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# Understanding the Economic Impacts of Greenhouse Gas Mitigation Policies on Shipping

## What Is the State of the Art of Current Modeling Approaches?

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## Abstract

The International Maritime Organization's initial strategy on reduction of greenhouse gas emissions from ships stipulates that the international shipping sector should assess the impacts on states prior to adoption of the mitigation measures included in the strategy. This assessment should be undertaken as a matter of urgency, and disproportionately negative impacts should be assessed and addressed as appropriate. This paper aims to contribute to this discussion by reviewing the state-of-the-art research on the economic impacts of greenhouse gas mitigation measures on states, using model-based analysis. Specifically, the paper: (i) identifies four areas of economic impacts and their relationships, (ii) compiles the latest findings on the estimated magnitudes of these impacts, and (iii) presents relevant modeling approaches along with best practices for selecting and applying these approaches in impact assessments. The paper concludes that introducing greenhouse gas mitigation measures, such as carbon prices applied to bunker fuels in the range of 10 to 50 USD/ton of carbon dioxide, might increase maritime transport costs by 0.4 percent to 16 percent. However, this would only marginally increase the import prices of goods (by less than 1 percent). For transport choices, the increased cost of maritime transport induced by greenhouse gas mitigation measures might only slightly reduce the share of maritime transport, by 0.16 percent globally. Furthermore, a global carbon tax applied to all transport modes might stimulate a shift toward maritime transport from all other modes. The impacts of a carbon price in the range of 10 to 90 USD/ton of carbon dioxide on national economies are expected to be modest (–0.002 percent to –1 percent of GDP).

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Produced by the Research Support Team

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# Related documents

An **executive summary** of this paper which has been developed for policy-makers in international maritime transport can be found online:

http://documents.worldbank.org/curated/en/718061546900387225/
or
http://tiny.cc/econ-model-ship-exec-sum

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3. **International Transport and Energy Modelling 4 Workshop**, 29-31 October 2018, International Institute for Applied Systems Analysis, Vienna
4. **UNCTAD & CPLC Shipping Expert Workshop** on GHG policy induced economic impacts on States and related mitigation options, 19-20 November 2018, UNCTAD, Geneva.

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# Table of contents

1. Context ... 0
    1.1 Climate change, the IMO Strategy, and its impacts ... 0
    1.2 The role of models and data as evidence in policy debates ... 0
    1.3 Objectives of this paper ... 1
2. Potential impacts of GHG mitigation measures ... 2
    2.1 Linkages between GHG mitigation policies and economies of States ... 2
    2.2 Four economic impact areas ... 3
        2.2.1 Transport costs ... 3
        2.2.2 Transport choices ... 6
        2.2.3 Import prices of goods ... 6
        2.2.4 International trade and economies of States ... 8
3. Current findings: Scale of impacts induced by GHG mitigation measures ... 9
    3.1 Transport costs ... 9
    3.2 Transport choices ... 10
    3.3 Import prices of goods ... 12
    3.4 International trade and economies of States ... 13
4. Models for economic impact assessments ... 15
    4.1 Economic trade models ... 16
        4.1.1 Regression models ... 16
        4.1.2 Input/Output models ... 16
        4.1.3 (Spatial) Computable General Equilibrium models ... 17
    4.2 Transport models ... 18
    4.3 Combined trade-transport models ... 19
5. Advantages, disadvantages, and best practices for economic modeling approaches .. 20
    5.1 Economic trade models ... 20
        5.1.1 Regression models ... 20
        5.1.2 Input/Output models ... 21
        5.1.3 (Spatial) Computable General Equilibrium models ... 21
    5.2 Transport models ... 22
    5.3 Combined trade-transport models ... 22
6. Data availability and gaps for economic impact assessments ... 23
7. Conclusions and overall recommendations ... 23
References ... 26

# 1. Context

## 1.1 Climate change, the IMO Strategy, and its impacts

The negative impacts of climate change and its alarming trends have been widely studied and recognized in the past decade (Ripple et al., 2017), especially in the latest Intergovernmental Panel on Climate Change (IPCC) report on the impacts of global warming of 1.5°C above pre-industrial levels (IPCC, 2018). These impacts include rising sea levels, increased sea surface temperatures, and more frequent extreme weather events. If no appropriate measures are taken, the majority of low-lying small island states could be submerged and uninhabitable by 2100 (News, 2018). Not only will climate change threaten human lives, but an OECD report also shows that the economic damages caused by climate change far outweigh its benefits, adversely affecting global production and consumption, and reducing average global GDP by an estimated 2% by 2060 (Dellink et al., 2017).

The shipping sector could also be adversely affected by climate change due to the increase in the frequency of extreme weather events, which disrupts shipping activities and logistics infrastructure. Limiting the global average temperature increase to below 2 degrees Celsius—and pursuing a limit of 1.5 degree Celsius, as stated in the Paris Agreement—is crucial to avoiding the devastating impacts of climate change. Reducing greenhouse gas (GHG) emissions is a key step to this end.

In April of this year, at the International Maritime Organization's (IMO) 72nd Marine Environment Protection Committee (MEPC) meeting, the shipping sector made an important contribution toward the temperature goals of the Paris Agreement. An initial strategy with a list of potential candidate measures to reduce GHG emissions from international shipping ("Strategy") was defined and adopted. The Strategy stipulates that any GHG reduction measure should be considered in the light of its impacts on States. This means that these impacts should be assessed and taken into account as appropriate before adoption of the measure. The Strategy further notes that the impact assessment procedure should be specified and agreed on as a matter of urgency as part of the follow-up actions and that disproportionately negative impacts should be assessed and addressed as appropriate.

The implementation of GHG reduction measures will potentially increase maritime transport costs, which contributes to trade costs between States. A substantial increase in maritime transport costs can increase in trade costs. This could eventually lead to changes in global patterns and volume of international trade. The IMO decision-making process is committed to paying particular attention to the emerging needs of developing countries, particularly Small Island Developing States (SIDS) and Least Developed Countries (LDCs) (see IMO resolution A.1110(30)), and many of these countries have signaled concern over the possibility of disproportionately negative economic impacts of GHG mitigation measures, particularly regarding trade competitiveness. Such disproportionately negative impacts must be addressed, as appropriate.

## 1.2 The role of models and data as evidence in policy debates

In addition to the third guiding principle of the Strategy which highlights the need to consider the impacts of measures on States, the fourth guiding principle substantiates the need for evidence-based decision-making balanced with the precautionary approach. In response to these needs and recognizing the complex relationship between international trade, freight transport activities, economic performance of States, and GHG emissions, this paper describes and discusses state-of-the-art economic modeling approaches that can be used to test the impacts of GHG mitigation measures.

Although a multitude of models is available, most of these focus on very specific elements of the global economy, such as production, consumption, international trade, or transport patterns in isolation. For instance, this means that some models are focused on testing the impact of measures on transport costs (UNCTAD, 2010; Vivid Economics, 2010), or import prices of goods (Vivid Economics, 2010), whereas other models are focused on the impact on transport activities (ITF/OECD, 2017), and future trade flows (Avetisyan, 2018; Cristea et al., 2013; Lee et al., 2013; Sheng et al., 2018). As a result, these models are often constrained in their ability to describe broader changes in interlinked systems. Multidisciplinary approaches are often required to study the comprehensive economic impacts of mitigation measures.

An unexplored aspect of the application of these models is their suitability for answering policy questions on the economic impacts of GHG mitigation measures on international trade and shipping. In this context, knowledge on the available modeling approaches and their advantages and disadvantages is valuable to policy makers who would like to conduct effective and efficient impact assessments of GHG mitigation measures.

## 1.3 Objectives of this paper

This paper presents a review of model-based studies with the aim of understanding the economic impacts of GHG mitigation measures on States. Literature was reviewed that analyzes different economic impacts of GHG mitigation measures and compiled an overview of the impacts across relevant systems.

The focus was set on four types of impacts that are primarily related to economic performance of States: i) Transport costs; ii) Transport choices; iii) Import prices of goods; and iv) Trade flows and economies of States. The economic impacts considered in this paper can be used to cover seven of the eight specific aspects of impact noted in the Strategy (the paper did not cover "6 disaster response"). Figure 1 provides a mapping between economic impacts considered in this paper and the those listed in the Strategy.

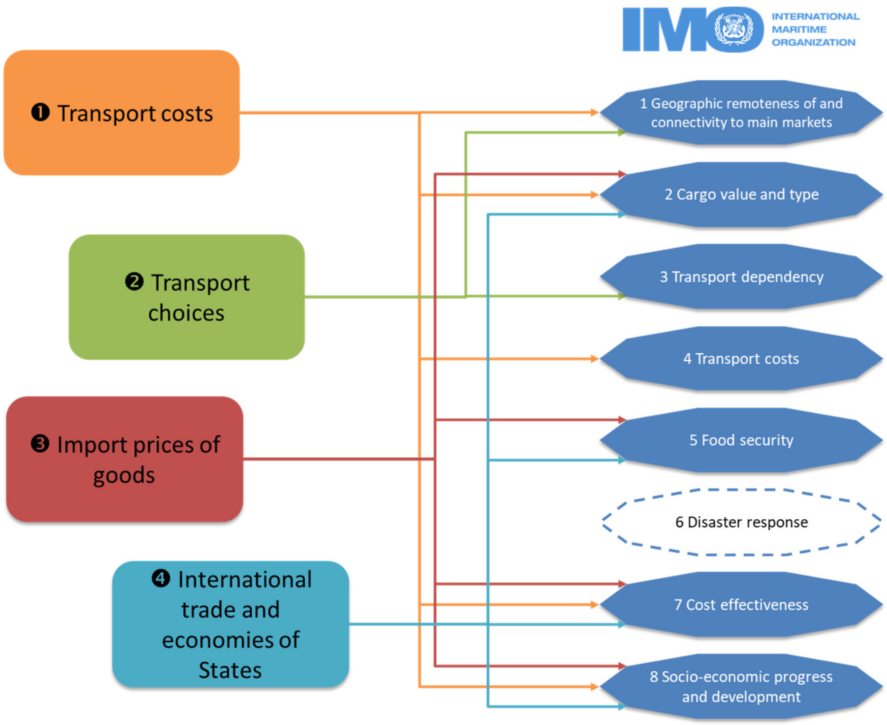

**Figure 1:** Mapping between economic impacts considered in this paper and eight aspects of impact assessment in the Strategy

Furthermore, a categorization was established for different types of models based on the scope of system responses included in the modeling exercises. This paper's contribution is threefold: First, with regard to GHG mitigation measures it identifies potential areas and mechanisms of economic impacts on the economies of States. Second, it compiles the latest findings on economic impacts of GHG mitigation measures based on the existing literature. Third, it presents state-of-the-art modeling approaches, their theoretical and practical advantages and limitations, and best practices for each.

# 2. Potential impacts of GHG mitigation measures

## 2.1 Linkages between GHG mitigation policies and economies of States

The interdependencies between transport and trade systems have been widely recognized and studied. International shipping has for centuries played a critical role in international trade and its growth. By implication, changes in transport policies or other interventions in the transport market, like GHG mitigation measures, will likely be felt through international trade systems and the economies of States.

