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Abstract

This thesis analyzes the design and effects of carbon pricing in the national and international freight transport sector, with a particular focus on maritime shipping. It brings together four papers that examine both short- and long-term behavioural responses and welfare effects of carbon pricing. The responses studied include reductions in sailing speed, changes in freight demand, investments in research and development (R&D) and learning-by-doing to reduce abatement costs through technological development, abatement of carbon emissions (e.g. alternative fuels), modal shifts, and adjustments in shipment sizes. The thesis also investigates the role of international cooperation and the incentives created by unilateral carbon pricing and carbon-intensity limits on marine fuels.

The first paper investigates short-run responses in the shipping sector and shows that ships reduce their sailing speed when fuel costs increase, indicating that carbon pricing can lower emissions even in the short run. The second paper studies carbon pricing in international shipping under the constraint that participating countries should be better off with the policy than without it. The results suggest that bilateral agreements can reduce emissions when countries differ in their willingness to pay, though their effectiveness is limited in static settings with high abatement costs. The third paper extends this analysis by considering the dynamic effects of unilateral carbon pricing. It shows that such policies can foster investments in research and development, thereby lowering future abatement costs and increasing the likelihood that other regions will adopt complementary policies.

The fourth paper broadens the perspective beyond shipping sector. Using a calibrated mode- and route-choice model for domestic freight transport in Sweden, it examines the welfare-optimal internalization of external costs from carbon emissions, air pollution, accidents, noise, and infrastructure. Internalizing external costs increases shipment sizes and shifts freight from waterborne and road transport to rail. However, the effects are modest, implying that the

potential for large-scale modal shift from road to rail or waterborne transport is limited.

In summary, the thesis shows that reducing carbon emissions in the shipping sector is challenging for two main reasons: abatement is very costly, and reductions in freight volumes entail welfare losses. Moreover, shipping is an inherently international sector, where efficient carbon pricing would need to be globally coordinated, but this is hampered by large differences in the willingness to price carbon emissions across countries.

Overcoming these difficulties, the thesis underlines the importance of accounting for both short- and long-term behavioral responses, the role of international cooperation, and the dynamic incentives created by unilateral policies. The thesis is relevant for policymakers seeking to align maritime and freight transport policy with broader climate and welfare objectives.

Keywords: Maritime transport, Shipping, Freight transport, Carbon pricing, EU ETS, FuelEU Maritime

Populärvetenskaplig sammanfattning

Denna avhandling analyserar utformningen och effekterna av prissättning av koldioxid inom den nationella och internationella godstransportsektorn, med särskilt fokus på sjöfarten. Avhandlingen består av fyra individuella artiklar som undersöker både kortsiktiga och långsiktiga anpassningsmekanismer samt välfärdseffekter av koldioxidprissättning. De studerade anpassningsmekanismerna är bland annat reducerad seglingshastighet, förändringar i efterfrågan på transporter, investeringar i forskning och utveckling, överflyttning mellan transportslag samt justeringar av sändningsstorlekar. Avhandlingen studerar också internationellt samarbete och koldioxidprissättning.

Den första artikeln estimerar bränslepriselasticiteter för seglingshastighet och visar att fartygen anpassar sig till höjda bränslekostnader genom att sänka hastigheten, vilket indikerar att koldioxidprissättning kan leda till utsläppsminskningar även på kort sikt. I den andra artikeln studeras välfärdseffekter av bilaterala avtal om koldioxidprissättning inom internationell sjöfart. Resultaten indikerar att bilaterala avtal kan minska utsläppen, speciellt när länderna har olika preferenser för koldioxidprissättning. Utsläppsminskningar är dock begränsade på grund av höga kostnader för grön teknologi. Den tredje artikeln utvidgar analysen genom att studera dynamiska och långsiktiga effekter av unilateral koldioxidprissättning. Studien visar att unilateral koldioxidprissättning stimulerar investeringar i forskning och utveckling, vilket reducerar framtida kostnader för grönteknologin och ökar sannolikheten för att andra regioner implementerar kompletterande styrmedel.

Den fjärde artikeln breddar perspektivet till hela godstransportsektorn och studerar de välfärdsoptimala färdmedelsandelarna. Internaliserade externa kostnader leder till större sändningsstorlekar och en överflyttning av gods från sjöfart och vägtransporter till järnväg. Resultaten visar att potentialen för en omfattande modal överflyttning från väg till järnväg eller sjöfart är begränsad.

Sammanfattningsvis visar avhandlingen att reduktion av koldioxidutsläpp inom sjöfartssektorn är utmanande av två huvudskäl: kostnaderna för utsläppsreduktion är höga och minskningar av godsmängder medför välfärdsförluster. Vidare är sjöfarten en internationell sektor, där effektiv koldioxidprissättning kräver globalt samarbete, vilket försvåras av betydande skillnader i länders betalningsvilja för koldioxidprissättning.

För att hantera dessa utmaningar understryker avhandlingen vikten av att beakta både kort- och långsiktiga anpassningsmekanismer, internationellt samarbete samt effekter på utrikeshandeln. Avhandlingen är relevant för beslutsfattare som strävar efter att harmonisera sjöfarts- och godstransportpolitiken med övergripande klimat- och välfärdsmål.

