annex I	China	CHN	Non-ferrous metals	NFM
	Dynamic Asian Economies	DAE	Mineral products	NMM
	Middle East	RME	Chemical, rubber and plastics	CRP
	Brazil	BRA	Paper products, publishing	PPP
	Net Energy Exporters	NEX	Other manufactures	OMN
	Net Energy Importers	NEM	Agriculture	AGR
			Processed food	PRF
			Trade and transport	T_T
			Services	SER

4.3 Experimental design

Three experiments are carried out with GTAP-E. The benchmark equilibrium is based on data of 1995, representing early-Uruguay Round trade conditions. First, a 2010 counterfactual equilibrium is calculated without CO_2 targets or trade liberalization. This 2010 counterfactual benchmark is based on scenario assumptions on the growth of endowments, factor productivities and "autonomous" energy efficiency improvements, based on Hertel et al. (2000) and OECD (1999). Assumptions on the development of supply and demand of the energy sectors (coal, crude oil, gas and electricity) are based on IEA (1998). The 2010 benchmark approximately replicates an OECD/IEA scenario developed for OECD's GREEN model (OECD, 1999).[3]

Subsequently, two policy experiments were carried out. First, carbon emissions in the Annex I regions were constrained to the amount specified by the Kyoto protocol, without changing in import tariffs. Second, carbon emissions were constrained and import tariffs were adjusted to reflect the full implementation of the Uruguay Round trade negotiations. The difference between experiments 1) and 2) is a measure of the net effect of trade liberalization, given the carbon policies in the Annex I region.

Experiment 1: Business-As-Usual Scenario (BaU)

Assumptions on the regional growth of factors of production and technological progress were taken from Hertel et al. (2000) and adjusted so as to replicate as good as possible

[3] GTAP includes factors of production that are specific to certain industries (land, natural resources). Projections of the quantity growth of these factors is problematic. A common procedure in projections is to fix prices instead. In our projection we assume that the real price of natural resources does not change over the projection period. The price of agricultural output is assumed to fall at the same rate as the growth of total factor productivity in agriculture.

the main variables (GDP and CO_2) of the Business as Usual (BaU) scenario of OECD's GREEN model and regional supply and demand projections of coal, oil and gas of IEA (1998). Improvements in energy efficiency were calculated within the model, as a fraction of a region's increase in labour productivity. Projected increases in the quantity index of GDP are 34 per cent for the Annex I region (OECD´s projection is 37 %) and 69 per cent for Non-Annex I region (OECD´s projection is 67 %). CO_2 emissions in Annex I grow by 30 per cent (OECD's projection is 29 %), hence somewhat slower than the growth of GDP. Non-Annex I emissions rise somewhat faster than GDP: by 75 per cent (75 % in the OECD projection). Among the non-Annex I regions, the fastest growing CO2 emitters are China (115 %), the net energy importers (67 %), and the dynamic Asian economies (57 %).

The updated database is used as a starting point for the above-mentioned, two policy experiments.

Experiment 2: Implementing Kyoto Targets (Kyoto)

The next experiment simulates the imposition of mandatory greenhouse gas emission reductions for the Annex I regions, as agreed in the Kyoto Protocol. The Kyoto Protocol specifies targets for Annex I countries in the period 2008-2012 as a percentage of their 1990 emissions of six greenhouse gases. The allowable emissions are called "assigned amounts". The assigned amounts for our Annex I regions are shown in the first column of Table 3. In the Annex I region, the assigned amount is about 95 percent of its 1990 level. To calculate the required reduction percentage of CO2 per region, account has to be taken of the change in emissions of CO2 in the period 1990-1995 and of the possible contribution of the five "other" greenhouse gases to the required reduction.

In a recent paper, Burniaux (2000) assessed the optimal reduction mix for greenhouse gases, including CO2, methane (CH4) and nitrous oxide (N2O). Including the cost-effective abatement of methane and nitrous oxide would reduce the required reduction of CO2 in Annex I from 22 per cent to 18 per cent, on average (Table 3, second and third column).

Table 3 Emission reduction targets for Annex I regions

Regions	Assigned Amounts % of 1990 emissions	CO2 reduction from 2010 BaU (%)	CO2 reduction, corrected for CH4 and N2O abatement (%)
USA	93	-37	-35
JPN	94	-25	-25
E_U	92	-23	-19
O_O	99	-34	-30
CEE	93	-17	-9
FSU	100	0	0
Annex 1	*95*	*-22*	*-18*

So-called sinks, natural ecosystems that sequester carbon, also play a role in the Protocol, although this role is controversial and not yet very clear. We neglect any potential complications by sinks. For the moment we also neglect the possibility of emissions trading among the Annex I regions and the possibility to acquire emission reduction credits in non-Annex I countries through the Clean Development Mechanism.

