

## Trade and Climate Policies: Do Emissions from International Transport Matter?

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### 1. INTRODUCTION

TRADE and climate negotiations are at the forefront of the international policy agenda. They appear as relatively odd bedfellows, in particular for environmentalists, who have claimed that increased globalisation means more transport activities. Additionally, it is suspected to lead to an international relocation of emission-intensive production towards countries with low environmental standards, resulting in an increase in worldwide emissions. So far, scholars have overwhelmingly worked on the effect of trade on production-related emissions and have almost entirely neglected the amount of additional emissions generated by increased transport activity. Only in life cycle analysis, transport-related emissions are systematically included (See Roy et al. 2009 for a recent survey on life cycle analysis). Furthermore, there is no generally accepted criterion for the allocation of responsibility for CO<sub>2</sub> emissions from international transport and such emissions are not included in the reduction goals of the Kyoto Protocol. As a result, and in a nutshell, we know little about the interplay between trade, transport and the environment.

The overall share of international freight and passenger transport in global energy-related CO<sub>2</sub> emissions in 2001 was roughly 5 per cent. This is a rather small fraction, but it is expected to increase strongly in the next years for the following two reasons. First, with worldwide globalisation, trading activity and hence total international transport are predicted to increase. Second, air transport, at least 30 times dirtier per ton-km transported than ocean shipping, is becoming an increasingly important mode of freight transport. Manufactured goods traded by air grew by 7.4 per cent per year over the period 1975–2004, while goods traded by ocean grew by 4.4 per cent (Behar and Venables 2011).

If international trade is bound to become more important in the future, a better understanding of the underlying mechanisms at work is crucial. This paper provides first orders of magnitude of those mechanisms in a stylised world trade framework. It extends the existing literature on emissions related to international transport in three novel ways. First, we investigate the interaction between trade policy and climate policy in a carefully adjusted computable general equilibrium (CGE) framework at the worldwide level. Increased trade liberalisation leads to more transport activities, while at the same time transport activities are emission intensive and should therefore be reduced from a climate perspective. This calls for a careful explanation of the choices on the energy mix and transport modes, which are endogenised in the modelling exercise. Second, we integrate

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in our analysis various combinations on how trade and climate policies could go forward (regional or global, with or without exemptions). Regional trade liberalisation for instance is expected to lead to increased short-distance transport and decreased long-distance transport. A regional carbon tax may lead to an increase in emissions by non-taxing countries, through the much discussed carbon leakage effect. Moreover, transport activities may be exempted from the carbon tax, as illustrated by climate policies so far. This calls for a discussion of several alternative scenarios, as proposed by the paper. Third, in addition to the direct modelling results, we decompose the changes in emissions into the well-known scale, composition (between regions and sectors) and technique effects used in the theoretical and empirical literature. These separate calculations help increasing our understanding of the structural patterns and the driving forces that underlie the overall changes in world emissions.

Section 2 gives an overview of the relevant literature; Section 3 describes the scenarios which are modelled in terms of trade and climate policies, Section 4 lays out the modelling framework and the data used, Section 5 discusses the results and Section 6 concludes.

## 2. LITERATURE REVIEW

This paper proposes to compare trade-related emissions from production, with trade-related emissions from international transport. As the former type of emissions has already been widely discussed in the literature, we limit our presentation below to those points that are of direct interest for the present paper. The rest of the section is devoted to the studies on the latter type, which has received very limited attention in the academic world.

Investigating the link between globalisation, environmental regulation and production-related emission changes, Grossman and Krueger (1993) identified three effects through which trade liberalisation may affect the environment: (i) a scale effect stating that increased economic activity from trade liberalisation leads *ceteris paribus* to increased emissions; (ii) a composition effect highlighting that trade liberalisation may lead to changed specialisation patterns across countries and sectors with different emission intensities, which can trigger changes in overall emissions; and (iii) a technique effect which indicates that through increased income and technology transfer, trade can lead to cleaner production technologies. This decomposition has been used in many empirical studies, and the exercise will be taken up in this paper in Section 5. Also, a large number of studies have investigated directly or indirectly the empirical importance of the ‘pollution haven’ effect, which states that laxist environmental regulation in low-income countries would give them a comparative advantage in emission-intensive industries (see for example Antweiler et al. 2001; Cole and Elliott 2003; Levinson and Taylor 2008; Grether et al. (2012)).<sup>1</sup>

<sup>1</sup> Within this context, Ederington et al. (2005) put forward the importance of transport costs, most importantly because industries with the largest pollution abatement costs (an often used proxy for the stringency of environmental policy) also happen to be the least geographically mobile. Controlling for the ‘mobility’ of sectors, they find a significant effect of pollution abatement costs on imports from developing countries, and in pollution intensive, footloose industries. Determinants of transport costs and their impact on the volume and nature of traded goods are analysed in Limao and Venables (2001), Bæier and Bergstrand (2001), Jacks and Pendakur (2010) and Hummels (2007).

Turning to the impact of trade on transport-related emissions, few studies have addressed the question at a global level.<sup>2</sup> Using simple back-of-the-envelope calculations, Grether et al. (2010) investigated the effects on SO<sub>2</sub> emissions when going from a world without trade (each country produces what it consumes) to the observed degree of globalisation. For year 1990, they found that this change generates an increase in world emissions by 10 per cent due to production-related emissions and by 6 per cent due to emissions related to international transport activity. For year 2000, the corresponding figures become 3 per cent and 9 per cent.

Schäfer and Jacoby (2005) use a combination of a CGE model and an energy transport systems model (MARKAL) to estimate the effect of climate policy on the transport sector. They find for the US that a Kyoto-consistent reduction of GHG emissions by 7 per cent below 1990 by 2010 and then maintaining this level of emissions through 2030 would lead to a reduction of emissions by 16 per cent for purchased transport including freight transport compared with an unconstrained reference scenario.

More recently, using a multiregion CGE model, Abrell (2010) simulated different carbon dioxide policies in Europe. He finds that the exemption of transport from carbon policy (with a higher reduction burden for the other sectors) leads to welfare improvements compared to the case where transport is included in the EU emission trading system. This at first sight counter-intuitive result is explained by high pre-existing fuel taxes in the transport sector, which can be interpreted as an already existing carbon price in that sector. Hence, exempting transport leads to 'more uniform' carbon prices and increases the cost-effectiveness of carbon regulation. This result, however, heavily depends on the strong assumption that transport activities do not generate any other externalities than carbon emissions.

Avetisyan et al. (2013) is, together with the present paper, the first attempt to quantify the effect of trade liberalisation on transport-related CO<sub>2</sub> emissions using a general equilibrium framework at a global level. They use GTAP data to simulate different liberalisation scenarios proposed under the current Doha negotiations, full liberalisation and different growth rates in country level GDP. The changes in trade flows from the model are then linked (outside the general equilibrium model) to transportation activity and emission coefficients. Doing so, they impose several hypotheses. They assume that modal shares for a given bilateral trade flow and sector do not change with trade liberalisation and the existing transportation fleet and its emissions are unchanged by the liberalisation exercise. This means that the focus is entirely on how trade affects fuel use and greenhouse gas emissions, and any feedback effects from international transport's fuel use and emissions to trade are ignored. In this set-up, setting all existing tariffs and subsidies to zero increases world trade in value or weight terms by roughly 5 per cent, with the largest effects taking place for agriculture, textile and wearing apparel. In terms of ton-km and emissions, trade grows twice as fast. Distant trade rises and land modes fall.

