The cost impacts of Fit for 55 on shipping and their implications for Swedish freight transport

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Abstract

The purpose of the paper is to analyze the cost impacts of policy instruments that are part of the European Commission's climate policy package "Fit for 55". A disaggregated approach for the cargo ships calling at Swedish ports is applied to study the effects of different designs of the extension of the Emissions Trading System (EU ETS) to shipping and the changed Energy Tax Directive (ETD), which implies the introduction of taxes for marine fuel. Three scenarios are compared to the actual situation: the Main scenario is based on the European Commission's proposal that ships with at least 5,000 gross tonnage (GT) must be included in the EU ETS and that taxes for marine fuels are introduced, the Low scenario assumes no fuel taxes and the High scenario that ships with at least 400 GT must be included in the EU ETS. A major conclusion is that cargo ships calling at Swedish ports with at least 5,000 GT account for 56 % of all cargo ships and for 78 % of all CO2 emissions from these ships, which implies that a significant part of the CO2 emissions is missed when the European Commission's proposal regarding the inclusion of shipping in the EU ETS is applied. The share of missed CO2 emissions could further increase if ships smaller than 5,000 GT are chosen to avoid the EU ETS. Calculations with the Swedish national freight transport model Samgods confirm that firms have incentives to shift to ships smaller than 5,000 GT in the Main scenario while they have incentives to shift to ships larger than 5,000 GT in the High scenario. A recommendation is therefore that smaller ships than 5,000 GT should also be included in the EU ETS, and if this cannot be done immediately, the EU should clearly plan for ships with less than 5,000 GT to also be included in the long term and signal this to the market. This would reduce the incentives for the market to make socioeconomically undesirable adjustments to avoid paying for emissions. The fuel cost increases due to the implementation of the policy instruments are estimated per ship and aggregated to nine ship segments. In the Main scenario, the fuel cost increases due to the inclusion of shipping in the EU ETS are in the range of 11-42 % within the European Economic Area (EEA) and in the range of 5-21 % for transports to/from the EEA. In the High scenario, the costs in all segments are roughly 40 % within the EEA and 21% for the sea transports to/from the EEA. The introduction of fuel taxes is estimated to increase the fuel costs for all ships operating within the EEA by about 6 %. Calculations with the Samgods model indicate that the estimated higher fuel costs for shipping have limited impacts on the firms' choices of mode and port and their total logistics costs.

Keywords

Climate policy; policy design; impact analysis; shipping

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Q58; R48

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1 Introduction

Although shipping is considered to have good energy performance in comparison with other transport modes, it accounts for almost 3 % of the total global greenhouse gas (GHG) emissions annually (IMO, 2021). These emissions are expected to continue to increase significantly in the coming years as transport activity keeps growing and there are not enough corresponding improvements in energy efficiency or sufficient implementation of emission reduction measures and the sector is still highly reliant on fossil fuels (European Commission, 2021). Despite its climate impact, shipping has in large measure been exempted from any comprehensive international regulation or policy covering other transport modes because of the difficulty in enforcing corrective policies. However, some steps have been taken by the International Maritime Organization (IMO) regarding energy efficiency measures. In 2013, an index on energy efficiency for new ships (EEDI) and an energy efficiency plan for all ships (SEEMP) came into force. The regulations prescribe the minimum energy efficiency level per capacity mile for new ships for different ship segments and offer guidance to improve the energy efficiency of ships cost-effectively (EEOI). In addition, a data collection system (DCS) where ships must record and report their fuel oil consumption (MARPOL Annex IV) has been introduced. In 2018, the IMO adopted a mitigation strategy (Initial IMO strategy on reduction of GHG emissions from ships) for reducing the sector's carbon footprint by at least 50 % of the levels from 2008 by 2050 and reaching climate neutrality in the longer run (MEPC, 2018). To reach the global and regional climate targets, stronger regulations are needed for the crucial abatement of GHG emissions from shipping.

At the regional level, leaders of the European Union have settled on achieving climate neutrality already by 2050 in the Union which has been established in the European Climate Law (European Commission, 2021). The European Union's climate law specifies, among other things, that the net GHG emissions must have decreased by at least 55 % by 2030, compared to 1990. To establish a road map towards the 2030 target, the European Commission has drawn up proposals for policy instruments that are collectively called "Fit for 55" (FF55). The proposed instruments cover road, air, and sea transports and are expected to lead to increased transport costs, especially for goods transported by sea, as shipping initially only pays to a small extent for its GHG emissions. The FF55 package comprises four main parts that affect sea transport costs: 1) the extension of the Emissions Trading System (EU ETS) to shipping, 2) the changed Energy Tax Directive (ETD) which means an end to tax exemption for marine fuel, 3) the proposed “FuelEU Maritime” which means that a greenhouse gas intensity standard for marine fuel is implemented and 4) the proposed Directive of Deployment of Alternative Fuels Infrastructure (DAFI). This paper focuses on the first two parts.

For the extension of the EU ETS to shipping, a cap will be set on net maritime CO_2 emissions where the shipping company (i.e., the shipowner or other entity responsible) will have to surrender emission allowances that correspond to their emissions. Initially, it is suggested that only ships included in EU’s system for monitoring, reporting and verification (MRV database) will be included in the scheme. This means that ships with a gross tonnage (GT) of at least 5, 000 will be included which correspond to around 90 % of the total CO_2 emissions. However, the trading scheme is expected to be extended to smaller ships over at least 400 GT in the following years. The extension to the maritime sector is expected to start gradually in 2024 and increase over time to fully cover maritime emissions in 2026. The geographic scope has not yet been decided on but the main suggestion from the European Commission is that all emissions from voyages within the European Economic Area (EEA) and 50 % from all incoming and outgoing voyages to and from EEA ports to non-EEA ports will be covered (European Commission, 2021).

The suggested revision of the ETD would introduce a tax on marine fuel and energy products that have previously been exempted from taxation. Some of the proposed minimum taxation rates are € 0.9/GJ on HFO (Heavy Fuel Oil), € 0.6/GJ on LNG (Liquid Natural Gas), and € 0.15/GJ on electricity. Unlike the coverage of the EU ETS, it is suggested that the ETD cover all ships irrespective of size and apply to all energy usage within the EEA. The bunker procurer would be responsible for the tax payments (European Commission, 2021/0213).

The objective of the paper is to i) estimate the impacts of different designs of the extension of the EU ETS to shipping and the changed ETD on the fuel costs for cargo ships that call at Swedish ports and ii) model the implications of the higher fuel prices for shipping on the freight transports. No other greenhouse gas emissions than CO_2 emissions are considered.

Section 2 reviews and summarizes existing literature on market-based measures (MBMs) in the maritime sector. Section 3 presents the method and data used and section 4 presents the results. Both sections are divided into three parts: ships calling at Swedish ports, increased fuel costs for shipping, and adaptation to increased fuel costs for shipping. Section 5 provides a discussion and conclusions as well as recommendations drawn from the results and findings of the paper.

2 Earlier studies

In the literature, there is much written about the economics and potential for MBMs to reduce carbon emissions from the international maritime sector. MBMs are common tools to correct market failures by introducing a ‘polluter pays’ principle and internalizing the external cost of GHG emissions. The classic example of a policy measure to address market failures is to put a price on emissions, either as a tax or by setting a cap-and-trade system (Pigou, 1921).

Previous studies have examined the cost-effectiveness and potential for reducing emissions by either studying the optimal design of MBMs for successfully achieving the climate goals or by constructing different scenarios assessing the effects of a policy on the increased costs for the shipping sector and their carbon emissions. An example of a study on the climate policies suggested in the FF55 package is Ovaere & Proost (2022) who analyze the cost efficiency of the current proposals from the European Commission on addressing the externalities from the transport sector. They carry out a micro-economic partial equilibrium analysis for the different policy suggestions, for instance, the extension of the EU ETS to the maritime sector and the ETD and show that further improvements are needed to reach the EU’s climate targets at the lowest cost; higher taxes are needed on aviation and shipping to address the unbalance in the tax system between different transport modes which is foreseen in the current proposals. Similar findings are presented by ben Brahim et al. (2019), examining pathways for the Danish shipping sector to achieve CO_2 neutrality by 2050. The results indicate that a carbon price in the range of € 350 – 450/tCO_2 would be needed to generate the transition. In comparison with today’s carbon price of € 70/tCO_2, this means a substantial price increase, and the average cargo transport costs of today would double. However, for the price of transported goods, a carbon price in that range would only lead to a 6 – 8 % increase.

