International Transport Forum

The Cost of Reducing Greenhouse Gas Emissions in Shipping

Discussion Paper

178 Roundtable

Tristan Smith
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The International Transport Forum

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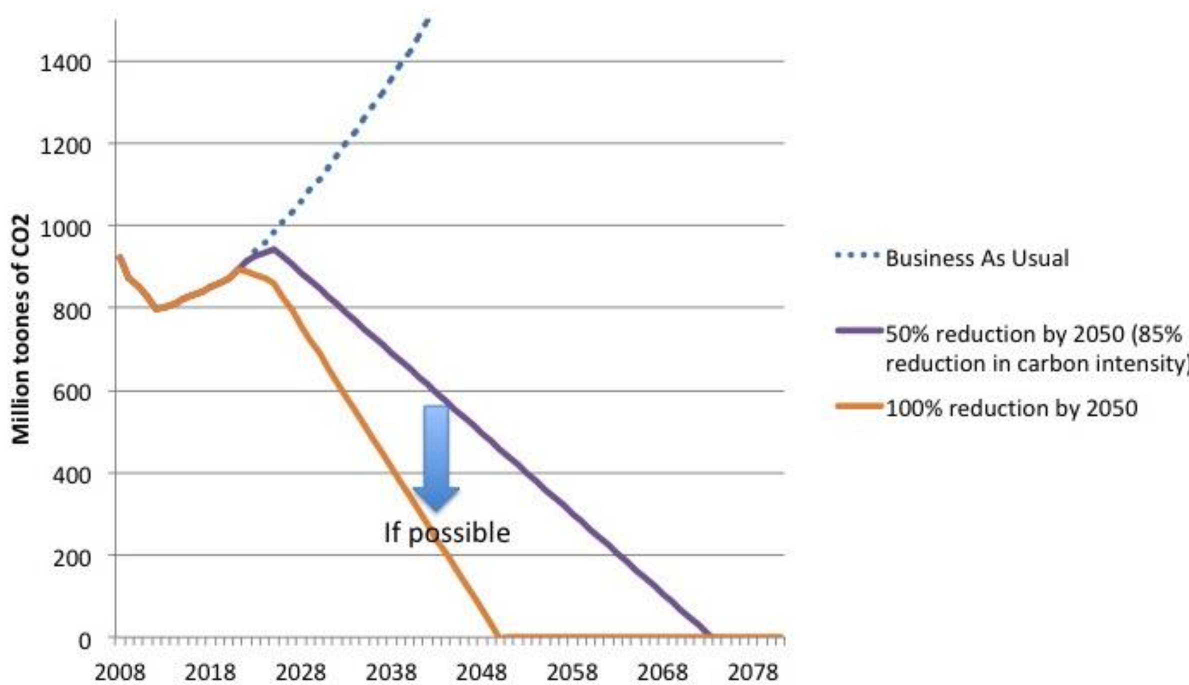
Introduction

In April 2018, the International Maritime Organization (IMO) adopted the IMO Resolution MEPC.304(72), to be known thereafter as the Initial IMO Strategy. It sets a greenhouse gas (GHG) emission reduction of "at least" 50% of 2008 emission levels by 2050, with a strong emphasis on increasing the cut towards 100% by 2050 if this can be shown to be possible. This is approaching the ambition of the United Nation's 2015 Paris Agreement and represents a significant shift in climate ambitions for a sector that accounts for 2-3% of global carbon dioxide emissions. Figure 1 illustrates these targets.

Figure 1. Carbon dioxide emissions reduction goals for international shipping

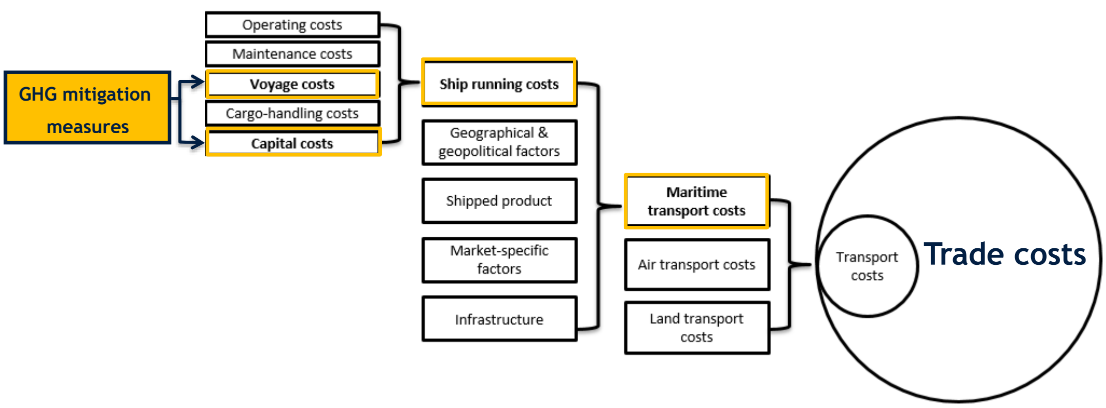


With the Initial IMO Strategy in place, the IMO is in the process of developing legally binding GHG-reducing measures that could include increasing ships' technical and operational energy efficiency, a low- and zero-carbon fuels implementation programme, national action plans and market-based measures. These measures would be in addition to the existing IMO measures on energy efficiency.

GHG mitigation measures can modify both technology specifications of a ship and the fuel choices. Carbon pricing could increase voyage costs similar to an increase in fuel price. Broadly, therefore, GHG mitigation could increase two determinants of maritime transport costs: voyage and capital costs.