GHG mitigation measure affect the economies of States through a causal chain:

First, the GHG mitigation measure will lead to higher ship running costs for carriers, be it through higher fuel prices (due to a levy or other market mechanism) or higher capital costs as carriers invest in new technologies and vessels or other solutions that reduce emissions. These higher ship running costs will lead to higher transport costs for the client (also referred to as transport prices for the shipper). Most literature on freight transport defines transport costs as monetary expenses for the firms or shippers to transport goods from their origin to their destination. This means that transport costs include costs of running certain modes of transport (air, rail, road, waterways, and maritime); other costs that occur due to intermodal transport operations, such as handling costs; additional tariffs linked to certain transport policy measures, such as road pricing and tolls; and time value of the commodities. Higher ship running costs may not pass immediately to the shipper, depending on market structures, trade balances, or possible cross-subsidies. In the long term, though, it can safely be assumed that higher ship running costs will lead to higher transport costs.

Second, higher transport costs will change shippers' modal, route, and port selection. This might also eventually impact the demand for maritime transport. For instance, when the application of a GHG mitigation measure results in an increase in maritime transport costs, shippers might find it worthwhile to consider switching from maritime to potentially cheaper alternative modes of transport, like road or rail. This is especially true when other modes might offer shorter travel time, which is attractive for high-value and time-sensitive products.

It is worth noting that other modes of transport tend to have higher GHG emissions per ton-km than shipping, thus, to some extent, counteracting some of the intended impacts of the mitigation measure. Furthermore, increased transport costs could induce changes in the routes of shipping companies; they may adapt their port rotation schedules to minimize the total transport costs incurred. The analysis of impacts of transport policies (such as GHG mitigation measures) on shipper's transport choices typically draws on transport modeling approaches.

Third, the increase in transport costs, when substantial, may increase import prices of goods, since transport costs are a component of commodities' market price. This increase in import prices is generally not proportional to increase in transport costs given import prices depend on several other factors, such as the share of maritime transport costs in product prices and the ability of importers to transfer costs to the consumers (cost pass-through rate).

Fourth, the changes in import prices of goods may trigger changes in the behavior of other stakeholders, including firms, labor, and governments. For example, a substantial increase in transport costs due to GHG mitigation measures can affect the trade costs of goods between States. As a result, firms may relocate their manufacturing facilities to States that offer lower trade costs with the destination markets by way of, proximity (also called near-shoring). On a global scale, this may lead to a reconfiguration of the global logistics network, which also affects the trade relationships between States: States will trade more with geographically closer producing/consuming States and trade less with more remotely located trade partners. Another possible impact is the increase in consumption of domestic products. These changes in trade relationships can lead to changes in States' export and import volumes, which eventually impact States' gross domestic products (GDP) and other socio-economic performance indicators. Analysis of impacts of transport policies on global trade and economies of States typically draws on economic modeling approaches.

A high-level relationship between GHG mitigation measures and economies of States is described in Figure 2.

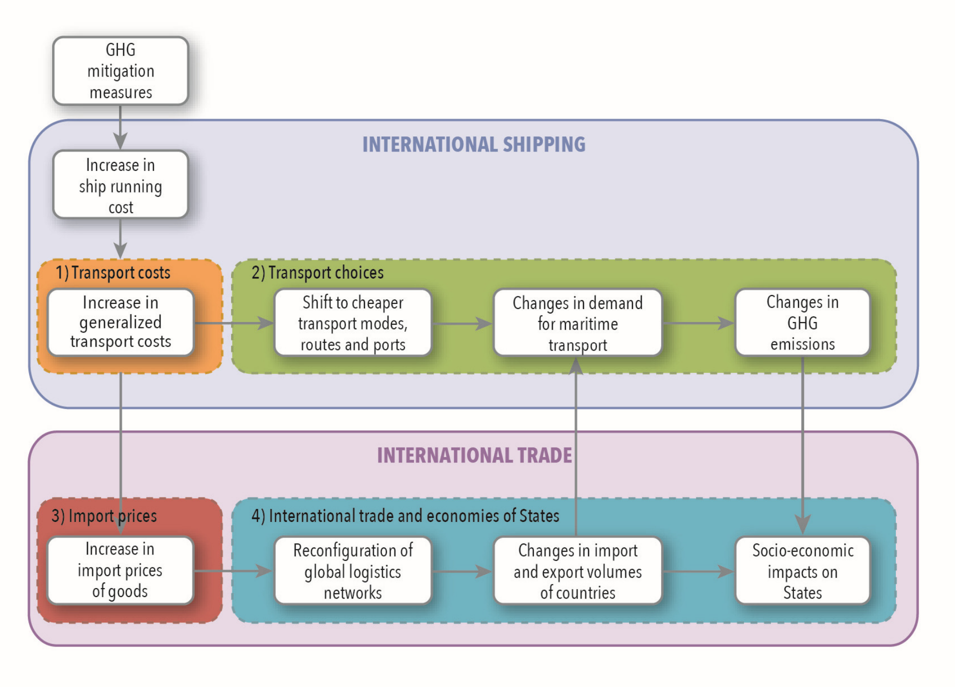

**Figure 2:** High-level relationship of GHG mitigation measures and economies of States

## 2.2 Four economic impact areas

This section presents a detailed description of the possible impacts of GHG mitigation measures on transport and trade systems. Based on the schematized relationships between GHG mitigation measures and economies of States in section 2.1 (Figure 2), four economic impact areas can be identified and linked to the implementation of GHG mitigation measures: i) Transport costs; ii) Transport choices; iii) Import prices of goods; and iv) International trade flows and economies of States.

### 2.2.1 Transport costs

In order to understand how GHG mitigation measures may increase transport costs, it is useful to look at the determinants of maritime transport costs and their relative contributions, as discussed in the literature. (Clark et al., 2004; Korinek & Sourdin, 2010; Rojon et al., forthcoming 2019; UNCTAD, 2015) identify five different categories of determinants of maritime transport costs: ship running costs, geographical and geopolitical factors, shipped product, market-specific factors, and infrastructure.

### 1. Ship running costs

These are costs that represent all fixed and variable costs that occur due to the running of a ship. According to Stopford (2009), elements of these costs include operating, maintenance, voyage, cargo-handling, and capital costs.

This is a cost component where GHG mitigation measures would have immediate impact. Carriers will incur either higher fuel costs or higher capital costs through investment in new technologies or ships. They may also choose to slow-steam, which will reduce expenditures on fuel but require additional ships on a given loop.

The importance of the other determinants of transport costs discussed below will vary with the ship running costs. For example, distance becomes more relevant if fuel is more expensive (see point 2 below). Furthermore, the value-to-weight ratio will become more relevant with higher fuel costs (see point 3 below). Whether, and how, higher ship running costs are passed on to the shipper will depend on the market structure and trade balances (see point 4 below). The choice of route and port will be influenced by fuel costs, as carriers may, for example, invest in different vessel sizes; larger ships save fuel on the sea-side, but may lead to additional intermodal transport costs (see point 5 below).

### 2. Geographical and geopolitical factors

These factors contribute to transport costs due to geographical distance, shipping connectivity, and security and safety risks that depend on the political relationships between States. This implies that the increase in transport costs due to the application of GHG mitigation measures will vary across routes and country pairs.

### 3. Shipped product

Cargo characteristics such as the average shipped volume, value of time, value-to-weight ratio, and specific transport requirements contribute to the freight rate and determine the elasticity of demand (i.e. the magnitude of change in demand when transport costs increase). Cargo with higher value of time, like fashion apparel and perishables, may need to be transported faster and, consequently, incur higher transport costs per unit cargo. This implies that the increase in transport costs due to GHG mitigation measures will also vary depending on the commodity type under consideration.

### 4. Market-specific factors

Market-specific factors include trade balances, competition dynamics, and market regulation. Trade imbalances pose an efficiency problem for container and bulk shipping services since they create a major disruption in the capacity utilization of ships between outbound and inbound services. The costs of unutilized capacity due to empty containers or empty bulk carriers in a voyage are generally added to the total operation costs of a shipping company and, in turn, determine transport costs charged to shippers. To remain profitable, the loss of margin while transporting empties needs to be compensated by a higher margin in shipping services with higher volume.

### 5. Infrastructure and services

National logistics infrastructure plays a very important role in determining maritime transport costs. Ports play a central role as interfaces between hinterland and maritime subsystems. They function as the facilitator of intercontinental trade, and they sustain economic growth of States and regions (ITF/OECD, 2015). Furthermore, Wilmsmeier et al. (2006) conclude, for instance, that port efficiency is the most important element of international transport costs in Latin American countries. A model-based analysis undertaken by Tavasszy et al. (2011) finds that port costs strongly determine a port's attractiveness and competitiveness in attracting international cargo. Port-hinterland infrastructure also strongly determines international maritime transport costs because it directly affects the efficiency of last-mile logistics activity. Halim et al. (2016) have shown that port-hinterland connectivity plays a crucial role in the port choice of shippers and, thus, the routing and volumes of transported goods.

Besides port-hinterland infrastructure, port-hinterland transport services also determine transport costs. Hinterland transport costs, on average, constitute 80% of the total transport cost of intermodal shipment, while hinterland transport covers only 10% of the total transport distance (Rodrigue & Notteboom, 2012). Hence, efficient port-hinterland transport services that are able to maximize economies of scale (by better consolidation and planning at ports or distribution centers) and minimize operational costs (by route optimization) would help further reduce transport costs.

Based on the breakdown of transport costs above and the claim in Rojon et al. (forthcoming 2019), GHG mitigation measures like carbon pricing could increase two determinants of maritime transport costs: voyage and capital costs. Voyage costs are affected due to the short-term increase in fuel expenditures. Capital costs are due to the mid-/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 3 presents the breakdown of these determinants and how the GHG mitigation measures impact maritime transport costs.

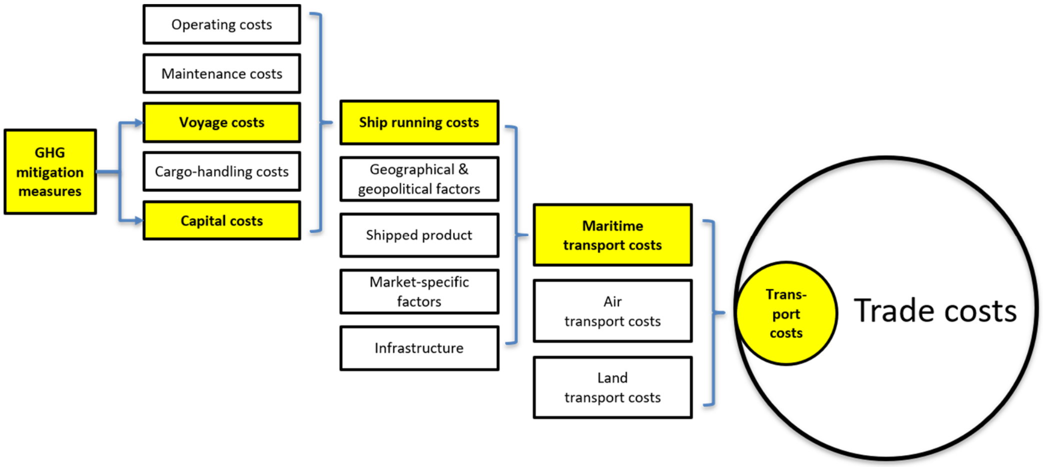

**Figure 3:** Breakdown of the components of maritime transport costs (derived from: Rojon et al. (forthcoming 2019))

Based on the cost structure of maritime transport costs, it is clear that a reasonable carbon price would not increase maritime transport costs with the same magnitude as the carbon price might increase voyage and/or voyage costs alone. This is because voyage and capital costs are just two components that determine maritime transport costs, which account for a fraction of wider trade costs.

