International Transport Forum

International Freight and Related CO_2 Emissions by 2050: A New Modelling Tool

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Discussion Paper 2014 • 21

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OECD

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December 2014

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INTRODUCTION

International trade has grown rapidly in the post-war era with trade volume growing twenty-seven fold between 1950 and 2007, three times faster than world GDP growth (WTO, 2007). Growth in trade is expected to outpace the GDP growth also over the next 50 years, according to recent OECD projections. The value of international trade is estimated to grow by a factor of four by 2050 in real terms (Fontagné et al., 2014). Trade patterns will however change due to fragmentation of production processes and integration of emerging markets into global markets. Trade liberalisation, either at global or regional level, will also have an impact on global patterns.

Global value chains, dependent on relatively inexpensive and reliable transport links are key to economic development and will be potentially affected by changes in trade and manufacturing. The transport sector is interrelated with changes in international production and consumption patterns as well as location choices of multinational companies. Freight transport as derived demand depends on the volume and type of goods produced and consumed at different locations. Location of global production and consumption, structure of trade in terms of nature of goods trade and transport costs all influence the volume of freight as well as related mode and route choice.

Yet, long-term impact of trade flows' evolution on global transport flows has been overlooked in research, with the exception of some long term aggregate projections over the RUBMRIO model (Du and Kockelman, 2012). There is also limited evidence on environmental effects caused by the implied transport movements. This is probably partly due to lack of data and related projections, and partly due to inability to estimate the transport component of international trade. Literature has therefore focused in examining local or regional transport flows in production centres and evaluating them under traditional location theories to understand companies' strategies (van Veen-Groot and Nijkamp, 1999). There is also extensive literature on how transport costs affect international trade (WTO, 2007; Hummels, 2007; Hummels and Skiba, 2004; Milner and McGowan, 2013; Venables and Behar, 2010).

The most comprehensive effort to estimate international transport flows and related greenhouse gas emissions associated with changes in trade flows was carried out by Cristea et al. (2013). They use data on trade value, weight and modal share for different origin-destination pairs for a base year, distances between each bilateral pair and the greenhouse gas intensity of each transport mode to arrive at related tonne-kilometres and CO2 emissions. The results for this initial year are then projected up to 2020 using computable general equilibrium model for changes in value and composition of trade resulting from tariff liberalisation and GDP growth.

This method presents some shortcomings. The authors underline the lack of heterogeneity in terms of products and geographical location, but also the linearity of the approach, not accounting for the reduction in "fixed costs" with distance, especially in the maritime option. Furthermore, the outputs of the model are based on great-circle distances, not accounting for the geographical and network availability specificities which can produce significant biases.

We build upon this work by developing a new international freight model which takes into account changes in location, changes in value/weight ratio for products over time and reduction in “fixed costs” with distance. This work is part of the *ITF Transport Outlook* prepared by the International Transport Forum at the OECD (for a more elaborate discussion of results, see OECD/ITF 2015). We develop a four step model based on a global freight network model (using actual routes and related real distances) that converts trade in value into freight volumes in tonne-kilometres and related CO_2 emissions by transport mode and route for the period 2010-2050 for 26 regions and 25 product groups depending on alternative trade liberalization scenarios.

As cargo does not stop at ports but continues to economic centres, we also estimate this domestic link by introducing centroids for production and consumption, allowing us to estimate the freight performed by road or rail from/to ports to/from consumption/production centres.

In subsequent sections we present the model in detail and some preliminary results describing global freight flows related to international trade up to 2050. Finally, we discuss some of the policy implications of our results and present future research needs.