Voyage costs are affected by the short-term increase in fuel expenditures. Capital costs are affected by the mid- to long-term adjustments in the design and technical specifications of ships that will be needed to reduce GHG emissions and the burden of paying the carbon price. Figure 2 presents the breakdown of these determinants and how the GHG mitigation measures impact maritime transport costs.

Figure 2. Breakdown of the components of maritime transport costs



Source: derived from: Rojon et al. (2019).

The consequence of an increase in maritime transport costs could be, inter alia:

- a loss of competitiveness of maritime transport relative to other modes of transport and, therefore, a shift from shipping to those other modes
- an increase in the prices of imports, causing substitution for local production or alternative sourcing of imported goods
- an increase in the cost of exports, causing a reduction in competitiveness and demand.

Potentially significant policy-induced increases in costs are likely on the near horizon. As a result, these potentially important responses in the system of global trade, which can be applied individually or in combination, need to be understood.

Policies formulated at the IMO (and elsewhere) have many potential impacts on trade. Policies created to address safety or environmental issues, for example, include the 0.5% sulphur limit and ballast water management regulation. Both of these policies could potentially raise the cost of shipping operations via increases in capital or voyage costs. However, the potential for impacts on trade arising from GHG policy is particularly salient because the Initial IMO Strategy includes an explicit commitment:

> …identifying actions to be implemented by the international shipping sector, as appropriate, while addressing impacts on States and recognising the critical role of international shipping in supporting the continued development of global trade and maritime transport services… (paragraph 1.7, Objectives of the Initial IMO Strategy, IMO 2018)

This objective is partly clarified in paragraph 4.3:

> …Disproportionately negative impacts should be assessed and addressed, as appropriate…

However, there is no clarity on what constitutes "disproportionality". An identifiable first step in producing evidence for further deliberations at the IMO is, therefore, to understand both the overall potential impacts on trade and the relative magnitudes of impacts experienced in different countries. Hence the two main questions of this paper:

- What is the potential and scale of the possible increase in maritime trade costs?
- What could be the impacts on total global trade flows, import substitution and transport mode shifts?

In order to answer these questions, this paper draws heavily from two existing publications, directly using their results and arguments:

- IMarEST (2018), "The costs of GHG reduction in international shipping ISWG GHG 3-3", Submitted by IMarEST to the Third IMO Intersessional Working Group on GHG emissions, London, April 2018
- Halim, Smith and Englert (2019), "Understanding the Economic Impacts of Greenhouse Gas Mitigation Policies on Shipping: What is the State of the Art of Current Modelling Approaches?", World Bank report WPS8695.

Potential and scale of increased maritime trade costs

There are multitudes of technical and operational modifications that can help reduce the carbon intensity of shipping. These can be divided approximately between two groups: 1) abatement options for improving energy efficiency and 2) abatement options for reducing the carbon factor of the energy source.

Improving energy efficiency for a given size and type of ship is ultimately limited by the laws of physics. The hydrodynamic resistance of a hull, the efficiency of a propeller and the efficiency of an internal combustion engine are impossible to improve beyond certain limits (i.e. the laws of physics and thermodynamics). As those limits are approached, the improvements have increasingly diminishing returns, and become challenging from a cost-effective perspective. While every effort should be made to identify and incentivise further improvements in energy efficiency to reduce the amount of energy needed in shipping, efficiency improvements alone will not enable the achievement of the Initial IMO Strategy objectives.

Efforts to estimate the potential and scale of an increase in maritime trade costs focus on the cost of energy efficiency technologies. This is because the ultimate cost of the decarbonisation of international shipping is partly influenced by these costs, though they are ultimately capped by the cost of the zero CO_2 emissions fuels and technologies Smith et al. (2016).

Shipping's zero emissions future fuels, technologies and costs

An understanding of the potential increase in shipping costs can be built from an estimate of the likely costs of the technologies and fuels that will be necessary to achieve the Initial IMO Strategy's objectives. Studies (DNV GL, 2018; LR and UMAS, 2019) describe the current leading options as:

- battery electrification
- biomass derived fuels (to the extent they are sustainable and available)
- synthetic fuels (e.g. fuels derived from electricity and renewable feedstocks, or fossil fuels with Carbon Capture and Sequestration (CCS)).

In order to estimate the overall impacts on maritime transport costs associated with these options, it is necessary to consider the capital cost of machinery, the capital cost of fuel storage, the lost cargo carrying capacity (due to additional volume/weight of fuel needed), and fuel prices. Assumptions for these cost components can be derived both from currently available data in the industry and academic literature on performance specifications, costs and prices, and some conservative projections of how these costs and specifications might evolve by 2030.