Lagouvardou et al. (2022) evaluate the effectiveness of a global bunker levy in achieving GHG emissions reduction by influencing a vessel’s speed reduction. The authors employ an optimization model optimizing the speed of a tanker vessel in the period 2010 to 2018 and show that a high bunker levy in the range of $ 900 – 1200/t could help reduce the GHG emissions from tanker vessels by up to 43 % as well as stimulate investments in alternative fuels and new technology. Hence, speed reduction alone is not enough to reduce the emissions by 50 % and achieve the goals of IMO. These results are in line with the findings of Ollila et al. (2022) that the average speed levels are already low, and it is uncertain if the speed can be further reduced to gain emission reductions.

In another study, Lagouvardou & Psaraftis (2022) investigate the risk of container ships engaging in evasive port calls by replacing EEA ports with nearby non-EEA ports: Piraeus by Izmir and Algeciras by Tanger. The authors find that the preference for a non EEA-port is attractive for carbon prices well below € 25 per tonne of CO_2 . In all cases, the switch from an EEA-port to a non-EEA-port results in a rise in the overall CO_2 emissions linked to the transport service which amplifies the risk of carbon leakage, leads to a revenue loss for the EU ETS and a penalization of the EEA ports in close proximity.

Moreover, another branch of studies has carried out impact assessments of different MBMs. Rojon et al. (2021) analyze the impact of a maritime carbon pricing measure on maritime transportation costs and find that the introduction of a carbon price has a limited impact on total costs as the cost increase only affects the ships’ running costs. However, the transport cost share of the value of imports seems to vary heavily from the product and region hitting ‘Small Islands Developing States’ and ‘Least Developed Countries’ the hardest. Based on a review of previous literature (e.g., Faber et al., 2010; Anger et al., 2013; Sheng et al., 2018), the authors conclude that a price on carbon in total would increase the average freight costs by between 0,4-16 % while the price of import only increases by around 1 %. The magnitude of the effects varies with the exogenous assumptions for the estimations, e.g., the fuel and carbon prices and for which vessel segments.

In another paper, Psaraftis et al. (2021) examine the potential of different MBMs (e.g., bunker/carbon levy and a global/EU ETS) for the reduction of GHG emissions from ships by carrying out a comparative evaluation of previous studies on MBMs on the maritime sector. Based on the review, a levy-based MBM exhibits several advantages over an ETS-based MBM, providing lower administrative costs and a more flexible implementation. Based on the results from previous studies on carbon levies (e.g., Devanney, 2010; Gkonis & Psaraftis, 2012; Kapetanis et al., 2014), the authors summarize that a fuel price increase by more than 50 % would result in over 50 % lower CO_2 emissions from oil- and dry-bulk ships. Higher prices on fossil fuels increase the incentives to use a higher share of renewables, low-carbon fuels, and technologies. Furthermore, to ensure a level playing field and avoid distortions, the authors argue that all ships should be subject to the regulation without exclusions, differentiations or rebates.

The European Commission (2021) has conducted an assessment of the impacts on maritime transport from the implementation of the EU ETS into the shipping sector, focusing on the possible changes in GHG emissions, risk of evasion (e.g., modal shift), and economic impacts. The assessment is carried out by using a comprehensive set of tools (e.g., the PRIMES-Maritime module and the GEM-E3 economic model) assuming a carbon price in the range of € 45. The European Commission estimates that the maritime sector would reduce its CO_2 emissions in 2030 by 45 million tonnes and the increased costs from the EU ETS are estimated to be around 7 % in 2030 and result mainly from allocation payments amounting to around € 7.7 billion. In the long term, an average increase in total costs is estimated to be approximately 16–20 % by 2050 stemming from the high penetration rate of renewable and low-carbon fuels which leads to higher fuel and capital costs. Regarding the risk of evasion, the increased cost of shipping could cause a shift from shipping to other modes such as road or rail. Nevertheless, the risk of a modal shift under the suggested policy is considered most unlikely. Yet, there might occur evasion of carbon pricing by operating ships below the threshold of 5, 000 GT in specific shipping sectors where the use of smaller vessels is common and where the compliance costs for the EU ETS are higher than the gain in efficiency related to the use of larger vessels. For the other policies, it is noted that the envisaged tax on maritime bunker fuel under the ETD would have a much smaller effect on costs than the EU ETS.

Wang et al. (2021) assess the effects of the EU ETS in three areas: investments in new technology, modal shift, and fleet composition. The findings imply that increased costs for CO_2 emissions create incentives for investing in abatement technology but might also result in a modal shift from shipping to rail or road as the transportation costs for shipping increase, in contradiction to the predictions by the European Commission (2021). The impacts of an EU ETS on the maritime sector and its effectiveness in promoting innovations within the sector are also studied by Cariou et al. (2021), who base their study on a sample of over 38, 000 European voyages carried out by oil tankers between 2017– 2019 estimating their annual emissions using AIS-data and assuming that all shipping into and from the EU is included in the ETS. The results show that a carbon price of \$ 10/ tCO_2 would increase the costs for a VLCC (Very Large Crude Carrier) by \$ 77,525 per voyage which corresponds to approximately 8.4 % of the ship's revenues from transportation. In contrast to what is discussed by Rojon et al. (2021), Cariou et al. (2021) argue that this could eventually lead to higher final prices of products if these cost increases are passed onto cargo owners. As found by Wang et al. (2021), the results show that the costs of carbon dioxide emissions induced by the EU ETS are enough to provide incentives for the industry to spur innovation and adaptation to new technologies as the price of the allowances is higher than the investment costs for sustainable technology.

Christodoulou et al. (2021) also assess the economic impacts of the inclusion of shipping in the EU ETS using the MRV database on the CO_2 emissions within the EEA. The authors use a scenario-based approach with different policy scenarios regarding price incentives, geographical scopes, and allocation methods. The findings indicate that the geographical scope is of most importance for deep sea shipping segments such as containerships and tankers, while short sea shipping segments such as

Ro-Ro and Ro-Pax are more or less affected in the same way irrespective of the scope. The findings also suggest that in the case of no free allocation of emission allowances, the effect will be asymmetrical on increased costs for different maritime segments, where Ro-Ro and Ro-Pax having the highest fuel consumption would be most affected by cost increases from the policy. As a result of these disproportional effects, the authors identify a risk for competition with other transport modes where increased freight rates could result in a modal shift.

Furthermore, Faber et al. (2022b) have on behalf of the Dutch Ministry of Infrastructure and Water Management conducted an analysis of the average annual costs of the FF55 measures for vessels sailing under the Dutch flag and/or command. The estimations are based on data from the MRV database on reported total fuel consumption and CO_2 emissions filtered on ship type size and the Dutch fleet. The costs are estimated for two periods, 2025– 2029 and 2030– 2034 assuming a fixed average fuel consumption and CO_2 emissions for each ship type and ship class during the periods. The results show that the additional costs from 2025 consist of the ETS, GHG intensity regulations in 'FuelEU Maritime' and ETD: a cost increase ranging between 61–73 % depending on the assumed price for biofuels. Divided by ship type, another study by Faber et al. (2022a) analyzes the EU ETS in terms of allowance costs for nine sample ships for the years 2025 and 2030, proving that Ro-Pax is the most impacted segment for the EU ETS in 2030 imposing additional costs ranging from € 2.52– 3.78 million. Similarly, Solakivi et al. (2022) have examined the effects of the suggested policies EU ETS, ETD, and 'FuelEU Maritime' for the Finnish maritime sector. Their estimations show that the costs for Finnish shipping could increase within the bandwidth of € 1, 000 to 1, 700 million in the year 2040 by the implementation of the policies. Almost 80 % of the value of the Finnish international trade is transported by sea with countries within the EEA area. Hence, these regulations might have a specifically strong effect on small open economies, such as Finland and Sweden. Based on an emission factor of 3.1 for a mix of conventional fuels and an EUA price (i.e., EU ETS carbon price) of € 80, the costs are estimated to increase by around 40 % per tonne of fuel. For a single ship segment, the authors also find that the fastest ships such as Ro-Ro and Ro-Pax are the segments most affected by the regulations since they consume the most fuel.