Experiment 3: Implementing Uruguay Round Tariff Reductions (UR)

In this experiment, we simulate, together with the Kyoto emission reduction constraint, a global reduction in trade barriers, roughly comparable to the implementation of the trade agreements under the Uruguay Round (UR). The UR was concluded in 1994 and allows for yearly staged reductions in tariffs, with most final offer rates due to come into effect by January 1, 1999 (Verikios & Hanslow, 1999). Therefore the GTAP4E database, based on 1995 trade and production statistics, only partially reflects the implementation of the UR. Francois and Strutt (1999) calculated the remaining cuts in import tariffs in relation to the GTAP4 database.[4]

Table 4 Bilateral import tariff rates for ferrous metals (I_S) and chemicals (CRP) of EU in 1995 database and Post-Uruguay Round

	1995 import tariffs of EU (%)		Post-Uruguay import tariffs of EU (%)	
Exporting region	I_S	CRP	I_S	CRP
USA	4.7	3.3	4.7	2.7
JPN	2.2	2.3	1.2	1.8
O_O	1.5	1.5	1.2	1.1
CEE	3.8	8.3	3.8	6.2
DAE	6.9	6.8	4.7	6.7
NEM	21.6	22.2	11.1	13.3

source: calculations after Francois & Strutt (1999)

Table 4 presents the change in EU import tariffs for two energy-intensive products from selected regions. Table 4 shows that the remaining tariff cuts can be substantial for some products, especially in developing countries.

5. Results of experiments

It is assumed in the experiments that the Annex I regions abate CO2 emissions efficiently, that is through the implementation of a carbon tax or through a system of domestic emissions trading. Because of the assumption of no emission permit trading among the Annex I regions, the optimal carbon taxes differ from a zero tax in FSU, a modest tax in CEE (USD 6.20 per ton of CO2), to higher taxes in the E_U (USD 22.74), and the highest taxes in O_O (USD 28.02), JPN (USD 31.10) and USA (USD 31.49).

[4] The Uruguay Round Trade negotiations did not only result in agreement on cuts in import tariffs. Other areas of agreement, for example on the abolition of the Multi Fiber Agreement for textiles and clothing, and other protective measures in agriculture, should ideally also be considered.

Industry adjusts by substitution of fuels and by substitution between fuels and other factors of production (the technique effect), by cutting back on production (the scale effect) and/or by changing its composition towards a less energy-intensive structure (the composition effect). Private households also save on the use of fossil fuels. Private households and firms can further adjust by increasing their imports of CO2-intensive products and intermediates from non-regulated countries. Because of the zero carbon tax, FSU is *de facto* a non-regulated country. Emissions in FSU rise, without, however, exceeding its assigned amount. The Annex I regions reduce their emissions by 3844 Mt CO2, while the non-Annex I regions increase their emissions by 436 Mt CO2. Hence, carbon leakage to non-Annex I countries is 11.3 per cent of the reduction of Annex I. But what causes this leakage? Is it caused by a shift of output and employment to the developing countries? Hardly so.

If the reduction of CO2 emissions is decomposed into a scale, a composition and technique effect, it appears that the scale and composition effects (the change in emissions in Annex I caused by contraction and restructuring of industry) are relatively minor, compared to the technique effect (see Table 6 below). That is, CO2-intensive industry in Annex I adjusts predominantly by reducing the CO2 intensity of its production. The loss of market share is modest. This is confirmed if we look in more detail at the economic impacts on the trade-intensive and energy-intensive industries that were distinguished in Section 2.2 above: ferrous and non-ferrous metals, chemicals and mineral products. Without the carbon tax, the share of energy costs in total costs of these industries is on average 7.3 per cent for the USA and 10.7 per cent for the EU. With the carbon tax, and after all adjustments are made, these shares rise to 8.2 per cent and 10.9 per cent, respectively. The impacts on the volume of exports do not exceed -4.5 per cent, and are -2.0 per cent for the OECD countries on average. Moreover, the market prices of these products increase, also on the world market. For the Annex I region in total and also for the OECD countries individually, the welfare gain due to the improvement of the terms of trade of these products surpasses the reduction of allocative efficiency, resulting in a slight welfare gain (0.26 per cent of the value added of the combined production). The "gross costs" [5] of the carbon taxes are primarily in the energy producing sectors (especially the coal industry) and these sectors are, in general, not very trade-intensive. The gross costs (measured in equivalent variation) are 0.11 per cent of GDP in Annex I. Remarkably, the gross costs are higher in non-Annex I countries (0.27%), dominated by gross costs of 4.5 per cent of GDP in the Middle East.