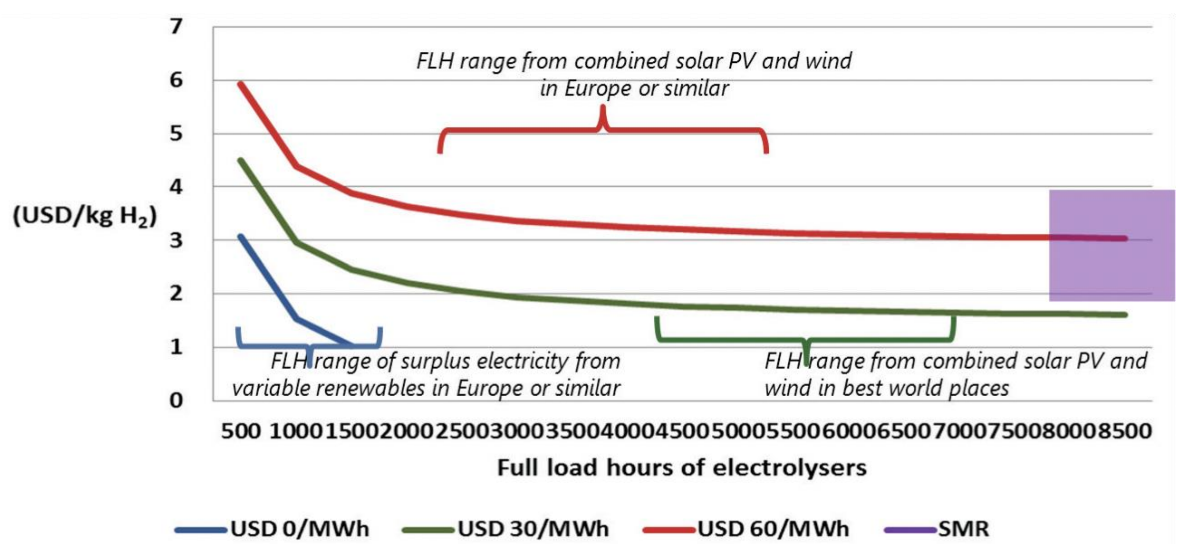
LR and UMAS (2019) believe that synthetic fuel options (hydrogen, ammonia) are currently the most competitive. Biomass-derived fuels may have a partial role, but are not likely to be available in the volumes required to achieve the Initial IMO Strategy's objectives.

Ammonia and hydrogen are both produced by chemical processes for which a fossil fuel (most often natural gas) is the feedstock. Their production, therefore, can result in significant CO_2 emissions upstream from their use. Electricity, if produced from fossil fuels, can also have significant upstream CO_2 emissions. All these production processes could theoretically be coupled with CCS technology to continue to use fossil fuels while reducing upstream CO_2 emissions.

Alternatively, ammonia and hydrogen can be produced from 100% renewable or nuclear energy. They can also be produced through electrolysis, a process for which only water, air and electricity are the required inputs. The combination of decarbonisation policy in the wider energy system and the increasingly low cost of renewable electricity is already making "green" zero-upstream-emissions versions of these fuels competitive with their alternative fossil-derived production processes.

OECD/IEA (2017) analysed the potential costs of production of "green" renewable electricity-derived hydrogen and ammonia to understand the costs associated with replacing their current fossil-dependent processes. They found that for both of these potential fuels, cost scenarios were bound by renewable electricity prices. Furthermore, the report identifies the potential for even lower cost production of these fuels when very low marginal price electricity was available from electricity grids with high renewables penetration (e.g. due to unmanageable variability in the availability of wind and solar).

Figure 3. The cost of hydrogen and ammonia production at various electricity prices



Source: OECD/IEA (2017).

Estimating the potential change in components of maritime trade costs

The derivation of estimates of the costs of potential solutions (technologies, fuels) is one component of the overall estimate of the change in maritime trade costs. The transition of the global fleet from its current dependence on fossil fuels to a new fuel type is complex, not least given the range of different ship types and sizes that make up the global fleet.

This paper refers to the GloTraM model described in Smith et al. (2016) to consider the shipping sector's overall response to policy implemented to increase the energy efficiency of shipping and reduce the carbon intensity of fuels at levels required to meet the Initial IMO Strategy's objectives. This model includes assumptions on the cost and performance of the most currently known options for energy efficiency improvements, as well as a variety of alternative machinery (e.g. fuel cells, electric motors, etc.) and alternative fuels. The model also uses ship-operating speed as a parameter, so the average speeds of different ship types are calculated and can increase or decrease. Investment and operational (speed) decisions are modelled for each ship type, size and age category, which potentially could maximise a ship-owner's profits under a given regulatory and macroeconomic environment. The model uses marginal abatement cost curves (MACCs) to convert outputs from the modelling into estimates pertinent to the discussion of impacts on trade.

Table 1. Scenarios and assumptions for the estimation of changes in maritime costs

<table>
<tr><th rowspan="2"></th><th colspan="3">2030</th><th colspan="3">2050</th></tr>
<tr><th>Biofuel available (EJ)</th><th>FO price USD/t (HFO, MDO, LSHFO, LNG)</th><th>Other fuel price USD/t (H2, NH3)</th><th>Biofuel available (EJ)</th><th>FO price USD/t (HFO, MDO, LSHFO, LNG)</th><th>Other fuel price USD/t (H2, NH3)</th></tr>
<tr><td>Scenario A (bio central, high fuel price and capex)</td><td>1.71</td><td rowspan="4">514,
747,
598,
546</td><td>3 025,
666</td><td>4</td><td rowspan="4">664,
943,
754,
744</td><td>3 764,
829</td></tr>
<tr><td>Scenario B (bio high, high fuel price & capex)</td><td>4.7</td><td>1 857,
338</td><td>11</td><td>2 311,
421</td></tr>
<tr><td>Scenario C (bio central, low fuel price & capex)</td><td>1.71</td><td>1 857,
338</td><td>4</td><td>2 311,
421</td></tr>
<tr><td>Scenario D (bio high, low fuel price & capex)</td><td>4.7</td><td>3 025,
666</td><td>11</td><td>3 764,
829</td></tr>
</table>

Note: EJ = exajoule; FO = fuel oil; HFO = heavy fuel oil; MDO = marine diesel oil; LSHFO = low-sulphur heavy fuel oil; LNG = liquefied natural gas; H2 = hydrogen; NH3 = ammonia

Source: Smith et al. (2016).