Another recently published study by Jivén et al. (2022) examines the cost implications for the Swedish shipping industry of the suggested policy measures within the FF55 package on an aggregated level by modeling different cost scenarios. The estimated costs are based on an energy consumption development scenario for fuel purchased within Sweden and total CO_2 emissions within the whole lifecycle (i.e., "well-to-wake", WTW). For the estimations, an EUA price of € 100 is taken as exogenous. In the short term, the results show that an implementation of the EU ETS would increase the costs for the shipping companies for fuel by around 70–80 %. These cost projections are higher than those found in the assessments by the European Commission (2021) and Solakivi et al. (2022). Reasons for this high-cost estimation might be the use of higher fuel costs as a base, counting emissions WTW instead of TTW ("tank-to-wake", accounting only for the emissions resulting from burning a fuel in the tank), and using an aggregated approach including all ship sizes and disregarding the threshold for inclusion. For ETD, the costs of fueling the ships would only increase by some 10 %.

There is also literature discussing different options for ship owners to react to the higher fuel costs imposed by the EU ETS and the ETD (e.g., European Commission, 2021; Faber et al., 2022b). To summarize, they can reduce their exposure to the EU ETS or ETD in the following ways by: i) shifting to other modes, ii) adding a port outside the EEA to minimize the amount of CO_2 emissions in the EU ETS scope, iii) changing the order of the ports in an existing schedule in such a way that a port close to the EEA is the first port of call in the EEA region, iv) removing EEA ports from the schedule and feedering to these ports from a non-EEA port, v) transshipping cargo in a non-EEA port to a smaller ship that is not included in the EU ETS, vi) optimizing the use of the fleet by using the best-performing ships on EEA-related routes and the less well-performing on non-EEA routes.

To our knowledge, this is the first paper to analyze the effects of the EU ETS and ETS proposals on shipping fuel costs using a disaggregated approach covering all cargo ships calling at Swedish ports. This paper is also the first to model the logistical and transport adaptation response of firms to higher fuel costs for shipping as well as effects on total logistics costs.

3 Method and data

The approach of this paper can be divided into three parts. Part one aims to give an overview of maritime freight transports to, from and within Sweden pre-FF55 EU maritime policy. This information is used in the Base scenario. It focuses on the composition of ships calling at Swedish ports in terms of size (in terms of GT), sailed port-to-port connections, and CO_2 emissions. Both ship size and sailed port-to-port connections are considered in the proposed design of the EU ETS while CO_2 emissions are estimated to assess the scope of the proposals. Part one is also meant to contextualize the results of Parts two and three. In Part two, the same sample of ships as in Part one is used to estimate the increased fuel costs of a full implementation of the EU ETS and ETD compared to the Base scenario. The estimated fuel cost increases are used in Part three as input in the modeling of the firms' adjustments to increased fuel costs and how the adjustments affect the logistics costs. The Swedish Transport Administration's freight transport model Samgods version 1.2 is used for the modeling. Furthermore, since at the time of writing this paper, negotiations are still underway regarding the designs and implementations of EU ETS and ETD, three different scenarios based on alternative designs are examined.

The Main scenario has been adopted based on the European Commission's proposal that ships with a minimum GT of 5,000 have to be included in the EU ETS and that the coverage must be 100 % within the EEA and 50 % for voyages to and from the EEA (extra EEA) and that the ETD should be changed so that marine fuel is taxed at € 0.9/GJ for HFO, MGO and MDO and € 0.6/GJ for LNG. In addition, a Low scenario has been adopted that assumes no EU ETS for voyages to/from the EEA (extra EEA) and no ETD tax, and a High scenario that presumes a minimum of 400 GT for the EU ETS. See Table 1. The High and Low scenarios are based on those examined in the impact assessment on the EU ETS by the European Commission (2021/0213) with different geographical coverage and size thresholds, and for ETD, the tax levels for the High scenario are based on the higher tax levels proposed for other energy products, while the Low scenario (assuming no tax on maritime fuel) are based on the likelihood that the ETD proposal will not be agreed upon at the EU negotiations.

Table 1. Assumptions regarding design of EU ETS and ETD in scenarios.

	Main scenario	Low scenario	High scenario
Minimum GT for EU ETS	5 000	5 000	400
EU ETS (intra EEA) EU ETS (extra EEA)	100 % 50 %	100 % 0 %	100 % 50 %
ETD (intra EEA) Tax HFO/MGO/MDO, €/GJ Tax LNG, €/GJ	0.9 0.6	- -	0.9 0.6

The price per emitted tonne of CO_2 is assumed to be € 80 (in agreement with the Swedish National Institute of Economic Research) and all scenarios are based on a static time perspective, i.e., the implementation of the policy instruments over time is not modeled. Instead, the scenarios are based on costs in 2026, when shipping should be completely included in the EU ETS according to the actual plans. Sailed kilometers, and CO_2 emissions are estimated for 2019 (the last year before the COVID-19 pandemic) and relative fuel cost increases are estimated for cargo ships calling at Swedish ports. It would have been possible to choose one or several future years as base scenario. However, using assumptions about the development of various factors would add further uncertainty to the analyses.

3.1 Ships calling at Swedish ports

To describe pre-FF55 maritime traffic to and from Swedish ports we use a disaggregated approach utilizing data from the Swedish Maritime Administration (n.d.) (SMA) on commercial vessel calls in 2019. It lists all calls at Swedish ports made by ships required to pay fairway dues, which excludes very small ships (<300 GT), towage vessels, search-and-rescue vessels and vessels operating in local public transport. However, the focus of this paper is on Swedish maritime *freight* transports of which this data gives a comprehensive record. Estimations are made at the individual ship level which are then aggregated into nine ship segments based on the coding system StatCode5 (level 3); see Table 2. Passenger ships are excluded, as mentioned. However, the included cargo ship categories cover approximately 96 % of the ships in the SMA data.

Ships in the SMA data are identified via IMO numbers enabling matching with external databases that provide additional information on ship attributes. The European Maritime Safety Agency (2022) MRV system is used for data on reported fuel consumption and CO_2 emissions in 2019 and a commercial ship database provided by IHS Markit (2020) gives information on ships' GT, deadweight tonnages (DWT), and classifications. MRV is the proposed monitoring system to be used for measuring CO_2 emissions for the EU ETS. CO_2 emissions in MRV are measured as TTW. Only ships of at least 5,000 GT are required to report to MRV, thus only approximately 56 % of the ships in the SMA data are represented. For ships under 5,000 GT, replacement values are produced by estimating linear relationships between size and fuel consumption by ship segment in MRV and then extrapolating values for smaller ships. See Appendix A.

Table 2. Ship segment classification.

Ship Segment	Statcode5 (level three) classes included
Chemical Tanker	"Chemical"
Container	"Container"
Dry Bulk	"Bulk Dry", "Other Bulk Dry", "Self Discharging Bulk Dry"
Gas Tanker	"Liquefied Gas"
General Cargo	"General Cargo", "Other Dry Cargo"
Oil Tanker	"Oil"
Ro-Pax	"Passenger/Ro-Ro Cargo"
Ro-Ro	"Ro-Ro Cargo"
Additional	"Barge", "Other activities", "Refrigerated Cargo"

For each port call, SMA also lists the ship's port of departure and its destination (when available). In other words, for each call a ship made in a Swedish port, two port-to-port connections are known as well. A sailed port-to-port connection is henceforth referred to as a voyage. We use these port-to-port connections in two ways. First, to trace ships in the travel patterns of Swedish maritime traffic in terms of extra- and intra-EEA voyages. Second, to estimate total fuel consumption and CO_2 emissions by estimating each ship's total traveled distance to or from Swedish ports and then multiplying these distances by each ship's average fuel consumption per kilometer and average CO_2 emissions per kilometer respectively.

