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The impacts of carbon pricing on maritime transport costs and their implications for developing economies

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ABSTRACT

We provide an in-depth review of the extant literature on the impact a maritime carbon pricing measure might have on maritime transport costs. First, we analyse the relative importance of the determinants of maritime transport costs for trade and economic development, and secondly assess the transmission channels and economic effects of a carbon price on maritime transport costs. We argue that the introduction of a carbon price has a limited impact on total maritime transport costs for the average country. However, Small Island Developing States and Least Developed Countries are more likely to be negatively impacted by such a measure in terms of maritime transport costs as we provide novel evidence that the relationship between per unit transport costs and trade flows is negative and elastic at least for the case of Pacific Small Island Developing States.

1. Introduction

In April 2018, the International Maritime Organization (IMO) – the United Nations' specialised agency for international shipping - adopted the Initial IMO Strategy on Reduction of Greenhouse Gas (GHG) Emissions from Ships. The headline target in the Initial IMO GHG Strategy is to reduce total annual GHG emissions by at least 50% by 2050 compared to 2008, while pursuing efforts towards phasing out GHG emissions this century as a matter of urgency, consistent with the Paris Agreement temperature goals [40].

Under 'business as usual' scenarios, shipping's CO_2 emissions are expected to increase by between 90% and 130% by 2050 compared to 2008, depending on future energy developments and economic growth prospects [24]. In light of these projections, additional policy measures to reduce GHG emissions from shipping will need to be adopted and implemented if the IMO climate target is to be met. The Initial IMO GHG Strategy includes a non-exhaustive list of candidate short-, mid- and long-term measures and stipulates that impacts on States of climate mitigation policy measures are assessed and taken into account before their adoption, paying particular attention to the needs of developing countries, especially small island developing States (SIDS) and least developed countries (LDCs) [40]. This requirement was a response to concerns of these countries that additional climate mitigation policy measures in shipping could negatively impact their economies. An IMO procedure for assessing impacts on States outlines different steps related to submitting and commenting on impact assessments and provides some details on what information the assessments should include [41].

So far, several impact assessments for candidate short-term measures targeting increased ship energy efficiency have been conducted [14,18,32,46,63]. A subsequent review by the United Nations Conference on Trade and Development (UNCTAD) however criticised that these impact assessments did not fully address all parameters outlined in the IMO procedure, highlighted several challenges, including limited availability of data and the existence of many uncertainties, and recommended ways to enhance impact assessments [42]. A comprehensive impact assessment of a combined IMO short-term measure was consequently conducted. It revealed that the aggregate global impacts of the measure on maritime logistics costs could be considered small relative to typical market variability of freight rates [43,45]. Compared to the longer-term impact of other disruptions (e.g. pandemics, climate change factors), the global impact on GDP and trade flows could also be considered small. However, it was found that some developing countries, SIDS and LDCs would likely require support to mitigate increased maritime costs and alleviate consequent negative impacts on their real income and trade flows [43,45].

With the adoption of short-term energy efficiency measures in 2021, the discussions will turn to the mid-term measures which include market-based measures (MBMs) [94]. Previous IMO discussions on

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MBMs did not come to an agreement (inter alia due to fears of potential negative economic impacts) and were put on hold in 2013. For the history of regulatory developments at the IMO with regards to reducing GHG emissions as well as an overview of previous MBM proposals, please see, e.g. [15,51,72]. Several recent submissions demonstrate Member States' appetite to restart the MBM discussions [5,10,19,29,54,60,61,74,77] and a new concrete proposal for a GHG levy has been submitted to the IMO for discussion [93]. In light of this, we focus on the economic impacts of carbon pricing measures.

Halim et al. [33] identify four different but interrelated areas of economic impact that could result from introducing maritime GHG mitigation measures such as carbon pricing: transport costs; transport choices; import prices; and international trade and economies of Member States. The IMO Initial Strategy also lists transport costs as one of eight factors impact assessments should pay attention to [41].

In this article, we focus only on the impact of maritime carbon pricing on transport costs, especially in developing countries, SIDS and LDCs, whilst fully recognising that there may be other potential impacts. By providing an in-depth overview of the existing research on the topic to date, we aim to achieve two main objectives. The first objective is to analyse the importance, role and determinants of maritime transport costs for trade and economic development, with a particular focus on developing countries. This is done in Sections 2 and 3. The second objective is to identify how and if the impact of a carbon price for maritime transport would affect maritime transport costs, discussed in Section 4. Section 5 concludes.

2. Transport costs, trade and economic development

Over 80% of global trade by volume and more than 70% of its value are carried onboard ships [85,86]. As such, the cost of shipping goods by sea represents an important part of overall trade costs which also include costs associated with policy barriers, information, contract enforcement, exchange rate fluctuations, local distribution and legal and regulatory costs [2] – essentially "anything that drives a wedge between the producer price in the exporting country and the consumer price in the importing country" ([6], p. 10).

Transport is an enabler of international trade which explains why transport costs are an important factor in determining a country's ability to participate in the world economy. Limão and Venables [53], for example, estimate that a 10% increase in transport costs reduces trade volumes by 20%. Higher transport costs can negatively affect economic growth in different ways, including the following [92]:

- They lower income earned from the export of goods, thereby reducing a country's savings available for investments.
- They increase prices of imported goods which decreases real investments directly.
- Countries paying higher transport costs are likely to allocate a smaller share of their output to trade and are less likely to attract export-oriented foreign direct investment. Trade and foreign direct investment being important channels for the diffusion of knowledge, this may remove a country further from the world technology frontier and slow rates of productivity growth.

According to Hummels [35], there are three ways to measure the relative magnitude of transport costs. First, the cost of transporting a good can be compared to its value – referred to as ad valorem transport costs. UNCTAD [85] finds that in 2016, global average transport costs represented about 15% of the value of imports. It also highlights the marked differences in ad valorem transport costs depending on countries' development status: Developed countries spent on average about 11% of the value of imports on international transport and insurance, while landlocked developing countries paid 19%, LDCs 21% and SIDS almost 22% of the value of imports (see Fig. 1). Focusing on SIDS, Moon [58] finds that between 2004 and 2013, the average expenditure on transport costs for importing goods was 2% higher than the world average of 8.1%, with the Comoros, Seychelles, Solomon Islands and Grenada facing the highest expenditures at 17–20.2%.

The reasons for such large differences in ad valorem transport costs are detailed in Section 3.

The second way to understand the importance of transport costs is by comparing them to other known trade barriers. With tariffs and non-tariff barriers steadily decreasing, the relative importance of transport costs as a trade barrier has been increasing across time and it is argued that transport costs can be as large a barrier to trade as tariffs, if not larger [35]. The impact of transport costs relative to tariffs is underlined in World Bank [92] which shows that for the majority of US trading partners, transport cost barriers outweigh tariff barriers. In the case of Chile and Ecuador, Clark et al. [17] find that transport costs surpass the average tariffs they face in the US market by more than 20 times. Amjadi et al. [1] conclude that for Africa, transport costs for importers were a more significant trade barrier than import tariffs and trade restrictions.