Our work is complementary to Avetisyan et al. (2013) in several aspects. The two papers have in common the full trade liberalisation scenario and the comparison between production-

<sup>2</sup> Using Spanish data and an input-output framework, Cadarso et al. (2010) compare emissions due to international transport of imported inputs required by one unit of final output with emissions embodied in inputs directly and indirectly required to produce a unit of final output in each sector. The majority of sectors show a scale of emissions from international transport of over 5 per cent and some account for more than 15 per cent. 'Offshoring sectors', which allow production to be divided into tasks and distributed across different geographical areas (i.e. sectors related to knowledge and information technologies and some traditional industries), report relatively high shares. Over time, from 1995 to 2000, this share increased for all but two sectors (Tobacco; Rubber and plastic).

related and transport-related emissions from international transport. The main difference in the methodology comes from the fact that we represent international transport and emissions directly in the CGE model and therefore capture all income and price effects. Hence, we cover feedback effects on input prices, and modal shares are determined endogenously.<sup>3</sup> Concerning the sectoral and regional coverage, we are restricting ourselves to a rather small number of regions and sectors. This makes the model easier to understand, but has the drawback that we will not be able to present disaggregated results. Trade flows and transport activities between countries in a given modelling region are however still modelled as international activities. Hence, our model should be seen as a stylised model. Another difference comes from the way emissions are attributed to transport activities. While we directly refine the transport data from GTAP-EG in the CGE model, CO<sub>2</sub> emissions are attributed using data from the International Energy Agency (2008). Avetisyan et al. (2013) decide to convert trade flow data expressed in value terms carefully into ton-km and then apply emission coefficients. Both approaches lead to the same emission levels, if data are compatible.

### 3. SCENARIOS

The stylised scenarios are selected to identify the role that international transport plays for emissions allowing for interactions between trade and climate policies. These scenarios also reflect the actual uncertainty of international policy, where both multilateral and regional action may take place over the next few years (See Mathys and de Melo 2011 for a discussion of political economy aspects of trade and climate policies). These scenarios do not reflect real-world policies, but rather to allow us to obtain first insights about the mechanisms at work with strong, simple and clear-cut policies (For a recent illustration of an analysis of actual trade policy proposals, see for example Laborde et al. 2011).

Starting from the status quo (situation in base year 2001 with no additional trade nor climate policy), on the one hand regional and multilateral trade liberalisation (all existing tariffs and trade subsidies are eliminated) and on the other hand regional and multilateral climate policy (CO<sub>2</sub> taxes) are simulated. Climate policy is more precisely a carbon dioxide tax of 40\$/tCO<sub>2</sub>, which is applied either to all sectors or to all sectors except international air and water transport. This set of scenarios allows identifying the effects of trade policy and of the carbon dioxide tax on emissions related to production and international transport. The simulated trade and climate policy scenarios, as compared to the reference case, are

- GL: global trade liberalisation taking place in all countries.
- RL: regional trade liberalisation, that is country groups liberalise trade completely inside the region, while trade barriers with respect to outside countries are left unchanged.
- Regions are defined in the following way:
  - Europe: Germany, UK, France, Italy, Former Soviet Union, Rest of Europe
  - America: USA, Canada, Mexico, Brazil, Rest of America
  - Asia: China, Japan, Rest of East Asia, South Asia, Middle East, Australia
  - Africa: North Africa, Sub-Saharan Africa
- GT: global CO<sub>2</sub> tax of 40\$/tCO<sub>2</sub> applied to all countries and all sectors in the sample.

<sup>3</sup> Subsection 4.2 describes in detail the international transport part of our model.

TABLE 1  
Simulated Scenarios

<i>Scenario</i>	<i>Description</i>
GL	Global liberalisation
GL_GT	Global liberalisation combined with global CO <sub>2</sub> tax of 40\$/tCO <sub>2</sub> without exemption
GL_GXT	Global liberalisation combined with global CO <sub>2</sub> tax of 40\$/tCO <sub>2</sub> exempting international transport activities by air and water
GL_RXT	Global liberalisation combined with regional CO <sub>2</sub> tax of 40\$/tCO <sub>2</sub> exempting international transport activities by air and water
RL	Regional trade liberalisation
RL_RXT	Regional trade liberalisation combined with regional CO <sub>2</sub> tax of 40\$/tCO <sub>2</sub> exempting international transport activities by air and water

- GXT: global CO<sub>2</sub> tax of 40\$/tCO<sub>2</sub> applied to all countries and all sectors except the international freight transport sectors aviation and navigation.
- RXT: regional CO<sub>2</sub> tax applied to all sectors, except the international freight transport sectors aviation and navigation, in the following subset of countries: USA, Canada, Japan, Australia, Germany, United Kingdom, France, Italy and Rest of Europe.

We report results for several combinations of these trade and climate policy scenarios (see Table 1 for an overview). We start with the global liberalisation scenario (GL) and combine it with a global tax scenario (GL\_GT). This is an optimistic scenario in the sense that it assumes that both trade and climate negotiations result in ambitious agreements. Although this seems currently unrealistic, GL\_GT can be understood as a second, positive benchmark scenario, against which the other scenarios can be compared. Due to the global nature of international long-distance transport, it is difficult to tax international air and water transport fuel.<sup>4</sup> Also, so far, the (international) transport sector managed to be excluded from climate policies such as the EU ETS. Hence, we are also interested in the scenario GL\_GXT, which excludes international transport by air and water from CO<sub>2</sub> taxation. It is assumed that international transport by rail and road cannot be meaningfully separated from national transport for fuel taxation, so these modes are still taxed in this scenario. If climate negotiations turn out to be too difficult at a multilateral level, the scenario GL\_RXT gives further insights. If multilateral trade negotiations continue also to be blocked, it might well be that trade liberalisation will also only take place on a regional basis. We try to capture that situation with the regional liberalisation scenario (RL). If regionalism is having its revival, climate policies might also be decided at the regional level. This is analysed using the RL\_RXT scenario.

#### 4. MODEL AND DATA

##### *a. General Features of the Model*

GENEwMod is a stylised global multiregional computable general equilibrium model. It simulates the interaction of economic agents on factor and commodity markets. Households

<sup>4</sup> As an example, the UNFCCC identified eight options for how to allocate emissions from international bunker fuels.

maximise utility, firms maximise profit, and governments collect tariffs and taxes, give subsidies and supply public goods. Flexible prices assure that factor and commodity markets are cleared. Markets are competitive, which implies that firms do not earn profits.