METHODOLOGY

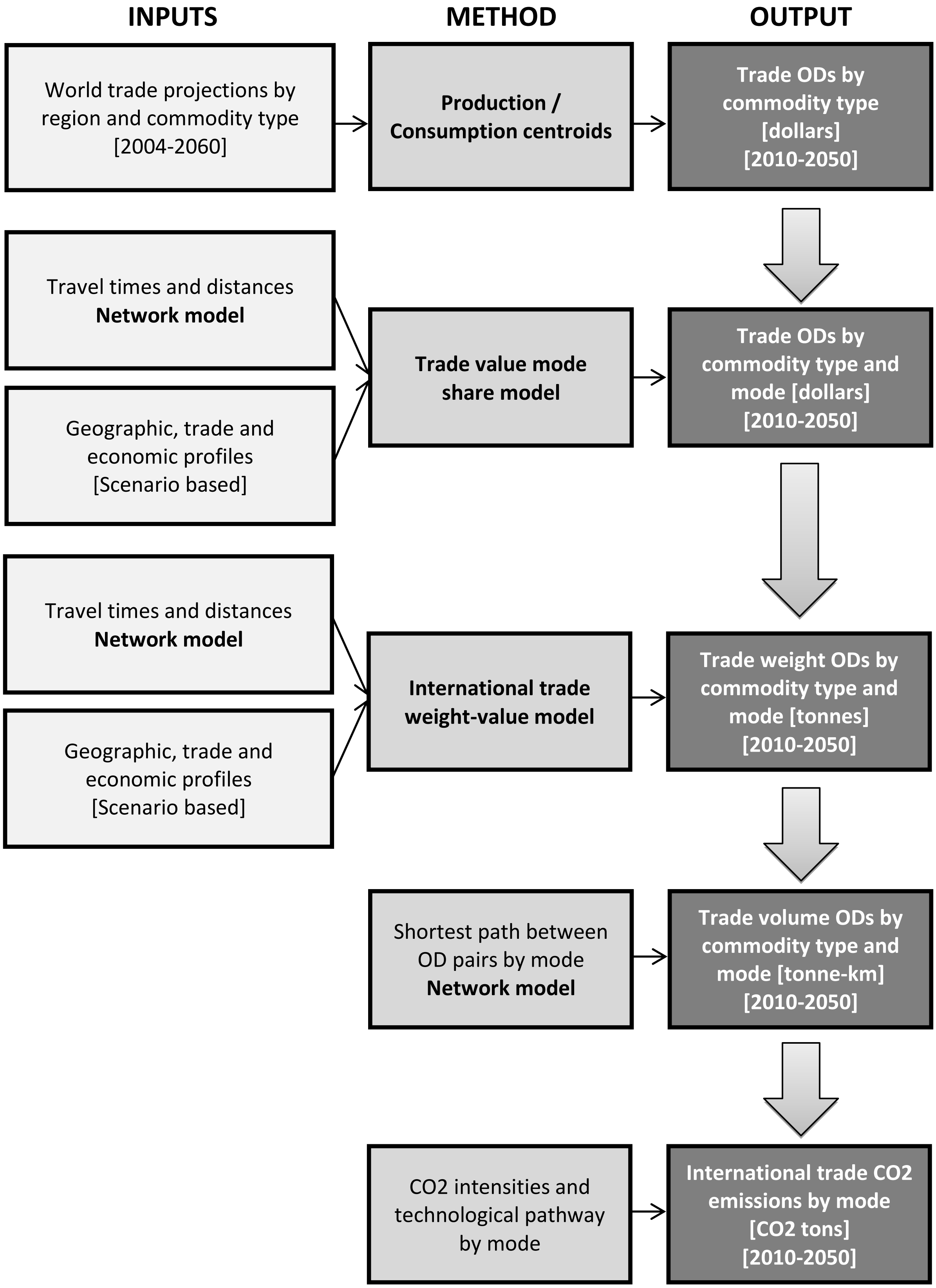
General framework

The model projects international freight transport activity up to 2050 based on alternative world trade scenarios. The five main components are presented in Figure 1:

- A general equilibrium model for international trade, developed by the OECD’s Economics Department (ECO) in collaboration with the Centre d’Etudes Prospectives et d’Informations Internationales (CEPII), covering 26 world regions and 25 commodities of which 19 requiring transport (Fontagné et al., 2014);
- A global freight transport network model based on 2010 data;
- An international freight mode choice model (in value) calibrated using Eurostat and UN Economic Commission for Latin America and Caribbean (ECLAC) data;
- A weight/value model (based on above data) to convert trade value into weight, calibrated for each commodity and transport mode;
- CO_2 intensities and technology pathways by mode.

Each model component output is used to feed the next step. The final model output is freight tonne-kilometres by transport corridor from international trade by mode and related CO_2 emissions.

Figure 1. **Schematic description of the model**



Underlying trade projections

The OECD's Economics Department (ECO) has published, in co-operation with the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII), trade scenarios up to 2060 using a framework that integrates long-term macro projections for the world economy with a sectorial trade model reproducing the key trade driving forces and specialisation past trends (Johansson and Olaberría, 2014).

The long-run growth model in the OECD Economic Outlook (OECD, 2013) provides long-term projections for GDP, savings, investments and current accounts for OECD and non-OECD G20 countries, augmented with projections by Fouré et al. (2012) for other countries.

The trade model is a version of MIRAGE, a multi-country, sectorial dynamic micro-founded model developed by CEPII (Fontagné et al., 2014; Fontagné and Fouré, 2013). This computable general equilibrium model (CGE) analyses the global evolution of bilateral trade and sectorial specialisation and covers the world economy aggregated into 26 regions and 25 sectors in the ECO framework (of which 19 requiring transport). These 26 regions can either represent large countries (i.e. United States, China) or economic regions with special trade agreements (i.e. Euro Area, European Free Trade Association - EFTA). Although the model aggregates results into regions, it also considers all international trade within broader regions. The model only excludes domestic trade.

Combining aggregate projections and individual (consumers and firms) behaviours underlines the impact of both global trends and country-specific policies on future trade and specialization patterns, acknowledging international spill overs. Trade projections are given in value terms, in fixed 2004 USD.

The model results indicate that over the coming half century, world trade is expected to continue to outpace GDP growth but at a slower rate than previously. An important conclusion of the forecast is that the geographical centre of trade is likely to continue to shift towards emerging economies:

- China, India and other Asian economies will continue to strengthen their role in manufacturing trade with exports climbing up the global value added ladder;
- In parallel with shifts in trade patterns, the industrial structure in emerging economies should gradually become similar to that of the present OECD, whereas it remains fairly unchanged in OECD economies.

The OECD model was computed for three trade policy scenarios (10):

1. *Baseline trade scenario* (BS), which considers that the current world trade agreements maintain until 2060;
2. *Bi-lateral trade agreements scenario* (BI), which considers:

- A free-trade agreement (FTA) is established in 2012 between NAFTA, the European Union (EU), Switzerland, EFTA, Australia, New Zealand, Japan and South Korea. Trade barriers are progressively phased out in this region;
- Tariffs on goods are abolished by 2060 and transaction costs for goods are reduced by 25%;

- Regulatory barriers in services as measured by ad valorem tariff equivalents converge to half the average intra-EU level for non-EU countries within the FTA, while barriers between EU members are reduced by a further 10%;
- In 2030, bilateral trade agreements are negotiated with key partners of the FTA including South Africa, The Russian Federation, Brazil, China, India, Indonesia, other ASEAN countries and Chile. With these countries, the FTA bilaterally reduces tariffs by 50% progressively.

3. Multi-lateral trade agreements scenario (ML), which considers:

- From 2013 tariffs on goods are reduced on a multilateral global basis by 50% by 2060 and transaction costs are reduced by 25%;
- In the FTA, tariffs on goods are abolished by 2060 and transaction costs for goods are reduced by 25%;
- Regulatory barriers in services converge to half the average intra-European Union level for non-EU countries within the FTA, while barriers between EU members are reduced by a further 10%;
- From 2013 agricultural support is reduced by 50% by 2060 in the EU, the United States, Japan, Korea, Canada and in EFTA countries.

Discretising regional flows into centroids

The regional aggregation of the model, while convenient for economic modelling of trade activity, introduces significant uncertainties from a transport perspective as it does not allow a proper discretisation of the travel path used for different types of product.

We discretise the regional OD trade flows into a larger number of production/consumption centroids. To identify centroids, we used an adapted p-median procedure over all the cities around the world classified by United Nations in 2010 relative to their population (2,539 cities). The objective function for this aggregation is based on the minimisation of a distance function, including two components: GDP density and geographical distance.

Instead of imposing a predefined number of p centroids, we consider no more than one centroid or region closer than 500 km within the same country. With these premises the algorithm obtained a solution with 294 centroids, where a rather stable and spatially balanced result was obtained for all the continents (America – 69; Europe – 74; Africa – 34; Asia - 110; Oceania – 7), and where each centroid is designated by the name of the respective city.