The third way of putting transport costs into perspective is by examining to what extent they alter relative prices of goods. This largely depends on the type and value of the product in question, volume shipped, value-to-weight ratio and product-specific transport

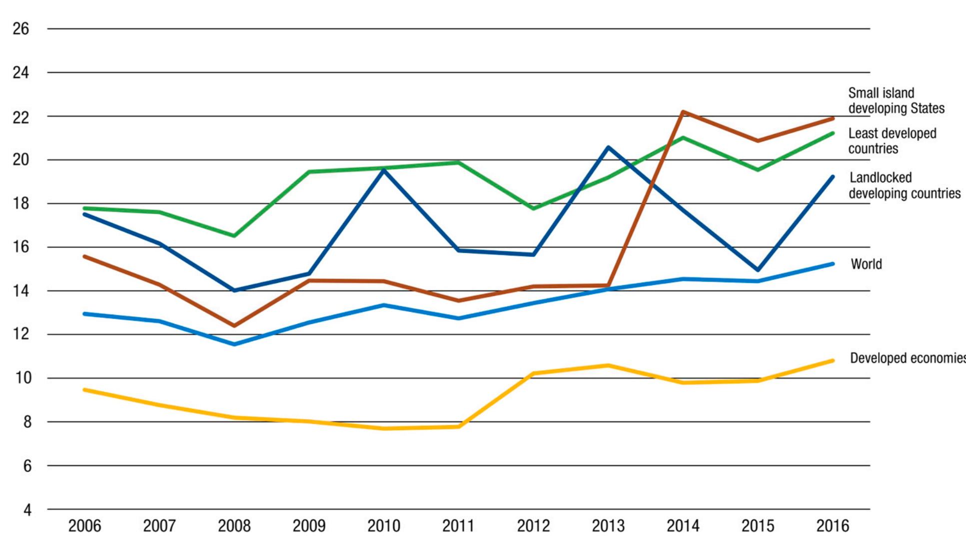

Fig. 1. Transport and insurance costs of international trade, 2006–2016 (percentage share of value of imports). Source: UNCTAD [85] (Reproduced with permission from UNCTAD).

requirements. In general, the share of shipping costs in the import value of goods with a higher value per ton is lower than that of goods with a lower value per ton. Korinek and Sourdin [47] report that 5.1% of the value of imported manufactured goods can be ascribed to shipping and insurance, compared with 10.9% for agricultural goods and 24.1% for industrial raw materials, which they explain with the higher value-to-weight ratio of manufactured compared to agricultural goods and industrial raw materials. This means that the impact of increasing transport costs on import prices of commodities with a low value per ton would be relatively high, but relatively low for commodities with a high value per ton.

3. Determinants of maritime transport costs

Considering the substantial variation in transport costs across regions and economic groupings, it is essential to improve our understanding of the factors that determine maritime transport costs and by extension gain an insight into the underlying reasons for these variations. This will ultimately assist us in identifying the impact of a carbon price on maritime transport costs. To date, various studies have attempted to provide explanations for transport cost variation by studying their determinants. In this section, we provide a comprehensive literature review to systematically synthesise various disconnected explanations for maritime transport cost variations and define them with the perspective of potentially impacted countries in mind.

Prior to commencing this analysis, it is important to distinguish the term "transport costs". In this paper, it is characterised as the cost that is incorporated in the final price of a good that is available at the importing country. The destination price of a good or "Cost, Insurance and Freight" (CIF) price incorporates the value of a set of all existing trade costs between the origin and the destination countries. These costs are a multiple of the factory price or "Free on Board" (FOB) price of the commodity that is traded [2,27]. The elements of the set of trade costs can be geographical and cultural differences, tariffs, trade agreements, and transport costs. Given that the provider of the transport service, the carrier, operates using a characterised cost function, the price they set, also called the freight rate, will be a function of the marginal cost and any existing markup. Thus, the CIF-FOB differential attributed to transport costs is determined by the cost function of the carrier which incorporates information about the costs of (un)loading goods, their shipment from one location to another, accounting for geographical and geopolitical factors, the market which the carrier operates in and the characteristics of the transported goods. For the carrier the generated revenue from transporting the commodity is defined as the freight. In this paper, the two terms, freight and transport costs are identical, however we will adopt the latter term for consistency with the literature on international trade which predominantly uses this term. Based on Clark et al. [17], Korinek [48], UNCTAD [84] and the literature reviewed therein, there are five different groups of determinants that affect the production function of a carrier, and thus maritime transport costs.

3.1. Geographical and geopolitical factors

Geographical and geopolitical factors include geographical distance, shipping connectivity, position within the global shipping network, piracy and other risks. The impact of geographical distance from one market to another is the most studied element of transport costs [48], and it affects the production function of a carrier in terms of time and fuel. This positive causal effect of distance on maritime transport costs lies between 14% and 30% for every doubling in distance [17,34,35,37,53,89].

The economic distance, expressed in terms of shipping connectivity and a country's position within global shipping networks, is further important for determining maritime transport costs. Analysing containerised maritime intra-Latin American trade, Wilmsmeier and Martínez-Zarzoso [90] find that being peripheral in the maritime network has a higher impact on maritime transport costs than distance. Relatedly, Wilmsmeier and Sanchez [91] show that if a country can 'double' its centrality in the maritime network and thus significantly increase its direct liner services to more countries, its transport costs can decrease by up to 15.4%. These results "underline the fact that the position within the network has a more significant impact than the notion of distance, the latter only expressing the geographical distance between the trading partners, but not the level of quality to breach that distance" ([91], p. 62).

Building on UNCTAD's Liner Shipping Bilateral Connectivity Index, Fugazza [31] demonstrates that lacking a direct maritime connection with a trading partner is associated with a drop in export value by between 42% and 55% and that any additional transhipment to connect country pairs is associated with a 20–25% lower value of exports. Lazarou [52] finds that remote countries trading by utilising at least one maritime hub incur 26% less transport costs compared to them trading directly with those partners. He concludes that trading via a geographically advantaged location improves market access, own and transit infrastructure while reducing exposures to trade costs.