National representative agents (households) and governments respect their income balance, including a balance of payment surplus or deficit that is fixed to its value in the reference case. Equal yield constraints are implemented assuring that any changes in tax revenues or expenditures for subsidies are compensated through variations in the income tax rate, thus keeping public goods provision constant. The model takes into account the following country-specific ad valorem taxes – or, in the case of a negative rate – subsidies:<sup>5</sup>

- Income taxes are modelled as sector-specific factor input taxes with differentiated rates on capital and labour.
- Input taxes or subsidies may apply also to any intermediate input in production and are sector specific.
- Output taxes or subsidies are also sector specific.
- Commodity-specific taxes on private and government demand mostly represent value added taxation.
- Import and export tariffs and subsidies are differentiated by commodity and bilateral trade flow. Next to ordinary tariffs, they represent anti-dumping duties, export subsidies, voluntary price undertakings, voluntary export restraints and domestic support instruments.

For this paper, we have chosen a static representation of a putty-clay capital structure, that is, existing capital is sector and country specific, while new capital is perfectly mobile. Labour is domestically mobile across sectors. Labour supply is elastic to wages, because households choose between labour and leisure.

We have aggregated the world to the following countries (or country groups): China, Japan, rest of East Asia, South Asia, Middle East, North Africa, Sub-Saharan Africa, Australia, USA, Canada, Mexico, Brazil, rest of Latin America, Germany, United Kingdom, France, Italy, former Soviet Union and rest of Europe (see Table A1 in Appendix C for the composition of the country groups).

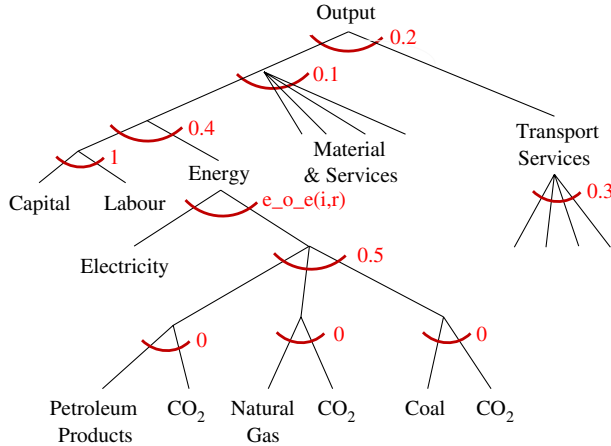
Production, demand and bilateral Armington trade is represented for the following commodities: coal, natural gas, crude oil, petroleum and coal products, electricity, energy-intensive goods, agriculture, rest of industry, road transport, rail transport, international water transport, international air transport, rest of services (see Table A2 in Appendix C for a correspondence with the GTAP sectors). Fixed resources are modelled in fossil fuel extraction sectors, which allows calibrating the supply elasticity of fossil fuels to values found in the literature.

### *b. Transport in the Model*

We distinguish four transport modes: road, rail, marine and aviation. Each transport mode is represented as a sector with a zero-profit condition (cost function = value of output). For marine transport and aviation, our goal has been to construct the cost functions such that they

<sup>5</sup> For details on the construction of the data, please consult the GTAP6 data base documentation at [https://www.gtap.agecon.purdue.edu/databases/v6/v6\\_doco.asp](https://www.gtap.agecon.purdue.edu/databases/v6/v6_doco.asp).

FIGURE 1  
Constant Elasticity of Substitution (CES) Production Function for Transport Modes (Nesting Tree)  
(Numbers are Elasticities of Substitution<sup>a</sup>)



Note:

(i) <sup>a</sup> $e_{o_e}$  Elasticities are zero for air and water, 0.1 for road and country-specific for rail, based on Serletis et al. (2010).

reflect technologies in international freight transport. Especially, data from the International Energy Agency (2008) has been used to determine emission intensity and thus fossil fuel inputs.

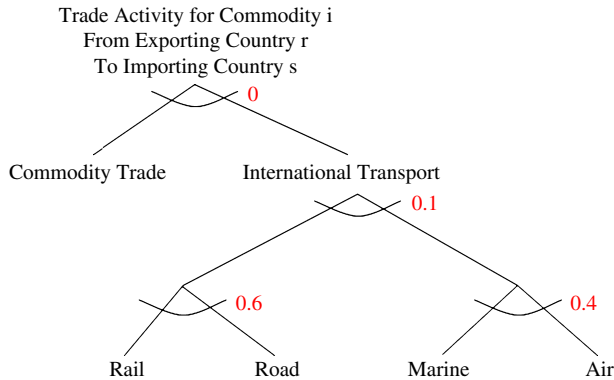
The underlying nested constant elasticity of substitution (CES) production function can be represented with the nesting tree depicted in Figure 1. The numbers give the elasticities of substitution in the respective nests.

At the lowest level, zeros between fossil fuel inputs and CO<sub>2</sub> emissions imply constant input-related CO<sub>2</sub> emission coefficients, that is, CO<sub>2</sub> emissions are proportional to the input of the respective fuel. The elasticity of interfuel substitution is 0.5. This does not imply a large potential for substitution to natural gas or even coal, because petroleum products (diesel and petrol) greatly dominate the benchmark fuel demand in transport. Similarly, substitution between fossil fuels and electricity is irrelevant in aviation and marine transport ( $e_{o_e}$  is zero for these two modes) and still hardly relevant in road transport ( $e_{o_e} = 0.1$ ). For railways, it is relevant, and we used country-specific estimates from Serletis et al. (2010) for the elasticities of substitution wherever possible.<sup>6</sup>

The two aggregated production factors are combined in a Cobb-Douglas nest. Energy and aggregate factor demand trade-off at an elasticity of substitution of 0.4. This reflects the option to reduce energy use by investing in energy efficiency. Of the 0.4 is a lower medium range choice for this elasticity as compared to other applied general equilibrium models (Kemfert and Welsch 2000; Paltsev et al. 2005). This parameter is supposed to largely influence the cost of emission reductions, which is why we included it in the sensitivity analysis.

<sup>6</sup> The resulting elasticity values are 0.112 for the US, 0.152 for Canada, 0.196 for Africa, 0.550 for Japan, 0.141 for the rest of East Asia as well as for South Asia, 0.151 for the Middle East as well as for the former Soviet Union, 0.223 for the UK, 0 for France, 0.003 for Italy, 0.173 for other high income regions, 0.26 for other middle regions.

FIGURE 2  
Constant Elasticity of Substitution (CES) Nesting Tree Representing Choices in International Transport  
(Numbers are Elasticities of Substitution for Most Sectors<sup>a</sup>)



Note:

(i) <sup>a</sup>See Table A3 in Appendix C for a complete list of elasticities of substitution by sector.

Moving further up the nesting structure in Figure 1, material and non-transport service inputs offer very limited opportunities for substitution. At the top level, there is the opportunity to outsource more or less activities to other transport providers. The elasticity of modal substitution in domestic intermediate demand is 0.3.

Like other sectors, the land transport sectors (rail and road) supply both to domestic and export markets. On each national market, they meet the demand by firms, household and government. In addition, land transport sectors as well as marine and air transport sectors of each country supply to an international pool. Each bilateral trade is linked to international transport services that are taken from this international pool. The nesting structure in Figure 2 reflects modal choice in international transport.