Uruguay Round

The second policy experiment concerned a reduction of global trade barriers of industrial goods, together with the unilateral CO_2 reduction policy in the Annex I region. Table 6 also presents the decomposition of the effects of this scenario. Total reduction of CO2 in the Annex I region is slightly less than in the previous experiment (- 10 Mt), due to a further increase in emissions in FSU. Emissions in non-Annex I countries are increased in

[5] The term "gross costs" was coined by Lawrence Goulder to denote the welfare sacrifices associated with environmental tax policies, abstracting from the welfare benefits associated with the change in environmental quality (Goulder, 1995).

comparison to the implementation of Kyoto without the tariff reductions (+112.5 Mt). The rate of carbon leakage has therefore increased from 11.3 per cent to 14.3 per cent.

What is interesting is that trade liberalization has not, on average, shifted 'dirty' production to the non-regulated countries. In fact, Table 6 shows that with trade liberalization, the composition effect for the Annex I region is less negative than it was without trade liberalization. The difference between the with and without situation (column C) is positive for the composition effect, indicating that trade liberalization encourages a shift to energy- (and capital) intensive production in the Annex I region. The four energy- and trade intensive industries in Annex I improve their export position relative to the Kyoto implementation without trade liberalization (volume of exports falls by 1.5 per cent, compared to 2 per cent in the non-liberalization case). However, the market prices of the products also increase less. Because of these effects, the improvement in terms of trade is marginally less than in the non-liberalization case, but the total welfare effect is slightly bigger (0.3 % of value added).

*Table 6 Decomposition of change in CO_2 emissions because of Kyoto with and without UR trade liberalization (Mt CO2) **

	A. Without Uruguay Round		B. With Uruguay Round		C. Difference (B-A)	
	Annex I	Non-Annex I	Annex I	Non-Annex I	Annex I	Non-Annex I
Scale effect	- 74.2	+ 31.5	- 74.0	+ 41.3	+ 0.2	+ 9.9
Composition effect	-165.9	- 8.3	- 125.3	- 5.1	+ 40.6	+ 3.2
Technique effect	-3137.7	+ 369.3	- 3164.7	+ 443.5	- 26.9	+ 74.2
Household consumption	- 466.2	+ 43.5	- 470.0	+ 68.7	- 3.7	+ 25.2
Total change	- 3844.0	+ 436.0	- 3833.9	+ 548.5	+ 10.1	+ 112.5

*) see Appendix 1 for details of the calculations

Table 7 presents the sum of scale and composition effects for all individual regions. The first column presents the regional emissions in the BaU scenario as a point of reference. The second and third column present the composition effects (in Mt CO2) in the Kyoto and Uruguay scenarios, respectively. The fourth column presents the difference of the composition effect between the Kyoto and Uruguay scenarios, and it indicates the net effect of trade liberalization. The fifth column presents this net effect as a percentage of the BaU emissions.

The composition effects are rather small, not surpassing 1 per cent of the BaU emissions. This means that the implementation of the Uruguay Round tariff reductions does not lead to major adjustments in industrial composition. The sign of the changes of the composition effects indicate that the composition of industry in OECD countries (except for Japan) shifts in the direction of CO2-intensive industries. The other countries offer a more diverse picture. CO2-intensive industries are strengthened in FSU, China, the Middle East and Brazil, while the reverse is true for the other regions, especially the energy-importing developing regions (NEM).

If we go back to the discussion on the Pollution Haven hypothesis and the Factor Endowment hypothesis in Section 2.5, it appears that the distinction between developed and developing countries that was implicit in that discussion may not so clear-cut. There are small but clear differences between countries and regions within the group of developing countries, just as there are differences within the Annex I region. The composition effects presented in Table 7 do not unambiguously support one of the two competing hypotheses in the case of this particular environmental and trade policy scenario.