To do this, port-to-port connections are matched with two external databases on port-to-port over water distances, one from the Swedish transport statistics agency (Transport Analysis, 2019) and one from Eurostat (n.d) used for port-to-port connections not covered by Transport Analysis. Both databases identify ports using codes in the UN/LOCODE system (henceforth referred to as port codes) while SMA identify ports of departure and destinations with location names. Thus, to enable matching, ports in the SMA data are first assigned port codes by matching port names with the United Nations Economic Commission for Europe list of all ports assigned a UN/LOCODE (UNECE, 2022).[1] Port-to-port connections are then matched to the distance databases and, using port codes, classified as intra- or extra-EEA. One exception are ships in the segment Ro-Pax where most ports of departure and destinations are missing in the SMA data. For these ships, traveled distances are instead estimated using output from the Swedish Meteorological and Hydrological Institute Shipair model which covers CO_2 emissions in the Baltic Sea and some surrounding areas (Windmark, 2020).

Excluding Ro-Pax, 72 % of all voyages to or from Swedish ports can be assigned distances over water. Remaining port-to-port connections are assigned replacement distances by taking the average distance of port-to-port connections to and from the same Swedish port of arrival as for the missing connection. This yields a final coverage rate of 95 %. The remaining 5 % are due to 23 Swedish ports of arrival not being part of any of the available distance databases. The share of voyages with replacement distance varies between ship segments by an average of 26 %. Ro-Ro has the highest share, 41 %, and Container the lowest, 3 %.

As mentioned, data on ports of departure and destinations are not available for all calls. Voyages between two Swedish ports are listed twice in the SMA data, since two calls in Swedish ports are made, even though the port-to-port connection is only sailed once. Thus, when data on the destination of a ship is missing, the same voyage is counted twice if the missing destination is a Swedish port. However, it is unlikely that all missing ports are Swedish, and the share of missing destinations is ≤ 2 % for all ship segments apart from Dry Bulk, 11 %, and Ro-Ro, 17 %.

3.2 Increased fuel costs for shipping

To estimate increased fuel costs due to the EU ETS and ETD, the datasets from the SMA and MRV are used. As in Part one, we use a disaggregated approach where relative increased fuel costs are first estimated for each ship and then averaged for each ship segment as defined in Table 2. To be as current as possible, pre-FF55 fuel costs are based on the average prices of 2021 i.e., € 595 per tonne for ships using MGO, MDO or HFO and € 968 per tonne for ships using LNG.[2] To distinguish ships (likely) using LNG, the same approach as in IMO (2021) and information on ship attributes from the IHS database are used. Approximately 2 % of the ships are estimated to use LNG in 2020.

The estimates of increased costs per km per ship are also used to estimate input for the Samgods model. However, Samgods has its own classification of vehicles and ships: maritime transports are represented by 21 ship types used today that are defined by ship category and size measured in DWT.

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[1] The United Nations Code for Trade and Transport Locations (UN/LOCODE) is an international standard of five-letter codes that uniquely identify locations of transportation and trade. It is administered by the United Nations Economic Commission for Europe (ECE).

[2] Based on information from shipandbunker.com.

Samgods comprises as “ship types” four Container ships, three Ro-Ro ships, three Ro-Pax ships, one Rail ferry and ten “Other ships”. To estimate increased fuel costs per km for these ship types, ships in the sample from SMA are grouped based on the best Samgods ship type match. Each group includes all ships of a corresponding ship category whose DWT falls within a +/- 40 % interval of each Samgods ship type. The averaged fuel cost increase for each ship type is then estimated. Samgods version 2.1 uses the base year 2016/17. Thus, fuel costs per km in 2026 in scenarios run using the model are estimated by increasing the fuel cost per km for each ship type, compared to the base scenario that describes the pre-FF55 situation, by the same magnitude as the costs were estimated to increase for each corresponding group.

3.3 Adaptations to increased fuel costs for shipping

The Samgods model is a scenario-based freight transport tool (see de Jong & Baak, 2020; Edwards, 2019; de Bok et al., 2020; Swedish Transport Administration, 2020a,b,c). Its main use is to offer a methodological scientific decision basis for Swedish national transport infrastructure planning, for example, providing forecasts and assessing the effects of infrastructure investments, but it is also used to carry out impact assessments for different policies. Recent studies have used the Samgods model to examine the economics of electric roads (Börjesson et al., 2021) or the introduction of driverless trucks (Engholm et al., 2021). Typically, an investigation scenario is compared to a base scenario. In this paper, the three scenarios regarding the implementation of EU ETS and ETD described in Table 1 are used as investigation scenarios compared to the Base scenario.

Samgods uses a deterministic cost-minimizing commodity-based approach to find transport patterns along multi-mode multi-vehicle type transport chains from exogenous data on trade patterns, infrastructure, and logistics costs. Logistics costs comprise transport costs, warehouse costs and order costs. Using a multi-mode multi-vehicle and ship type model is important to assess any effects on modal shift and vehicle size shift. Decisions made on a disaggregated level are based on minimizing logistics costs, where individual firms can act differently in the case of a cost perturbation, thus analyses of such changes of costs are well suited for this model. Changes in costs might change what vehicle/ship type is used (within or to another mode) or the usage of infrastructure (e.g. ports).

A modification of the Samgods model was required to include the costs generated by the EU ETS and ETD. The cost changes estimated in Part two are specific with respect to i) ship type/size and ii) port-to-port relationship. The latter means that these costs do not fit Samgods' cost structure, which is not differentiated between specific ports. The procedure developed to consider this works as follows: after Level of Service matrices (LOS matrices) are calculated, cost increases are calculated per port-to-port connection using information about the distance between ports (Equation 1) and added as a per passage-dependent cost in the LOS matrix. The procedure is different from the approach applied to model the impacts of higher fuel costs for shipping in the Sulfur Emission Control Area (SECA) that comprises the Baltic Sea and the North Sea (See Vierth et al., 2015), where a distance-dependent cost was converted to a per passage-dependent cost and applied to transport within a defined geographic area.