The upper nest implies that there is a fixed relationship between each bilateral trade and the associated need for international transport services. The value of international transport services associated with a given bilateral trade flow thus only changes when the level of bilateral commodity trade changes. In addition, there can be shifts between the transport modes, especially when CO<sub>2</sub> taxes make the more emission intensive transport modes 'air' and 'road' more costly. The intensity in mode shifts depends on the elasticities of substitution and on the share of each mode in the reference case.

If one transport mode is very dominant today, this is an indication that there are no good alternatives (e.g. to marine transport in shipping coal from Australia to China). If, however, two or more modes already compete today, this indicates that shifts between these modes are possible to a certain extent (e.g. for shipping agricultural goods from France to the UK).

In international transport, marine and air transport are usually employed to ship commodities over large distances between countries. A large part of land transport associated with international trade concerns transport in the region of origin or destination. Hence, we decided to assign road and rail transport on the one hand, and marine and air transport on the other hand to different nests. Between the two aggregates, elasticities of substitution are low (at 0.1). Elasticities of substitution within each lower nest are higher, and elasticities of substitution between rail and road transport (0.6 in general) are generally higher than elasticities of substitution between marine and air transport (0.4 in general). Due to the special requirements

for logistics, elasticities of substitution between modes are generally lower for agricultural goods than for other commodities. For details on sector-specific elasticity values, see Table A3 in Appendix C.

### *c. Data*

#### *(i) GTAP6*

Input–output as well as trade and protection data come from GTAP 6 with the reference year 2001.<sup>7</sup> The economic data are supplemented with energy data from the OECD International Energy Agency (IEA) statistics (See Rutherford and Paltsev 2000; Rutherford 2005).

GTAP data are the only internationally coherent data source and widely used in general equilibrium modelling. It is however based on heroic assumptions concerning transport margins and modal shares. Concerning transport margins, the cif/civ<sup>8</sup> ratio is used to identify import charges, representing the aggregate cost of all freight, insurance, and other charges incurred in transporting the goods from alongside the carrier at the port of exportation and alongside the carrier at the first port of entry. The use of transport cost obtained by a cif/civ ratio as opposed to a cif/fob ratio can eliminate problems associated with the inconsistencies existing in reported merchandise trade between partners (see also Hummels and Lugovskyy 2006 for a discussion of the use of cif/fob ratios to estimate transport costs). Data are available at a detailed sectoral and bilateral trade level. Variations in transport margins are greater across commodities for a given partner than for different trading partners for a given commodity. Some of the highest margins can be found in the minerals sector due to its bulkiness, with small value/weight ratios. Coal has the highest transport margins among energy carriers. US data are used as a representative example for global transport costs. The average trade weighted margin is applied to all trade flows except on intraregional trade and for selected commodities. For commodities where the NAFTA trade-weighted average margin is lower than the non-NAFTA margin, the NAFTA margin is applied to intraregional trade flows. The combination of accurate, detailed transportation cost data at a commodity level and a simplified procedure for adjustment have been the main objectives of the revision of transportation cost margin data since version 4. Given the lack of better available data, we use the transport margins from GTAP.

#### *(ii) Modifications to transport modes*

Concerning modal shares, the original GTAP data are based on US bilateral information with all its trading partners and applied to all countries in the world. Given the importance of the transport mode for emissions and this rough assumption, we supplement these data with modal share information on European bilateral data with all European trading partners derived from Eurostat. A number of adjustments were necessary to match Eurostat data with the model's framework (see Appendix A for details). As a result, modal shares are based on direct import and export data for both the US and European countries (Eurostat), covering most of worldwide trade flows. For the remaining bilateral trade flows, the original GTAP assumptions on modal shares are kept.

<sup>7</sup> Data can be downloaded free of charge from the website: <https://www.gtap.agecon.purdue.edu/databases/v6/default.asp>. More recent versions of GTAP exist, but are not freely available. Further research would be needed not only to update GTAP data, but also to improve data on transport modes and emissions.

<sup>8</sup> Cif: cost insurance and freight, Civ: customs import value, fob: free on board.

GTAP data distinguishes between land, air and water transport. Land transport covers all together railways, road, pipeline and other transport. From an environmental point of view, transport by train and by road is however different. Average emission intensities per ton-km shipped for road can be as much as 5.5 times higher than for train (Giannouli and Mellios 2005). We use again data from Eurostat, for average transport operating costs and calibrate country-modal shares to match the information reported by Hummels (2009).

Furthermore, we made the following assumptions: for rail and road, we assumed that the national and the international transport services are using the same production structure (and have hence the same input structure), but that they are country specific. This is reasonable, since the rail and road infrastructure is different between countries but is used for both national and international transport activities. On the other hand, and according to the focus of this paper, marine and air transport sectors have been modified to adequately represent international freight transport. Domestic and passenger transport in these sectors were added to rest of industry. Data on CO<sub>2</sub> emission intensities are derived from the International Energy Agency (2008) to determine fossil fuel inputs in international navigation and aviation.

For the split between rail and road, the contribution to the common pool has been estimated using trade in services from the UN database. The land transport production column from the input–output tables has been split into rail and road transport, taking into account, among other information, ton-kilometre shares, electrification rates and fuel efficiencies (see Appendix B for details).

### (iii) Elasticities

Generally, elasticities are taken from the EPPA model, as far as similarities in structure allow. For the elasticities of substitution between energy inputs, country-specific estimates from Serletis et al. (2010) are used. Elasticities of substitution that are relevant for transport modelling are described in subsection 4.2. Table A3 in Appendix C provides an overview of sector-specific elasticities of substitution. Given the many uncertainties that surround these values, it is apparent that our comparative static simulations are applied modelling with elaborate, but still rather stylised data.<sup>9</sup> The results from the next section should thus not be interpreted as quantitative forecasts that are anywhere close to precision.

We disaggregated regions to the highest possible extent to include as many bilateral trade flows as possible in the model. Even if some country groups are large (e.g. the former Soviet Union or the rest of East Asia), international trade within each country group is still accounted for. To be able to simulate with a larger data set, we compromised somewhat the value of Armington elasticities, because high values for Armington elasticities are notorious for jeopardising solvability. Hence, we chose Armington elasticities of substitution of 1.5 between domestic and foreign goods and of 1.8 between different foreign goods. Admittedly, the latter value is on the low side (see for example parameters suggested in Dimaranan et al. 2006), and this assumption may somewhat dampen the welfare effects of trade policies. Other important elasticities include: elasticities of transformation between supply to domestic markets and exports, which we set at 2 for the grid-based commodities electricity

<sup>9</sup> Rich et al. (2011) state that reviews of transport elasticities for freight transport demand are based on a rather limited number of studies, and due to methodological and geographical differences the variation of elasticities is quite large.

and natural gas, and at 4 for all other sectors. Supply elasticities for fossil fuels are assumed to be 0.4.