MACCs are formulated as a composite for absolute GHG reduction on 2008 levels of CO_2 emissions for five ship types (container ship, oil tanker, bulk carrier, chemical tanker and gas carrier) for the years 2030 and 2050. The input assumptions listed for the scenarios in some instances contain projected cost reductions of certain technologies (in 2030) taken from current literature (REF). Beyond this, the MACC is calculated, and analysis does not assume any technology cost learning for the machinery/technologies due to, for example, the increase in production volumes, or as a consequence of further R&D and technological developments. They can, therefore, be considered conservative estimates of the abatement cost.

While many sources are available for estimates of key input parameters, significant uncertainty remains on the overall availability of sustainable biofuel, prices of fuels (conventional fossil fuels and alternative zero-upstream / zero-emissions fuels), and the capital costs of equipment. To manage this uncertainty, MACCs are produced for a number of different sets of assumptions that are derived as foreseeable scenarios and are listed in Table 1. Global experts in this field have high agreement on the sustainable availability of a total of 100 exajoules (EJ) of biofuel by 2050 (Creutsig F. et al., 2014). Two different potential levels of availability are derived for international shipping from that overall availability – a central case (4EJ) and a high case (11EJ).

Figure 4 shows the estimated MACCs. After initial increases in abatement cost, the cost curve reaches a plateau at a value that represents the carbon price needed to make zero-emissions technologies competitive with conventional propulsion. Beyond a certain level of absolute GHG reduction, significant further GHG reduction can be achieved with only small increases in cost. This result is the consequence of the cost-ceiling associated with zero-emissions fuels and related technology and machinery.

The findings show that to achieve the Initial IMO Strategy's objective of 50-100% absolute reductions in GHG emissions by 2050, a marginal carbon cost currently conservatively estimated to range from USD 100-500/t, depending on the scenario, is required as a price signal.

In Scenario A, which has the most challenging input assumptions for decarbonisation (central estimate of bioenergy availability and high fuel price and capex), emissions in 2030 and 2050 start higher than in the baseline year 2008, consistent with expectations that for business-as-usual (BAU) scenarios CO_2 emissions from international shipping are expected to increase (Smith et al., 2015).

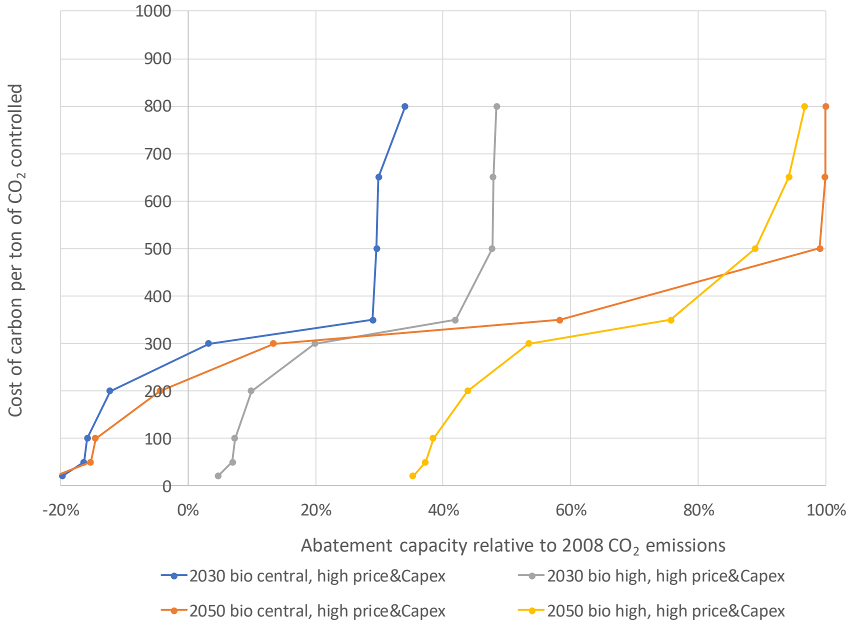
The MACCs show that significant absolute emissions reductions could be achieved even at low marginal cost of carbon (USD 50/t) because of the assumption about the availability of bioenergy, which, in these scenarios, is significant relative to international shipping's total demand for energy. In this modelling, bioenergy is assumed to enter the fuel mix as a substitute for fossil fuels and, therefore, at the same price as the fossil fuel equivalent and is not dependent on additional carbon price to stimulate its up-take.

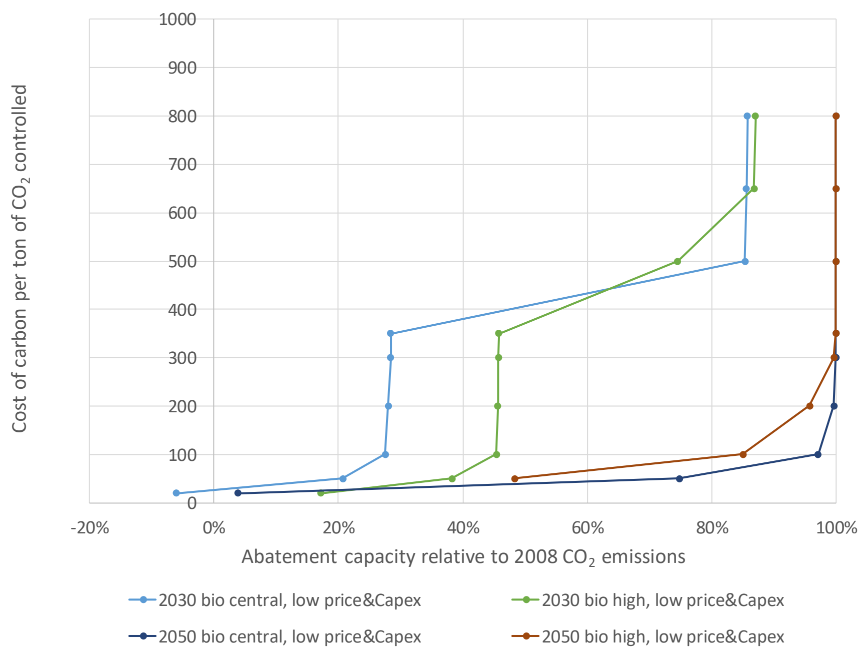
The MACCs for 2030 show a significant further increase in carbon prices after the plateau which is associated with the cost of achieving very low or zero carbon intensity for the fleet built with conventional technology (e.g. the current specification of internal combustion engines) and without an expectation of having to achieve such high rates of decarbonisation. The plateau occurs at the price point that the zero-emission fuel/machinery becomes viable, for example, ships built before 2020 that would only be ten years old in 2030.