The cost generated by the EU ETS and ETD is calculated according to

$$ETS\ ETD\ cost^{f,od} = c_{dist}^{f} \cdot c_{rel}^{f,od} \cdot L^{od}$$

Equation 1

where

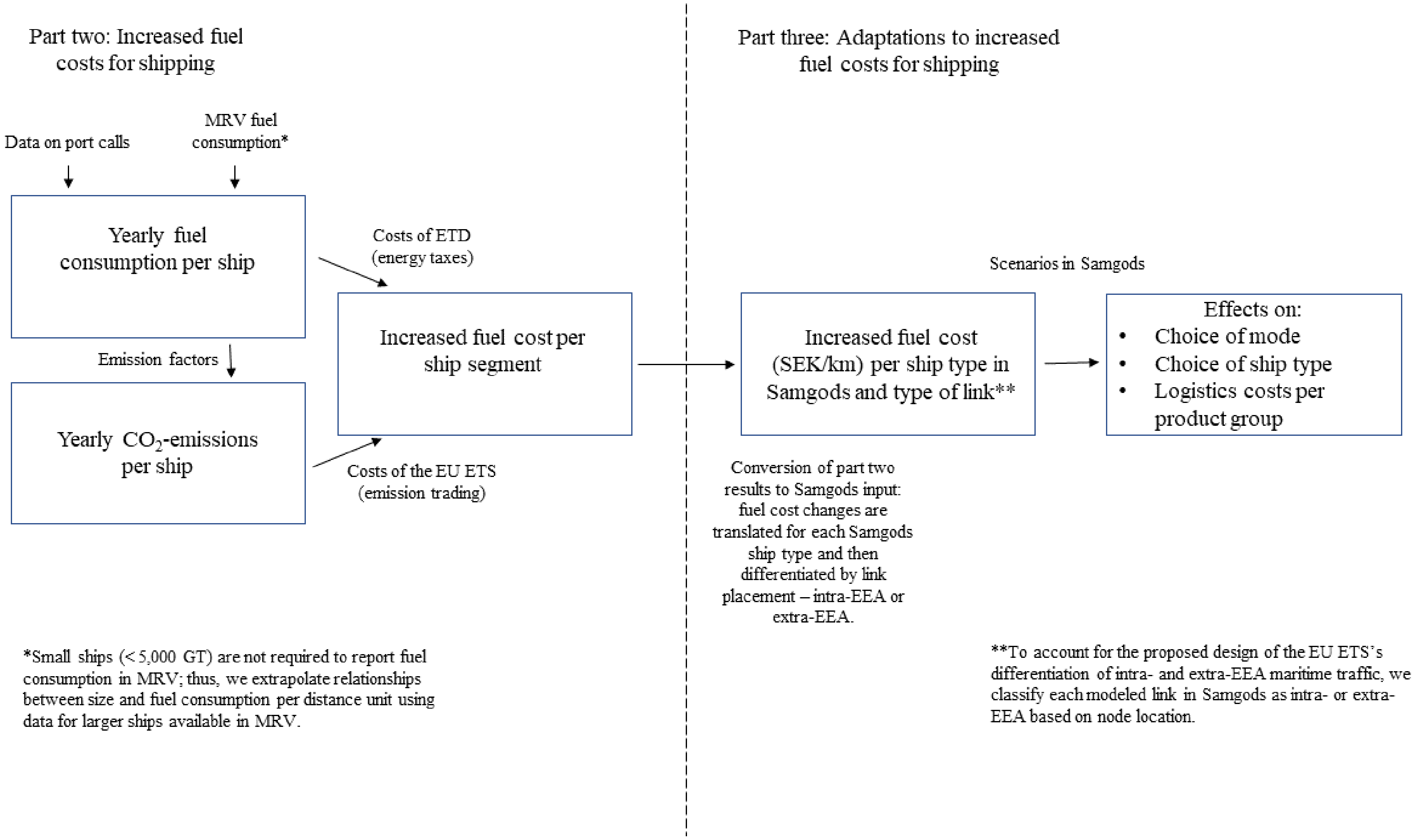
c_{dist}^{f} is the ship type-specific distance-dependent cost [SEK/km] for ship type f,

$c_{rel}^{f,od}$ is the relative cost change (estimated in Part one) specific to ship type f and the port-to-port relationship od,

L^{od} is the length [km] of the port-to-port relationship od.

Introducing the additional costs using this approach means that logistics choices are affected by the higher fuel costs, while route choice between ports is not affected. Since the EU ETS and ETD increase fuel costs for shipping, it is interesting to get a feeling for the magnitude of the fuel cost in relation to other cost components. Clearly, this depends on many factors, but the overall aggregated estimated ranges related to shipping based on the base scenario in the Samgods model are: i) the transport cost share of the total logistics cost, where the range is mainly estimated at 20-80 %., ii) the fuel cost share of the transport cost between two ports is estimated to be up to 50 % and ii) the fuel cost share of the total logistics cost is estimated to be up to 20 %.

The different steps in Part two and Part three are illustrated in Figure 1.



Conversion of part two results to Samgods input: fuel cost changes are translated for each Samgods ship type and then differentiated by link placement – intra-EEA or extra-EEA.

*Small ships (< 5,000 GT) are not required to report fuel consumption in MRV; thus, we extrapolate relationships between size and fuel consumption per distance unit using data for larger ships available in MRV.

**To account for the proposed design of the EU ETS's differentiation of intra- and extra-EEA maritime traffic, we classify each modeled link in Samgods as intra- or extra-EEA based on node location.

Figure 1. Illustration of the steps taken in Part two and Part three to estimate the increased costs and subsequent effects of the EU ETS and ETD.

4 Results

4.1. Ships calling at Swedish ports

Table 3 gives an overview of maritime freight traffic to, from and between Swedish ports in 2019 by ship segment and ship size (in GT). The second column shows the number of ships per segment while columns three to five show their travel patterns in terms of the estimated number of voyages to Swedish ports and whether these voyages were to or from a port within the EEA. In total, 96 % of all port-to-port connections could be identified such that they could be classified as intra- or extra-EEA, including the segment Ro-Pax where all voyages are assumed to be intra-EEA. The remaining 4 % results in a difference between the total number of voyages (column three) and the sum of intra- and extra-EEA voyages (columns four and five). Column six shows the estimated total traveled distance to and from Swedish ports and column seven presents CO_2 emissions.

In total, 56 % of the ships calling at Swedish ports are “large ships” of at least 5,000 GT and account for 78 % of all CO_2 emissions. Notably, the share covered by the EU ETS in the Main scenario for Swedish maritime traffic is 13 % lower than the share covered for the entire EU reported by the European Commission (2021). The distribution of “large ships” and “small ships” in Swedish maritime traffic is in part driven by the segment General Cargo which is the only segment with a larger share of ships under 5,000 GT. It is also, in terms of number of ships, the single largest individual ship segment.

97 % of all identified voyages to or from Swedish ports are intra-EEA. 81 % of intra-EEA voyages and 46 % of extra-EEA voyages are traveled by large ships of at least 5,000 GT and in the main scenario would be covered by the EU ETS (extra-EEA voyages 50 % covered). The high percentage of extra-EEA voyages by small ships is again driven by the ship segment General Cargo as “small ships” in this segment account for 50 % of all extra-EEA voyages. 99 % of these extra-EEA voyages by small General Cargo ships are to or from either the United Kingdom (62.6 %) or Russia (36.7 %).

The European Commission's proposal regarding the EU ETS that is assumed in the Main scenario misses a considerable share of CO_2 emissions. The share of missed emissions could further increase if transports are moved to ships smaller than 5,000 GT to avoid the EU ETS. Such movements could also impact the energy efficiency as illustrated in Figure 2. The figure shows plots for each ship segment with (deadweight) tonne-kilometers on the y-axis and GT on the x-axis.[3] The black vertical lines mark 5,000 GT. Since 5,000 GT is the lower limit for required reporting to MRV, all values on the left side of the vertical lines are based on estimated emission factors (as described above and in Appendix A*)* and are thus affected by some uncertainty and normalization. As such, the size of the shown relationships should be interpreted with some caution. Still, Figure 2 shows a clear tendency for CO_2-emission efficiency to decrease with size, with some variation between ship segments.

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[3] Deadweight tonne-kilometers are used as a proxy for tonne-kilometers – deadweight tonne-kilometers corresponds to tonne-kilometers when a ship is at full capacity.

Table 3. Maritime freight traffic to and from Swedish ports in 2019.

Ship segment	Number of ships	Number of voyages	Intra-EEA voyages	Extra-EEA voyages	Estimated distance (thousand km)	Share of CO_2-emissions (%)
Chemical Tanker						
≥5000	329	3813	3008	298	3239.3	62.8
<5000	156	3673	3187	115	2242.5	37.2
Container						
≥5000	124	3932	3762	150	2548.9	93.4
<5000	8	329	325	3	206.4	6.6
Dry Bulk						
≥5000	132	519	369	129	686.1	57.2
<5000	20	1483	1012	0	835.1	42.8
Gas Tanker						
≥5000	64	569	333	194	537.2	58.6
<5000	39	666	574	43	471.2	41.4
General Cargo						
≥5000	310	2911	2272	446	2878.7	22.7
<5000	881	16322	12150	2085	12293.0	77.3
Oil Tanker						
≥5000	190	900	470	286	854.1	79.7
<5000	22	1669	1619	28	433.2	20.3
Ro-Pax						
≥5000	86	96102	96102	0	10739.3	99.8
<5000	2	6900	6900	0	34.3	0.2
Ro-Ro						
≥5000	192	4868	2929	279	3696.0	99.8
<5000	2	10	10	0	11.7	0.2
Additional						
≥5000	40	778	609	139	403.7	87.1
<5000	11	331	310	9	101.8	12.9
All Ships						
≥5000	1467	114392	109854	1921	25583.3	77.9
<5000	1141	31383	26087	2283	16629.3	22.1