These findings should be seen against the background that less than 20% of coastal country pairs have a direct maritime connection between them, meaning that transhipment is required and that in developing countries, the average number of direct maritime connections is half compared to developed ones [85]. The problem of low connectivity is particularly pronounced for SIDS across all regions. Most SIDS are geographically remote and lie outside the major maritime trade routes. Maritime belts or corridors carry around 85% of global containerised trade flows but do not traverse the southern hemisphere where many SIDS are located. Due to their low trade volumes, many SIDS have to rely on hub-and-spoke services which increase maritime transport costs as they are served by smaller vessels with the associated higher costs per cargo unit [58,83].[2]

3.2. Ship running costs

Ship running costs determine the portion of the freight rate requested by the carrier to transport goods between two locations and costs, and concern the operation and ownership of the vessel. The costs of running a ship are determined by fixed or variable factors. In the absence of an internationally accepted standard cost classification for the shipping industry, Stopford [75] outlines five major cost categories:

1. Operating costs – ongoing expenses involved with running the ship, including costs for crew, stores and consumables, maintenance and repairs and insurance. Excludes fuel costs.
2. Periodic maintenance costs - incurred when the ship is drydocked for major repairs.
3. Voyage costs – costs associated with undertaking a specific voyage, including fuel/diesel oil, port charges and canal dues (if applicable).
4. Cargo-handling costs – costs related to loading, stowing and discharging cargo.
5. Capital costs – depend on the ship financing and may include interest/dividend and debt repayment over a period of time depending on the financing mechanism.

The type of shipping contracts determines who bears the above-mentioned costs. There are a number of shipping transport contracts, but ultimately, these fall into two main types - the spot and time charter.

[2] UNCTAD [85] gives a few examples of SIDS' low connectivity: Sao Tome and Principe (Atlantic) are served by five ships on two services, Antigua and Barbuda (Caribbean) by four ships on two services, the Maldives (Indian Ocean) by two ships on two services, and Nauru and Tuvalu (Pacific) by just one ship on one service.

Rehmatulla and Smith [68] provide more details on the allocation between the different types of contracts.

Geographical and geopolitical factors may affect the carrier's ship running costs and/or their relative share in an ameliorating or a compounding manner. They could impose decisions on the carrier concerning the frequency of trips, choice of ship size and transhipment, or appropriateness of deviations. Ultimately, endogenizing these factors in the marginal cost of transporting the commodity defines the freight rate.

3.3. Shipped product

Factors relating to the shipped product (e.g. volume shipped, value of the product, value-to-weight ratio and product-specific transport requirements) influence the freight rate and determine the elasticity of demand, i.e. the shipper's willingness to pay higher rates. With regards to the value of the product, shippers of higher value goods are likely to require more careful or specialised handling and faster shipment to protect their product and ensure timely delivery [38]. Besides, insurance charges for products with a higher unit value are higher per unit of weight [57]. Wilmsmeier et al. [89] find that doubling the unit value of the shipped product leads to a freight charge increase of 26.6%. Wilmsmeier and Sanchez [91] show that a 10% rise in the value of containerised food imports to South America increases transport costs by around 7.6%.

Furthermore, there is an empirical link between the volume of shipment and transport costs because a higher cargo volume enables economies of scale, both on the sea leg as well as in port. As the individual shipment increases, the transport costs per ton decrease. Wilmsmeier et al. [89] find that a 10% increase in the volume of a transaction leads to a reduction of freight charges by about 0.1%. Economies of scale do not just apply at the vessel level but are also related to the total volume of trade between two regions and can be realised if utilisation ratios are high. This may be because more transited routes are covered by larger ships or because they present more competition due to the higher number of companies covering the route [17]. Skiba [73] estimates that a 10% increase in the regional volume of shipping reduces transport costs by about 0.6% in the short run and by about 2.5% in the long run, whereas Wilmsmeier et al. [89] find that a 10% increase of the bilateral containerisable trade only reduces freight charges by 0.065%.

Over the past few decades, the participation of developing countries in seaborne trade has grown significantly and in 2017, their share in goods loaded and unloaded worldwide has amounted to 60% and 63% respectively [86]. However, contributions by individual countries or country groups are uneven. For example, in 2017, the share of world merchandise exports and imports of LDCs as a group was just below 1% and at 1.4% respectively and even lower for SIDS at 0.1% for exports and 0.2% for imports [79]. Such low trade volumes generally result in higher maritime transport costs which in turn further impedes trade.

3.4. Market-specific factors

Market-specific factors refer mainly to market segment, market size, trade imbalances, competition, market regulation and the performance of the logistics sector. Seaborne freight occurs mainly through two types of market segments: liner services and tramp services [75]. Liner services operate a regular service between ports whereas tramp shipping operates on voyage basis and each of these have different cost implications. Tramp shipping, which mainly carries bulk cargo, is focussed on reducing the unit cost through economies of scale whereas liner services are more concerned with speed, reliability, and quality of service [75]. On some bulk shipping routes, ships sail full in one direction and return nearly empty in the other. Liner services with spare capacity often accept a lower freight rate than those whose ships are already full. Trade imbalances are particularly important for the cost of container transportation as the repositioning of empty containers must be factored in. Consequently, freight rates will be higher for the shipments transported on the leg of the trip with more traffic (front-haul), in part reflecting that roundtrips are made with lesser paying legs (back-haul). Furthermore, overcapacity on the trip with less traffic will increase the competition between liner services, resulting in generally lower freight rates [69,91]. Fuchsluger [30] observes this phenomenon in the bilateral trade between the US and the Caribbean where in 1998, 72% of containers sent from the Caribbean to the United States were empty which implied that a United States exporter paid 83% more than a United States importer to ship the same type of merchandise.

Most SIDS across the world experience significant trade imbalances, relying heavily on imports but often exporting comparatively little. Table 1 shows the merchandise imports and exports for SIDS and highlights that apart from Trinidad and Tobago, Mauritius, Seychelles and Solomon Islands, import values in 2017 were multiples of export values.

Another relevant market-specific factor is price-setting. To a large degree, price-setting in transport markets depends on the level of free competition which in turn is contingent on effective market regulation and the size of the market. Hummels et al. [38] find that more carriers operating and competing on a route lowers the shipping prices and reduces the carriers' ability to discriminate prices across products. According to Hummels et al. [38], prices for shipping Latin American imports are, on average, 30% higher than those for US imports and one-third of this difference is due to the limited number of carriers serving Latin American importers. The number of carriers is related to the total trade volume: Trade growth along a route promotes entry of and hence competition between firms, thereby lowering costs for both importers and exporters. In contrast, on routes with low trade volumes – characteristic for many SIDS -, shipping companies are often in a mono- or oligopolistic situation in which higher volumes need not bring in additional competition to reduce prices [48,84].

The number of carriers also depends on effective market regulation: Impediments to free competition, the potential existence of collusive behaviour and monopolies are all likely to impact price structures [84]. According to Fink et al. [28], trade liberalisation and breaking up private carrier agreements would, on average, reduce liner transport prices

Table 1
Imports and exports of merchandise in 2017 (percentage of GDP).