### 2.2.2 Transport choices

There are two aspects of transport choices made by shippers that increased transport costs may affect: choice of modalities and choice of transport routes and port.

#### 1. Choice of modalities

A mode of transport with lower transport costs is typically more attractive to shippers, which, in turn, increases the likelihood of the mode's selection relative to available alternatives. By this logic, an increase in maritime transport costs could potentially result in a shift to other competing modes like road, rail, or even air transport if their costs remain unchanged. Within a long-haul international transport context, the shift from maritime to rail or air transport might benefit certain countries that see an increase in their transit traffic, in turn increasing the potential for further developments of their infrastructure. For example, the rise in transport demand from China to Europe using rail mode may provide economic benefit to Central Asian countries and the Russian Federation.

#### 2. Choice of transport routes and port

The relationship between shipping routes and transport costs has been well established in the freight transport modeling literature (Tavasszy & de Jong, 2014). Increased transport costs can make shippers reconsider their initial choice of route. Similar to modal choice, routes with lower transport costs are generally more attractive for the shippers.

In the context of international freight transport, this decision could also impact the choice of using important logistic nodes, such as ports, terminals, and distribution centers. This means that the competitive ability of a port to attract international cargo, either as a gateway or transshipment port, can be influenced by changes in the transport costs of the routes that make use of that port. Given that ports can contribute significantly to the economy of a State (ITF/OECD, 2015), changes in port throughput will impact the economic performance of a State or region.

UNCTAD (2012) suggests three strategies to reduce maritime freight rates for States, with two of these strategies focused on developing port competitiveness and port-hinterland connections and one on efficient linkages between inter-continental, regional, and national shipping services. The difference in States' policies and capacities to develop their port will inevitably bring different impacts on the transport costs from and to the individual States. Hence, even though GHG mitigation measures may be implemented uniformly at the global level, the resulting economic impact on States could be far from uniform.

### 2.2.3 Import prices of goods

According to OECD data, transport costs vary widely between various products and countries of origin and destination (OECD, 2011). For instance, on average, 5% of the imported value of manufactured goods can be attributed to maritime transport costs, compared with 11% for agricultural goods, and 24% for industrial raw materials. Furthermore, according to UNCTAD data (UNCTAD, 2017), this variation is also reflected across different country groupings such as SIDS, LDCs, landlocked developing countries, and developed economies. For the first three country groups, international transport costs generally account for higher shares in import values of goods compared to the last country group (Figure 4).

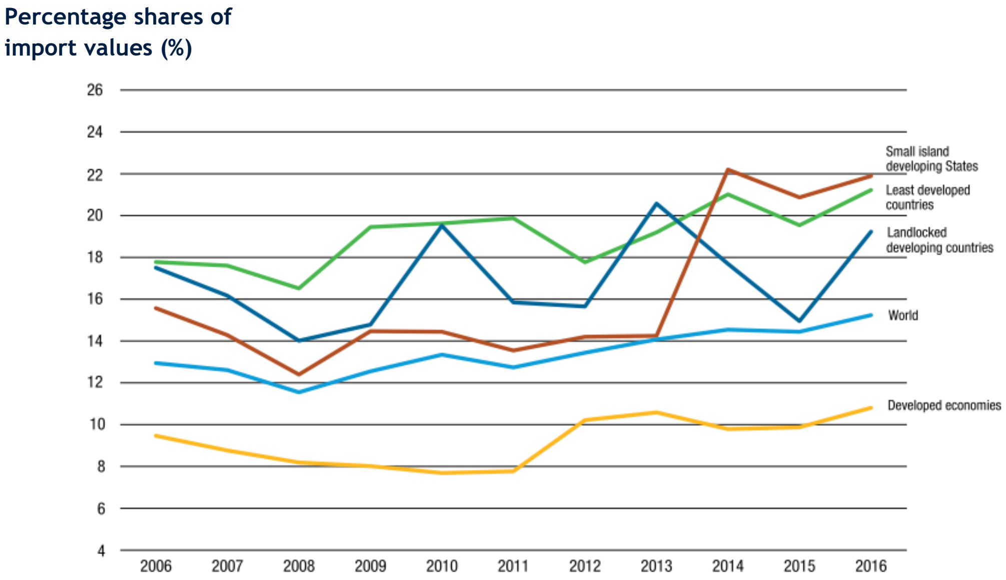

**Figure 4:** Costs of transport and insurance of international trade measured as percentage share of import values for different country groups (source: UNCTAD (2017))

This implies that increased transport costs due to GHG mitigation measures are likely to have varied impacts on the price of imported goods across different countries, commodities, and transport routes. Based on one study (Vivid Economics, 2010), the impact of measure such as a bunker levy on import prices of goods depends on factors such as:

1. The elasticity of freight rates in relation to bunker prices;
2. The share of maritime transport costs in product prices (which is also affected by distance and efficiency of transport service); and
3. The ability of importers to transfer costs to the consumers (cost pass-through rate).

For example, for the Chinese iron ore import market, the study (Vivid Economics, 2010) found that a 10% increase in bunker price would cause import prices from distant countries such as India and Brazil to increase relatively more compared to nearer countries such as Australia. In other words, each commodity and route may have different elasticity of import prices linked to changes in bunker price.

Furthermore, according to Vivid Economics (2010) cost pass-through rate is determined by the dependence of domestic consumption on imports and the competitiveness of local markets to take market share from importers. That is, lower share of imports for domestic consumptions and higher competitiveness of the local markets would lead to lower cost pass-through rate and vice versa. The (Vivid Economics, 2010) estimated that the pass-through rate for furniture import market in the European Union (EU) can be as high as 90% due to the high share of sea-based import (69%). This, in turn, causes the potential increase in the market price to be between 0.15-0.23% per ton, which is higher than other products. (Apparel has a cost-pass through rate of about 10-40%.)

A possible consequence of the increase in import prices of goods due to the application of GHG mitigation measures is the reduction of the amount of goods transported (in tons). In other words, the value-to-weight ratio of different commodities—that is, the price per ton of commodity traded—might increase.

Understanding the value-to-weight ratio for different commodities is important for estimating the impact of GHG mitigation measures on the import prices and the volume of traded goods. This is especially true since trade values (in monetary terms) and volume (in tons) are decoupled. While the total trade volume grew in 2015, its value has been declining since 2010. World trade values decreased by 13%, from USD 19 trillion in 2014 to USD 16.5 trillion in 2015; seaborne trade volume increased by 2.1% in 2015 (ITF/OECD, 2017).

The majority of the literature that studies factors affecting value-to-weight ratio (Martínez et al., 2015; Ong & Sou, 2015) shows that an increase in transport costs, within certain boundaries, will cause a decrease in trade volume (by weight) of commodities for the same trade values (monetary). However, the scale of the decrease will differ by country, commodity, transport mode, and trade route. Section 3.3 details the possible impacts of increasing transport costs on the volume of trade.

### 2.2.4 International trade and economies of States

The linkage between transport costs and economic performance of a region has been studied extensively. From a trade modeling perspective, transport costs are one of the main determinants of trade costs (Bachmann, 2017; Brocker & Kancs, 2001; de Jong et al., 2017; Johansen & Hansen, 2016). This, in turn, can impact the magnitude of trade activities and its spatial distribution between regions. Tanabe et al. (2016) show that a 35% reduction in border crossing time can reduce the total trade costs between China and Central Asian countries. In this context, it has been estimated that such time-savings could increase trade flows between the two regions by 10-90%, depending on transport infrastructure and the projected production and consumption of these countries.[4] On the contrary, an increase in travel time due to congestions can increase trade costs, which can lead to a decline in trade volume between China and Central Asia. it can be inferred from this that any global level GHG mitigation measure that impacts trade costs would have the potential to influence the volume of international trade and the economies of States.

Within the context of international trade, producing regions whose cost structures imply relatively higher import costs for the consuming regions will become less attractive for certain importers. Existing trade relationship are likely to be reconsidered and other producers from competing regions, which produce the same commodities, might be favored; consumers will substitute products from different producers depending on changes in import prices and according to the elasticity of substitution.

Figure 5 illustrates the impact of GHG mitigation measures on import prices of goods and import volumes of State A from States B and C. Suppose, in the baseline scenario, where there is no GHG mitigation measure being applied, State A imports more commodity from State B (70 ton) than State C (30 ton) since the import prices from State B is relatively cheaper than State C (left picture). 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 may suffer a decline in its GDP. Note that increased import prices from both States B and C may also cause an increase in the consumption of domestic products due to consumers in State A substituting domestic for foreign commodities. This may positively impact State A’s GDP, if the increase in domestic consumption is higher than the decrease in productivity and consumption due to higher prices.

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[4] The wide range of increase in trade flows is due to multiple countries in Central Asia seeing varying increases in trade flows. It is noteworthy that the effect of changes in travel time on trade flows is not linear. As a consequence, an increase in transport costs due to GHG mitigation measures may not necessarily result in the reduction of trade flows with the same magnitude as that which is induced by reduction in travel time.

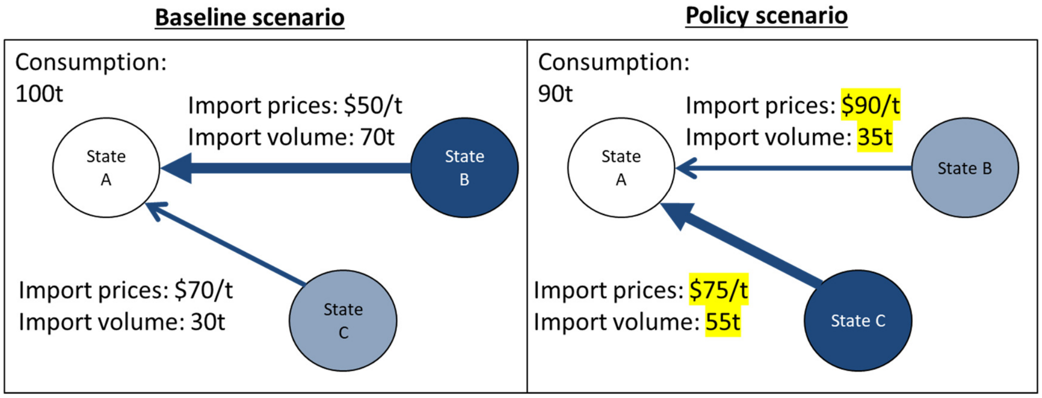

**Figure 5:** Illustration of impact of GHG mitigation measures on import costs and trade volumes between States. Baseline scenario (left), policy scenario (right)

# 3. Current findings: Scale of impacts induced by GHG mitigation measures

Based on existing literature, this section presents estimates of the impacts defined in section 2 and discusses their implications for future impact assessments.