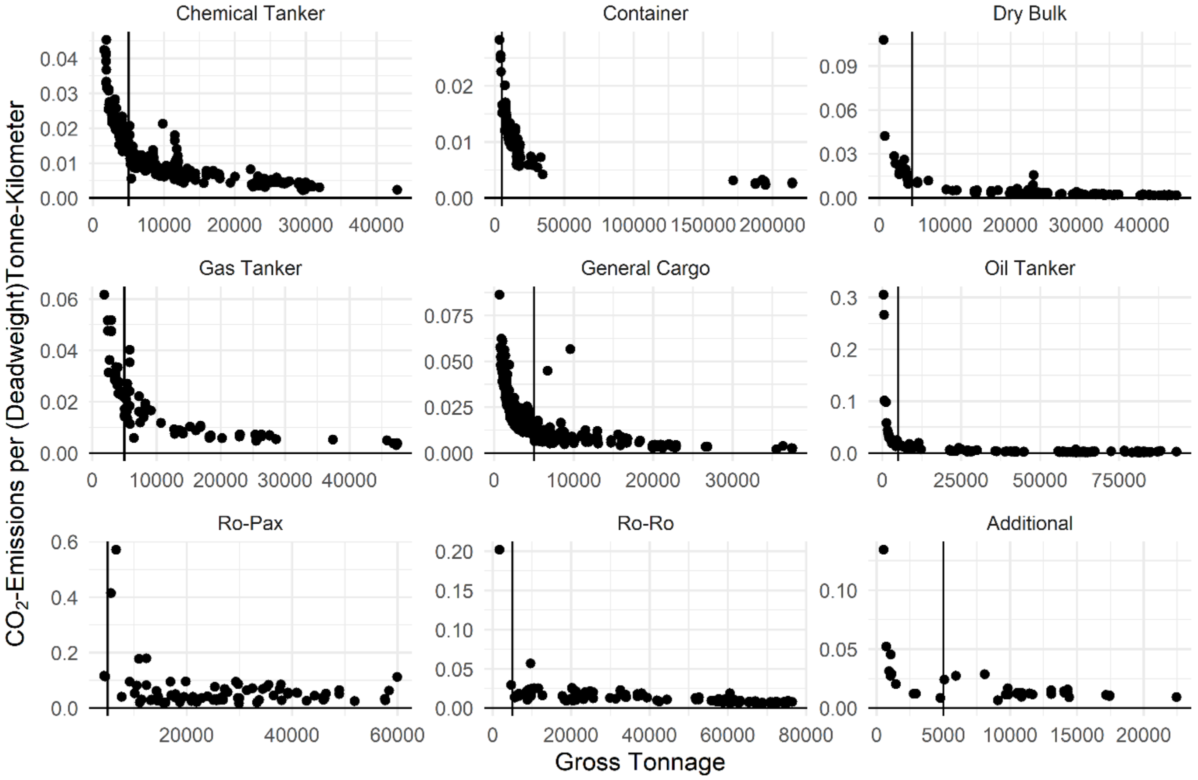

Figure 1. The relationship between average CO_2 emissions per (deadweight) tonne-kilometers and GT for each ship segment. The vertical black lines mark 5,000 GT i.e., the proposed lower limit for inclusion in the EU ETS in the Main scenario. CO_2 emissions are in kg.

4.2 Increased fuel costs for shipping

Looking at the increased average fuel costs per km of the EU ETS and ETD, their impacts differ from each other. Table 4 shows the relative average fuel cost per km of including shipping in the EU ETS by ship segment and scenario. In the Main scenario, the impact of the EU ETS on fuel costs within the EEA varies across the nine segments in the range of 11 – 42 %. General cargo has the lowest average cost increase and Ro-Ro the highest. The main factor behind the large spread is the different size compositions of the segments. For General cargo, ships of at least 5,000 GT are estimated to account for 23 % of all dry cargo ships' CO_2 emissions, while Ro-Ro ships of at least 5,000 GT are estimated to account for almost 100 % of all Ro-Ro ships' CO_2 emissions (see Table 3).

The spread in increased fuel costs is significantly reduced in the High scenario, where all ships with a minimum of 400 GT are included in the EU ETS. In this scenario, fuel costs increase within the EEA by roughly 40 % for all ship segments. This result is in line with Solakivi et al. (2022); however, Jivén et. al. (2022) calculates approximately twice as large cost increases (70 – 80 %) due to the inclusion of shipping in the EU ETS. The difference from this paper can be explained by the fact that the authors do not apply a threshold of 5,000 GT, that they use the emission factor for WTW- emissions instead of TTW (like the MRV system and thus the estimations in this report and Solakivi et al. (2022) are based on), and that they assume a price of € 100 per emitted tonne of CO_2 and a lower base price for marine fuel.

In the proposed revision of the ETD, unlike the EU ETS, there is no lower size limit for inclusion. In the Main scenario and High scenario, the two scenarios that include ETD, the fuel costs per kilometer increase by about 6 % on average for all segments. Thus, the effects of ETD on fuel costs are both lower and a lot less variable over the ship segments than the effects of the EU ETS.

Table 4. The relative fuel cost per km due to the EU ETS for each ship segment.

	Main Scenario		Low Scenario		High Scenario	
Ship Segment	Increase intra-EEA (%)	Increase extra-EEA (%)	Increase intra-EEA (%)	Increase extra-EEA (%)	Increase intra-EEA (%)	Increase extra-EEA (%)
Chemical Tanker	29	14	29	0	42	21
Container	40	20	40	0	42	21
Dry Bulk	37	18	37	0	42	21
Gas Tanker	25	12	25	0	40	20
General Cargo	11	5	11	0	42	21
Oil Tanker	39	19	39	0	43	21
Ro-Pax	41	20	41	0	42	21
Ro-Ro	42	21	42	0	42	21
Additional	32	16	32	0	41	21

4.3. Adaptations to increased fuel costs for shipping

Below it is shown how the higher fuel costs for shipping are modeled to affect firms' transport solutions in terms of mode choice, port choice and ship choice; responses in terms of such factors as changing fuel or investing in emission-reducing technology is not modeled. Finally, the impact on firms' total logistics costs is calculated.

Overseas transports are not likely to compete with the land-based modes; therefore the mode choice analysis is limited to Swedish territory. In the Main scenario, the sea tonne-kilometers are calculated to decrease by about 2 % (compared to the Base scenario) while the road tonne-kilometers increase by about 1 %. This implies that less than 1 % of the total freight tonne-kilometers are moved from sea to land. The same tendencies are calculated for the other scenarios. The result that the modal split is relatively inelastic is in line with the results that were calculated before the introduction of the sulfur directive in the SECA (Vierth et al.,2015). The result is also consistent with the impact assessment of the European Commission (2021).

The throughput in the Swedish ports is calculated to decrease by about 1 % in the Main scenario and High scenario and is constant in the Low scenario. There is a certain redistribution from ports in the northern part of the country to ports in the southern part of the country, which is intuitive as the length of the sea voyages and the exposure to the EU ETS or ETD are reduced.

Table 5. Impact on mode choice calculated according to Equation 1, tonne-kilometers per mode on Swedish territory.

	Main scenario (%)	Low scenario (%)	High scenario (%)
Road (50,25 tonne-kilometers in Base scenario)	1	1	1
Rail (21,42 tonne-kilometers in Base scenario)	0	0	1
Sea (32,07 tonne-kilometers in Base scenario)	-2	-1	-3

In all three scenarios, no shifts to ports in countries that are not part of the EEA, such as the UK, are calculated. Due to Sweden's geographical location, the extra costs for adding a port outside the EEA and/or transshipping cargo in a non-EEA port to a ship that is not included in the EU ETS are higher than the compliance costs. The result is in line with Faber et al. (2022a) who assess the possibilities to evade the EU ETS costs based on five case studies and find that the impact of the evasive behavior on EEA ports is likely to be limited. However, the result is in contrast to that of Lagouvardou & Psaraftis (2022) who deliberately study the "competition" of two container ports in the EEA (Piräus and Algecira) that are in proximity to ports outside the EEA and find that there is a risk for loss of the EU ETS revenues, carbon leakage and penalization of EEA ports.

It is not possible to model the use of a specific fleet with the help of the Samgods model, but what can be calculated is how the 21 ship types in the model are used under different conditions. As shown in section 4.1, the risk is that ships under 5, 000 GT are used, and the consequent CO_2 emissions increase is larger for those cargo ships calling at Swedish ports than for all ships calling at EEA ports.