Region/country	Imports	Exports	Region/country	Imports	Exports
Caribbean			**Pacific**		
Antigua and Barbuda	33.6%	2.5%	Fiji	45.2%	17.9%
Bahamas	25.6%	4.7%	Kiribati	70.6%	8.2%
Barbados	32.1%	9.8%	Marshall Islands	43.3%	19.3%
Dominica	38.1%	2.3%	Micronesia (Federated States of)	50.6%	12.7%
Grenada	37.3%	2.7%	Nauru	32.1%	17.9%
Jamaica	39.3%	8.8%	Palau	55.1%	2.2%
Saint Kitts and Nevis	31.0%	5.0%	Samoa	43.2%	5.4%
Saint Lucia	36.1%	7.0%	Solomon Islands	47.7%	41.7%
Saint Vincent and the Grenadines	41.7%	5.4%	Timor-Leste	22.3%	0.9%
Trinidad and Tobago	30.7%	38.9%	Tonga	46.9%	3.8%
Average	**34.5%**	**8.7**	Tuvalu	60.5%	0.5%
			Vanuatu	42.1%	5.3%
Indian Ocean			**Average**	**46.6%**	**11.3%**
Comoros	23.6%	3.6%			
Maldives	49.8%	6.7%	**West Africa**		
Mauritius	39.6%	17.7%	Cabo Verde	44.6%	2.8%
Seychelles	86.6%	36.4%	Sao Tome and Principe	40.2%	4.1%
Average	**49.9%**	**16.1%**	**Average**	**42.4%**	**3.5%**

Source: [78,79]

by one-third and lead to cost savings of up to US$3 billion on goods carried to the United States alone. Bertho et al. [13] find that maritime transport costs on routes with restrictive liner shipping policies are between 26% and 68% higher than on 'open' routes, and this is estimated to reduce trade flows by 48–77%, depending on the level of restrictiveness.

Wilmsmeier and Sanchez [91] investigate the impact of the logistics sector's performance on transport costs, finding that countries with higher levels of logistics competence have lower transport costs for imports and that higher reliability in terms of shipments reaching the consignee within schedule has a significant impact on reducing transport costs.

3.5. *Infrastructure*

Infrastructural factors include port infrastructure and performance, private sector participation and inter-port connectivity. Port infrastructure and performance are vital for the efficiency and effectiveness of the maritime network and their importance for determining maritime transport costs has been well established in the literature. According to Wilmsmeier et al. [89], port efficiency is the most important determinant of international maritime transport costs in Latin American countries and doubling port efficiency of two ports involved in bilateral trade has the same impact on international transport costs as halving the distance between them. They also show that port infrastructure, inter-port connectivity and private sector participation all have significant impacts on transport costs. Micco and Perez [57] and Clark et al. [17] find that improving port efficiency from the 25th to the 75th percentile in an international rating lowers shipping costs by 12% or the equivalent of 5000 miles in distance, whereas inefficient ports are equivalent to being 60% farther away from markets to the average country. Upgrading a country's infrastructure from the 75th percentile to the 25th percentile is found to reduce the country's transport costs by 30–50%. The same authors [17,57] also highlight that institutional factors play an important role in port efficiency: for example, an increase in organised crime from the 25th to the 75th percentiles reduces port efficiency from 50th to 25th percentiles.

The time in port is an indicator for a port's efficiency and trade competitiveness: short turnaround times save ports, carriers and shippers money on port infrastructure investments, capital expenditures on ships and holding costs of inventory, whereas longer times in port have the reverse effect [84,87]. Hummels and Schaur [36] estimate that each additional day cargo spends in transit is equivalent to an ad valorem tariff of 0.6–2.1%, and Wilmsmeier et al. [89] estimate that cutting the time it takes to clear customs by 10% reduces the maritime freight charges by about 0.5%. Batista and Lazarou [9] find that the top ten Brazilian ports spend over 1.6 times longer to handle the same volume of cargo compared to the US top ten ports.

Two indicators can shed light on the performance and efficiency of ports across the world: the 'Efficiency of Seaport Services' indicator of the Global Competitiveness Index 2019 and the 'median time in port' indicator by UNCTAD, see Table 2. They show that the efficiency of seaport services is highest and the median time ships spend in port lowest for developed countries which further contributes to explaining their relatively lower transport costs. Developing economies score worse on both indicators, with LDCs scoring lowest: the average port turnaround time in LDCs is more than twice that in developed countries. Perhaps surprisingly, SIDS score second-best on both indicators[3] which UNCTAD [87] explains is due to low frequencies – no congestion or waiting times - and low volumes (un)loaded at each port call.

Landlocked developing countries face particular difficulties: their lack of access to international seaports means that to access global markets, they need to rely on connections through transit countries and hence they do not just depend on the state of their own infrastructure and regulations, but also on those in their neighbouring countries, as well as on the application of specific rules regarding freedom of transit [6,52]. ESCAP [23] estimates that the level of development in landlocked developing countries is, on average, 20% lower than it would be were they not landlocked, that their trade costs are twice as high compared to the transit countries and that their share of global exports was less than 1% in 2015.

Table 2
Indicators of port performance and efficiency for different economic groupings.

Development Status	Global Competitiveness Index 2019 – Efficiency of Seaport Services[b]	Median time in port (in days, for all ships, 2018)
Developed economies	4.88	1.00
Economies in transition	3.15	1.66
Developing economies	3.82	1.54
LDCs	3.00	2.35
SIDS	4.24 (majority of SIDS not covered)	1.43

[b] Response to the survey question "In your country, how efficient (i.e. frequency, punctuality, speed, price) are seaport services ferries, boats)?" [1 = extremely inefficient, among the worst in the world; 7 = extremely efficient, among the best in the world].
Source: [70,76,80]

3.6. *Measures to decrease maritime transport costs*

Being landlocked or far from the world's economic centres typically increases transport costs, as do poor physical infrastructure, low trade volumes and trade imbalances. As shown in the preceding sections, many of these factors are associated with low-income economies, in particular SIDS and LDCs, which explains why developing countries generally pay (often substantially) higher transport costs, thereby increasing the barriers to participate in international trade. While some of the determinants of maritime transport costs are out of reach of policymakers (natural barriers), artificial barriers can be influenced through measures taken at an international, regional, national or company level.

UNCTAD [82] suggests three different strategies that national policy-makers could focus on to lower their transport costs, i.e. 1) developing coastal shipping, e.g. by opening cabotage, improving maritime infrastructure; 2) developing port competitiveness which would increase competition between ports, e.g. by improving port administration, management structures, operations and infrastructure; and 3) developing port hinterland connections, e.g. by improving the intermodal interface.

Related to the second and third strategies, Wilmsmeier and Sanchez [91] identify that development of ports as gateways, capacity and knowledge building in the transport sector and policies that target innovation, easing of border crossings, promoting cargo consolidation and warehousing could reduce maritime transport costs.

To improve port connectivity, Benamara et al. [12] recommend exploring the opportunities arising from digitalisation; linking domestic, regional and global networks; ensuring competition between terminal operators; modernising ports; widening the hinterland; promoting sustainability and monitoring ports' connectivity. Ship turnaround times in ports could be reduced through port call optimisation initiatives and by ensuring that once a ship arrives at the pier, operations start immediately – the latter could be facilitated through implementation of relevant international agreements.