## 3.1 Transport costs

The IMO's initial Strategy considers many candidate policy measures. This literature review uses examples mainly related to modeling the economic impacts of a carbon price. In this context, the concept of a carbon price appears as a useful working proxy to estimate the impacts of GHG mitigation measures in general. Existing literature often refers to a 'fuel price increase' as being representative for any policy-induced increase in transport costs, be it due to a carbon price, a bunker fuel levy, or regulation mandating the use of certain fuels. However, since current literature considers a limited range of policy measures, the impacts of these measures should be treated as only illustrative of the impacts of various GHG mitigation measures.

Based on the work of (Anger et al., 2013; Chowdhury & Dinwoodie, 2011; Faber et al., 2010; Faber & Rensma, 2008; Kronbak et al., 2009; Miao & Fortanier, 2017; Purvis & Grausz, 2012; UNCTAD, 2010; Vivid Economics, 2010), Rojon et al. (forthcoming 2019) found that a carbon price or bunker levy of 10-50 USD/ton $CO_2$ would increase maritime transport costs from 0.4-16%. While some commodity types such as grains (Vivid Economics, 2010) might see an increase in the lower bound of the range (2.5%), the upper range is found for containerized products (16%) (Faber et al., 2010). This wide range of increase in transport costs can be explained by differing freight rate elasticity for each commodity and route. It is also noteworthy that most of the studies about the impacts of GHG mitigation measures on transport costs have not taken into account the potential impact of IMO's 2020 sulphur cap regulation. Figure 6 exemplifies this different elasticity rate by comparing the container freight rate for Asia-EU and EU-Asia routes together with the bunker price in Singapore between 1993 and 2010.

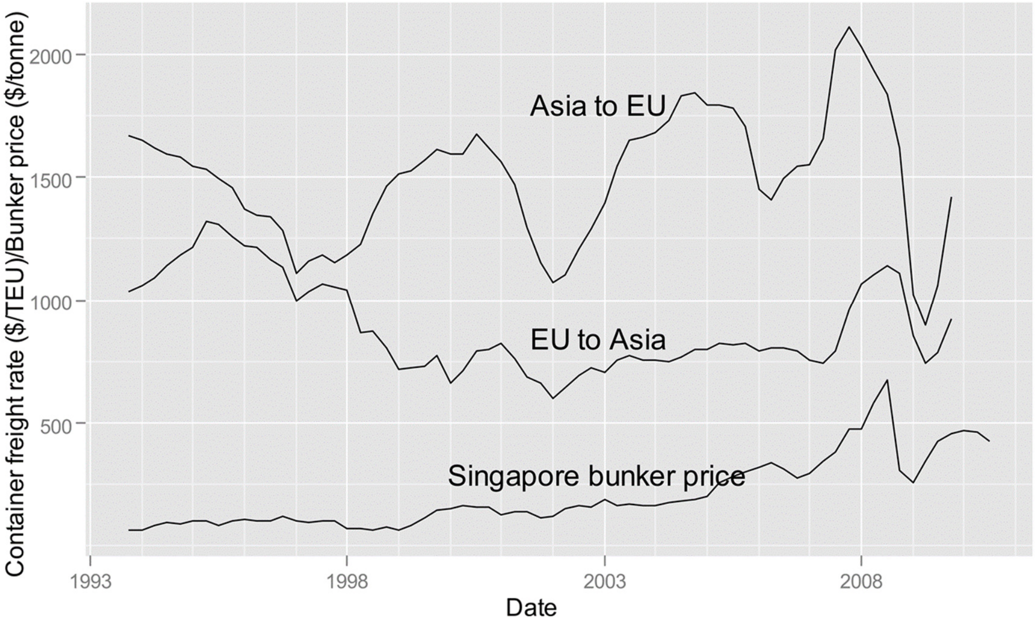

**Figure 6:** Container freight rates with different elasticity in relation to bunker rate (source: (Vivid Economics, 2010))

## 3.2 Transport choices

### 1. Impact on modal choice of shippers

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

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

Another study carried out by (ITF/OECD, 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 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 (Table 1). The share of sea transport could decline by around 0.16%. This represents approximately 34 MTon of freight volume annually, equivalent to the total amount of crude oil imported by sea to Africa. The majority of the shifts are expected from sea to both road (13 MTon) and rail (18 MTon). One reason for this is the high difference in generalized transport costs between different modes, where sea transport remains the cheapest mode serving major trade lanes like those between Europe and Asia and the U.S. 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.

Moreover, Avetisyan (2018) studied the impact of a global carbon tax of 27.3 USD/ton $CO_2$ applied to transport sectors of all modes (i.e. industry sectors which 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, the transport of high-value products (e.g. micro-chips and seeds) would shift to maritime transport from air transport, while 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 1:** Impact of 100% increase in maritime transport costs and 65% speed reduction on global modal share of international freight transport by 2030 (source: (Halim et al., 2018))

| | 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 |

From the references above, it can be deduced 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 China-Europe case, can vary from regionally depending on the characteristics of transportation networks.

## 2. Impact on route and port choice

There are few studies that focus on the impact of mitigation measures on route and port choice (Tavasszy et al. (2016). In general, the effect of changes in shippers' routing decision can be driven by two mechanisms. First, changes in the spatial patterns of trade between States due to new trade relationships may change the position of transit ports. Second, the application of mitigation measures might increase transport costs of each route to various degrees. Routes that are longer but cheaper due to, for instance, a hub and spoke structure may no longer be cheapest after GHG mitigation measures are applied. Shippers will switch to cheaper routes based on these changes in transport costs.

In the study, they found that the application of a carbon price of up to 49 USD/ton $CO_2$ by 2040 could lead on average to a 0.5% decrease in the annual container throughput of ports worldwide. The decrease is not uniform across different commodity types. For example, coal is the most affected commodity with a 4.3% decrease, followed by agriculture (3.1%), and construction materials (0.7%). However, the study does not detail the impact of changes in shippers' routing decisions on port throughput. Further investigation is needed to assess the potential impacts of changes in route choice of shippers on port traffic worldwide.

Another study conducted by (Tavasszy et al., 2011) presents a scenario where a drastic reduction in ship operational speed (14-15 knots instead of 22-24 knots) is implemented by global shipping companies. Also called slow steaming, this can be done to cut fuel consumptions and ship emissions. Even though the impact on port throughput is marginal, the study found that slow steaming could encourage the use of other shipping services at the next intermediate hub due to the relaxation on port rotation schedule (i.e. prolonging the total travel time of the shipment services). This may in turn increase sea-sea transshipment operations worldwide by 1.3 million TEU.

### 3.3 Import prices of goods

Despite the wide range in increased transport costs, most studies (Anger et al., 2013; Chowdhury & Dinwoodie, 2011; Faber et al., 2010; Faber & Rensma, 2008; Kronbak et al., 2009; Miao & Fortanier, 2017; Purvis & Grausz, 2012; Vivid Economics, 2010) report a marginal increase in the more import important indicator of import price of goods. This increase is reported as less than 1%, except for containerized goods (<1.9%). Furthermore, heavy, low-value commodities such as iron ore, cooking and steam coal, and bulk commodities tend to have relatively higher increases in import prices. This finding is especially important since import prices of goods will be the main driver for changes in trade flows between States. That is, when import prices of goods do not increase or decrease significantly, changes in trade relationships between States due to consumer substitution will also be marginal.

Among different commodities studied by the (Vivid Economics, 2010), including iron ore, crude oil, grain, and containerized goods, only iron ore imported to China is estimated to potentially see considerable increases in import price under GHG mitigation measures. This is because iron ore has the highest sensitivity to bunker price among the different commodities studied. Furthermore, it also has a high *ad valorem* freight rate (25-53%) of product values. Lastly, iron ore in China is mostly transported by sea (about 50% of modal share).

The study also found that a high share of maritime transport into countries whose economies are dependent on imports may lead to a high cost pass-through rate. Figure 7 illustrates that countries that are dependent on imports using maritime transport for their grain products, such as Kenya and Saudi Arabia, may see higher increase in import prices.

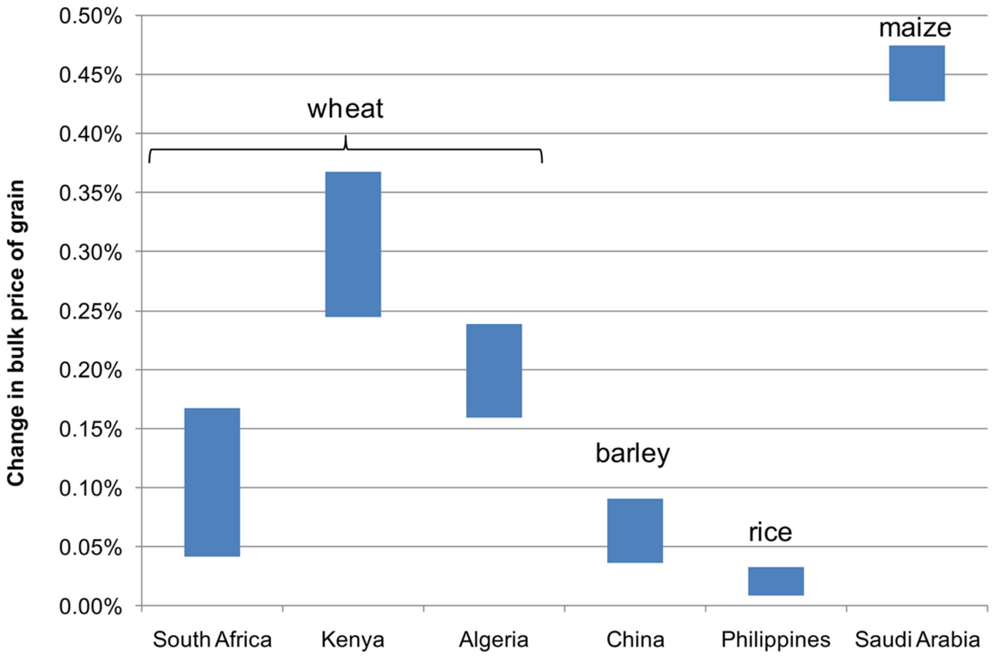

**Figure 7:** Countries that depend on long-haul maritime transport for imports tend to have higher increases in import prices for grain as a result of 10% increase in bunker price (source (Vivid Economics, 2010))

With regard to volume of goods, several model-based studies have shown that there is a significant correlation between transport costs, import price indexes of goods, and the volume of different commodities (Martínez et al., 2015; Ong & Sou, 2015). Specifically, Martínez et al. (2015) showed that the volume of most commodities (in tons) decreases when transport costs increase due to longer transport time. Volume of goods may decrease by approximately 10% per 100-hour increase in time. Furthermore, a higher GDP of the exporting country is found to be correlated with higher volumes of goods exported. That is, each one percent increase in GDP percentile of a country may lead to a 27% increase in the volume of goods.