The trade flow between economic regions provided by the OECD (Fontagné, et al., 2014) is then converted into trade flows between centroids, using the regional GDP around each centroid as weights. The regional GDP for the base year (2010) was obtained from the Brookings Institution (Istrate et al., 2012) and Pricewaterhouse Coopers (2009). The growth projections of centroids are based on the growth rates at the country level obtained from OECD (2014). The share of trade flow between OD pairs within the same country will be constant over time as the growth rates of centroids are at the country level. The resulting equation for the estimation of the trade flow between the centroid pairs for each type of commodity is given by

$$Trade\ Flow_{ijCt} = Trade\ Flow_{[Region\ i][Region\ j]Ct} \cdot \frac{GDP_{it}}{\sum_{k \in Region\ i} GDP_{kt}} \cdot \frac{GDP_{jt}}{\sum_{l \in Region\ j} GDP_{lt}} \quad (1)$$

where *i* and *j* represent the origin and destination centroids respectively, *C* the commodity and *t* the year of analysis.

Network model

One of the key components of our model is a new GIS based global freight transport model, based on open GIS data for different transport modes. Our main contribution is the consolidation and integration of all different modal networks into a single global freight network.

For road network, we integrate two main sources: Global Roads Open Access Data Set (gROADS) (http://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1; accessed 1 April 2014) and OpenStreetMap (www.openstreetmap.org; accessed in 1 April 2014). Only the first and secondary road networks were considered (i.e. motorways, main roads and truck roads). For the rail network, the model integrates data from the Digital Chart of the World (DCW) (http://www.princeton.edu/~geolib/gis/dcw.html; accessed 1 April 2014) project updated with the OpenStreetMap data on rail lines and rail stations as intermodal points of connection between road and rail. The actual maritime routes are taken from the Global Shipping Lane Network data of Oak Ridge National Labs CTA Transportation Network Group (http://www-cta.ornl.gov/transnet/Intermodal_Network.html; accessed 1 April 2014), which generates a routable network with actual travel times for different sea segments. We connect this network to ports, based on data from the latest World Port Index Database of the National Geospatial-Intelligence Agency (http://msi.nga.mil/NGAPortal/MSI.portal; accessed 1 April 2014). The commercial air links between international airports were integrated using data from OpenFlights.org database on airports, commercial air links and airline companies (www.OpenFlights.org; accessed 1 April 2014).

Finally, all these networks were interconnected by transport links between the centroids using road network and rail stations together with data on intermodal dwelling times.

In order to estimate travel times for the different types of infrastructure, as well as dwelling times between transport modes, we use average speeds based on available information by region (see Table 1).

The network model is then used to compute all the shortest paths between centroids for each transport mode (if the transport is available as an option), generating two main inputs:

- The average travel time and distance by mode to link each country based on a weighted average for all pairs of centroids between the country OD pairs (using the regional GDP procedure described above); and
- The shortest paths between the centroids for each transport mode.

These inputs are used either in the calibration of the other model components or as an element of the model itself.

Table 1. **Speed and dwelling time used in the network model by different world regions**

Speed [km/h]			
Infrastructure type	**Europe and Japan**	**Australia, Canada and United States**	**Rest of the world**
Road [a]			
Major highways	80	80	70
Secondary highways	65	65	55
Beltways and national roads	40	40	30
Tracks or unpaved roads	10	10	5
Rail [b]			
Electrified	40	35	25
Non electrified	30	30	15
Sea [c]			
Bulk vessels		22.2	
Container vessels		41	
Air [d]		600	
Connectors [e]			
Road connector		30	
Sea connectors to ports		15	

Dwelling times [h]			
Intermodal connection	**Europe and Japan**	**Australia, Canada and United States**	**Rest of the world**
Air/Air	4	4	72
Air/Road - Road/Air	4	4	72
Air/Rail – Rail/Air	4	4	72
Air/Sea – Sea/Air	22	22	72
Rail/Sea – Sea/Rail	49	49	96
Rail/Road – Road/Rail	31.5	31.5	31.5
Road/Sea – Sea/Road	49	49	96

Source: a) Authors' estimates based on speed limits and road infrastructure quality; b) UIC, International Railway Statistics 2010; c) UNCTAD, Review of Maritime Transport 2010 ; d) Authors' estimates based average travel times for commercial flights Europe to other continents obtained from <www.travelmath.com> retrieved in April 2014; e) Authors' estimate for the setting of road and sea connectors. For dwelling times. source Fluidity Indicator Project (Canada's Gateways), Transport Canada 2012.

Mode share model for international freight

The mode share model (in value) for international freight flows assigns the transport mode used for trade between any OD pair of centroids. The mode attributed to each trade connection represents the longest transport section. All freight will require intermodal transport both in the origin and destination. This domestic component of international freight is usually not accounted in the literature, but our model integrates this component.

We use a standard multinomial logit (MNL) formulation including a commodity type panel term. It was calibrated using exports data from Eurostat and ECLAC, which contain information of the value, weight and mode of transport of export activities from the European Union and Latin America to the rest of the world. For each OD pair, we estimate the modal share in value by product group. Data on travel times and distances for each mode were taken from the global network model at the centroid level. Two geographical and economic context binary variables were added: one describing if the pair of countries have a trade agreement and the other for the existence of a land border.

The dataset contained 17,427 observations, with an average weighted mode share in value of 26% for road, 22% for air, 50% for sea and just 2% for rail. The calibrated model has ρ^2=0.22, showing a satisfactory explanatory power of the mode choice while all the variables are statistically significant, except for one panel term (*Coal*), which presented a similar value to the base commodity considered (*Chemicals*) (see TABLE 2).

The results show greater relation with the sea alternative, mainly for low raw material values and non-perishable nature of products, but also due to security issues (i.e. *Crude oil*). Transport related variables present an interesting behaviour that clearly distinguished sea transport from the other available options. While increase in distance may reduce the utility of transporting value by sea, longer journeys make this mode more attractive. The utility of a sea trade connection will depend on the balance between distance and travel time, given by travel speed: sea routes, requiring a big diversion from the direct link, such as Europe to Asia with links not using the Suez Canal, may not be very attractive.

An opposite relation is observed for the air mode, where long distances are favourable. However, if no direct flights are found (increasing significantly the travel time) the utility is reduced significantly. Road and rail present a similar behaviour to air, with some specificity:

- Rail distance presents a huge penalty, suggesting the alternative may be more attractive for shorter connections. This may stem from border control difficulties as well as interoperability of systems, which introduce large delays and loss of liability of the cargo with the large number of rail operators involved to cross several countries;

- Trade agreements between countries seem to favour road transport over rail transport, indicating again border crossings issues with freight rail services; and

- A land border between countries favours exports through road and rail.