## 5. RESULTS

Given the stylised nature of the model, our results should be considered as a first estimate of the orders of magnitude, and the following caveats should be kept in mind: concerning trade liberalisation, non-tariff barriers are difficult to represent (see Fugazza and Maur 2008 for a discussion) and abolishing prohibitive tariffs in the model does not increase trade flows, since CES functions show no increase for demands with benchmark quantities of zero. In addition, as stated above, we use rather low estimates for Armington elasticities and relatively aggregated regions. Our global liberalisation results are therefore lower bound estimates. We might expect larger increases in terms of consumption and trade (and hence transport activities and related emissions) in a real-world setting. Concerning climate policies, benefits of decreased carbon dioxide emissions and hence mitigated global warming are not captured in our model. The consumption effects of climate policy in the model are therefore negative, which does however not indicate that mitigating climate change actually reduces welfare.

The presentation of results is organised along two lines. First, we discuss the general results of the simulations with the CGE model. In a second step, we present the decomposition exercise, which is performed outside the CGE model. Decomposition results help to better understand the mechanisms at work and to make the link with the trade and environment literature, with a particular focus on international transport.

### *a. Global Modelling Results*

Table 2 reports consumption, emissions and trade effects of our six policy scenarios. We obtain a set of intuitive findings. First, the decrease in consumption implied by the implemented climate policy more than compensates the increase in consumption due to trade liberalisation. This comes not as a surprise as we are working with an already open trading system, rather low Armington elasticities and a significant climate policy. Second, total emissions are strongly reduced when a carbon policy is enacted (−11 per cent with a regional policy, −29 per cent with a global policy). Third, international trade increases in all scenarios in between 2 per cent and 7 per cent. In the full liberalisation scenario, the outcome is very similar to the findings in Avetisyan et al. (2013). Fourth, when regional trade or climate policies are used instead of global policies, the magnitude of the effects is roughly halved.

Table 3 reports changes in emissions from international transport detailed by mode. When considering pure trade liberalisation, the increase in emissions is quite large (around 10 per cent for global and 5 per cent for regional liberalisation), with no strong overall differences across transport mode. This may appear slightly surprising as global liberalisation is in principle expected to promote long-distance transport (i.e. air and water), while regional liberalisation should be more biased towards short-distance transport modes (road and rail). However, this prediction fails to materialise due to our definition of large ‘regions’, which are in fact continents including very distant countries. As a result, intraregional and inter-regional trade do not differ strongly in terms of transport modes.

TABLE 2  
Results on Consumption, Total Emissions and Total Exports (% Deviations from Benchmark)

<i>Scenario</i>	<i>Total Consumption</i>	<i>Total Emissions</i>	<i>Total Exports</i>
GL	0.1	0.5	6.8
GL_GT	-0.3	-28.9	5.2
GL_GXT	-0.3	-28.7	5.8
GL_RXT	-0.1	-11.2	6.2
RL	0.03	0.2	2.7
RL_RXT	-0.1	-11.5	2.1

Note:

(i) See Table 1 for a definition of the scenarios.

TABLE 3  
Results on Emissions from International Freight Transport by Mode (% Deviations from Benchmark)

<i>Scenario</i>	<i>Long-distance Transport</i>		<i>Short-distance Transport</i>	
	<i>Air</i>	<i>Water</i>	<i>Road</i>	<i>Rail</i>
GL	11.4	10.9	13.7	8.9
GL_GT	2.9	3.4	-1.9	-25.1
GL_GXT	15.1	12.7	-1.8	-25.2
GL_RXT	13.0	11.4	11.1	12.0
RL	5.2	5.0	6.6	4.8
RL_RXT	6.6	5.4	4.1	7.5

Note:

(i) See Table 1 for a definition of the scenarios.

Results are more contrasted when carbon policy is introduced. The GL\_GT scenario implies a strong decrease in emissions in road and particularly rail, which illustrates the weaker fuel inputs substitutability of the long-distance transport modes (air and water). This emission decrease is basically due to the adoption of a cleaner energy mix in two country groups: China and the former Soviet Union. When air and water transport are exempted from the carbon tax (GL\_GXT), their emission increase is even larger than in the pure trade liberalisation scenario (GL), as they benefit from cheaper fuel prices. Finally, when the carbon tax is limited to rich countries (GL\_RXT), the difference across transport modes tends again to vanish. This tends to confirm that the emission reduction under the global tax scenarios is essentially achieved in non-rich countries (in particular the former Soviet Union, China and the rest of East Asia).

To better understand the mechanisms at work behind the changes in emissions, we next discuss their decomposition into scale, composition and technique effects.

### *b. Decomposition Analysis of Emissions*

We decompose emission changes into scale, between country, between sector and technique effects, depending on whether the change in emissions is due to a change in economic activity, to a reallocation across countries (or across sectors) or to a change in

emission intensities (input substitution), respectively. This is done for each group of activities, namely emissions from international transport, emissions embodied in exports, emissions embodied in products for domestic consumption (production minus exports) and emissions directly coming from final consumption (households). We follow the additive decomposition approach of Dietzenbacher and Los (1998) (see Appendix C for further details), which is path independent.<sup>10</sup>

Table 4 reports the results from the decomposition exercise. All figures in the table refer to changes with respect to the benchmark, except for the first line of each scenario (in italic), which corresponds to the net contribution of each category to the overall change in emissions (i.e. the horizontal sum gives the number appearing in the total emissions column of Table 2 up to differences due to rounding).<sup>11</sup> The analysis leads to four major stylised facts.

First, as the bulk of worldwide emissions is due to production for domestic use (more than 70 per cent of global emissions), it is essentially this sector that drives the global outcome. Within this category, the only large effect is the technique effect, which is  $-12$  per cent when the carbon tax is regional, and more than twice as large when the carbon tax is global. If there is no carbon tax, all the different effects are small. The household category follows roughly the same pattern, but with a technique effect which is three times smaller, and a share in global emissions which is four times smaller.

Second, composition effects, that is, between sectors and between countries, usually do not matter much for the determination of the total effect, as they are several orders of magnitude smaller than the scale and technique effects. The only exception is in the case of a global carbon tax, where the between-sector effect for both exports and domestic production is around  $-4$  per cent. This reflects the substitution towards less carbon-intensive sectors that is likely to appear under such scenarios.

Third, the largest scale effect is in international transport, and it is almost twice as large as the scale effect for exports. This may come as a surprise at first sight, given that the aggregation technology between exports and transport services is Leontief. In fact, this means that growth in exports is biased towards sectors for which the international transport needs per dollar are high. More specifically, more than 50 per cent of the difference between the scale effect for exports, and the scale effect for international transport is due to agriculture. This 'agricultural effect' makes sense, because on the one hand, the major part of remaining protection at the worldwide level is in that sector, so that agricultural exports are boosted by global or regional trade liberalisation, and on the other hand, the value of agricultural exports per kilogram is quite low, implying a large share of international transport in the value of agricultural exports.