The results show that in scenarios where higher amounts of sustainable biofuels are available to shipping at the prices assumed, marginal carbon costs are lower for the same level of absolute GHG reduction. However, they also show that even if biofuels are not highly availability, high levels of absolute GHG reduction can be achieved through the use of synthetic fuels.

Beyond the input assumptions, the modelling approach used in GloTraM does not incorporate any cost reductions resulting from R&D spending (recycling of revenues), innovation or from the increased production of technologies for use in other sectors. In this respect, the model is conservative and as these are all factors that would normally reduce technology capital costs, zero-emission fuel production costs would be expected to reduce the magnitude of the marginal abatement costs as calculated.

Figure 4. Results for the marginal abatement cost curves produced using GloTraM





Note: Cost is in USD per tonne and estimated under different scenario assumptions as listed in Table 1.

Source: IMarEST (2018).

Overall, the different scenarios show significant variations in marginal carbon cost. This shows the sensitivity of the MACCs to assumptions used about the prices and availability of future shipping energy sources, particularly electricity, biofuel, hydrogen and ammonia. It also illustrates how rapidly the evidence is evolving on how low these energy prices could fall as the energy system increasingly shifts towards renewable energy sources.

A correction could be made to the above-mentioned estimated range of USD 100-500/t to take into account the potential for revenue recycling (the reinvestment of revenues raised from carbon pricing to help reduce the costs and accelerate the implementation of technologies and fuels required for decarbonisation). Applying a starting assumption that 100% of the revenues raised are reinvested in this way, the magnitude of the carbon price needed to achieve the Initial IMO Strategy's objective would then be USD 50-250/t. This estimate can be converted into an estimate of a change in fuel price by applying the factor that relates the CO_2 emissions produced when combusting one tonne of fuel, and expressed as a percent increase relative to the assumed underlying fuel price.

Table 2. Upper- and lower-bound estimates of the overall additional costs for achieving the Initial IMO Strategy's objectives

	Carbon price USD/t CO_2	Fuel price increase USD/t	% increase relative to 2050 HFO price
Lower bound	50	150	23%
Upper bound	250	750	130%

Source: IMarEST (2018).

How transport costs impact global trade flows, import substitution and transport mode shifts

From a trade modelling perspective, transport costs are one of the main determinants of trade costs (Bachmann, 2017; Brocker and Kancs, 2001; de Jong et al., 2017; Johansen and Hansen, 2016). The modelling literature suggests that any change in transport costs can impact the magnitude of trade activities and its spatial distribution between regions. There are naturally two different types of country-level perspectives on a policy-related change in maritime transport cost:

- one that looks at the impact on imported goods and the cost of living, and
- another that looks at the impact on exported goods and export good-led economic development.

In combination, changes for importers and exporters may modify the total volume of world trade and global economic development.

The impact of policy-related maritime transport cost increases on import price: the importer's perspective

Costs and cost structures vary significantly between ship types and sizes. However, at an aggregate level, shipping costs are approximately 10% of average landed import prices (Keen et al. 2013, Table 4) and fuel costs are approximately 50% of ship operating costs (OECD/ITF, 2017). A 23% increase in fuel prices, therefore, increases average import prices by approximately 1%, which is broadly consistent with estimates discussed in Keen et al. (2013). A 130% increase in fuel costs increases average import prices by approximately 6.5%.

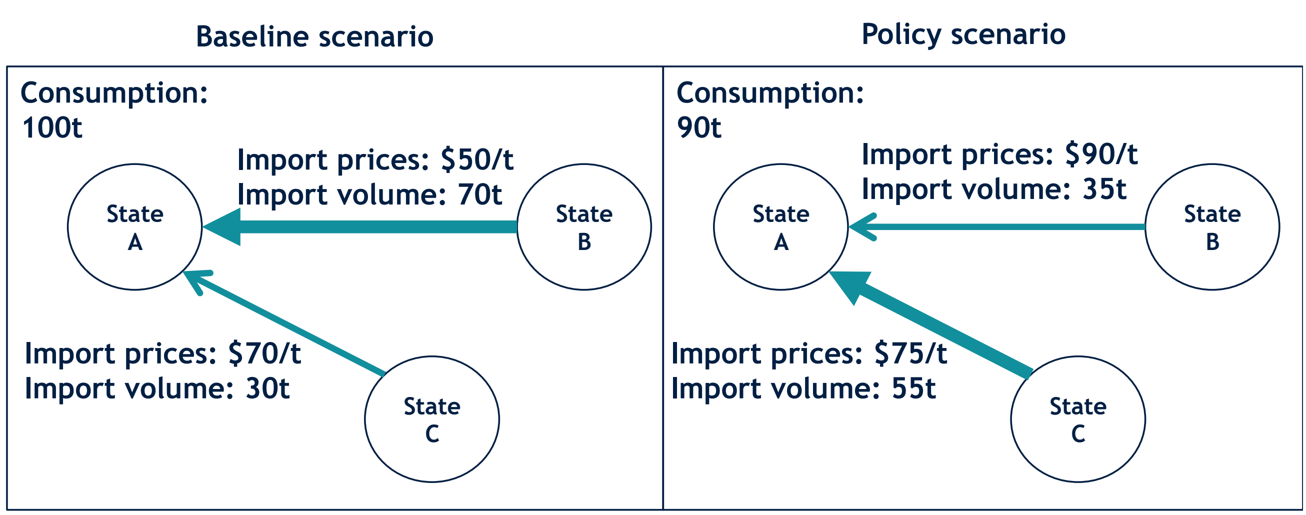
However, this simple calculation assumes that the entire fuel price increase is translated into an increase in the import prices. In practice, substitutions can occur that switch a good from one producer economy to another or to local (in country) production. In the case of substitution, the price of related imports may still increase but by less than the amount estimated.