Table 6 reveals the calculated adaptations for Ro-Ro-, Ro-Pax-, Container- and Other ships. It is shown that the tonne-kilometers (without territorial limitation) performed by Ro-Ro ships are calculated to decrease by about 16 % while the tonne-kilometers performed by Ro-Pax ships increase by about 1 %, which indicates that a shift between these ship types takes place. For Ro-Ro ships and Ro-Pax ships, roughly the same cost increases are calculated (48 % and 47 % respectively). However, Ro-Pax ships often serve as "land bridges" with usually shorter sailing distances than Ro-Ro ships. The shift from Ro-Ro- and Ro-Pax ships implies that transport chains that comprise a higher share of land-based transports are chosen.

For Container ships and Other ships, the importance of the EU ETS threshold is illustrated. In the Main scenario and the Low scenario which assume a threshold of 5,000 GT), the total tonne-kilometers performed by Container ships are calculated to decrease by around 2 %. Unsurprisingly, Container ships with a GT of at least 5,000 are used to a lesser extent. In the High scenario (which assumes a threshold of 400 in GT) a redistribution is calculated from ships with less than 5,000 GT to ships with at least 5,000 GT. In other words, we see an evasive response in the Main scenario and the Low scenario and a response that leads to a more efficient solution in the High scenario. Similar results are calculated for Other ships. See

Table 6. The findings that ship owners and operators operate ships below the threshold of 5,000 GT in sectors where the use of smaller vessels is common and where the compliance costs for the EU ETS are higher than the gain in efficiency related to the use of larger vessels are consistent with European Commission (2021). The envisaged fuel tax according to the ETD alone would have a much smaller effect on the fuel costs than the EU ETS.

Table 6. Impact on ship choice calculated according to Equation 1, based on tonne-kilometers per ship type.

Ship type	Main scenario (%)	Low Scenario (%)	High scenario (%)
Ro-Ro total (22,58 billion tonne-km in Base scenario)	-16	-15	-11
Ro-Pax total (5,11 billion tonne-km in Base scenario)	1	1	3
Container <5 000 GT (77,16 billion tonne-km in Base scenario)	0	-1	-3
Container ≥5 000 GT (12,64 billion tonne-km in Base scenario)	-14	-6	21
Container total (89,80 billion tonne-km in base)	-2	-2	0
Other <5 000 (206,70 billion tonne-km in Base scenario)	2	2	-1
Other ≥5 000 (351,75 billion tonne-km in Base scenario)	0	0	0
Other total (558,45 billion tonne-km in Base scenario)	1	1	0

Based on the Samgods model, the fuel costs for shipping are calculated to constitute up to 50 % of logistics costs, and most of the shares are up to 20 %. The fuel cost increases for shipping are calculated to influence the total logistics costs to a relatively small extent. In the Main scenario, the change, rounded to whole numbers, amounts to 0 % and in the High scenario to 1 %. One reason for the low impact is that the fuel cost increases for shipping are small relative to other costs. Another explanation is that the adjustments to the higher fuel costs for sea transports dampen the cost increase.

The highest cost increases are calculated for cargo that is transported in chains that comprise shipping: on the export side primarily EUROSTAT's commodities *03 Metal ores and other mining and quarrying products; peat; uranium and thorium* and *02 Coal and lignite crude petroleum and natural gas* and on the import side the commodities *02 Coal and lignite crude petroleum and natural gas* and *07 Coke and refined petroleum products.* As far as we know, our paper is the only one that studies the impact of the higher fuel costs for shipping due to the implementation of the EU ETS and ETD on firms' logistics costs. This implies that it is not possible to compare specifically the impacts of higher fuel for shipping on firms´ logistics costs. It is obvious that the calculated and observed effects vary with the assumptions for e.g., the fuel and carbon prices and differ for different commodities, type of transports and ship segments. However, the overall picture in the literature is that the considered MBMs do not lead to large fuel costs increases for shipping and secondary effects. Rojon et al. (2021) find that the introduction of a carbon price generally has a limited impact as the cost increase only affects the ships' running costs (which mainly exist of the fuel costs), but that the transport cost share of the value of imports can vary between commodities and regions concerned. Based on a review of previous literature, Rojon et al. (2021) conclude that a price on carbon would increase the average freight costs by between 0.4-16 % while the price of import increases by around 1 %.

4. Discussion and conclusions

The impacts of different designs of the extension of the EU ETS to shipping and the changed ETD on the fuel costs for cargo ships that call at Swedish ports have been estimated. The factors that vary across the scenarios are linked to the design of the policy instruments, i.e., minimum ship size and geographical coverage for the EU ETS and the geographical coverage for the ETD. The price per emitted tonne of CO_2 has been assumed to be € 80. All scenarios are based on a static time perspective, i.e., the implementation of the policy instruments over time is not modeled. The scenarios are based on costs in 2026, when shipping should be completely included in the EU ETS and minimum taxes according to the ETD are implemented according to the European Commission’s actual plans.

In the Main scenario, which is based on the European Commission’s proposal to include ships with at least 5,000 GT in the EU ETS, the estimated cost increases due to the implementation of the EU ETS are in the range of 11 - 42 % within the EEA and in the range of 5 - 21 % for the traffic to/from the EEA. The change in ETD is estimated to increase the fuel costs for all ships operating within the EEA by about 6 %. These fuel cost increases are in line with the European Commission (2021) and most other studies. As in several other studies, for example, Solakivi et al. (2021) and Christodoulou et al. (2021), the highest fuel cost increases are estimated for Ro-Ro- and Ro-Pax ships. While the other studies mention the high fuel consumption of the Ro-Ro- and Ro-Pax ships, our paper shows that nearly all ships have at least 5,000 GT and their voyages are carried out in the EEA.

An overall conclusion is that the cargo ships calling at Swedish ports with at least 5,000 GT account for about 78 % of the CO_2 emissions from cargo ships, while these ships make up 56 % of all cargo ships. This means that a significant part of the CO_2 emissions is missed with the expected design of the EU ETS for shipping that is assumed in the Main scenario. Generally, there is a risk that the problem increases when the ship owners and operators are given incentives to make greater use of ships that are not covered by the EU ETS due to their size. The risk that smaller ships were chosen was confirmed in the modeling of the firms´ adaptations to the higher fuel costs while the impact on firms’ mode choice and port choice is calculated to be limited.

A recommendation is that even ships of lower than 5,000 GT should be included in the EU ETS, and if this cannot be done immediately, the EU should clearly plan for this and signal to the market that even ships with a gross tonnage of less than 5,000 should be included in the long term. This would reduce the incentives for the market to make socioeconomically undesirable adjustments to avoid paying for emissions. In the High scenario, which assumes that the EU ETS includes ships with at least 400 GT the cost differences between different ship segments and sizes disappear and the cost increases are in the range of 40-43% within the EEA and in the range of 20 - 21% for the sea transports to/from the EEA.

Our analysis shows that the heterogeneity of the shipping sector requires a disaggregate approach. The methods applied in Parts one to three are based on several data sources and assumptions. It is not possible to validate the calculated CO_2 emissions and fuel costs in the Base scenario for example, as the official energy and emissions statistics for international shipping are based on fuel sold in Sweden, regardless of where in the world the fuel is consumed. The split between domestic and international shipping is based on Statistics Sweden’s monthly survey on supply and delivery of petroleum products. In 2020, the CO_2 emissions from international shipping were calculated to be about 13 times higher for international shipping than domestic shipping. Fluctuations in international bunker volumes between years are dependent on factors such as fuel prices and fuels offered in Sweden and other countries (United Nations, 2022).

Recently, the statistics for domestic shipping have been improved by using the Shipair model that calculates the total fuel consumption based on AIS data and information about the ships' type, size, and engine power (Windmark et al., 2017). In addition, a survey is employed to collect information about which fuel types are used. Given the importance of international shipping, we see a need to compile official data on the ships' fuel consumption and CO_2 emissions in a similar way to that for domestic shipping as a complement to the official statistics. There is also a need for information about where and how the ships that call at Swedish ports bunker; this information is needed, for instance, for the monitoring of the ETD that is planned to cover the EEA.