Fourth, when carbon policy is enacted, the reduction of emissions through the technique effect in exports is substantially larger than the reduction of emissions due to the technique

<sup>10</sup> This decomposition into the scale, composition and technique effects follows the idea of Grossman and Krueger (1993), is performed outside the CGE model and is different from the central path approach used in the CGE. The latter methodology allows for example to identify the contribution of different countries or sectors to welfare changes (see e.g. Harrison et al. 2000; Paltsev 2001; Boehringer and Rutherford 2004).

<sup>11</sup> Note that the scale effect figures for exports in Table 4 do not match exactly the growth in exports reported in the last column of Table 2 (in particular for the scenarios with a global carbon tax). This is due to the fact that each reported effect also depends on the magnitude of the other effects, as it is an average on all possible decomposition paths (see procedure described in Appendix C).

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TABLE 4  
Decomposition of Emission Changes (Percentage Changes with Respect to Benchmark, Except for  
Figures in *Italic*)

	<i>International Transport</i>	<i>Exports</i>	<i>Domestic</i>	<i>Households</i>
<i>GL</i> (net contribution to total change)	<i>0.3</i>	<i>0.4</i>	<i>-0.1</i>	<i>0.0</i>
Scale effect	11.3	6.7	-0.9	0.1
Between country effect	-0.0	1.0	-0.5	-0.2
Between sector/mode effect	0.0	-2.0	0.8	n.a.
Technique/Input-substitution effect	0.4	0.4	0.5	0.1
Total effect	11.6	6.1	-0.1	0.0
<i>GL_GT</i> (net contribution to total change)	<i>0.0</i>	<i>-1.0</i>	<i>-26.0</i>	<i>-1.8</i>
Scale effect	8.7	4.5	-1.6	-0.2
Between country effect	-0.3	-0.5	-2.1	-1.1
Between sector/mode effect	-0.1	-4.1	-3.9	n.a.
Technique/Input-substitution effect	-6.6	-18.0	-27.1	-9.5
Total effect	1.6	-18.0	-34.6	-10.7
<i>GL_GXT</i> (net contribution to total change)	<i>0.2</i>	<i>-1.0</i>	<i>-26.0</i>	<i>-1.8</i>
Scale effect	9.9	5.0	-1.6	-0.2
Between country effect	-0.4	-0.5	-2.1	-1.1
Between sector/mode effect	-0.1	-4.2	-3.8	n.a.
Technique/Input-substitution effect	-0.3	-18.0	-27.1	-9.5
Total effect	9.1	-17.7	-34.6	-10.7
<i>GL_RXT</i> (net contribution to total change)	<i>0.3</i>	<i>-0.0</i>	<i>-10.6</i>	<i>-0.7</i>
Scale effect	10.5	5.9	-1.3	-0.0
Between country effect	0.3	1.7	-0.1	-0.4
Between sector/mode effect	0.2	-1.7	-1.3	n.a.
Technique/Input-substitution effect	0.6	-6.0	-11.5	-4.0
Total effect	11.6	-0.1	-14.2	-4.4
<i>RL</i> (net contribution to total change)	<i>0.1</i>	<i>0.1</i>	<i>0.0</i>	<i>0.0</i>
Scale effect	5.2	2.6	-0.4	0.0
Between country effect	0.0	0.2	-0.2	-0.0
Between sector/mode effect	-0.0	-0.5	0.4	n.a.
Technique/Input-substitution effect	0.2	0.1	0.3	0.0
Total effect	5.4	2.4	0.0	0.0
<i>RL_RXT</i> (net contribution to total change)	<i>0.1</i>	<i>-0.2</i>	<i>-10.6</i>	<i>-0.7</i>
Scale effect	4.5	2.0	-0.8	-0.1
Between country effect	0.3	0.7	0.1	-0.3
Between sector/mode effect	0.1	-0.2	-1.7	n.a.
Technique/Input-substitution effect	0.4	-6.2	-11.6	-4.1
Total effect	5.3	-3.7	-14.1	-4.4

## Notes:

(i) See Table 1 for a definition of the scenarios. (ii) Figures for the scale effect in exports do not match with the growth rate of exports reported in Table 2 because, due to the decomposition procedure described in Appendix C, each reported effect also depends on the magnitude of the other effects, as it is an average on all possible decomposition paths.

effect in international transport. This is obvious when transport is exempted from the carbon tax (i.e. in the *GL\_GXT*, *GL\_RXT* and *RL\_RXT* scenarios), where the technique effect for international transport becomes positive. But even in the *GL\_GT* scenario, the technique effect in international transport appears more than 50 per cent smaller than the technique

effect in exports. This reflects that input-substitution possibilities are more limited in international transport than in exports.<sup>12</sup> These stylised facts help us regroup detailed outcomes in two broad families.

Overall, we find that, in the absence of carbon policy (GL, RL), as the net change in emissions due to domestic production and household is close to zero, exports and international transport become pivotal. Moreover, as there is no significant technique effect, the most important factor becomes the scale effect, which is positive, and larger for international transport than for exports (due to the above-mentioned ‘agricultural effect’, which compensates the fact that the benchmark emissions share is smaller for international transport). Thus, overall emissions increase, and exports and international transport are the essential contributors to that growth.

Trade liberalisation cum carbon policy scenarios (GL\_GT, GL\_GXT, GL\_RXT, RL\_RXT) changes the picture. Important technique effects come into play, which have a dual impact on the net contribution of international transport. On the one hand, as the net contribution of domestic production and households is now strongly negative, the relative contribution of trade-related categories is weaker (< 5 per cent of the overall change in emissions). Second, the technique effect overstates the scale effect for exports, as it does for the domestic categories, and whatever the scenario. As a result, the contribution of exports to global emissions is negative. However, for international transport, the reverse occurs. This is due to the combination of the two stylised facts mentioned above (i.e. a larger-scale effect and a more limited technique effect for international transport). In short, overall emissions decrease, exports and international transports contribute only marginally, but the former reinforces the decrease while the latter works against it unless international transport activities are also subject to the carbon tax.

A final comment regarding the GL\_RXT scenario is in order. In that case, as the carbon tax is limited to rich countries, ‘carbon leakage’ may appear, in the sense that emission reductions in rich countries may be partially offset by emissions increase in the rest of the world. Our calculations suggest a leakage rate, that is, a ratio between emissions increase in non-taxing countries and the absolute emission decrease in taxing countries, of around 15 per cent, which is in line with the empirical literature. When expressed as a percentage of the same denominator, the increase in international transport emissions in that scenario amounts to 2 per cent, that is slightly more than 1/8 of the leakage rate.

### *c. Sensitivity Analysis*

Given that our framework shares the weaknesses of any CGE model and our results directly depend on parameter assumptions, we perform sensitivity tests. We half and double the following parameter values sequentially: the elasticity of substitution between energy and value added ( $EEV^-$ ,  $EEV^+$ ) and the elasticities of substitution in transport demand ( $ETD^-$ ,  $ETD^+$ ). Further, we half the Armington elasticities ( $ARM^-$ ) (unfortunately, the model cannot be solved with Armington elasticities that are doubled). The main results for two scenarios, GL and RL\_RXT, are reported in Table 5.