[3] It should be noted that the Global Competitiveness Index does not cover the majority of SIDS.

4. The impact of a carbon price on maritime transport costs

From a conceptual point of view (see Fig. 2), the introduction of a maritime carbon price would increase fuel expenditures and thus voyage costs, could lead to increased maintenance costs and might result in higher capital costs if adjustments to the technical specification of the ship were needed in response to the introduction of the carbon price. These factors are all captured under ship running costs, one of the determinants of maritime transport costs. As the ship running costs constitute just one component of maritime transport costs, one would not expect the impact of a given carbon price to be an equivalent percentage increase in maritime transport costs. The latter are part of overall transport costs which in turn contribute to wider trade costs. Transport costs' share of the value of imports varies depending on the product and region, but for the average country, amounted to approximately 9% during the decade 2005–2014 [84]. This means that the impact of a given carbon price on the prices of imported goods would be even further diluted than the impact on maritime transport costs.

We proceed by first reviewing the literature that has attempted to assess the potential impact of introducing a carbon price on maritime transport costs and, by extension, on the costs of imported products. This is followed by a case study on how rising maritime transport costs could affect export quantities in Pacific SIDS.

To date, several studies have been conducted which assess the range of impacts of introducing a carbon price on maritime transport costs and the price of imported goods. Table 3 presents an overview of these studies.

Faber and Rensma [26] assess the effect of a carbon price for shipping on, inter alia, transport costs, import costs and food prices. At a fuel price of around US$700/tonne HFO (US$450/tonne HFO), a carbon price of US$30/tonne CO_2 would add 13% (21%) to fuel costs and 4–8% (6–12%) to total transport costs. Based on a transport cost increase between 4% and 8% and a share of transport costs in value of 4–10%, the average cost increase of imports is estimated to be less than 1%. For islands most dependent on food imports by sea, the study estimates that as a share of GDP, costs of food imports may increase by 0.03% for a carbon price of US$10/tonne CO_2 and by up to 1% for a carbon price of US$50/tonne CO_2.

Anger et al. [3] assess inter alia the economic impacts of a GHG emissions fund for international shipping and an Emissions Trading Scheme (ETS). For the fund, they use carbon prices between US $2.4–14.2/tonne CO_2 in 2015 rising to approximately US$6.6–38.8 in 2050. Allowance prices for the ETS start at US$56/tonne CO_2 in 2020 and rise to US$1022/tonne CO_2 in 2050. One key assumption is that 95% of total revenues raised would fund climate change adaptation and mitigation in SIDS, LDCs and landlocked developing countries, with the fund generating up to US$11.85 billion and the ETS US$446.72 billion by 2050 for this purpose. For both schemes, they find impacts on export and import volumes, as well as on import prices of food and drink and agricultural products to be negligible to very small. Slight positive increases in global GDP, as well as in GDP of developed, developing and least developed countries are identified. However, the authors highlight that under the ETS, LDCs' GDP is projected to grow by 2.46% by 2050, which shows the positive impact large revenue transfers for climate projects could have.

Kronbak et al. [50] analyse how introducing a GHG contribution towards an International Fund for GHG emissions from ships might affect maritime transport costs. Using container transport as an example, taking vessel speed into account and assuming a fuel cost of US $550/tonne, a GHG contribution of US$45/tonne of bunker fuel (which based on heavy fuel oil would be roughly equivalent to a carbon price of US$14/tonne CO_2) is calculated to lead to an 8% increase in fuel costs and a 1–5% increase of the sea transportation unit cost, with larger container ships having a slightly lower rate of increase than smaller ships. The authors find that the distance of the voyage and the ship's load factor have little effect on the rate of the sea transportation unit cost increase, whereas vessel speed and fuel price both have a significantly positive effect on the increase rate of the unit cost, meaning that these two variables should be focused on when discussing the impact of a GHG contribution on transport costs. Based on the higher increase rate of 5% and information on the freight rate as a percentage of the commodity price, the potential impact on commodity prices of introducing a GHG contribution of US$45/tonne fuel was calculated to be between 0.15% and 1.86% for the commodities examined. The study also found that the GHG contribution could to some extent alter the competitive situation for competing commodities in favour of the provider with a shorter sea transport route.

Faber et al. [25] analyse the impacts of a maritime emissions trading scheme on the shipping sector, as well as on different regions and country groups, assuming full auctioning of allowances. Based on fuel prices of US$360.5/tonne HFO and an allowance price of US$30/tonne CO_2 (US$15/tonne CO_2), the costs increase for six different ship types considered ranges from 7% to 16% (4–8%) of total shipping costs. Higher allowance prices increase the share in total costs, whereas higher fuel prices lower the share in total costs. The price increase of goods would range between 0.4% and 3% (0.2–1.4%). The overall economic impact on regions and country groups is low, however the study finds that developing countries face higher costs relative to GDP than developed countries. In first-order approximation, the cost increase in maritime transport at an allowance price of US$15–30/tonne CO_2 (US $10–50/tonne CO_2) would vary from 0.02% to 0.04% (0.01–0.06%) of GDP for developed countries to 0.07–0.15% (0.05–0.25%) of GDP for most groups of developing countries. For SIDS, however, the impact would be considerably higher at 0.45–0.89% (0.3–1.49%) of GDP.

IMO [39] contains the report of the Expert Group on Feasibility Study and Impact Assessment of possible MBMs which assesses different MBM proposals against nine criteria, including their cost-effectiveness and their potential impacts on trade and sustainable development, drawing on studies by DNV [20] and Vivid Economics [88], and other information provided to the expert group. Assuming that an MBM would increase bunker fuel prices by 10%, the study estimates that the effect on the total value of imports would be less than 0.2% and finds similar results for exports. The impacts of a 10% increase in bunker fuel prices on four types of cargo and ship types are then analysed:

- Iron ore (Capesize): UNCTAD [81] finds that iron ore freight costs would increase between 8.9% and 10.5%. Vivid Economics [88] estimates iron ore freight costs would increase by 5–14%, depending on the route and the size of the exporting firms.
- Crude oil (VLCC): UNCTAD [81] finds that tanker freight rates would rise by about 2.8%. Vivid Economics [88] estimates that the average VLCC freight cost would increase by 3.2–3.7%, with a range of 1.2–6%, depending on the route and importing country. The impact of increases in freight rates on crude oil prices is estimated to range between 0.2% and 0.4%.
- Grains (Panamax): Impacts vary by grain type and by market. Vivid Economics [88] calculates that freight costs would rise by 2.5%, wheat prices in South Africa by 0.2%, wheat prices in Kenya by 0.4%, and maize prices in Saudi Arabia by 0.7%.
- Furniture and clothing (container): Vivid Economics [88] estimates that prices for apparel and furniture would increase by 0.2% or less.