Increased import prices may also cause an increase in the consumption of domestic products due to consumers substituting domestic for foreign commodities. This may have a positive effect on a State's GDP if the increase in domestic consumption is higher than the decrease in productivity and consumption due to higher prices. This perspective, the potential for a policy-related increase in prices of imported goods and the consequences for cost of living deserve more detailed investigation.

The impact of policy-related maritime transport cost increases on global trade: an exporters perspective

Exporter countries may experience policy-related increases in the costs of getting their goods to market. Existing trade relationships may be reconsidered and other producers from competing regions, which produce the same commodities, might be favoured. Consumers may substitute products from different producers depending on changes in import prices and according to the elasticity of substitution.

Figure 5. Impact of GHG mitigation measures on import costs and trade volumes between States



Source: Halim, Smith and Englert (2019).

Figure 5 provides a simplified example to illustrate how an increase in import prices aimed at mitigating GHG emissions may modify import volumes of State A from states B and C. Suppose, in the baseline scenario where no GHG mitigation measure is applied, that State A imports more commodity from State B (70 tonnes) than State C (30 tonnes) since the import prices from State B are relatively cheaper than State C. In the policy scenario, a GHG mitigation measure may increase the prices of the goods that State A imports from states B and C.

This condition may lead to a shift of volume of demand from State B to State C. As a result, State C will see an increase in the volume of commodities exported to State A, whereas State B may lose export volume to State A. Eventually, State C's GDP may increase, whereas State B's may suffer.

Estimations of impacts on the volume of international trade and global Gross Domestic Product

A number of studies have attempted to model the consequences of policy-related transport cost increases on the global trade system reaching a new equilibrium pattern of trade, both in terms of volumes traded globally and the global GDP. The findings of the studies are summarised in Table 3.

Lee et al. (2013) studied the impact of a carbon tax on the global economy by focusing their economic model on containerised commodities. They considered six scenarios: three different levels of potential maritime carbon tax (USD 30, 60, 90/tonne CO_2) across two geographical scopes (the European Union and Global). Particular attention was given to the GDPs of States and the changes in volume of container flows in the year 2007. They found that only the highest carbon tax (USD 90/tonne CO_2) might result in a measurable economic impact (i.e. GDP loss) to the world's economy, while the low- and medium-carbon taxes (USD 30 and 60/tonne CO_2) might not result in measurable changes in GDP. Average global GDP loss was 0.0003%. In terms of the volume of containers transported globally, a carbon tax of USD 90/tonne CO_2 would result in the reduction of 915 000 TEU.

Table 3. Summary of the impact of a carbon price on trade flows and global Gross Domestic Product

Literature	GHG mitigation measures	Economic Indicators	Findings
Lee et al. (2013)	Carbon price USD 30, 60, 90/tonne CO_2 for the year 2007	Real GDP	-0.002% to +0.004%,
			Global average: -0.0003%
		Volume of container flows	Reduction of 925 KTEU (Twenty-Foot Equivalent Units) globally
Sheng, Shi and Su (2018)	Carbon price USD 40/tonne CO_2 by 2030	Real GDP	-0.06% to +0.001%
		GDP growth	-0.17% to +0.01%
Tavasszy et al. (2016)	Carbon price EUR 49/tonne CO_2 by 2040	Global trade flows	-0.9% in total trade flows
		Commodity trade flows	-0.2% (food) to- 4.2% (agriculture)
Anger et al. (2013)	Carbon price EUR 10, 30, 50/tonne CO_2 by 2025	Real GDP	<-0.01% in global GDP
		Real GDP changes for case study countries	-1% GDP for one country <-0.2% for majority

Source: Halim, Smith and Englert (2019).

Sheng, Shi and Su (2018) studied the impact of a global carbon tax applied to international bunker emissions on several economic indicators, including import and export volumes, GDP growth and real GDP of countries, along with the countries' market share of their export commodities. The study covered

13 regions of the world and 21 commodity groups. They found that under a carbon tax of USD 18/tonne CO_2, there would be only a modest negative impact on GDP growth for all States by 2030.

Tavasszy et al. (2016) investigated the effect of increased transport costs due to internalising external costs (like GHG emissions) on global trade volumes of ten commodities. The study found that, by 2040, there is a slight reduction (-0.2% to -4.2%) in the trade of all commodities, with the agricultural sector potentially experiencing the largest decrease. The study suggests that the decrease in agriculture trade is mainly caused by the substitution of foreign production for domestic production.