Furthermore, high-value and heavy commodities, especially electronics, metal products, fishing products, and manufacturing and transport equipment (including vehicle) seem to be more sensitive to increases in transport time. Increased transport time may for these products lead to a greater reduction in volume transported. Another study (Ong & Sou, 2015) showed that the value-to-weight ratio of different commodities is affected by historical patterns of import and export price indexes, trade flow direction, and mode of transport used. According to the study, import price indexes are the most influential variables: Higher import price indexes tend to lead to a reduction in the volume of goods imported in the short- and medium-term, and vice versa lower import price indexes lead to an increase in the volume of goods imported.

## 3.4 International trade and economies of States

Looking at the global supply chain, Tavasszy et al. (2016) investigated the effect of increased transport costs due to internalizing 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 with domestic production.

Lee et al. (2013) studied the impact of a carbon tax on the global economy by focusing their economic model on containerized commodities. They considered six scenarios: three different levels of potential maritime carbon tax (30, 60, 90 USD/ton CO2) across two geographical scopes (EU 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 the highest loss in GDP for a country was estimated to be around -0.002% (estimated for China at a carbon price of 90 USD/ton CO2). In contrast, another study estimated a GDP loss of up to -1% (estimated for Samoa at a carbon price of 30 USD/ton $CO_2$, (Anger et al., 2013)), with some countries potentially even seeing a slightly positive change in their gross domestic products.[5]

In terms of the volume of containers transported globally, the study from Lee et al. (2013) found that a carbon tax of 90 USD/ton $CO_2$ would result in the reduction of 915 thousand TEU. The U.S. would be the most strongly affected State with a reduction of 325 thousand TEU in imports. The results of the study 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-UK, Northern Europe-Mediterranean) could be expected. Most of these shifts suggest an intra-regionalization of trade due to more expensive international long-haul trade costs.

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[5] While seeming counter-intuitive that a carbon price of 30 USD/ton $CO_2$ might have stronger GDP impacts than a carbon price of 90 USD/ton $CO_2$, two aspects should be noted. First, these percentages do not represent global averages, but apply to individual countries. Consequently, a GDP loss of 0.002% for a large developing country at a carbon price of 90 USD/ton $CO_2$ can be much bigger in absolute value than a GDP reduction of 1% for a SIDS at a carbon price of 30 USD/ton $CO_2$. Second, different studies use different models, input data and assumptions.

Sheng et al. (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 covers 13 regions of the world and 21 commodity groups. They found that under a carbon tax of 18 USD/ton $CO_2$, there would be only a modest negative impact on GDP growth for States by 2030. 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 U.S., EU, and Japan experienced no effect of a slight GDP increase due to their connectivity. Based on the results of these studies, changes in the real GDP of countries are projected to be relatively small in general.

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 five 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 GDPs with a carbon price of 30 USD/ton $CO_2$ would be relatively small (-0.004% to -0.08%). However, 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.

The findings of the studies discussed above are summarized in Table 2. So far, the study of the impact of carbon pricing on economies of States has experimented with prices up to 90 USD/ ton $CO_2$. In the real world, the actual carbon price might exceed this upper bound. However, it can be deducted from the current findings that unless the carbon price level is significantly higher than 90 USD/ton $CO_{2,}$ its impacts on the economies of States might still remain modest.

Furthermore, the application of carbon pricing is likely going to allow an accumulation of revenues from the carbon taxes. In general, these revenues can be used in different ways to advance the decarbonization 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 measures. They can also help accelerate the maturity and commercial feasibility of low-carbon technologies that are currently expensive. The potential magnitude of revenues raised, and its redistribution mechanism are topics that require further research.

**Table 2:** Summary of findings on the impact of a carbon price on trade flows or economies of States

| Literature | GHG mitigation measures | Economic Indicators | Findings |
|---|---|---|---|
| **Lee et al. (2013)** | Carbon price 30, 60, 90 USD/ton $CO_2$ 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 et al. (2018)** | Carbon price 40 USD/ton $CO_2$ by 2030 | Real GDP | -0.06% to +0.001% |
| | | GDP growth | -0.17% to +0.01% |
| **Tavasszy et al. (2016)** | Carbon price 49 euros/ton $CO_2$ 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 10,30,50 euros/ton $CO_2$ by 2025 | Real GDP | <-0.01% in global GDP |
| | | Real GDP changes for case study countries | -1% GDP for one country<br><-0.2% for majority |

## 4. Models for economic impact assessments

Based on the literature, this section provides a review of modeling approaches for examining the economic impacts of GHG mitigation measures. Within this context, the focus was set on modeling approaches that can assess the economic impacts of changes in maritime transport costs on the spatial patterns of trade and on the wider economic indicators relevant for States, such as GDP or welfare. In order to maintain the focus of this paper, the goal was not to provide an exhaustive list of all models; but rather to highlight key models that apply state-of-the art methodologies. Specifically, models with these common characteristics were looked at:

1. Applicable on an international level; and
2. Able to assess the economic impact of changes in maritime transport costs on trade volumes and the economic performances of States.

Based on the literature, relevant modeling approaches in assessing the economic impacts of GHG mitigation measures can be categorized in three main groups: (i) Economic trade models; (ii) Transport models; and (iii) Combined trade-transport models.

These models can be applied to the four main economic impacts discussed in this report and most of the important aspects of impact assessments that are listed in the IMO's Strategy. Table 3 provides a summary of the three-abovementioned models and the mapping between these models, economic impact areas, and aspects of impacts listed in the Strategy.

**Table 3:** Mapping between three main models, types of economic impacts, and aspects of impacts in the IMO Strategy

| | Economic impact areas/ Modeling approach | ❶ Maritime transport costs | ❷ Transport choices (mode, route, port choice) | ❸ Import prices of goods | ❹ International trade flows and economies of States |
|---|---|---|---|---|---|
| Economic trade models | Regression models | 🟩 | | 🟩 | 🟩 |
| | Input/Output models | | | | 🟨 |
| | SCGE models | | | 🟨 | 🟩 |
| Transport models | Gravity models | | | | 🟩 |
| | Input/Output models | | | | 🟩 |
| | Value to weight model | | | 🟩 | |
| | Route choice models | | 🟩 | | |
| | Mode choice models | | 🟩 | | |
| Combined trade-transport models | SCGE models + freight transport models | | 🟩 | 🟩 | 🟩 |
| | **Related impact assessment aspects listed in IMO's initial Strategy** | 1 Geographic remoteness and connectivity to main markets,<br>2 Cargo value and type,<br>4 Transport costs,<br>7 Cost-effectiveness,<br>8 Socio-economic progress and development | 1 Geographic remoteness of and connectivity to main markets,<br>3 Transport dependency | 2 Cargo value and type,<br>5 Food security,<br>7 Cost-effectiveness,<br>8 Socio-economic progress and development | 2 Cargo value and type,<br>5 Food security,<br>7 Cost-effectiveness,<br>8 Socio-economic progress and development |

🟩 State of the art efficacy
🟨 Limited state of the art efficacy

## 4.1 Economic trade models

Economic trade models are built on economic theories that typically describe the behavior of economic systems based on the rationality of agents and their interactions. The models in this category include: regression models, input/output models, gravity models analyzing trade flows, and computable general equilibrium (CGE) models.

### 4.1.1 Regression models

A regression model is a mathematical model that describes the relationship between predictor (independent) variables and the response (dependent) variable using observed data. Regression analysis is one of the most common approaches to predict economic impacts of mitigation measures due to its relatively intuitive principles. There are more than 10 variants of regression models. With regard to the economic impact areas presented in section 2.2, regression models have been used to: predict the elasticity of import prices of goods and transport costs as they relate to bunker price (Vivid Economics, 2010); estimate the value-to-weight ratio of commodities traded globally (Martínez et al., 2015; Ong & Sou, 2015); and predict the volume of production, consumption, and trade in a multiple-region input-output (MRIO) model as a function of $/year or freight transport model as a function of GDP.

### 4.1.2 Input/Output models

Input/output (I/O) models can be used to study the interaction between sectors of the economy. I/O models were originally predecessors of CGE models (Robson et al., 2018). However, I/O models do not integrate the trade and the production systems, whereas SCGE models do, based on Krugman's theory of New Economic Geography. I/O models represent the interaction and dependency between industry sectors by describing how the output (in monetary terms) of one industry sector may be used the other sectors as an input for their production. The model therefore requires data on the revenues and expenses of each sector of the national/regional economy. I/O models that are used to model international trade system typically incorporate multiple regions and a spatial element using gravity modeling or random-utility-maximization-based models. These are called multi-regional I/O models (MRIO). The discrete choice variant of this type of model is also known as a random utility-based multi-regional input-output model (RUMBRIO). Bachmann et al. (2014) provide extensive examples of the application of RUMBRIO models in transport economics.

### 4.1.3 (Spatial) Computable General Equilibrium models

Among different economic trade models, CGE models have gained prominence due to their advantages in analyzing the wider economic impacts of a policy or exogenous trends (Robson et al., 2018). Specifically, a CGE approach simulates the whole economy by analyzing supply and demand for every market and their interactions. In this way, a CGE modeling framework allows the extraction of various economic indicators, including GDP, prices, demand elasticity, among others.

A CGE model is a nexus of mathematical equations that represents the evolution of a whole economy and takes into account its macroeconomic constraints and the microeconomic behavior of individual economic agents and their interactions. The CGE framework is built on modern micro-economic theory, which explains the conditions for economic equilibrium for all economic agents given certain demand and supply transactions. In CGE models, aggregate agents are used to represent the behavior of the whole population or of an industrial sector as a single economic agent. These agents are modeled based on the assumption that they follow a cost-minimizing behavior in performing their trade transactions. The price equilibrium conditions follow the basic market condition in which there has to be a balance in the demand and supply levels. The equilibrium is solved on a yearly basis and the model provides forecasted annual trade between economic agents as its output.