Table 7 Composition effects

	BaU	Kyoto	Uruguay	Difference	Difference
	Mt CO2	Mt CO2	Mt CO2	Mt CO2	%
USA	7096.5	-135.3	-108.8	26.5	0.37
JPN	1325.0	-7.2	-8.3	-1.1	-0.08
E_U	3872.5	-49.3	-44.9	4.4	0.11
O_O	1194.1	-5.6	-5.6	0.0	0.0
CEE	972.4	-18.7	-20.5	-1.8	-0.19
FSU	2807.3	50.2	62.8	12.6	0.45
Annex I	*17222.8*	*-165.9*	*-125.3*	*40.6*	*0.24*
CHN	6539.7	3.8	16.5	12.7	0.19
DAE	1255.3	4.4	4.3	-0.1	-0.01
RME	991.6	-1.9	2.3	4.2	0.42
NEX	2565.3	-9.6	-9.7	-0.1	0.0
BRA	313.0	1.2	3.2	2.0	0.64
NEM	2083.2	-6.2	-21.8	-15.6	-0.75
Non-Annex I	*13748.1*	*-8.3*	*-5.2*	*3.1*	*0.02*

6. Sensitivity analysis

The results above might be sensitive to particular assumptions on (policy) scenarios and model parameters. The literature survey of Section 3 identified a number of potentially sensitive assumptions. In this section, we vary these assumptions in order to investigate the robustness of our results, in particular the results with respect to the rate of carbon leakage and the composition effect. The results are presented in Table 8 below. The first row of Table 8 presents the results of our base calculations (the “base” case).

There is a possibility that the results are sensitive to the particular assumptions underlying the BaU scenario. Therefore, the Kyoto and Uruguay scenarios were also carried out on the original 1995 database. The second row of Table 8 presents the results of this “BaU” scenario. The results appear not to be very sensitive to the BaU scenario assumptions, although both leakage and the composition effect for Annex I are smaller in magnitude than in the base case.

The literature suggested that the rate of leakage is dependent upon the efficiency of carbon reduction policies in the Annex I region. Table 8 confirms this suggestion. In the case of free CO2 permit trade among Annex I regions (AX1-trade), carbon leakage is about 4 percent-points lower than in the base case. However, the net effect of trade liberalization on carbon leakage and the composition effect is very similar to the base case.

The implementation of the Uruguay Round agreement on import tariffs is a particular trade policy scenario. An alternative scenario could be full trade liberalization (FTL) in which all bilateral tariffs were eliminated. This scenario has a strong effect on carbon leakage, it increases to more than 20 per cent. In this scenario, the composition effects are also larger, but not dramatically so. The sign of the composition effect in the non-Annex I region changes from positive to negative. This is due to a sign-change in China.

In GTAP-E, coal is treated as a normally traded commodity. Some analysts have suggested, however, that the price of coal is basically determined in regional markets and not (or to a very limited extent) in the world market. In the scenario COAL, zero trade elasticities for coal are assumed. This affects the rate of carbon leakage and it also affects the net effect of freer trade on carbon leakage. This confirms the idea that the level of integration of the international coal market is of importance to the issue of carbon leakage. The COAL scenario does not affect the composition effects.

Technical and economic possibilities to substitute from high-carbon to low-carbon fuels affect the costs of CO2 reduction policies in Annex I. In the scenario HALVE all energy substitution elasticities are halved, making substitution more difficult and hence increasing the costs of carbon reduction policies. More expensive carbon reduction policies have the effect of *reducing* leakage (from 11.3% to 10.3%). The effects on the net effect of trade liberalization and on the composition effect are very small.

In their early estimation of the climate-trade interaction effect, Babiker, Maskus and Rutherford (BMR) assumed relative large trade elasticities. The BMR scenario uses these large trade elasticities. Carbon leakage is higher than in the base case, but the net effect of trade liberalization is not very different. The composition effects for Annex I and non-Annex I are larger, but they do not change sign.

Table 8 Sensitivity analysis

	Leakage			Composition effect (%)	
	Kyoto (Mt)	Uruguay (Mt)	Difference (%-points)	Annex I	Non-Annex I
Base	11.3	14.3	+3.0	+0.24	+0.02
1995	8.8	12.3	+3.6	+0.19	+0.04
AX1-trade	7.4	10.1	+2.7	+0.23	+0.01
FTL	11.3	21.7	+10.4	+0.61	-0.19
COAL	8.0	8.6	+0.6	+0.22	+0.02
HALVE	10.3	12.6	+2.3	+0.17	+0.06
BMR	12.2	15.6	+3.4	+0.39	+0.19

7. Conclusions

Unilateral carbon reduction policies in OECD countries and Eastern Europe are partly offset by carbon leakage to developing countries. In the GTAP-E model, the main route of carbon leakage is due to producers and households in developing countries using more, cheaper fuels (the technique effect). Changes in scale and composition of industry are small. The fear of a massive relocation of output and employment because of the Kyoto agreements is not confirmed by our analysis. The largest output adjustments take place in the energy-producing sectors, especially the coal industry.