In Psaraftis' [64] review of previously submitted IMO MBM proposals, he expresses strong reservations with regards to some of the input assumptions underlying the modelling efforts in IMO [39], both regarding their accuracy and transparency, and advises that the numerical results of the model be interpreted with caution.

Chowdhury and Dinwoodie [16] determine the effect of spot bunker prices on spot freight rates for coking and steam coal. For every 10% increase in bunker prices, they find that spot maritime transport costs for coking coal are approximately unit elastic, as they increase by 11% with a standard error of 0.11 and by 10% with a standard error of 0.10 for

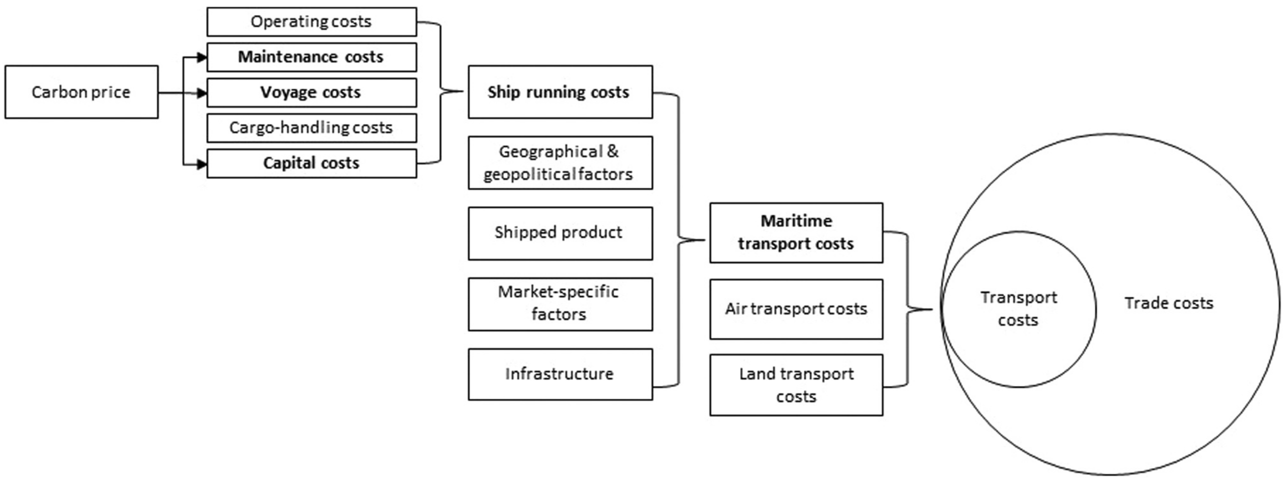

Fig. 2. Impact of a carbon price on the determinants of maritime transport costs.
Source: own figure.

steam coal. Average elasticities are higher for Panamax vessels and the Atlantic market than for Capesize vessels and the Pacific market.

Purvis and Grausz [66] estimate the impact of a maritime carbon tax of US$15–30/tonne CO_2 on the price of and demand for imports and exports in the United States. Using a baseline bunker fuel price of US $2.40/gallon (approximately US$741/tonne[4]), they find that prices of both US imports and exports would increase by 0.1–0.3%, with the price impact on imported raw materials and exported crude oil being highest (0.18–0.36% and 0.34–0.69%, respectively). The carbon tax would result in small demand reductions for US imports (0.6–1.2%) and exports (0.9–1.8%). However, the authors argue that the actual impacts could be much less because many studies estimate smaller demand elasticities for US imports and exports and because a significant share of lost imports would likely be replaced by additional domestic demand.

Anger et al. [4] assess the economic impacts of different MBMs for international shipping and aviation globally as well as on selected case study countries (Chile, China, Cook Islands, India, Kenya, Maldives, Mexico, Samoa, Togo, Trinidad and Tobago) for the period 2015–2025. Based on three different carbon prices (10, 30 or 50 US$/tonne CO_2), the study finds that globally, the reductions in GDP are on average less than 0.01%. The impacts on GDP are about 1% of GDP or less for all case study countries and MBMs considered, and less than 0.2% of GDP for most case study countries. The impact of MBMs on maritime transport costs is estimated to vary between 0.4% and 3.4% on average.

Miao and Fortanier [56] estimate the effects of distance, geographical incidence, time, oil prices, product unit values and infrastructure quality on international transport and insurance costs, expressed in ad valorem terms. Regarding oil prices, they find that an increase from US $25 to US$75 per crude oil barrel increases ad valorem costs by 1.4% points. Whilst this study focuses on the impact of rising fuel prices, an increase in oil price here is used as proxy for the equivalent increase in carbon price.

Sheng et al. [71] quantify the economic impacts of a global carbon tax on bunker fuels of US$18/ tonne CO_2 by 2030. Relative to the baseline scenario in 2030, the tax is projected to decrease global bunker emissions by 5.2%, generate approximately US$75 billion (in 2001 dollars) in revenues that year, raise import prices in each region by an average of 0.2% (but smaller changes to export prices) and lower import and export volumes by less than 0.4%. For select countries, the authors also simulate the impact of the tax on the annual GDP growth rate, as well as its aggregate economic effect considering different revenue distribution scenarios.

ben Brahim et al. [11] model pathways for the Danish maritime cargo sector to achieve CO_2-equivalent neutrality by 2050 for which they find that either a strong regulatory carbon budget or a carbon price of €350–400 (approximately US$387–443)/tonne CO_{2e} would be needed. This would double current average cargo transport costs, but only increase average import values by 6–8%.

The extant research summarised in Table 3 concludes that depending on the chosen input assumptions (transport segment and/or product studied, level of fuel and carbon price), the introduction of a carbon price on maritime transport would – in all except for one study - increase freight costs by between 0.4% and 16%, with most studies concluding that the increase would be below or around 10%. While this still presents a large spread, the impact on import prices is estimated to be small in most studies; mostly below 1%, with higher impacts generally estimated for commodities with a low value per unit of mass or volume. This is even the case for the assessment of high-rising ETS allowance prices in Anger et al. [3], but not so for ben Brahim et al. [11] who identify a doubling in transport costs and a 6–8% import price increase in response to a relatively high carbon price. Some studies show that the likelihood of SIDS and LDCs experiencing an increase in maritime transport costs and consequently in import prices is higher than for the rest of the world, further exacerbating the negative impacts experienced by SIDS and LDCs due to their already higher transport costs. The risk of SIDS and LDCs experiencing (disproportionately) negative impacts from a maritime GHG reduction measure is also highlighted by Psaraftis and Zis [65]. While the assessment was conducted for a candidate energy efficiency measure with presumably lower behavioural and technological responses than a carbon price, one can assume that such risks for SIDS and LDCs would increase with the introduction of a carbon price. Large revenue transfers for climate projects in SIDS, LDCs and landlocked developing countries could prevent such negative impacts and even result in positive ones, as shown by Anger et al. [3].