A particular extension of the CGE modeling approach is the incorporation of a spatial dimension in its model specifications, which gives birth to the Spatial Computable General Equilibrium (SCGE) model. SCGE models are able to account for price differentiations between regions and specify transport costs as one of the determinants of trade flows between regions. Examples of this modeling approach can be found in Bachmann (2017), who models the impacts of free trade agreements on transport costs and trade flows from and into Canada. Johansen and Hansen (2016) proposed a model to analyze the impact of transport infrastructure development programs on wider economic impacts in Norway. Lee et al. (2013) studied the impact of a carbon tax on the global economy by focusing on containerized commodities using an SCGE modeling approach from the Global Trade Analysis Project-Environment (GTAP-E). The model encompasses 129 countries and 29 sectors and is calibrated on the 2007 base year of the GTAP version 8 database. Sheng et al. (2018) studied the impact of a global carbon tax applied to international bunker emissions on several economic indicators using an SCGE model. The economic indicators studied include import and export volumes, GDP growth, and real GDP of countries and the countries' market share of their export commodities.[6]

Shahrokhi Shahraki and Bachmann (2018) provided a comprehensive review of SCGE models that have been applied to the domain of transportation. According to their study, the representation of transportation networks in SCGE models could influence the accuracy of model results, especially when the analysis requires a high level of disaggregation. Furthermore, Tavasszy et al. (2002) also noted the pitfalls of the applications of SCGE models in transport, which include oversimplification in the specification of transport costs of sectoral productions. Specifically, aggregate statistics on the share of transport costs in product values are commonly used in CGE models while,

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[6] SCGE models do not produce GDP as its direct output, but rather a variation of a welfare indicator that can be translated into a GDP prediction with additional assumptions.

in reality, a significant share of firms use transport services on their own account which are not captured in the aggregate statistics.

## 4.2 Transport models

Transport models are built on theories that try to explain and predict the behavior of actors in the transportation system. A transport model typically uses the classical four-step modeling framework: trip generation, trip distribution, modal split, and traffic assignment (Ortúzar & Willumsen, 2011). As such, this model is suited to assess the impacts of transport policies on transport choices of shippers. Each of the steps might be modeled with different approaches, such as regression and input/output models for trip generation, gravity models for trip distribution, discrete choice and elasticity-based models for modal split, and stochastic and general equilibrium models for traffic assignment. Given their focus, transport models are usually used to analyze the impact of GHG mitigation measures on transport systems. They cover transport costs and shippers' behavior in utilizing transportation network; this includes the value-to-weight ratio of goods, transported as well as mode and route choices of shippers. The following sections review existing types of transport models.

### Value-to-weight ratio models

A study conducted by Ong and Sou (2015) established the relationship between import and export price indexes and the value-to-weight ratio of commodities traded globally using an autoregressive moving average (AMA) model. The model was calibrated using data obtained from the U.S. Census Bureau's foreign trade division. Martínez et al. (2015) and (ITF/OECD, 2018) introduced a value-to-weight conversion model using a number of socio-economic indicators like GDP, GDP per capita, trade agreement, contiguity, transport time, and distance. The model is based on a Poisson regression model. It is calibrated using values and weights data for 25 commodities obtained from ECLAC (Economic Commission on Latin America and Caribbean) and the Eurostat database on exports. This model has developed to take into account the impact of transport costs for different commodities on commodities weight in (Halim et al., 2018). Cristea et al. (2013) constructed a database of weight-value ratios using U.S. imports and exports of merchandise; Eurostat Trade (covering the imports and exports of 27 EU countries), and the ALADI (The Latin American Integration Association) trade database.

### Mode choice models

Several global level models have been developed to estimate the impact of changes in socio-economic variables (such as GDP, trade agreement, transport costs, travel time, shared language, land contiguity, etc.) on the modal choices of international freight transport. A modeling study conducted by (Sou & Ong, 2016) makes use of a mode choice model to estimate the substitution between maritime and air transport modes for international freight. Martínez et al. (2015) and (ITF/OECD, 2018) developed a mode choice model for international freight transport that covers four major modes of transport: air, rail, road, and sea. The model takes into account commodity specific variables, travel time, and distance, as well as socio-economic indicators such as contiguity and trade agreement between countries. A cost-based mode choice model, which is built on this model, was introduced by (Halim et al., 2018). The model is based on a multinomial logit model and has been used to investigate the impact of increased maritime transport costs on the modal choice for freight transport for China-Europe and globally. Studies by (Tanabe et al., 2016; Tavasszy et al., 2011) specified network choice models, which make use of transport costs to estimate both mode and route choices for global cargo transport.

**Route choice models**

Several route choice models have attempted to investigate the impact of changes in transport costs on shipping routes and traffic through ports (Halim et al., 2016; ITF/OECD, 2017; Tanabe et al., 2016; Tavasszy et al., 2016; Tavasszy et al., 2011).

Economic impact assessments using transport models generally use gravity and input/output models to estimate the changes in trade flow patterns based on changes in transport costs (de Jong et al., 2017). Gravity models have been popular in trade modeling since they do not need a lot of data compared to input/output models. However, there are not many global level freight transport models. Most of the models are developed for a regional scale (de Jong et al., 2013) such as the European transport model Trimode (TRT, 2016) and TRANS-TOOLS (Nielsen, 2011). An exception is a multi-regional input-output model developed by Yoon et al. (2018) to study the drivers of GHG emissions from international transport. Despite linking international transport activities and GHG emissions, the model has not been designed to assess the impact of changes in transport costs on States' wider economic indicators, like GDP.

## 4.3 Combined trade-transport models

Combined trade-transport models merge economic and transport models in one framework to assess the impacts of policies in both transport and trade systems in a technically consistent manner. State-of-the-art models in this category typically use SCGE or MRIO models to predict international trade and economic indicators of States—the first two steps of the four-step model. They integrate this with the rest of the four-step components, like modal choice, route choice, and traffic assignment models.

This modeling approach amends the shortcomings of both transport and economic trade modeling. By using a combined model, the core behaviors of economic and transport systems can be assessed comprehensively. For example, for a given carbon tax, SCGE models are able to assess the impacts of the adjusted trade costs on the economy of States/regions, while transport models can estimate the changes in transport costs and modal and route choices of shippers. The latter will eventually determine the total amount of GHG emissions from shipping.

Brocker and Kancs (2001) presented one of the first modeling frameworks to combine economic and transport assessment models for studying the economic impact of changes in transport costs on trade flows in the European Union. At the global level, there are several combined trade and transport models that are able to assess the impact of changes in transport costs on global trade and transport patterns (see the model specified in (ITF/OECD, 2018)). This model has been used to estimate the impact of transport policies on the demand for international freight transport across major modes and their related GHG emissions based on trade projections from an SCGE model.

Furthermore, Sou and Ong (2016) developed a forecasting model that combines an SCGE model at the global level, a value-to-weight conversion model, and a modal choice model to forecast the amount of global seaborne container flows based on different trade scenarios. Tanabe et al. (2016) combined an SCGE modeling approach, a network choice model, and an equilibrium traffic assignment approach. Tanabe et al. (2016) estimate changes in trade flows between Central Asian countries, Russia, and China due to a reduction in border crossing times in Central Asian countries. Tavasszy et al. (2016) investigated the effect of increased transport costs due to internalization of external costs, like GHG emissions, on global trade volumes of ten commodities using the combination of SCGE and global freight network choice models. Shibasaki and Watanabe (2012) analyzed the future international cargo flows in the Asia-Pacific Economic Cooperation (APEC) region using a combined SCGE and network choice model.

# 5. Advantages, disadvantages, and best practices for economic modeling approaches

This section presents the best practices for different modeling approaches described in section 4. Table 4 presents the summary of advantages, disadvantages, and best practices.

**Table 4:** Summary of advantages, disadvantages, and best practices for each modeling approach

| Types | Modeling Approaches | Advantages | Disadvantages | Best practices |
|---|---|---|---|---|
| **Economic trade models** | **Regression models** | Easy to explain, less data hungry | Difficult to account long-term effects in prediction, focused only on one indicator per model | Prediction time horizon proportional to the available historical/ observed data |
| | **Input/output models** | Able to simulate interaction of transport and spatial economy | Unable to accurately estimate impacts on trade flows and productivity when changes in prices are significant | Used to assess redistribution of trade flows when the drastic import price changes are not expected |
| | **Computable General Equilibrium (CGE) models** | Simulates the whole economy taking into account how markets interact and respond to price changes | Requires extensive estimation process, extensive data, harder to trace causal relationships | Used to assess the long-term substitution and redistribution effect on global trade and wider economic indicators |
| **Transport models** | **Four step freight transport models** | Able to simulate redistribution of trade flows and shippers behavior (e.g. mode and route choice) | Analysis is limited to trade and transport flows for commodities and not wider economic impacts; no true economic model | Used when substantial mode and route shift are expected, especially for economies driven by ports; useful for CBA when knowledge of impacts in transport market is sufficient |
| **Combined models** | **SCGE + transport model** | Able to simulate trade and transport system responses | Requires extensive data for both models, complex and costly to build and maintain | Used when the scope of impact assessments cover both trade and transport systems |

## 5.1 Economic trade models

### 5.1.1 Regression models

The main advantages of a regression model are that it is relatively easy to interpret and data requirements can be adjusted to available data. The disadvantages are that it is difficult to account for the possible long-term evolution of the predictor variables, especially when the data used to estimate the model represents one point of time, and it is challenging to take into account spatial effects. Regression models, for instance, struggle to define the interaction between different economic variables from two different regions within the same geographical boundary.

Given the advantages and disadvantages of regression models, they are best used to estimate the impact of GHG mitigation measures on an economic indicator where the predictor variables are not heavily dependent on the result of spatial interaction with other, excluded variables. This is because the long-term evolution of these predictor variables can be difficult to represent in the model. For instance, it is difficult to estimate the throughput of a port based on the GDP of a country if the port serves as a gateway port for wide hinterland regions.

Three best practices for applying regression include, first, using time-series data, which contain observation of variables over multiple time periods whenever possible. Regression models typically have better long-term accuracy when the historical patterns of variables are included in the data. When time-series data is not available, these models are best used to estimate short- to medium-term impacts. Second, it is important to evaluate the goodness of fit of a regression model using different indicators such as the coefficient of determination (R-squared), root mean squared error (RMSE), and residual analysis. Third and finally, validation of a regression model generally benefits from sensitivity analysis on the short- and long-term predictions of the model using systematic changes in the variable values.

Regression models, due to their flexibility in explaining statistical correlations between variables, can be used to assess all aspects of impacts listed in the IMO Strategy.

### 5.1.2 Input/Output models

I/O models have several limitations that make them less preferable when modeling the wider economic impacts of mitigation measures (Bachmann et al., 2014). These limitations include the absence of macroeconomic feedbacks (such as how price-changes would induce changes in demand for commodities), assumptions of linear proportionality between input and output in economic sectors, and a lack of macroeconomic constraints from factors such as labor, capital, and, land. Nevertheless, I/O models have advantages in being relatively simple and able to simulate limited redistribution effects on trade flows due to mitigation measures.

According to Bachmann et al. (2014), I/O models may be used to reduce the burden of a CGE model when: i) The impacts of mitigation measures are not expected to cause a drastic price changes; ii) The main impacts of transport policies are expected to be within the transport networks (such as reduced travel time); and iii) The analysis is focused on changes in trade flow patterns assuming fixed total demand values. As such, I/O models are not suited to model indicators that are sensitive to price changes, such as GDP.

With regard to the impacts of mitigation measures, I/O models can be used to assess transport dependency, connectivity to main markets, socio-economic progress and development, cargo type and value, and cost-effectiveness.