Anger et al. (2013) studied the impact, both on select countries and globally, of potential market-based mechanisms (MBMs) in international shipping and aviation between the years 2015 and 2025. Specifically, the study tested the impact of four MBMs: an International fund for GHG emissions (for international shipping), a Global Emission Trading System (GETS) (for international shipping and aviation), Global Mandatory Offsetting complemented by a Revenue Generation Mechanism (for aviation), and the European Union Emissions Trading System (EU ETS). This study found that the reduction in global GDP with a carbon price of USD 30/tonne CO_2 would be relatively small (-0.004% to -0.08%).

Existing estimations of impacts on individual countries

As described by the importer and exporter perspectives, a modification to global patterns of trade that arises from policy-related maritime transport cost increases may not have the same consequences for all countries. Country-specific impacts may be greater or lesser than the global average because of differences in:

- contribution/role of trade in their economy
- dependency on imports and ability to substitute from current importers
- geographic specifics and distances from respective importers/exporters
- maritime connectivity.

Three of the papers that informed the estimates of policy-related transport cost increases on global trade summarised in Table 3 also include findings at country level that can provide some insight into potential impacts.

Lee et al. (2013) estimated that among all countries, the People's Republic of China could potentially suffer the largest loss in terms of real GDP (around -0.002% for a carbon price at USD 90/tonne CO_2). The United States was found to be the most strongly affected importer State by container volume, with a reduction of 325 000 standard containers (20-foot equivalent units: TEUs) in imports. The model also captured shifts in trade patterns. An increase in the container trade volumes between Asian countries (China-Japan, China-Republic of Korea) and European countries (Northern Europe-United Kingdom, Northern Europe-Mediterranean) could be expected. Most of these shifts suggest an intra-regionalisation of trade due to more expensive international long-haul trade costs.

Sheng, Shi and Su (2018) found that former Soviet Union countries face the largest potential decline in their GDP growth (-0.17%), followed by Indonesia (-0.11%). The same level of a carbon tax would also reduce export and import volumes of most countries included in the study. In terms of real GDP, shifting trade patterns negatively impacted the GDP of China (-0.06%), and Australia (-0.042%). On the contrary, the United States, the European Union, and Japan experienced no effect of a slight GDP increase due to their connectivity.

Anger et al. (2013) found that the impact on GDP for least-developed and remote countries would be greater: up to -1% for Samoa and -0.5% for the Cook Islands. In general, countries with a higher dependency on international trade and tourism appear more vulnerable to the economic impacts of MBMs.

Impact on transport mode shift

There has been little research on the impact of GHG mitigation measures on global-level modal shifts of international freight transport. Three exceptions are Halim et al. (2018), ITF (2018) and Avetisyan (2018).

Halim et al. (2018) studied the impact of increased maritime transport costs due to a carbon tax and a slow steaming measure on the modal choice of transport. They looked both at China-Europe trade and globally. The study tested a scenario that included an increase in sea transport costs of 100% and a 25-65% speed reduction by 2030. Table 4 summarises the results.

For China-Europe trade, the study found that modal share of maritime transport could be reduced by 1.37%, which represents 8.7 Mt of freight volume traded by the two regions annually. This amount equals approximately 669 230 TEU and is equivalent to the total export volume of the whole Oceania region. The research suggests that the majority of this volume would shift to rail transport (7.8 Mt). Although the reduction in the share of maritime transport is relatively small, the shift to rail represents a roughly 15% increase in the total volume of rail transport between the regions.

A study carried out by ITF (2018) also highlighted the potential modal shift from sea to rail transport for China-Europe trade due to two changes: improvements in Trans-Eurasian railways that connect China and Europe, and a potential 20-85% increase in transport costs for container shipping due to the IMO's 2020 global sulphur cap. Similar findings can be found in Halim et al. (2018) where the Eurasian rail corridors are estimated to reach an annual traffic volume of anywhere from 636 000 TEU (baseline scenario) to 742 000 TEU (best-case scenario) by 2027.

Based on Halim et al. (2018) the global impact of higher sea transport costs on modal share is less significant than the China-Europe case. The share of sea transport could decline by around 0.16%. This represents approximately 34 Mt of freight volume annually, equivalent to the total amount of crude oil imported by sea to Africa. The majority of the modal shifts from sea are expected to move to road (13 Mt) and rail (18 Mt). One reason for this is the high difference in generalised transport costs between different modes, where sea transport remains the cheapest mode serving major trade lanes like those between Europe and Asia and the United States and Europe. Furthermore, high value commodities are expected to be among the first commodity types that might shift their mode of transport to faster modes. This is because the time value of these commodities is typically higher than low-value bulk commodities.

Avetisyan (2018) studied the impact of a global carbon tax of USD 27.3/tonne CO_2 applied to transport sectors of all modes (i.e. industry sectors that provide transportation services) on modal choices of shippers globally. The study concluded that, under a scenario based on trade data from 2011 where a global carbon tax is applied to all transport modes: 1) the transport of high-value products (e.g. microchips and seeds) would shift to maritime transport from air transport; and 2) the transport for bulky products (e.g. paddy rice, wheat, and cereal grains) would shift to maritime transport from other land-based transport modes (rail, road).