Table 2. **Calibration results for international freight (in value) mode share model**

Variable	Coif.	Rob. Std err	Rob. t-test	Rob. p-val
Mode specific constant				
Air	-0.75	0.02	-41.50	0.00
Rail	-1.30	0.03	-40.22	0.00
Road	0.15	0.02	12.42	0.00
Sea	0.00	-	-	-
Commodity panel term in Sea utility function				
Chemicals	0.00	-	-	-
Coal	-0.02	0.08	-0.25	0.82
Crude oil	2.45	1.15	2.16	0.03
Electronics	-2.37	0.02	-95.67	0.00
Fishing	-0.80	0.09	-8.00	0.00
Food	0.50	0.02	21.17	0.00
Forestry	-1.03	0.04	-23.89	0.00
Iron and Steel	0.17	0.02	7.14	0.00
Livestock	-1.01	0.04	-22.77	0.00
Metal products	-0.20	0.02	-10.43	0.00
Non-ferrous metals	-0.15	0.03	-5.74	0.00
Non-metallic minerals	0.18	0.03	5.51	0.00
Other manufacturing	-0.37	0.02	-20.41	0.00
Other mining	0.73	0.03	23.63	0.00
Paper, pulp and print	-0.06	0.03	-2.83	0.00
Petroleum & coke	0.07	0.03	2.51	0.01
Rice and crops	0.30	0.02	13.52	0.00
Textiles	-0.09	0.02	-4.72	0.00
Transport equipment	-0.22	0.02	-9.44	0.00
Transport related attributes				
Distance air [10,000 km]	0.03	0.00	19.58	0.00
Distance rail [10,000 km]	0.06	0.00	11.70	0.00
Distance road [10,000 km]	0.02	0.00	5.52	0.00
Distance sea [10,000 km]	-0.07	0.00	-21.66	0.00
Time air [1,000 hours]	-0.02	0.00	-1.97	0.05
Time rail [1,000 hours]	-1.77	0.00	-12.19	0.00
Time road [1,000 hours]	-0.40	0.00	-35.42	0.00
Time sea [1,000 hours]	0.37	0.00	40.96	0.00
Context variables (trade agreement effect – TA, land border – LB)				
TA rail	-0.07	0.04	-1.65	0.10
TA road	0.38	0.01	26.21	0.00
LB rail	0.98	0.07	14.14	0.00
LB road	1.10	0.02	45.84	0.00

Weight-value model for the international trade

We formulated several Poisson regression models to estimate the rate of conversion of value units (dollars) into weight units of cargo (tonnes) by mode, using as offset variable the natural logarithm of the trade value in millions of dollars, and panel terms by commodity. The selection of this regression method was based on the observation of the statistical distribution of the sample showing a more suitable behaviour in a discrete statistical distribution than with continuous distributions (i.e. Normal, Lognormal), especially for low trade connections.

The model was calibrated using Eurostat and ECLAC data on exports. We added travel time and distance information as discussed above, and geographical and cultural variables: the binary variables for trade agreements and land borders used above and a binary variable identifying if two countries have the same official language. Moreover, economic profile variables were included to describe the natural trade relation between countries with different types of production sophistication and scale of trade intensity:

- The GDP percentile of the origin country ($p\%\ GDP_i$);
- The GDP percentile of the destination country ($p\%\ GDP_j$);
- The GDP per capita percentile of the origin country ($p\%\ GDP\ capita_i$);
- The GDP per capita percentile of the destination country list ($p\%\ GDP\ capita_j$);
- The natural logarithm of the GDP per capita ratio between OD countries ($ln \frac{GDP\ capita_i}{GDP\ capita_j}$).

All the economic variables were constructed using a relative order of countries instead of their absolute values to avoid their disproportional effect in the future relation of the value-weight ratio. This is not expected to happen as neither the products will become lighter for the majority of the commodities, especially from raw materials, or a disruption in the market that will change the valuation of some commodities over others. This will ensure the stability of the effect over time, improving the model’s forecast ability.

This resulted with a dataset for each transport mode with individual model calibrations. All models include an over dispersion Poisson term as they all showed a significant over dispersion.

Table **3** presents the calibration results for the four models with significant differences by mode.

The Sea model performs well in reproducing market patterns. Time is the only relevant transport factor, showing that more expensive goods are transported further away (less weight per value). Of the economic variables, only the $p\%\ GDP_i$ and the $ln\frac{GDP\ capita_i}{GDP\ capita_j}$ were found significant, presenting a positive impact on the weight that is being transported by value unit for both. This result shows that larger economies export greater quantities and that the export to less developed economies is more weight intensive than for more developed economies. The cultural relation between countries (set as a binary value that takes value one if the origin and destination country have a common official language and/or had a colonial relation in the past) was also found as significant, leading to exports of greater value products.

The Road model presents good fit indicators. Distance should increase the weight intensity of trade flows, while time produces the inverse effect. This highlights the importance of speed in road freight to determine the typology and value of goods being exported. Larger economies tend to export larger quantities, while exports to larger economies are simultaneously less weight intensive. This may be explained by a larger internal market that requires importing less differentiated and valuable products. As expected, more developed countries (higher GDP per capita) trade more value intensive goods. Land borders also leads to more valuable exports, while the presence of the same language and trade agreements may potentiate the quantities being exported.

The Rail model presents an acceptable quality fit indicators, where obtained ρ^2 of the model is high but the estimates obtained from the model are less able to reproduce the calibration data. This suggests that other factors, not included in the model, may impact the value-weight relation. Transport variables suggest an inverse logic that was obtained for the Road sector. This may reflect problems related to border crossing of the rail mode (i.e. interoperability), being attractive either for national flows or for large volume exports. Trade agreements may facilitate significantly the flow of products between countries using rail. The economic related variables present a different configuration. While larger economies tend to export more valuable goods by rail, the opposite occurs from an importing perspective, reinforced by the GDP per capita variables. This may indicate issues in infrastructure availability and quality in less developed countries, reducing the rail efficiency for freight transport.