### 5.1.3 (Spatial) Computable General Equilibrium models

Despite of the ability of CGE models to simulate the wider economic impacts of mitigation measures, these models also have their shortcomings. These include extensive estimation processes for numerous elasticity parameters, sensitivity of the model results to base-year calibration data, extensive data needs, and relatively more effort to explain complex causal relationships produced by the model.

Since CGE models are able to take into account the interaction of different markets and the behavior of economic agents at the micro level while taking into account macro-economic feedbacks, they excel at estimating the longer-term evolution of economic variables in a technically consistent manner. Furthermore, CGE models are typically able to produce multiple economic indicators of interest, such as GDPs,[7] trade flows, and welfare in a single run.

SCGE models are best suited to estimate the long-term redistribution of trade flows and economic indicators of States at the global level based on strong/disruptive mitigation measures that portend significant economic consequence. Within this context, it is also important for CGE models to use the proper specification of transport costs between States—that is, costs of transport that include the factors mentioned in section 2.2.1 to ensure the accuracy and the validity of the results.

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[7] SCGE models do not produce GDP indicators as their direct output but they are able to produce such indicators with additional assumptions, please also see footnote 2.

Among the aspects of impacts listed in the IMO Strategy, CGE models can be used to assess socio-economic progress, development, cost effectiveness, and food security.

## 5.2 Transport models

Four-step freight transport models generally rely on gravity models to estimate the impact of changes in transport costs on the pattern and volume of trade flows. However, since gravity models, like I/O models, are not designed to describe the behavior of other sectors in the economy, they cannot analyze wider economic indicators such as GDP or welfare without additional analysis and computation.

However, four-step freight transport models have the advantage of being able to estimate the impacts of increased transport costs on shippers' behavior. They are thus best used when mitigation measures are foreseen to induce changes in shippers' behavior, like mode and route choice, next to changes in the patterns of international trade.

Best practices in applying freight transport models include: i) The use of choice models rather than elasticity of substitution models, where the competition between all major modes of international transport are included rather than the competition between two modes; ii) Specification of transport networks at sufficient detail, especially for countries/regions that have multiple competing ports and transport routes/modes; and iii) The validation of the model results with observed statistics (e.g. port throughput or volume of transport flows over certain routes).

Among the aspects of impacts listed in the IMO initial Strategy, four-step freight transport models can be used to assess transport dependency, geographic remoteness of and connectivity to main market, socio-economic progress and development; cargo type and value; and cost-effectiveness.

## 5.3 Combined trade-transport models

Combined trade-transport models are, to date, the most comprehensive modeling approach that can be used to assess the economic impacts of mitigation measures. However, the wide range of impact assessments that are enabled with this kind of models come with several trade-offs: data requirements are much higher, since they come from both trade and transport sub-models; they are quite costly to build and maintain; and the estimation and validation of the models are much more difficult due to numerous parameters that need to be estimated and the multiple computation steps involved.

Given the above-mentioned strengths and drawbacks, combined models are best used when the scope of impact assessments include detailed transport and economic system responses at the global level. Specifically, combined models can provide valuable insights when: i) The impact of disruptive/strong mitigation measures may lead to significant increase in transport costs; ii) Redistribution of international trade is expected and the wider economic indicators of States such as GDP, welfare, and the production/consumption of different industry sectors, are of interest; and iii) Changes in shippers' behavior (choice of modes and routes) could affect the economy of States, especially those that are driven by port and shipping industry.

Furthermore, the development of combined models needs to adhere to certain best practices to ensure the accuracy and validity of outputs. These include the use of a consistent transport cost specification for both trade-transport sub models, the use of consistent commodity categories and level of geographical disaggregation, and validation of results for each computation step for both trade and transport models.

In terms of impact assessments of measures listed in the IMO initial Strategy, combined models can be used to assess socio-economic progress and development, cost effectiveness, food security, transport dependency, geographic remoteness of and connectivity to main market, cargo type, and value.

## 6. Data availability and gaps for economic impact assessments

This section includes a non-exhaustive list of some of the key data sets that are available for use in the different models described in sections 4 and 5.

- UNCTAD Comrade – includes values and weight of international trade between countries; not mode-specific.
- OECD Transport cost database – an estimate of the transport costs for flows of trade between countries.
- EUROSTAT –value, volume, and mode choice for trade flows between European countries and between Europe and the rest of the world.
- Customs data – both trade value and volume information highly disaggregated to individual shipments. The data are not available for every country.
- ECLAC trade database– a trade data set that includes trade value, volume, and mode choice between Latin American and Caribbean countries and the rest of the world.
- UNCTAD LSCI database – a database describing the Liner Shipping Connectivity Index for each country worldwide from 2006 to 2017.
- UNCTAD Container port throughput data – a data set containing the amount of container traffic handled by each country worldwide from 2004 to 2018. Information is aggregated at country level; traffic at the port level is not available.
- MDS Trans modal database on the schedule of liner shipping companies – a data set that contains the sequence of port calls and their schedule for the Liner Shipping Companies worldwide. The data are available for a fee.

One key issue is that many of these data sources are incomplete or not publicly available. This might restrict the full potential that they offer both in terms of geographical limits (e.g. some trade data for specific countries may be missing) and time limits (e.g. OECD transport cost data ends in 2007 and has not been updated since). In particular, there is an absence in some of these data sources for information on SIDS and LDCs, who may not have national statistics or reporting mechanisms. This is of particular concern, as the IMO sees a special need to consider the impacts of measures on these States (as noted by MEPC 68) and their emerging needs, as noted in resolution A.1110(30).

In such cases, it seems necessary to undertake supplemental analysis to estimate missing data (e.g. applying interpolation or proxies) or to acquire it through companies specialized in data collection. Alternatively, inferences could be made on the likely impacts for a State with missing data by drawing parallels to other States with similar economies, shipping activities, and distances to markets.

## 7. Conclusions and overall recommendations

This paper presents current state of model-based analysis as it applies to the economic impacts of GHG mitigation measures. This paper aimed to contribute to the objective of the IMO initial Strategy, particularly in regard to the impact assessment of GHG measures on the economies of States, by:

1. Identifying major areas of economic impact of GHG mitigation measures, and the mechanisms by which these impacts could spread through transport and trade systems and the economies of States.
2. Compiling the latest findings on the order of magnitude of economic impacts of GHG mitigation measures on these economic impact areas.
3. Presenting different modeling approaches for use in assessing economic impacts of GHG mitigation measures, along with the best practices on how to select and apply these models for efficient and effective impact assessments.

It was found that mitigation measures may impact the following economic areas: i) Transport costs; ii) Transport choices; iii) Import prices of goods; and iv) International trade flows and economies of States. Specifically, the application of a GHG mitigation measure may impact international freight transport systems, international trade systems, and the economies of States.

The application of GHG mitigation measures could increase transport costs and compel a shift to cheaper, alternative modes and routes of transport by international freight shippers. Increases in transport costs could also increase import prices of goods and reduce the volume of commodities traded worldwide. In the long term, increased import prices may cause firm to relocate their manufacturing facilities. This relocation applies, in particular, to States that are in closer proximity to the relevant markets. Another possible impact is more consumers substituting local for imported products. This may lead to a reconfiguration of global logistics network, where firms reorganize their supply chains to re-minimize production costs. These changes could lead to changes in States' export and import volumes, which eventually impact States' gross domestic products (GDP) and other socio-economic metrics.

The most recent studies to examine the economic impacts of GHG mitigation measures found that the estimated impacts on the above-mentioned economic areas are rather small. Specifically, the application of a carbon price within the range of 10-50 USD/ton $CO_2$ leads to a marginal increase in import prices of goods (<1%). Moreover, in most cases, carbon pricing in the range of 10-90 USD/ton $CO_2$ only modestly impacts the GDP of States, where GDP loss is estimated to be in the range of -0.002% (with a carbon price of 90 USD/ton $CO_2$) to -1% (with a carbon price of 30 USD/ton $CO_2$) (Table 2). There are also notable cases where a slightly positive impact on GDP is reported. On the other hand, negative impacts can be disproportionately high for particular States, such as SIDS and LDCs. These groups deserve special attention in future impact assessments.

Based on the findings in this paper, several recommendations for impact assessments can be provided:

1. For maritime transport costs and import prices of goods: impact assessments should focus on the few goods where maritime transport costs account for a significant share of overall consumer prices. Further research can focus on the potential cost pass-through rate for different commodities to understand how each stakeholder will be affected by increased transport costs.
2. Transport choices: the modal shifts from maritime transport to other modes as a result of increased maritime transport costs are estimated to be rather small globally. Therefore, analysis on modal shifts might be valuable when specific geographical locations, such as coastal areas, are considered. That said, modal shifts might not need to be the primary concern at the initial stages of impact assessments.
3. International trade and economies of States: The focus should be set on specific commodities, such as low-value bulky goods and low-value consumer goods. Both potentially negative (e.g. increase in import prices) as well as positive impacts (e.g. increased domestic production) should be taken into account.

Three types of models were identified that can be used to assess economic impacts of GHG mitigation measures on international maritime transport: economic trade models, transport models, and combined trade-transport models. Next to this, best practices for five different modeling approaches that relate to these models were provided (Table 4).

Beyond these specific recommendations, the following overall recommendations for policy makers interested in assessing the economic impacts of GHG mitigation measures can be shared:

**1. No need to reinvent the wheel**

Several models and studies are available to inform policy discussions through newly built and shared evidence. Much existing groundwork can be leveraged to better understand economic impacts, both globally and on specific States. There is no significant need for the development of new models or additional analytical tools.

**2. "Kaizen"[8] – continuously improve and innovate**

As modeling expertise, computing technology, and data availability continue to improve, the quality of information on economic impacts will continue to improve. Policy makers are encouraged to work closely with academic and business experts to effectively advance the relevant policy discussions.

**3. Prioritization**

This paper has reviewed different modeling approaches and shown that these can be applied in different contexts depending on the geographical scope of the study and the impacts that are anticipated to be of greatest importance. In other words, there is not a single model that can solely deliver on all possible impact assessment objectives. Prioritization is key, and these priorities must be reflected in the choice of model.

**4. Do not let perfect be the enemy of the good**

While a combined transport-trade model might be desirable to assess the comprehensive economic impacts of GHG mitigation measures, the use of such fully-fledged models might be more valuable when detailed and thorough country-specific insights are needed. The studies reviewed in this paper have shown that the use of simpler models with fewer data requirements can still provide very valuable insights on specific economic impact areas and can still make important contributions to the time-critical policy discussion.

**5. Seeing the forest for the trees**

Given there are numerous GHG mitigation measures that can be implemented, it is useful to consider certain principles that can increase the efficiency of the assessment process. For instance, impact assessments should be proportionate to the likely impacts of a measure. If initial studies in the literature suggest insignificant impacts, a full impact assessment for a mitigation measure might not be needed and scarce research resources can be allocated to more significant economic impact areas.

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[8] Kaizen is the Japanese term for continuous improvement.