Table 4. Impact of 100% increase in maritime transport costs and 65% speed reduction on global modal share of international freight transport by 2030

	Baseline 2030 (Mt)	Share (%)	100% increase in maritime transport cost and 65% speed reduction (Mt)	Share (%)	Difference in share (%)	Difference in weights (Mt)
Air	70	0.33	72	0.34	0.01	2.60
Rail	598	2.84	611	2.90	0.06	13.17
Road	2 539	12.06	2 557	12.15	0.09	17.92
Sea	17 813	84.65	17 780	84.49	-0.16	-33.70
Waterways	22	0.11	22	0.11	0.00	0.01

Source: Halim et al. (2018).

The literature referenced above shows that increased transport costs would have a marginal effect on modal shifts in global freight transport. However, the scale of this impact, as exemplified by the China-Europe case, can vary regionally depending on the characteristics of transportation networks.

There is a need to align the analysis of impacts of transport modal shift with the magnitude of carbon price that might be associated with the achievement of the Initial IMO Strategy's objectives. Much of the literature on impacts on States was developed prior to the IMO's adoption of its Initial Strategy. As a result, it is not based either on any indication by the IMO of what its level of stringency for GHG reduction objectives would be, nor on techno-economic modelling of what costs might be incurred by shipping to meet those objectives. With a stated IMO GHG reduction objective, and given that information on potential maritime cost implications is now more available, some calibration or recalculation of the literature on economic impacts is needed.

Many papers use examples of carbon price that are close to the lower-bound value estimated (USD 50/t). Certainly, with carbon price increases of this magnitude, even the upper-bound impact estimates in literature appear likely to be hard to detect in practice on a global scale (-0.06% impact on global real GDP, 0.9% reduction in global trade volumes).

However, none of the existing literature explores impacts at the upper-bound value estimated (USD 250/t). The impacts are unlikely to scale linearly with maritime transport costs because responses such as substitution will bring dynamics into the trade system for much of world trade. This *should* mean that a doubling of maritime transport cost will less than double the impacts. However, this moderation of impacts with the scale of transport cost increase may not occur for all States and trade flows, and obviously less for those with fewer substitution options. This is important because it appears likely that there is a strong correlation to countries between low economic development status, countries with poor transport links and countries with high import dependency (fewer options for local substitution). Therefore, further work is needed to:

- refine estimates of the potential impacts of GHG policy on maritime transport cost
- align modelling of impacts with ranges of potential maritime transport cost impacts
- ensure that modelling represents details of some of the States most at risk of negative impacts.

The results and evidence also indicate that policy specifically designed to address risks of impacts on specific countries may be necessary. The revenues from carbon pricing could be used in different ways to advance the decarbonisation of maritime transport in equitable and effective ways. For instance, the revenues can be used to help defray economic damages that occur due to the application of GHG mitigation action. They can also help accelerate the maturity and commercial feasibility of low-carbon technologies that are currently expensive, helping in turn to reduce the overall cost of the policy objective.

Conclusion

The topic of maritime transport costs and their relationship to trade flows is not new. However, with the recent adoption of the Initial IMO Strategy on GHG Reduction there is a renewed likelihood of a policy driver for change in the sector's technology/fuels and, by association, transport costs. In combination with the Strategy's attention to risks of negative impacts on trade, there is also a need to ensure that the trade consequences of those potential changes in maritime transport costs are understood, both at the global level and at the level of individual States (in particular developing countries, Small Island Developing States and least developed countries).

This paper suggests that guidance on the potential increase in maritime transport costs can be obtained from models simulating the GHG abatement options of the sector (their costs and benefits). Further, from these models an estimate of the range of increase in maritime transport costs related to a carbon price of USD 50-250/t is credible.

The range of maritime transport cost values represents uncertainty in the costs and prices of future fuels. The lower-bound cost increase (USD 50/t) is predominantly contingent on the availability of low-cost zero-emission renewable fuels (e.g. hydrogen or ammonia), with the higher-bound cost increase (USD 250/t) including significant conservatism about developments of low-cost production pathways. Planning, judicious investment activity and good policy design all have a role to play in ensuring that, in practice, the actual maritime transport cost increase is closer to that represented by USD 50/t than that represented by USD 250/t.

In the meantime, the uncertainty can be managed by evaluating risks of impacts on trade across this range of potential maritime transport increase. This will show either that the risks of impacts are negligible at both ends of the range, or that there are impacts that become significant at some point across the range of potential increases.

Current literature focuses at the lower end of this range of cost increase. However, it nevertheless provides useful indications of the potential impacts on trade flows. The evidence indicates that there could be a small reduction in volumes (less than 1%) and GDP (less than 0.1 %) at a global scale. Impacts on a specific country's economy could be higher than the global average. The Samoa case study illustrated approximately a 1% reduction in GDP at the lower-bound range of maritime transport cost increase. This work still needs to be extended to higher potential maritime transport cost increase values and more attention is needed for specific individual countries.

The evidence in current literature suggests that, for the scales of maritime transport cost increase – even close to the upper-bound of what might be necessary to achieve GHG reduction targets –, there is no significant impact expected on modal shift for the deep sea shipping sectors focused on in this paper and the wider literature. However, even a small reduction in shipping transport demand could create significant increases in demand on land transport, especially for certain routes. Modal shift risks for short-sea shipping were not considered in this paper, but are likely to be of greater sensitivity to changes in maritime transport cost.

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The Cost of Reducing Greenhouse Gas Emissions in Shipping

The shipping sector will need to reduce its greenhouse gas emissions significantly over the coming decades in order to align them with the Paris Climate goals. How could this be achieved? What will it cost to bring down the sector's emissions? Will these costs shift maritime trade flows? This paper offers answers to these questions and identifies areas for further investigation.

All resources from the Roundtable on Future Maritime Trade Flows are available at: www.itf-oecd.org/future-maritime-trade-flows-roundtable

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