In the analysis of the impact assessments conducted for candidate short-term measures, IMO [42] highlights major shortcomings, both regarding the availability and reliability of data on transport and trade costs, especially for SIDS and LDCs. This also affects the studies reviewed in this section. Most of them also suffer from another shortcoming identified by IMO [42], i.e. oversimplifying the impacts a carbon price-induced speed reduction.

To date, available official data on transport costs remain few and limited in their geographic scope, level of product disaggregation and

[4] Using OPEC conversion factors.

Table 3
Overview of key findings from existing studies on the impacts of a maritime carbon price on maritime transport costs and the price of imported goods.

	Inputs/assumptions			Findings	
	Specific focus, if any	Fuel price assumption	Carbon price or bunker contribution	Increase in Maritime transport costs	Increase in import prices of goods
[3]	Carbon price		US\$2.4–14.2/tCO_2 (2020); US\$6.6–38.8 (2050)	Not specified	0.00% (food & drink, agricultural products)
	ETS		US\$56/tCO_2 (2020); US\$1022/tCO_2 (2050)	Not specified	0.00–0.08% (food & drink) 0.00% agricultural products
[26]		US\$700/tonne US\$450/tonne	US\$30/tCO_2	4–8% 6–12%	< 1%
[50]	Container shipping; select commodities	US\$550/tonne	US\$45/tonne fuel (US\$14/tCO_2)	1–5%	0.15–1.86%
[25]	Handy- and Capesize bulker, Handysize product tanker, VLCC, container and ro-ro	US\$360.5/tonne	US\$30/tCO_2 US\$15/tCO_2	7–16% 4–8%	0.4–3% 0.2–1.4%
[39]			10% increase of bunker fuel price	Not specified	< 0.2% (similar for exports)
	Iron ore			5–14%	
	Crude oil			1.2–6%	0.2–0.4%
	Grains			2.5%	0.2–0.7%
	Furniture & clothing				< 0.2%
[16]	Coking and steam coal		10% increase in spot bunker price	10–11%	
[66]	all, but impacts only determined for US	US\$2.40/gallon (~US\$741/tonne)	US\$15–30/tCO_2	Not specified	0.1–0.28%
	Agriculture (only US)				0.14–0.29%
	Raw material (only US)				0.18–0.36%
	Crude oil (only US)				0.06–0.13%
	Manufacturing (only US)				0.1–0.2%
[4]	all	US\$738/tonne	US\$10–50/tCO_2	0.4–3.4%	
[56]	all	US\$25/barrel (~US\$184/tonne)	Fuel price increase to US\$75/barrel (~US\$551/tonne)	1.49%	
[71]			US\$18/tCO_2	Not specified	0.2%
[11]	Danish maritime cargo sector		US\$387–443/tCO_{2e}	100%	6–8%

time duration.[5] This is mainly attributed to difficulties in data collection, origin and destination matching of shipments, expressing in a common unit and aggregation to official product levels [8,56]. Notable databases are the International Transport Costs Database maintained by ECLAC with data limited to Latin America and the Caribbean [22], the International Transport and Insurance Costs of Merchandised Trade [56] and the Maritime Transport Costs Database [47] available by the OECD. An additional resource is the recently launched Global Transport Costs Dataset for International Trade by UNCTAD and the World Bank. It covers 200 exporting and 105 importing countries and 95% of the value of global merchandised trade transported using four modes of transport [8]. This dataset could be used to test the findings of this paper regarding the impact of a carbon price on maritime transport.

While this study only assesses literature examining the impact of a maritime carbon price on maritime transport costs specifically, it is worth noting that several studies assess questions of high relevance for the IMO's analysis of impacts on States. For example, Kosmas and Acciaro [49] compare the economic implications of two different levies - a unit-tax of \$10–300 per ton of fuel and an ad-valorem tax with charges of 5–80% per ton of bunker. They find that the extent of a speed reduction response in the unit-tax case relies upon fuel prices and the tax amount, whereas in the ad-valorem case it depends on the enforced tax percentage. Both levies are found to lead to declining industry profits and that the extent of cost pass-through from ship-owners to shippers depends on market characteristics. Avetisyan [7] documents the quantitative impacts of the imposition of a global US\$27.3/Mt CO_{2e} GHG tax. He finds that such a tax causes a decrease in global emissions of 3.4%, following a larger decrease in transport output in regions where air transport substitution is low compared with regions that can substitute air with sea transport, as the service becomes relatively more expensive. The impact is felt more in developing countries characterised by higher economic emissions intensities of transport services, causing a reduction in exports while enhancing the competitiveness of transport services and exports from most developed countries. Mundaca and Strand [59] identify strong yet variable negative effects of fuel cost increases (used as proxies for maritime carbon pricing) on weight times distance for traded goods, and on CO_2 emissions from sea freight, for the heaviest 6-digit HS level goods in global trade, with bunker-price elasticities ranging from − 0.03 up to − 0.52.

4.1. The impact of rising maritime transport costs on export quantities in Pacific SIDS

To better understand the higher vulnerability of SIDS and LDCs to negative impacts resulting from introducing a carbon price on maritime transport, we test if and how maritime transport costs affect the export quantities of Pacific SIDS.[6]

Fig. 3 illustrates the average per unit transport cost for SIDS versus the rest of the world in five equal bins of the distance distribution between 1991 and 2007. Two conclusions arise from this categorisation. First, per-unit transport costs for Pacific SIDS exporting to the rest of the world are on average 6% higher compared to the rest of the world, irrespective of how distant the importer is. The cost to ship the same unit of a good is 21% more compared to the rest of the world when importing countries are further than the median of the distance distribution, or 11,789 km. Second, average per unit transport costs are decreasing in

[5] For an overview of areas of missing data and recommendations on how to alleviate these, refer to [43,44].

[6] The focus on export quantities, rather than on import quantities, export and import values, is due to data paucity.