# References

1. Anger, Annela, et al. (2013). Research to assess impacts on developing countries of measures to address emissions in the international aviation and shipping sectors.
2. Avetisyan, Misak. (2018). Impacts of global carbon pricing on international trade, modal choice and emissions from international transport. *Energy Economics, 76*, 532-548. doi: https://doi.org/10.1016/j.eneco.2018.10.020
3. Bachmann, Chris. (2017). Modeling the Impacts of Free Trade Agreements on Domestic Transportation Gateways, Corridors, and Ports. *Transportation Research Record: Journal of the Transportation Research Board, 2611*, 1-10. doi: 10.3141/2611-01
4. Bachmann, Chris, et al. (2014). Applications of Random-Utility-based Multi-region Input–Output Models of Transport and the Spatial Economy. *Transport Reviews, 34*(4), 418-440. doi: 10.1080/01441647.2014.907369
5. Brocker, Johannes, & Kancs, d'Artis. (2001). Methodology for the Assessment of Spatial Economic Impacts of Transport Projects and Policies: Economics and Econometrics Research Institute (EERI), Brussels.
6. Chowdhury, N, & Dinwoodie, J. (2011). *The Potential Impact of A Levy on Bunker Fuels on Dry Bulk Spot Freight Rates, Glasgow*. Paper presented at the Low Carbon Shipping Glasgow.
7. Clark, Ximena, et al. (2004). Port efficiency, maritime transport costs, and bilateral trade. *Journal of Development Economics, 75*(2), 417-450. doi: https://doi.org/10.1016/j.jdeveco.2004.06.005
8. Cristea, Anca, et al. (2013). Trade and the greenhouse gas emissions from international freight transport. *Journal of Environmental Economics and Management, 65*(1), 153-173. doi: https://doi.org/10.1016/j.jeem.2012.06.002
9. de Jong, Gerard, et al. (2017). Modelling production-consumption flows of goods in Europe: the trade model within Transtools3. *Journal of Shipping and Trade, 2*(1), 5. doi: 10.1186/s41072-017-0023-9
10. de Jong, Gerard, et al. (2013). Recent developments in national and international freight transport models within Europe. *Transportation, 40*(2), 347-371. doi: 10.1007/s11116-012-9422-9
11. Dellink, Rob, et al. (2017). The Sectoral and Regional Economic Consequences of Climate Change to 2060. *Environmental and Resource Economics*. doi: 10.1007/s10640-017-0197-5
12. Faber, J, et al. (2010). A Global Maritime Emissions Trading System - Design and Impacts on the Shipping Sector, Countries and Regions *Results presented in MEPC 60/4/54, Impact Assessment of an Emissions Trading Scheme with a particular view on developing countries, submitted by Germany.* London: CE Delft.
13. Faber, J, & Rensma, K. (2008). Left on the High Seas: Global Climate Policies for International Transport *Results presented in MEPC 58/4/59, Benefits and possible adverse impacts of market-based instruments, submitted by WWF*. London: CE Delft.
14. Halim, Ronald A., et al. (2018). Decarbonization Pathways for International Maritime Transport: A Model-Based Policy Impact Assessment. *Sustainability, 10*(7), 2243.
15. Halim, Ronald A., et al. (2016). A scenario discovery study of the impact of uncertainties in the global container transport system on European ports. *Futures, 81*, 148-160. doi: https://doi.org/10.1016/j.futures.2015.09.004
16. IPCC. (2018). Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°Cabove pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the

threat of climate change, sustainable development, and efforts to eradicate poverty.: [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, Y.Chen, S. Connors, M. Gomis, E. Lonnoy, J. B. R. Matthews, W. Moufouma-Okia, C. Péan, R. Pidcock, N. Reay,M. Tignor, T. Waterfield, X. Zhou (eds)]. In Press.

17. ITF/OECD. (2015). *Port Investment and Container Shipping Markets*: OECD Publishing.
18. ITF/OECD. (2017). *ITF Transport Outlook 2017*. Paris: OECD publishing.
19. ITF/OECD. (2018). Decarbonising Maritime Transport: Pathways to zero-carbon shipping by 2035 *Case-Specific Policy Analysis*. Paris, France: ITF/OECD.
20. Johansen, Bjørn Gjerde, & Hansen, Wiljar. (2016). Predicting Market Allocations, User Benefits and Wider Economic Impacts of Large Infrastructure Investments for Freight Transportation. *Transportation Research Procedia, 16*, 146-157. doi: https://doi.org/10.1016/j.trpro.2016.11.015
21. Korinek, Jane, & Sourdin, Patricia. (2010). Clarifying Trade Costs: Maritime Transport and Its Effect on Agricultural Trade. *Applied Economic Perspectives and Policy, 32*(3), 417-435.
22. Kronbak, J, et al. (2009). Effects on sea transport cost due to an International Fund for Greenhouse Gas Emissions from ships, MEPC60/INF7. London: submitted by Denmark.
23. Lee, Tsung-Chen, et al. (2013). Economy-wide impact analysis of a carbon tax on international container shipping. *Transportation Research Part A: Policy and Practice, 58*, 87-102. doi: https://doi.org/10.1016/j.tra.2013.10.002
24. Martínez, L Miguel, et al. (2015). International Freight and Related Carbon Dioxide Emissions by 2050: New Modeling Tool. *Transportation Research Record: Journal of the Transportation Research Board*(2477), 58-67.
25. Miao, Guannan, & Fortanier, Fabienne. (2017). Estimating Transport and Insurance Costs of International Trade.
26. News, Climate Home. (2018). Graphics of Marshall Islands sea level rise 'brought EU ministers to tears'. Retrieved 4 September 2018, 2018, from http://www.climatechangenews.com/2018/06/22/graphics-marshall-islands-sea-level-rise-brought-eu-ministers-tears/
27. Nielsen, Otto Anker. (2011). TRANS-TOOLS ("TOOLS for TRansport Forecasting ANd Scenario testing"). Retrieved 23 September 2018, from http://www.transtools3.eu/about.html
28. OECD. (2011). Clarifying trade costs in maritime transport *Working paper*. Paris: OECD publishing.
29. Ong, Ghim Ping, & Sou, Weng Sut. (2015). Modeling Commodity Value–Weight Trends Between the United States and Its Trading Partners. *Transportation Research Record: Journal of the Transportation Research Board, 2477*, 93-105. doi: 10.3141/2477-11
30. Ortúzar, J., & Willumsen, L. (2011). *Modelling Transport* (4th edition ed.). Hoboken: John Wiley & Sons.
31. Purvis, N, & Grausz, S. (2012). *Sink or Swim: The Economic Impacts of an International Maritime Emissions System for Greenhouse Gases on the United States*: Brookings.
32. Ripple, William J., et al. (2017). World Scientists' Warning to Humanity: A Second Notice. *BioScience, 67*(12), 1026-1028. doi: 10.1093/biosci/bix125
33. Robson, Edward N., et al. (2018). A review of computable general equilibrium models for transport and their applications in appraisal. *Transportation Research Part A: Policy and Practice, 116*, 31-53. doi: https://doi.org/10.1016/j.tra.2018.06.003
34. Rodrigue, Jean-Paul, & Notteboom, Theo. (2012). Dry ports in European and North American intermodal rail systems: Two of a kind? *Research in Transportation*

*Business & Management, 5*, 4-15. doi: http://dx.doi.org/10.1016/j.rtbm.2012.10.003

35. Rojon, Isabelle, et al. (forthcoming 2019). Impacts of measures to reduce GHG emissions from ships on maritime transport costs and on States: UMAS.
36. Shahrokhi Shahraki, Hamed, & Bachmann, Chris. (2018). Designing computable general equilibrium models for transportation applications. *Transport Reviews*, 1-28. doi: 10.1080/01441647.2018.1426651
37. Sheng, Yu, et al. (2018). Re-analyzing the economic impact of a global bunker emissions charge. *Energy Economics, 74*, 107-119. doi: https://doi.org/10.1016/j.eneco.2018.05.035
38. Shibasaki, Ryuichi, & Watanabe, Tomihiro. (2012). Future Forecast of Trade Amount and International Cargo Flow in the APEC Region: An Application of Trade-Logistics Forecasting Model. *Asian Transport Studies, 2*(2), 194-208. doi: 10.11175/eastsats.2.194
39. Sou, Weng Sut, & Ong, Ghim Ping. (2016). Forecasting Global Maritime Container Demand with Integrated Trade–Transportation Modeling Framework. *Transportation Research Record: Journal of the Transportation Research Board, 2549*, 64-77. doi: 10.3141/2549-08
40. Stopford. (2009). *Maritime Economics*. New York: Routledge.
41. Tanabe, Satoshi, et al. (2016). Impact Assessment Model of International Transportation Infrastructure Development: Focusing on Trade and Freight Traffic in Central Asia. *Asian Transport Studies, 4*(1), 159-177. doi: 10.11175/eastsats.4.159
42. Tavasszy, L.A., & de Jong, G. (2014). *Modelling Freight Transport*. London/Waltham: Elsevier.
43. Tavasszy, L.A., et al. (2016). Effect of a full internalization of external costs of global supply chains
44. on production, trade and transport. In C. Blanquart, U. Clausen & B. Jacob (Eds.), *Towards Innovative Freight and Logistics*. Hoboken, New Jersey: John Wiley & Sons.
45. Tavasszy, L.A., et al. (2011). A strategic network choice model for global container flows: Specification, estimation and application. *J. Transp. Geogr, 19*, 1163-1172. doi: 10.1016/j.jtrangeo.2011.05.005
46. Tavasszy, L.A., et al. (2002). *Pitfalls and solutions in the application of spatial computable general equilibrium models for transport appraisal.* Paper presented at the European Regional Science Association.
47. TRT. (2016). TRIMODE - Transport Integrated Model for Europe. Retrieved 23 September 2018, from http://www.trt.it/en/PROGETTI/trimode_project/
48. UNCTAD. (2010). Oil Prices and Maritime Freight Rates: An Empirical Investigation *Technical report by the UNCTAD secretariat*. Geneva, Switzerland: UNCTAD.
49. UNCTAD. (2012). Review of Maritime Transport 2012. In UNCTAD (Ed.). Geneva, Switzerland: UNCTAD.
50. UNCTAD. (2015). Review of Maritime Transport 2015. In UNCTAD (Ed.). Geneva, Switzerland: UNCTAD.
51. UNCTAD. (2017). Review of Maritime Transport 2017. In UNCTAD (Ed.). Geneva, Switzerland: UNCTAD.
52. Vivid Economics. (2010). Assessment of the economic impact of market-based measures. London: Vivid Economics.
53. Wilmsmeier, Gordon, et al. (2006). The Impact of Port Characteristics on International Maritime Transport Costs. *Research in Transportation Economics, 16*, 117-140. doi: https://doi.org/10.1016/S0739-8859(06)16006-0

54. Yoon, Young, et al. (2018). An Analysis of CO2 Emissions from International Transport and the Driving Forces of Emissions Change. *Sustainability, 10*(5). doi: 10.3390/su10051677