The main subject of this paper is the effect of freer trade on carbon leakage and industrial competitiveness. The results of model analysis suggest that the effect on carbon leakage is positive, but small. Carbon leakage does not increase because of an increased relocation of industry, but by a reduction of prices of energy commodities on the world market.

The effect of freer trade on the pollution-intensity of the industrial structure of an economy is measured by the composition effect. In comparison to CO2 reduction policies alone, the combination of CO2 reduction policies and freer trade encourages a relatively more CO2-intensive industrial structure in most OECD countries. This result does not support the Pollution Haven hypothesis. Whether the results support the Factor Endowment hypothesis is not completely clear, as the effects in the non-Annex I region vary across countries and regions.

Sensitivity analysis with respect to assumptions on policies and parameters showed that the results on carbon leakage and the composition effect were in fact quite robust to changes in assumptions. The sensitivity analysis emphasized the crucial importance of assumptions on the international integration of the coal market.

.

References

Antweiler, W, B.R. Copeland, and M.S. Taylor (1998). *Is Free Trade Good For The Environment?* NBER Working Paper Series, National Bureau of Economic Research. Cambridge, MA. [forthcoming in American Economic Review].

Babiker, M.H., K.E. Maskus, and T.F. Rutherford (1997). *Carbon Taxes and the Global Trading Sytem*, Working Paper, University of Colorado.

Babiker, M.H. (2001). Subglobal climate-change actions and carbon leakage: the implication of international capital flows, *Energy Economics*, 23, 121-139.

Barker, T. and N. Johnstone (1998). International Competitiveness and Carbon Taxation, In: Barker, T. and J. Köhler [eds.]. *International Competitiveness and Environmental Policies*, Edward Elgar, Cheltenham, UK/ Northampton, MA, USA.

Barker, T. (1999). Achieving a 10% Cut in Europe's Carbon Dioxide Emissions using Additional Excise Duties: Coordinated, Uncoordinated and Unilateral Action using the Econometric Model E3ME, *Economic Systems Research*, **11**, 4: 401-421.

Böhringer, Ch., Th. F. Rutherford (2000). Decomposing the Costs of Kyoto: A Global CGE Analysis of Multilateral Policy Impacts, Paper presented at the *Tenth Annual Conference of the European Association of Environmental and Resource Economists*, Crete.

Bollen, J., T. Manders, and H. Timmer (2000). Decomposing Carbon Leakage, *Third Annual Conference on Global Economic Analysis*, June 27-30, Melbourne.

Burniaux, J.-M. and J. Oliveira Martins (1999). *Carbon Emission Leakage: A General Equilibrium View*, ECO/WKP(2000)15, Economics Department Working Papers No. 242, OECD, Paris.

Burniaux, J.-M. and P. O'Brien (1999). *Action Against Climate Change*. OECD, Paris.

CBS (2001). CBS News Report, 21 March 2001.

Cole, M.A., A.J. Rayner, and J.M. Bates (1998). Trade Liberalisation and the Environment: The Case of the Uruguay Round, *The World Economy*, **21**, 3: 337-347.

Cole, M.A. (2000). *Trade Liberalisation, Economic Growth and the Environment*, Edward Elgar, Cheltenham.

Francois, J.F. B. McDonald, and H. Nordstrom (1995). Assessing the Uruguay Round, in W. Martins and A.L. Winters (eds.), *The Uruguay Round and the Developing Economies*, World Bank Discussion Paper No. 307.

Francois, J. F and A. Strutt (1999). *Post Uruguay Round Tariff Vectors for GTAP Version 4*, mimeo.

Goulder, L.H. (1995). Environmental taxation and the "double dividend": a reader's guide, In: L. Bovenberg and S. Cnossen, *Public Economics and The Environment in an Imperfect World*, Kluwer Academic Publishers, Boston/London/Dordrecht, pp. 277-313.

Grossman, G. M. and A.B. Krueger (1991). *Environmental Impacts of a North American Free Trade Agreement*, NBER Working Paper Series, National Bureau of Economic Research, Cambridge, MA.