<sup>12</sup> Pursuing the analysis at the country level reveals indeed that for every region but for France and Japan (where nuclear electricity, which is almost emission-free, is dominant), the decrease of the average emission intensity is larger for exports than for international transport. Moreover, the reduction of emissions embodied in exports is biased towards those countries with a larger share in export emissions than in international transport emissions.

TABLE 5  
Sensitivity Analysis of Main Results for Scenarios GL\_GXT and RL\_RXT  
(% Deviations from Benchmark)

Scenario		Reported Results	EEV <sup>-</sup>	EEV <sup>+</sup>	ETD <sup>-</sup>	ETD <sup>+</sup>	ARM <sup>-</sup>
GL	Consumption	0.1	0.1	0.1	0.1	0.1	0.0
	Total emissions	0.5	0.4	0.5	0.5	0.5	0.4
	Total exports	6.8	6.8	6.9	6.8	6.8	2.4
RL_RXT	Consumption	-0.1	-0.1	-0.2	-0.1	-0.1	-0.2
	Total emissions	-11.5	-8.5	-15.1	-11.4	-11.4	-11.9
	Total exports	2.1	2.4	2.0	2.2	2.2	0.3

Note:

(i) See Table 1 for a definition of the scenarios.

The influence of the parameter values goes in the expected direction. It is rather weak for all parameters except for Armington elasticities, which have a significant effect on the magnitude of export results, and for the elasticity of substitution between energy and value added, which has a strong influence on total emissions in the case of a carbon tax. Our conclusions remain unchanged.

## 6. CONCLUSIONS

This paper provides original evidence on the importance and specificities of carbon dioxide emissions arising from international transport. It is one of the very few papers which look at the interaction between trade and climate change policies including explicitly international transport activities into account. Using the GTAP6-based static world trade model GENEw-Mod, endogeneising the energy mix and transport mode choices and adding data input on international transport and decomposition techniques, we obtain several results of interest. The general lesson is that emissions from international transport do matter, behave differently from other emission sources and are conditional on the type and extent of trade and climate policies considered, that is the assumed degree of international cooperation.

If international cooperation is limited to trade, with no climate policy enforced, about half of the increase in world emissions is due to international transport. This is so because of two reasons. First, even if the bulk of world emissions is due to domestic sources, as these sources are hardly affected by trade liberalisation, most of the impact comes from trade-related activities, namely exports and international transport. Second, although export-embodied emissions are almost double the level of international transport-related emissions in the benchmark scenario, the growth rate of the former is only half the growth rate of the latter, so that both emission sources contribute to the rise of global emissions in an identical way. The larger growth rate of international transport emissions is mostly due to an 'agriculture effect'. This sector is characterised by both large trade barriers and high transport costs. As a result, following liberalisation, agriculture accounts for more than half of the difference between the scale effect for international transport and the scale effect for exports.

If international cooperation includes both trade and climate policies, the situation changes dramatically regarding the share of trade-related emissions in the overall change. As domestic emissions now decrease because of strong substitution effects away from dirty inputs, trade-related emission sources become less important (in general < 5 per cent of the total change). However, international transport remains different. It is the only source of emissions to expe-

perience an increase, whatever the coverage of the carbon tax. This is so because substitution possibilities between fuel inputs are weaker for international transport (in particular air and water transport) than in other sectors of the economy. This leads to a technique effect which is relatively small, smaller in absolute terms than the large-scale effect. As the other effects (between-sector and between-country) are comparatively weak, emissions from international transport always increase, even in the most optimistic scenario in terms of international cooperation, that is when all countries apply a carbon tax in all sectors, including air and water transport.

Of particular interest is the (probably more realistic) scenario under which the carbon tax is limited to rich countries, and air and water transport are excluded from the tax. Under such a scenario, carbon leakage occurs between those countries enforcing the tax and the rest of the world. Our results suggest a leakage rate of approximately 15 per cent, in line with recent estimates. Regarding international transport, in that case, the technique effect almost vanishes, which leads to an increase of emissions from that sector by 11.6 per cent. Although domestic changes remain dominant, this increase in emissions from international transport is far from negligible, as it represents an additional 2 per cent when using the same base as the leakage rate (i.e. the absolute decrease in emissions by those countries enforcing the tax), that is 1/8 of the carbon leakage.

These results illustrate the importance of considering emissions from international transport when assessing the impact of international trade and carbon policies. With increased data availability on the subject, future studies should deepen this analysis to enlarge our understanding of an optimal set of policies that would lead to both acceptable levels of emissions and a more efficient allocation of production across the globe and hence increased consumption.

#### APPENDIX A: MODAL SHARES FOR EUROPEAN COUNTRIES

Initially, we take imports and exports reported by the EU-27 countries in Eurostat and aggregate these flows into the 19 regions. Then four caveats are addressed.

##### *a. Within European Union Trade Flows*

In principle, those flows do not include disaggregated within-EU flows, that is between the four large EU countries and the remaining 23 ones of the EU-27 (grouped in a unique residual category). So we construct those intra-trade data making sure that they are consistent with the totals. More specifically, what we assume for each product category, year and mode of transport is that intra-EU trade is spread across the  $5 \times 5$  matrix of intrazone trade according to the product of the border shares (except for the intracountry cells, which are set to zero, half of the corresponding theoretical share being spread out along the column and the other half along the line).

##### *b. Reconstructing the 'Rest of Europe' Region*

The original EUROSTAT data make the distinction between 'small' European Union countries (i.e. not Germany, France, Italy or the UK) and other European countries which are not in the European Union (i.e. Switzerland, Norway, etc.). These two categories are regrouped into a single one (the 'REU' region in the model).

Then, for all intra-European flows, the modal share is estimated by the average between the export and the import modal share for each particular combination of partners and industry.

### *c. Missing Combinations of Countries*

At that stage, a certain number of partner combinations are missing between European and non-European countries (between one-fifth and one-quarter depending on whether those are exports or imports). Those missing combinations are added using the *fillin* command of STATA (IBM: Armonk, NY). The corresponding modal shares are assumed to be equal to the simple average between three values: (i) the average modal export share of the reporter for all sectors in its relationship with this specific partner; (ii) the average modal import share of the partner for all sectors in its relationship with this specific reporter; and (iii) the average modal share of this sector in either European exports to non-European countries or European imports from non-European countries depending on the case.

### *d. Missing Modes*

Finally, for some original combinations of countries and sectors, some modes are missing. So we add those modes but assume simply that their share is zero.

## APPENDIX B: SPLITTING THE LAND TRANSPORT PRODUCTION COLUMNS OF INPUT-OUTPUT TABLES INTO RAIL AND ROAD TRANSPORT

The estimation of the diesel input shares of rail and road transport is based on the following steps:

- Use the ton-km-shares of each country's contribution to the common pool.
- Take into account, the electrification rate of the rail system in each country (West Toronto Chapter, Professional Engineers Ontario 2010; Indian Railways 2010). This decreases the share of rail proportionally.
- Taking proportionally into account, the different fuel efficiency between rail and road, using fuel inputs per ton-km of 25 for rail and 90 for road, which gives a rail share of 22 per cent.
- To convert quantities of diesel used into expenditures, diesel prices (including duties/subsidies for road) for all countries and duties for rail and road for European countries are used. It is assumed that rail never has to pay more taxes than road, and it is assumed that in all non-European countries, diesel used for rail is not subject to duties (GTZ 2003; Ecologic 2005).