The Air model presents the least quality of fit indicators, underlying the great variability of the sector. Nevertheless, the model shows significant effects of the variables considered. The transport variable coefficients present a similar behaviour to the Rail model, although the reasons behind may differ. The positive impact of time may indicate that the absence of direct flight connections with large dwelling times at airports may reduce significantly the value of transported good, while distance potentiates the transport of more valuable goods. The economic profile variables have a similar impact as in the Road model, where exports from larger economies may lead to the transport of more quantity but the most developed countries export more valuable goods. The panel commodity terms show that most of air transport is less weight intensive. For some commodities air weight transport may be much reduced, especially due to safety reasons but also because some products do not need to reach markets fast to be consumed (i.e. non-perishable products).

Table 3. **Weight-value model calibration results for each transport mode**

Parameter	Sea		Road		Rail		Air	
	Coeff.	**Sig.**	**Coeff.**	**Sig.**	**Coeff.**	**Sig.**	**Coeff.**	**Sig.**
Shortest path characteristics								
$Time_{ij}$ [100 hours]	-0.11	0.00	-1.09	0.00	0.38	0.00	0.50	0.00
$Distance_{ij}$ [1,000 km]	0.00	0.00	0.269	0.00	-0.24	0.00	-0.03	0.04
Economic profile of countries								
$p\%\ GDP_i$	0.24	0.00	0.77	0.00	-0.25	0.03	1.56	0.00
$p\%\ GDP_j$	0.00	0.00	-0.19	0.00	0.59	0.00	-0.58	0.00
$p\%\ GDP\ capita_i$	0.00	0.00	-1.77	0.00	-1.55	0.00	-2.52	0.00
$p\%\ GDP\ capita_j$	0.00	0.00	-0.81	0.00	0.79	0.08	-1.23	0.00
$ln \frac{GDP\ capita_i}{GDP\ capita_j}$	0.16	0.00	-0.30	0.02	0.75	0.01	-0.43	0.00
Economic, geographical and cultural relations between countries								
$Land\ border_{ij}$	0.00	0.00	-0.39	0.00	0.00	0.00	-1.34	0.00
$Same\ language_{ij}$	-0.11	0.00	0.48	0.00	0.00	0.00	-0.40	0.00
$Trade\ aggreement_{ij}$	0.00	0.00	0.14	0.00	0.74	0.00	0.66	0.00
Commodity panel term								
Chemicals	-7.13	0.00	-3.41	0.00	-5.78	0.00	-2.99	0.00
Coal	-4.27	0.00	-0.91	0.00	-3.56	0.00	2.12	0.45
Crude oil	-6.17	0.00	-3.66	0.00	-33.72	0.00	0.19	0.98
Electronics	-9.45	0.00	-2.30	0.00	-9.26	0.00	-3.47	0.00
Fishing	-7.28	0.00	-3.17	0.04	0.00	0.00	-2.92	0.00
Food products	-6.30	0.00	-3.29	0.00	-5.71	0.00	-1.82	0.00
Forestry	-4.66	0.00	-1.94	0.00	-3.42	0.11	-1.53	0.01
Gas	-5.49	0.00	-2.68	0.00	0.00	0.00	-23.12	0.00
Iron and Steel	-6.63	0.00	-3.00	0.00	-5.49	0.00	-1.03	0.01
Livestock	-7.50	0.00	-3.04	0.00	-4.06	0.07	-3.26	0.00
Metal products	-8.18	0.00	-3.73	0.00	-6.67	0.00	-1.87	0.00
Non-Ferrous Metals	-8.37	0.00	-4.65	0.00	-7.38	0.00	-5.94	0.00
Non-metallic minerals	-5.85	0.00	-1.85	0.00	-4.62	0.00	-1.82	0.00
Other manufacturing	-8.51	0.00	-4.43	0.00	-6.81	0.00	-2.77	0.00
Other mining	-6.50	0.00	-2.66	0.00	-5.17	0.00	-0.70	0.03
Paper, pulp and print	-7.48	0.00	-3.95	0.00	-7.82	0.00	-2.73	0.00
Petroleum & coke	-6.33	0.00	-2.44	0.00	-5.27	0.00	-0.39	0.31
Rice and crops	-5.79	0.00	-2.50	0.00	-5.89	0.00	-1.61	0.00
Textiles	-7.36	0.00	-3.05	0.00	-5.58	0.00	-3.18	0.00
Transport equipment	-8.46	0.00	-4.54	0.00	-7.71	0.00	-2.09	0.00
(Scale)	19379.55		8819.49		3266.30		722.91	
Pseudo-ρ^2	0.65		0.60		0.68		0.38	
Correl $(y,\bar{y})^2$	0.90		0.93		0.35		0.21	

Generation of the model outputs

Once all the components are set, the model is computed sequentially as presented in Figure 1. The results include the value, weight and distance travelled (with path specification) between 2010 and 2050, for each centroid pair, mode, type of commodity and year, stemming from international trade.

These results (in tonne-kilometres) are then combined with information on related CO_2 intensities and technology pathways by mode, obtained from the International Energy Agency's MoMo model (IEA, 2014) and the International Maritime Organization (IMO, 2009). In case of road and rail, these coefficients and pathways are geographically dependent, while the maritime and air CO_2 efficiency is considered to be uniform worldwide.

MODEL RESULTS

Initial benchmark of results for 2010

This section presents some preliminary results. For a more detailed discussion of results and policy implications, see OECD/ITF (2015).

We first provide comparison of our results with statistical data on international trade related freight transport (see Table 4). Our model yields results for total maritime and air tonnes and tonne-kilometres very close to data provided in other sources, showing that the model is able to reproduce adequately current market behaviour. For maritime CO2 emissions, our model estimate falls between the International Energy Agency and International Maritime Organisation calculations.

Table 4. **Comparison of model results for the baseline 2010 statistics**

Variable	Model estimates	Available statistics	Source
Maritime international trade volume [million tonnes]	8 372	8 408	UNCTAD review of Maritime Transport
Air international trade volume [million tonnes]	34	31.8	ICAO
Maritime international trade related freight [billion tonne-km]	60 053	65 599	UNCTAD Review of Maritime Transport
Air international trade related freight [billion tonne-km]	191	158	ICAO
Maritime international trade related CO2 emissions [million tonnes]	779	644 870	IEA IMO

Sources: UNCTAD Review of Maritime Transport 2012; ICAO Annual Report of the Council, 2012; IEA CO2 Emissions from Fuel Combustion Statistics; IMOGHG Study 2009, International Maritime Organization.