Hagel (1997). Senator Hagel Speech to the US Senate, Congressional Record: October 3, 1997 (Senate), Page S10308-S10311.

Hertel, Th. W., (ed.)(1997) *Global Trade Analysis Project: Modeling and Applications*, University Press, Cambridge.

Hertel, Th. W., K. Anderson, J.F. Francois, and W. Martin (2000). Agriculture and Non-agricultural Liberalization in the Millennium Round. Revised version of a paper presented at the *Global Conference on Agriculture and the New Trade Agenda; Interests and Options in the WTO 2000 Negotiations*, World Bank and WTO, Geneva, October 1-2, 1999.

IEA (1998). *World Energy Outlook*. International Energy Agency, Paris.

Jeppesen, T., H. Folmer, and R. Komen (1998). Impacts of Environmetal Policy on International Trade and Capital Movement: A Synopsis of the Macroeconomic Literature, *World Congress of Environmental and Resource Economists*, Venice.

Jorgenson, D.W. and P. Wilcoxen (1993). Reducing US Carbon Emissions: An Econometric General Equilibrium, *Resource and Energy Economics*, **15**, 1 : 7-25.

Krugman, P. (1994). International competitiveness: a dangerous obsession, *Foreign Affairs*, March-April, p.28-44.

Light, M, C. Kolstad, and T. Rutherford (1999). *Coal Markets and the Kyoto Protocol*, Mimeo.

Liu, J., N. Van Leeuwen, T. Thanh Vo, R. Tyers, and Th. W. Hertel (1998). *Disaggregating Labor Payments by Skill Level in GTAP*, GTAP Technical Paper 11, Purdue University, West Lafayette, IN.

McKibbin, W. J., M.T. Ross, R. Shackleton, and P.J. Wilcoxen (1999). Emissions Trading, Capital Flows and the Kyoto Protocol. *The Energy Journal* [Special Issue: Weyant, J.P. [ed.], The Costs of the Kyoto Protocol: A Multi-Model Evaluation], 287-333.

Nordström, H and S. Vaughan (1999). *Trade and Environment*, Special Studies 4, World Trade Organization, Geneva.

Truong, T. P. (1999). *The Use of Global Trade and Energy Volume Data for the Analysis of Global Energy-Environmental Issues - Some Illustrative Experiments*, Purdue University, West Lafayette, IN.

US Senate (1997). Byrd-Hagel Resolution, 105th Congress, 1st Session, S.RES.98.

Verikios, G. and K. Hanslow (1999). Modelling the Effects of Implementing the Uruguay Round: A Comparison Using the GTAP Model Under Alternative Treatments of International Capital Mobility, *Second Annual Conference on Global Economic Analysis*. 6-20-1999, Denmark.

Weyant, J.P. and J.N. Hill (1999). Introduction and Overview, *The Energy Journal* [Special Issue: Weyant, J.P. [ed.], The Costs of the Kyoto Protocol: A Multi-Model Evaluation], pp. vii-xliv.

Appendix I.

The scale, composition and technique effects interact with each other. In our calculations we evaluated the scale, composition and technique effects in a specific order. The sequence is 1) composition, 2) scale and 3) technique.

First we calculate the composition effect, holding the scale of the economy and the technique of production constant:

$$\left\{ \frac{\sum_{i=1}^{n} q_{i,0}}{\sum_{i=1}^{n} q_{i,1}} \times \left(\sum_{i=1}^{n} q_{i,1} \times c_{i,0} \right) \right\} - \left(\sum_{i=1}^{n} q_{i,0} \times c_{i,0} \right) \tag{1}$$

where q = industry output
c = CO_2 emission coefficient
i = industry index; $i \in n$ industries
0,1 = without, respectively with policy change

Then we calculate the scale effect, given the new composition, but holding technique constant:

$$\sum_{i=1}^{n} q_{i,1} \times c_{i,0} - \left\{ \frac{\sum_{i=1}^{n} q_{i,0}}{\sum_{i=1}^{n} q_{i,1}} \left(\sum_{i=1}^{n} q_{i,1} \times c_{i,0} \right) \right\} \tag{2}$$

Finally, we calculate the technique effect, given the new composition and scale:

$$\sum_{i=1}^{n} q_{i,1} \times c_{i,1} - \sum_{i=1}^{n} q_{i,1} \times c_{i,0} \tag{3}$$

The scale, composition and technique effects thus calculated add up to the total effect on industry emissions. Industry and household emissions (private and government) add up to total emissions.