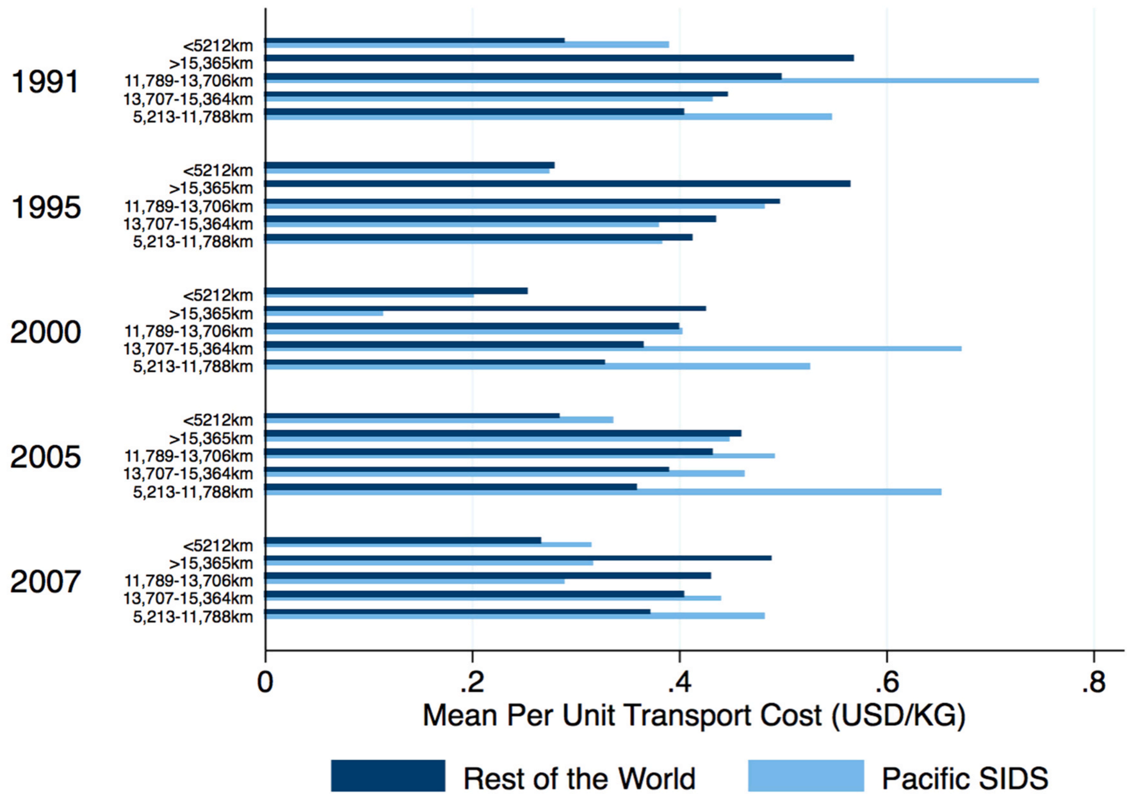

Fig. 3. Mean transport costs for Pacific SIDS compared to the rest of the world.
Source: Mayer and Zignago [55,62].

value across time. For the rest of the world, they decline by 11%, while for SIDS by 32%. The smaller the trading distance is, the larger the decline in transport costs across the period becomes. This effect is stronger for SIDS than the rest of the world and may be attributed to improved infrastructure in SIDS countries' enabling increasing participation in world trade over the past 30 years [83]. In this environment, the imposition of a carbon price will potentially lead to an increase in maritime transport costs and by negative correlation, a decline in traded volumes.

To test the impact of a rise in maritime transport costs on Pacific SIDS' export quantities, we consider a partial equilibrium gravity equation that links per-unit transport costs to the quantity exported with the inclusion of bilateral controls and fixed effects. The full model, data sources and tables of results are relegated to the Appendix.

We find that the quantity exported with respect to per-unit transport costs reduces between 8.3% and 18.5% for every 10% increase in per-unit transport costs. Insufficient data coverage prevents a conclusion for the Cook Islands, Kiribati and Solomon Islands. Fiji is the main driver of the aggregate result with exports decreasing between 8.3% and 19.8% for every 10% increase in per-unit transport costs. For Vanuatu, Papua New Guinea and French Polynesia, the impacts stand at 12%, 7% and 10% respectively, yet the IV estimation did not yield significant results and the estimates remain biased. Exports of coffee tend to be the most sensitive to changes in per-unit transport costs for the region with a decrease between 20% and 30% for every 10% increase in transport costs.

5. Concluding remarks

The first objective of this research was to analyse the importance, role and determinants of maritime transport costs for trade and economic development, focusing in particular on developing countries. The literature shows that transport costs are an important factor in determining a country's ability to participate in the world economy, with higher transport costs impeding this ability and often negatively affecting economic growth. On average, developing countries, and in particular SIDS and LDCs pay higher transport costs, effectively facing higher barriers to international trade participation. The underlying reasons for their higher costs can be identified when assessing the five groups of maritime transport cost determinants: ship running costs, geographical and geopolitical factors, shipped product, market-specific factors, and infrastructure. Many developing countries, SIDS and LDCs are landlocked or far from the world's economic centres and poorly connected, have low trade volumes and trade imbalances, as well as poor physical infrastructure. Jointly these factors are associated with higher transport costs. While some of these factors cannot be influenced by policymakers, there are many opportunities for transport cost reduction that could be achieved through measures taken at an international, regional, national or company level.

Secondly, this paper assessed how and to what extent the impact of a carbon price on maritime transport would affect maritime transport costs. Using the identified determinants of maritime transport costs, we find that a maritime carbon price would only affect one of these five determinants (ship running costs), hence one would not expect the impact of a given carbon price to be an equivalent percentage increase in maritime or even overall transport costs. As transport costs are just one of the constituents of wider trade costs, the impact of a given carbon price on the prices of imported goods would be even further diluted than the impact on maritime transport costs. This hypothesis is confirmed by research conducted to date which shows that depending on the chosen input assumptions, freight costs would – in all except for one study - increase by between 0.4% and 16%. The impact on import prices is estimated to be mostly below 1%, with higher impacts generally estimated for commodities with a low value per unit of mass or volume. Yet the likelihood of SIDS and LDCs experiencing an increase in maritime transport costs and import prices is higher than for the rest of the world which would further exacerbate the negative impacts experienced by SIDS and LDCs due to their already higher transport costs. We provide evidence in support of this argument by uncovering that the relationship between per-unit transport costs and the quantity exported from Pacific SIDS, tends to be negative and elastic. However, MBMs might also present opportunities for SIDS and LDCs, for example if the majority of revenues raised are invested in climate projects in their countries.

It should be noted that the carbon price assumptions in the existing research may not represent the level of carbon price needed for the shipping industry to reduce its GHG emissions in line with the IMO GHG Strategy's targets, either on its own or in combination with other climate mitigation policy measures. As upcoming IMO negotiations begin to clarify which measures will be further developed and at what stringency levels they will be implemented, more research will need to be conducted to understand impacts of those measures on transport costs and trade and other identified economic impacts, focusing in particular on those developing countries, SIDS and LDCs who already pay above-average transport costs. Furthermore, non-economic impacts such as transport dependency, food security and disaster response will need to be taken into consideration.

Finally, improving the availability and reliability of data on transport and trade cost, especially for SIDS and LDCs, will be pivotal for ameliorating the validity of future studies. To increase transparency and replicability of impact assessments and thereby increase trust in their findings, we also recommend developing common methodologies.

CRediT authorship contribution statement

Isabelle Rojon: Conceptualization, Investigation, Writing - original draft, Writing - review & editing. **Nicholas-Joseph Lazarou:** Methodology, Software, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Nishatabbas Rehmatulla:** Writing - original draft, Writing - review & editing. **Tristan Smith:** Conceptualization, Funding acquisition.

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Declarations of interest

None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2021.104653.

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