Inputs of coal are assumed to accrue exclusively to railways.

Electricity:

- For railways, it is assumed that the cost share for electric drive is at least 1/12 of the electrification rate (International Union of Railways 2005; Indian Railways 2010).
- For both modes, it is assumed that 0.2 per cent of output is cost of lighting, appliances, etc.
- Half of the remainder is added to railways, unless the electrification rate is at 1 per cent or less.

- The rest is distributed proportionally to output.

All other inputs are distributed in proportion to the remaining gap between the value of output and the costs allocated so far.

#### APPENDIX C: DECOMPOSITION OF EMISSION CHANGES

Global emissions ( $E$ ) can be seen as the product between global production ( $Q$ ) and the average global emission intensity ( $\gamma$ ). The latter term is a weighted average of national emission intensities ( $\gamma_i$ ) where the weight of country  $i$  ( $i = 1, \dots, n$ ) corresponds to its output share (i.e.  $\theta_i \equiv Q_i/Q$ ). In other words, we have two equations:

$$E = Q\gamma$$

and

$$\gamma = \sum_i \theta_i \gamma_i,$$

each equation involving a product (or a sum of products). Following the additive approach of Dietzenbacher and Los (1998), there are two ways to decompose the change of a product

$$\Delta(AB) \equiv A_{t=1}B_{t=1} - A_{t=0}B_{t=0} :$$

$$\Delta(AB) = A_{t=0}\Delta B + B_{t=1}\Delta A$$

$$\Delta(AB) = A_{t=1}\Delta B + B_{t=0}\Delta A.$$

As there are  $n + 1$  products involved in  $E$ , this means that we have  $2^{n+1}$  possible decompositions of the change in global emissions, each of those taking the following form (dropping the time subscripts, but remembering that they alternate for each product couple)

$$\Delta E = \gamma\Delta Q + Q\Delta\gamma$$

$$\Delta\gamma = \sum_i \gamma_i\Delta\theta_i + \sum_i \theta_i\Delta\gamma_i.$$

The first term on the RHS of the first equation represents the scale effect, while the first and second terms on the RHS of the second equation represent the between-country and the within-country effects, respectively. The within-country effect is further decomposed into a between-sector effect and a technique effect along similar lines. Note that  $\gamma_i = \sum_s \theta_{is}\gamma_{is}$  where  $\theta_{is}$  ( $\gamma_{is}$ ) is the output share (the emission intensity of sector  $s$ ).

In the simulations, we have 19 countries, that is 1,048,576 different possibilities. We calculate the average, the maximum and the minimum of each one of these effects, and only report the average value (note that for the scale effect, there are only two possible values, depending on whether it is the initial or the final value of  $\gamma$  which is used in the calculation; but for the other effects, we do have  $2^{n+1}$  possible values).

TABLE A1  
Country Group Aggregation

<i>Country Group</i>	<i>Groups in GTAP 6</i>
Australia	Australia, New Zealand, rest of Oceania
China	China, Hong Kong
Japan	Japan
Rest of East Asia	Korea, Taiwan, Indonesia, Malaysia, Philippines, Singapore, Thailand, Vietnam, rest of Southeast Asia, rest of East Asia
South Asia	India, Bangladesh, Sri Lanka, rest of South Asia
Canada	Canada
United States	United States
Mexico	Mexico
Brazil	Brazil
Rest of Latin America	Colombia, Peru, Venezuela, rest of Andean Pact, Argentina, Chile, Uruguay, rest of South America, Central America, rest of FTAA, rest of Caribbean
Rest of Europe	Austria, Belgium, Denmark, Finland, Greece, Ireland, Luxembourg, the Netherlands, Portugal, Spain, Sweden, Switzerland, rest of EFTA, rest of Europe, Albania, Bulgaria, Croatia, Cyprus, Czech Republic, Hungary, Malta, Poland, Romania, Slovakia, Slovenia, Estonia, Latvia, Lithuania
France	France
Germany	Germany
United Kingdom	United Kingdom
Italy	Italy
Former Soviet Union	Russian Federation, rest of Former Soviet Union
Middle East	Turkey, rest of Middle East
North Africa	Morocco, Tunisia, rest of North Africa
Sub-Saharan Africa	Botswana, South Africa, rest of South African CU, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe, Rest of SADC, Madagascar, Uganda, rest of Sub-Saharan Africa

TABLE A2  
Sectors Aggregation

<i>Sector</i>	<i>GTAP Sector</i>
Agriculture	Paddy rice; wheat; cereal grains nec; vegetables, fruit, nuts; oil seeds; sugar cane, sugar beet; plant-based fibres; crops nec; cattle, sheep, goats, horses; animal products nec; raw milk; wool, silk-worm cocoons; fishing; meat: cattle, sheep, goats, horse
Rest of Industry	Forestry; minerals nec; meat products nec; vegetable oils and fats; diary products; processed rice; sugar; food products nec; beverages and tobacco products; textiles; wearing apparel; leather products; wood products; paper products, publishing; chemical, rubber, plastic prods; metal products; motor vehicles and parts; transport equipment nec; electronic equipment; machinery and equipment nec; manufactures nec; water; construction
Coal	Coal
Oil	Oil
Gas	Gas; gas manufacture, distribution

TABLE A2 *Continued*

<i>Sector</i>	<i>GTAP Sector</i>
Petroleum, coal products	Petroleum, coal products
Energy intensive industries	Mineral products nec; ferrous metals; metals nec;
Electricity	Electricity
Rest of services	Trade; communication; financial services nec; insurance; business services nec; recreation and other services; PubAdmin/Defence /Health/Educat; Dwellings
Air transport	Air transport
Marine transport	Marine transport (modified to represent international freight transport only)
Road transport	Road transport, transport nec
Rail transport	Rail transport
Aggregate Investment	Aggregate investment

TABLE A3  
Sector-Specific Elasticities of Substitution

<i>Sector</i>	<i>Between Energy and Other Factors of Production</i>	<i>Between Electricity and Non-Electric Energy</i>	<i>Between Rail and Road Transport</i>	<i>Between Air and Water Transport</i>
Energy intensive sectors	0.5	0.4	0.6	0.4
Electricity	1.0	0.4	0.6	0.4
Refineries	0.0	0.0	0.6	0.4
Road transport	0.4	0.1	0.6	0.4
Rail transport	0.4	Region-specific, see footnote 10	0.6	0.4
Marine transport	0.4	0.0	0.6	0.4
Air transport	0.4	0.0	0.6	0.4
Agriculture	0.4	0.4	0.4	0.2
Sector 'rest of industry'	0.5	0.4	0.5	0.3
Other sectors	0.4	0.4	0.6	0.4
Final demand	n.a.	0.3		0.2 (one nest)

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