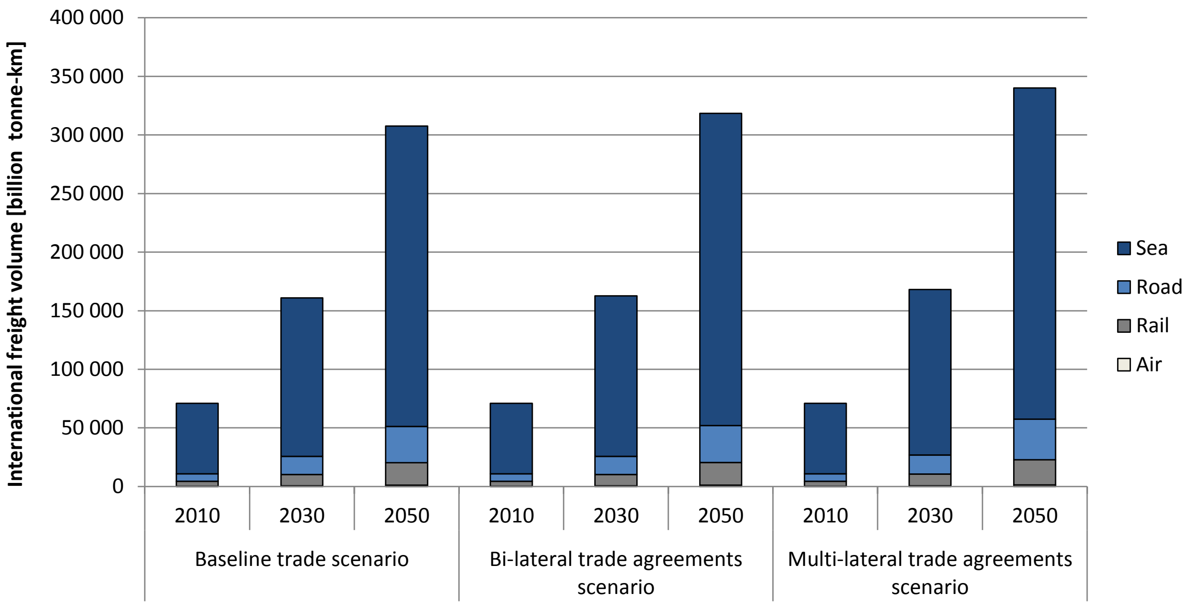
International freight flows under different trade liberalisation scenarios

Figure 2 shows the evolution of transport volumes related to international trade by different transport modes from 2010 to 2050. The growth in world trade in constant value by a factor of 3.4 by 2050 will translate into a growth of world freight volumes by a factor of 4.3 over the same period, measured in tonne-kilometres, under the baseline scenario. This increase is driven by the changes in the product composition but also by growth in the average hauling distance caused by changes in the geographical composition of trade. The average hauling distance is estimated to grow by 12% from 2010 to 2050. Sea remains the most relevant transport mode (measured in tonne-kilometres), accounting about 85% of the total volume in 2010, and around 83% in 2050 for all trade scenarios. Road freight is estimated to increase its share of the total over the period (from 6% to 10%). Our calculations include freight movement at the domestic link of international freight, usually carried by road. Excluding domestic link, sea accounts for 95% of total tonne-kilometres.

We also carry out a more in-depth analysis by geographical region and corridor. We divide the world into 12 different transport regions/corridors: 1) North America; 2) North Atlantic; 3) Europe; 4) Mediterranean and Caspian Sea; 5) Asia; 6) North Pacific; 7) South Pacific; 8) South America; 9) South Atlantic; 10) Africa; 11) Indian Ocean; 12) Oceania. Figure 3 presents the corridors spatial location along with the volumes by corridor in 2010 and 2050 in the baseline scenario. The growth of freight volume is far from uniform around the world, being significantly stronger in maritime routes and inland connections in Asia.

The North Pacific corridor is expected to surpass the North Atlantic as main world freight corridor (Figure 3). This partly reflects the shift of economic centre of gravity towards Asia. Freight volumes will increase also in the Indian Ocean and the Suez Canal, resulting from the bigger trade Asia-Africa and Asia-Europe. We also observe marked rise in inland connections in all continents. Significant growth is projected to take place in intra-Asian volumes, estimated to grow by over 380% by 2050. Intra-African freight volumes are also projected to grow even more significantly (+480%) although form low initial levels. These results mirror the trade increase within the Asia and Africa, and also the increasing traffic from/to ports from/to the consumption/production centres. Due the lack of efficient rail network, these movements are mostly carried by trucks.

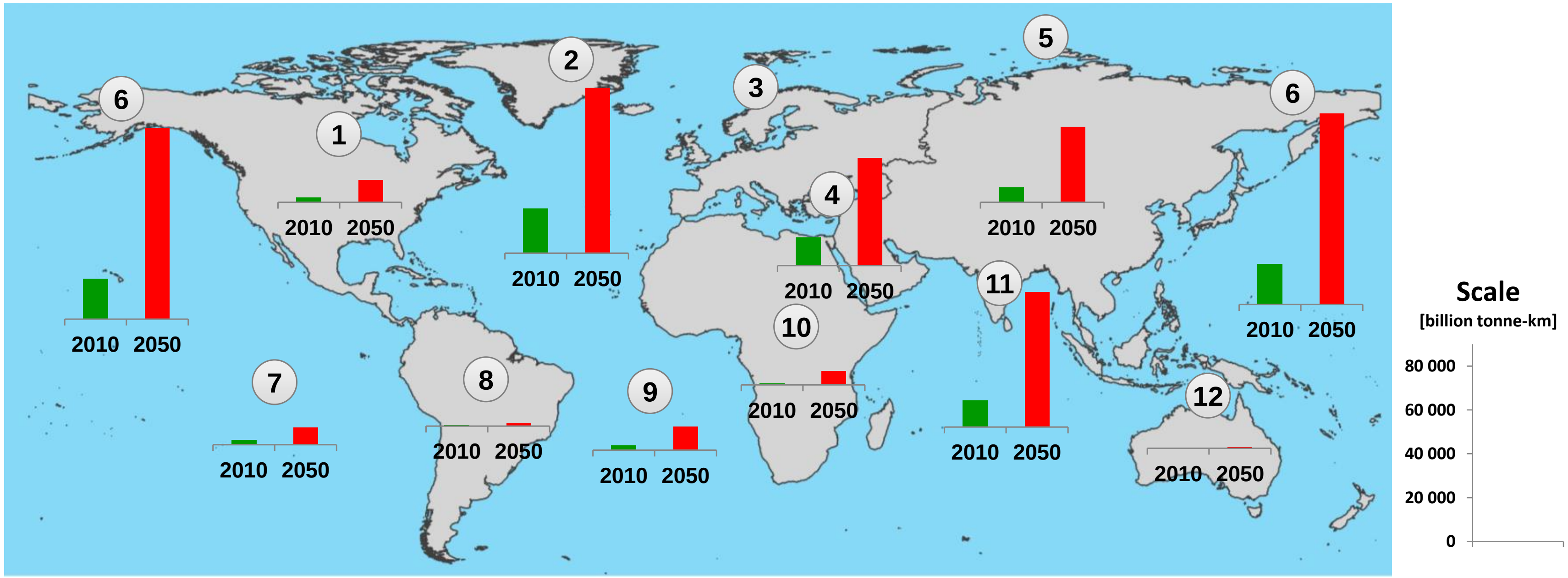
Figure 2. **International freight volumes under alternative trade liberalisation scenarios 2010-2050**