Against the background of the "Fit for 55" package, for example, we see a need to improve the possibilities to study the impacts of European and international policy instruments on stakeholders inside and outside Sweden. As ships calling at ports in the EEA are generally larger than ships calling at ports in Sweden, the share that is missed is higher for cargo ships that call at Swedish ports than for all ships that call at EEA ports. For the time being, results for this type of analysis are more difficult to interpret, because cross-border transports are less often analyzed and cannot be validated (and calibrated) against the official Swedish statistics.

Regarding the Samgods model that is applied to model how firms react to the higher fuel costs for shipping, there is a need to update the 21 ship types and sizes (in terms of capacity). It would facilitate the modeling if the ship types in the Samgods model could be more easily linked to international ship classification standards. Furthermore, large jumps in costs could be reduced if more ship types and sizes were used or if the ship types were designed as continuous in terms of size.

As further analysis, it is suggested to carry out a study that comprises all proposals in the "Fit for 55" package that are related to freight transport. The inclusion of the proposals related to road transport, such as the inclusion of road transport in the EU ETS, would enable a more detailed, complete, and secure description of how the package can be expected to affect freight transport costs.

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Appendix A. Estimation of fuel consumption per distance unit for ships smaller than 5,000 GT

The MRV system includes reported fuel use and CO_2 emissions per nautical mile for commercial ships of at least 5,000 GT. However, this excludes approximately 40 % of the commercial ships in the sample used in the paper. For these ships, fuel use and CO_2 emissions per nautical mile are estimated using a set of simple linear regressions where GT and a constant term explain fuel use. Since the relationship between ship size and fuel use can vary greatly between different types of ships, ships are divided into eight separate groups, based on ship type, with separately run regressions. The results of these regressions are also used to estimate CO_2 emissions by creating predicted values and multiplying these by the average emission factor for ships of the same type as each respective group.

The results are visualized in Figure A2 and Figure A3. As shown, the relationship between GT and fuel consumption is in many cases, such as Ro-Pax and container, strong but weaker for other groups such as Ro-Ro. The results and the estimated values in terms of fuel use and CO_2 emissions are naturally affected by some uncertainty; however, due to the unavailability of reported values, replacement values based on linearly extrapolated values are a good enough solution.

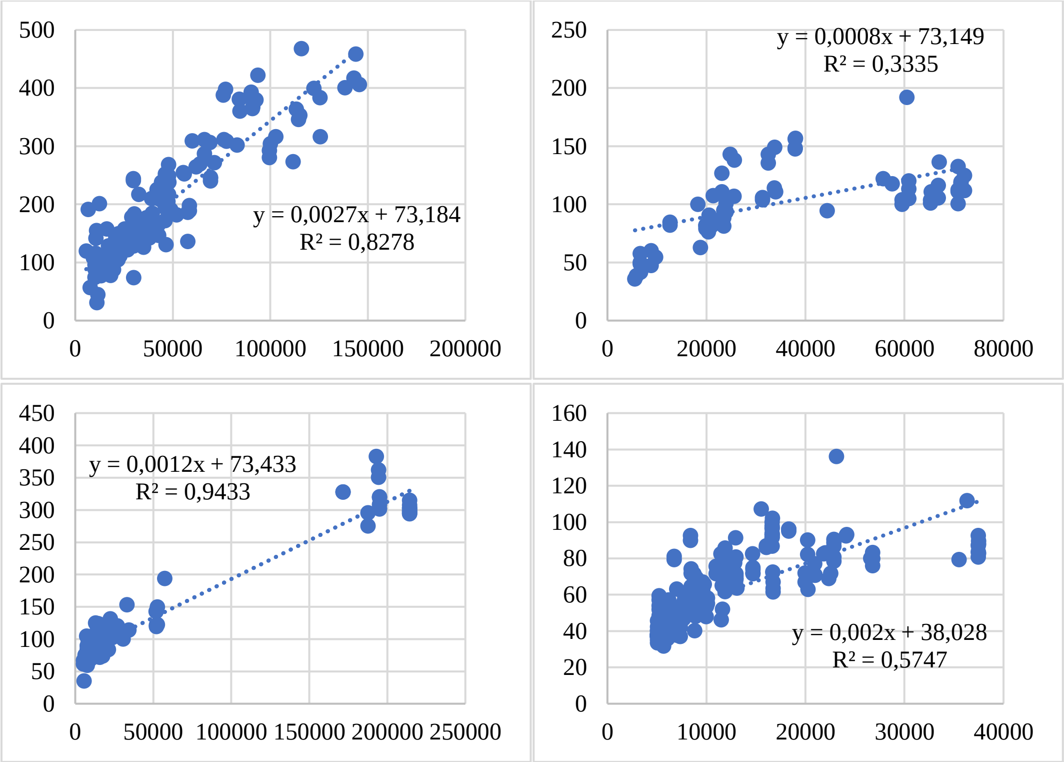

Figure A2. The relationship between gross tonnage (horizontal axis) and reported fuel use (kg) per nautical mile (vertical axis). The panel the top left shows this relationship for Ro-Pax, top right shows Ro-Ro, the panel at the bottom right shows Container and at bottom left General Cargo.

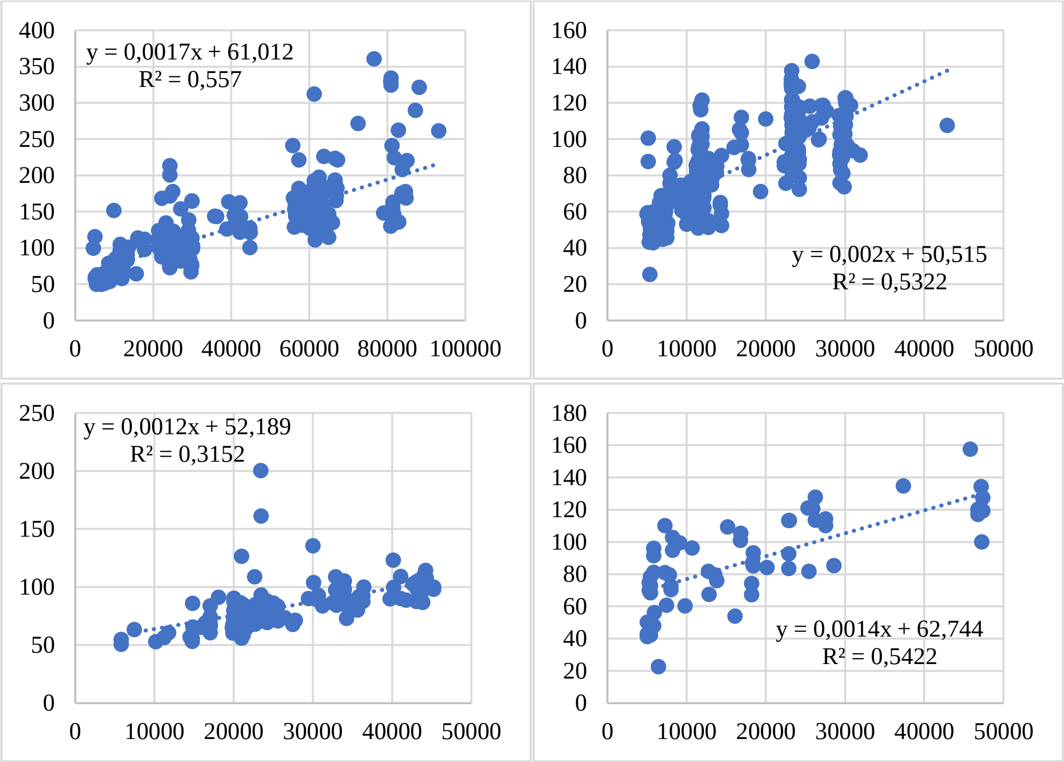

Figure A3. The relationship between gross tonnage (horizontal axis) and reported fuel use (kg) per nautical mile (vertical axis). The panel the top left shows this relationship for Oil Tanker top right shows Chemical Tanker, the panel at the bottom right shows Dry Bulk and at the bottom left Gas Tanker.