Source: Authors' estimates.

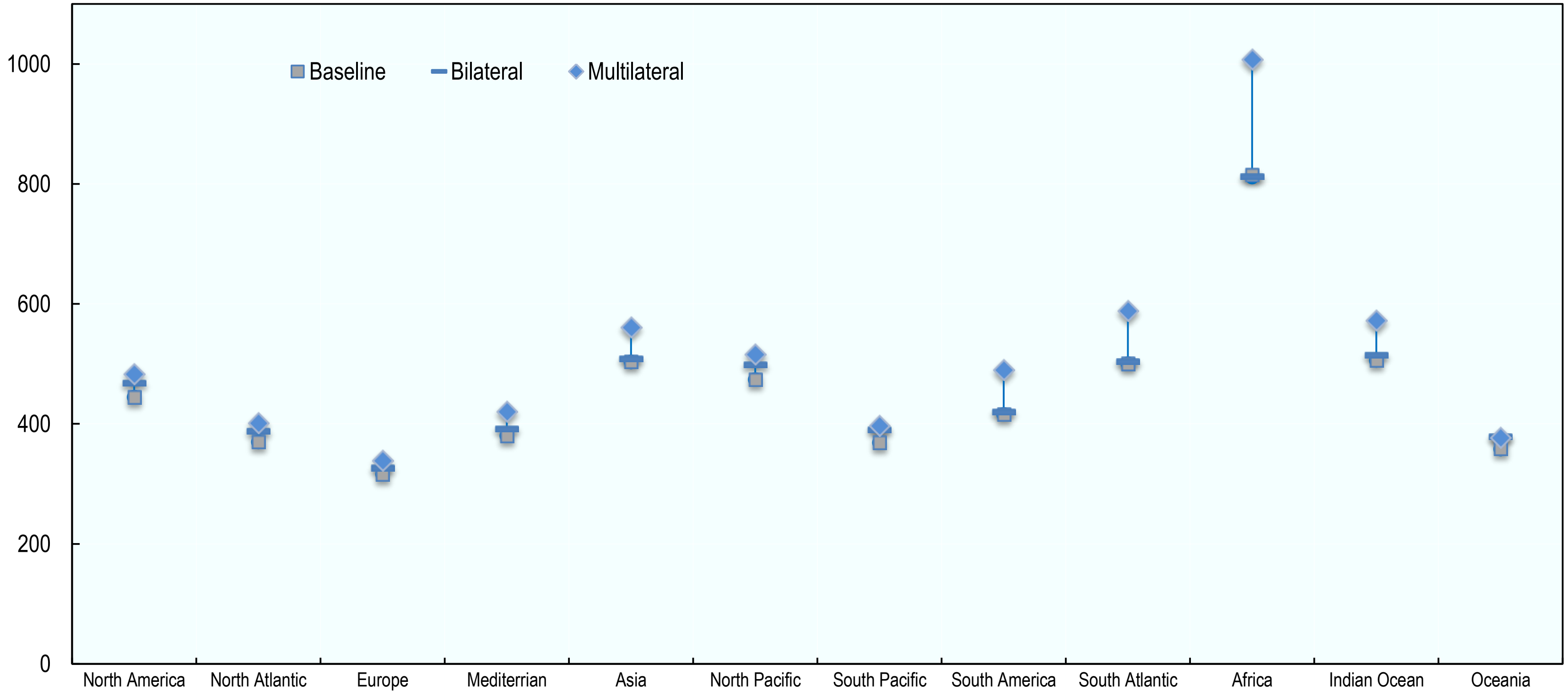
Overall, the results show that a bilateral trade liberalisation will not significantly affect freight volumes at any of the regions/corridors. In the bilateral scenario, freight volumes are estimated to grow by 350% (compared with 330% in the baseline). In the multilateral liberalisation scenario trade is reoriented towards the non-OECD area, reflecting comparatively larger reductions in tariffs than in OECD countries as well as stronger underlying growth performance in this area. As a result, global freight will grow by 380% in the multilateral liberalisation scenario by 2050. Multilateral trade liberalisation results with significantly more transport volumes especially in Africa, South America, South Atlantic, Indian Ocean and to some extent Asia (see Figure 4).

Figure 3. **International freight in tonne-kilometres by corridor: 2010 and 2050 (Baseline trade scenario)**



Source: Authors' estimates.

Figure 4. **Tonne-kilometres by corridor for alternative trade liberalisation scenarios, 2050 (2010=100)**



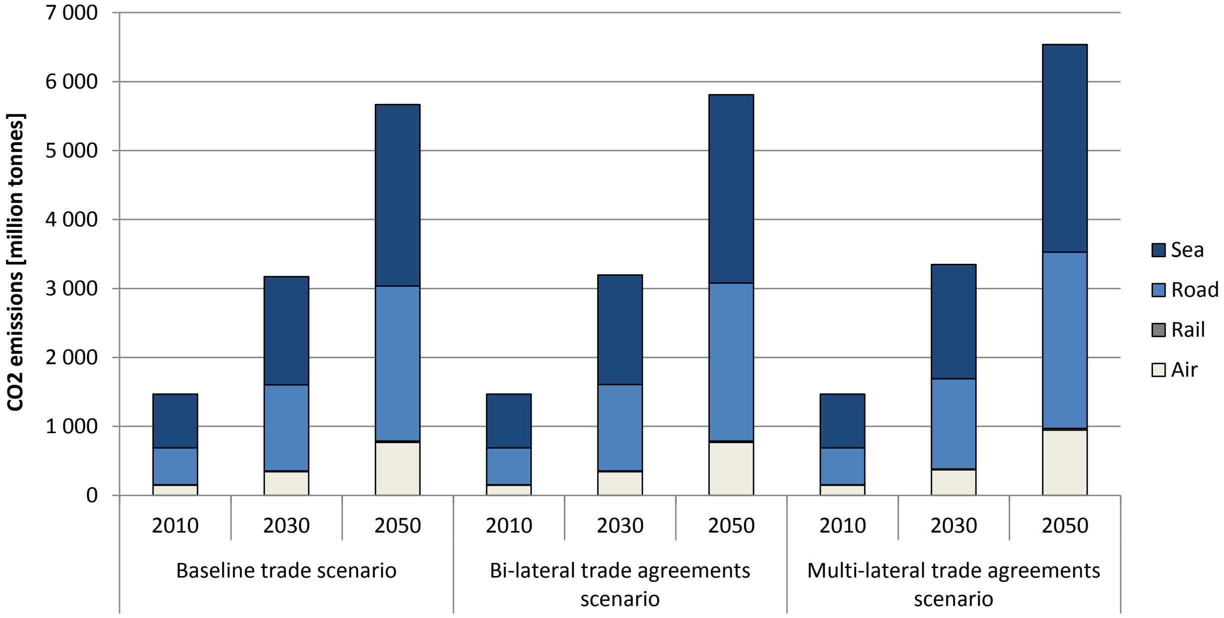
Source: Authors' estimates.

CO2 emissions

Over the period 2010-50, CO2 emissions related to international freight transport will grow by a factor of 3.9 in the baseline scenario. Road freight accounts for 53% of the total and its share is projected to increase to 56% by 2050. Also air transport will see an increase of 2 percentage points in its contribution to CO2 emissions by 2050. Sea share is estimated to fall from 37%to 32%. These changes are driven by the increasing share of trade by road and air and also by longer average haulage distances. The bilateral trade scenario results only with a 2% increase in CO_2 emissions compared with the baseline emissions in 2050. On the contrary, multilateral trade liberalisation would yield CO_2 emissions 15% more than in the baseline by 2050.

The results mirror the trade increase within the Asia and Africa, and also the increasing traffic from/to ports from/to the consumption/production centres. Due to the lack of efficient rail network, these movements are mostly carried out by trucks, setting significant pressure on increasing CO_2 emissions.

Figure 5. **CO_2 emissions from international freight under alternative trade liberalisation scenarios 2010-2050**



Source: Authors' estimates.

The relevance of domestic transport linked to international freight

As already discussed, the domestic freight related to international trade is often not accounted for. We estimate that this component represents around 10% of the total trade related freight globally and around 30% of the total trade related CO_2 emissions. It presents great variability, depending on the geographic location of the main producers/consumers in each country. In China, where most of the economic activity is concentrated in coastal areas, the domestic link presents 9% of the total international trade related freight volumes. In India, on the other hand, the share is 14% as a result of production and consumption centres being located inland.

Domestic transport linked to international trade represents a large share of total surface freight volume (national and international) in some countries. In China, we estimate this to grow from 9% in 2010 to 11%, assuming that the coastal pattern of GDP concentration in China remains. In the United States, this share is estimated to be 15% in 2010 (our estimate for 2010 corresponds to statistics provided by the US Bureau of Transportation Statistics) but can grow up to 40% by 2050 depending on future trade patterns. Overall, domestic freight related to international trade sets a significant pressure on national infrastructure capacity. This highlights the need to assess the capacity of existing national infrastructure such as port terminals, airports or road and rail infrastructure to deal with potential bottlenecks that may emerge.

CONCLUSIONS

This paper introduces a new model to project transport volumes and related CO_2 emissions resulting from international trade under different trade liberalisation scenarios. It aims at fulfilling the gap emphasised in earlier studies on modelling and measuring the environmental effects of international transport (Du and Kockelman, 2012).

Broadening international trade links have brought greater volume of good, moving further and in increasingly complex and interdependent ways. Freight is derived demand and a critical factor in the future growth of freight transport is related to the location of future production facilities and consumers. Our results show that increasing international trade will lead to increasing freight volumes also in the future. This increase in volume will set significant pressure for infrastructure development in critical areas, especially at ports and their hinterland connections. Our results also suggest that changes in the global production and consumption patterns would lead to an increase in average freight distance. Especially in developing countries, the current infrastructure may prove insufficient to match the estimated demand. This may hinder the economic development in these countries.

Our model in its current form has several limitations. It does not take into account capacity constraints or changes in the structure of global supply chains, among others. Given the complexity of the globalisation and future supply chain configuration, it is difficult to assess the scale of the environmental effects of future global trade. However, our results suggest that increasing global trade would lead to parallel increase in CO_2 emissions, while especially multilateral trade liberalisation can lead to a greater increase in emissions.

The effects of international trade on the environment are the result of changes in the scale and structure of the trade combined with technological and product effects. Current trends can be potentially changed by, for example by improving the emission intensity of existing fleet, through development of alternative transport modes, improvement of the efficiency of supply chains and by introducing new technologies. This would, however, require targeted policies to ensure positive benefits from increasing trade while simultaneously improving the energy efficiency of the transport system. We do not assess alternative technological pathways in this paper, however.

Already in its current form, the potential uses of the existing outputs of our model for policy analysis are broad. Apart from the traditional analysis of transport activity and related CO_2 emissions, the model may be used to assess the capacity of current infrastructure (port terminals, airports or road and rail infrastructure) to deal with the expected trade flow changes or to identify the main bottlenecks that may emerge in the worldwide transport network, among others.

One future extension of this study may also be the introduction of trade barriers in some corridors related with security (i.e. piracy, political stability) and the assignment of freight not only to the shortest path between OD pairs but use an equilibrium assignment procedure.

ACKNOWLEDGEMENTS

This paper presents the modelling framework as a part of the *ITF Transport Outlook*, developed by the Outlook team of the International Transport Forum at the OECD. Authors gratefully acknowledge the willingness of OECD and IEA to share their models for the development of this model.

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