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List of studies

I. Ollila, S., Merkel, A., & Börjesson, M. (2025). Effect of fuel prices on sailing speeds in short-sea shipping. *Applied Economics*, *57*(33), 4938–4954.
II. Ollila, S., Börjesson, M., & Proost, S. (2025). What can we expect from the climate agreements in the international shipping sector? Previous version published as a working paper in Working Papers, Swedish National Road & Transport Research Institute (VTI)
III. Ollila, S., & Börjesson, M., Unilateral emissions reduction policies and endogenous technological change in the shipping sector.
IV. Ollila, S., & Börjesson, M., Optimal pricing and modal shares for freight transport within Sweden.

Contributions

Contribution to studies:

Study I: The author of the thesis is responsible for drafting and designing the research question, methodology, software implementation, formal analysis, and writing.

Study II: The second study is co-authored with Maria Börjesson and Stef Proost. The author of the thesis has been responsible for methodology, software implementation, formal analysis, and writing. The author of the thesis has also contributed to drafting and designing the research question.

Study III: The third study is co-authored with Maria Börjesson. The author of the thesis has contributed with major work in drafting and designing the research question, methodology, software implementation, formal analysis, and writing.

Study IV: The fourth study is co-authored with Maria Börjesson. The author of the thesis is the main author of the study and has been responsible for methodology, software implementation, formal analysis, and writing. The author of the thesis has also contributed to drafting and designing the research question.

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Chapter 1

Introduction

Carbon emissions from maritime shipping account for 2-3% of global emissions and without any policy interventions the emissions are expected to grow, reaching 10% of global emissions in 2050 (T & E, 2025). Carbon pricing, including carbon tax and tradable permit systems, is widely recognized as a cost-effective instrument for reducing emissions in both the short and long term by incentivizing adoption of cleaner technologies, improvements in operational efficiency, and investments in low-carbon innovation. However, political resistance has slowed adoption of carbon pricing, and currently, shipping emissions are priced only by the European Union (EU), despite global initiatives (IMO, 2025a). Given the projected growth in emissions and the challenges of implementing carbon pricing, it is essential to understand its potential effects on the shipping sector and explore how to design carbon pricing that is politically acceptable.

This thesis brings together four individual studies that investigate both short- and long-term behavioral responses and welfare effects of carbon pricing in the national and international freight transport sector. The thesis primarily focuses on the effects and design of carbon pricing in the shipping sector, with the last study broadening the scope to road and rail transport to study the potential for modal shift. The effects analyzed include reductions in sailing speed, changes in freight demand, adoption of alternative fuels, shifts between freight modes, investments in R&D and learning-by-doing to reduce abatement costs through technological development, and adjustments in shipment sizes. Furthermore, the thesis explores the role of international cooperation and the incentives created by unilateral climate policies.

While working on the thesis, carbon pricing and emissions regulations in the shipping and freight transport sector have undergone several changes, which have also inspired the research questions.

The EU was first to introduce carbon pricing on shipping emissions by including shipping in the EU's Emissions Trading System (EU ETS) in 2024. The EU ETS covers all emissions from ships of at least 5,000 gross tonnage operating between two ports within EU jurisdiction (intra-EU), as well as half of emissions from voyages from and to the EU ports (extra-EU) (EC, 2025). The inclusion in the EU ETS is gradual, with all emissions from ships of at least 5,000 gross tonnage (GT) covered by 2027. In parallel with EU ETS, the EU introduced a regulation limiting the carbon intensity of marine fuels (FuelEU Maritime) starting in 2025 (European Parliament and Council, 2023). The limit on carbon intensity will gradually tighten, aiming for an 80% reduction by 2050. The EU's policies are significant as they not only regulate emissions within the EU but also influence its trading partners. The first and third studies of this thesis address the short and long-run effects of the EU policies.

While the EU has taken the lead in regulating emissions from the shipping sector, the global regulations lag behind. In 2023, the International Maritime Organization (IMO) introduced a long-term strategy to reduce emissions from the shipping sector, aiming for a 70-80% reduction by 2040 and near-zero emissions by 2050 (IMO, 2023). In April 2025, IMO adopted a draft on global emissions reduction policies, including a limitation on the carbon intensity of fuels and a carbon price for the share of emissions that exceeds the limit (IMO, 2025a). In October 2025, the member countries voted to postpone the decision to adopt global emissions reduction measures until 2026 (IMO, 2025b). The global emissions reduction policies are addressed in the second study, which proposes bilateral agreements as a way to reduce emissions in the international shipping sector since larger agreements often suffer from free riding, and as demonstrated by the postponed IMO agreement, are hard to agree upon.

The fourth study focuses on the Swedish freight transport sector, examining the optimal modal split between transport modes. Sweden's national freight transport strategy promotes a shift from road to rail and waterborne transport (Ministry of Enterprise and Innovation, 2018), which is also a common policy target in the EU (Beil et al., 2025). The welfare-optimal modal split is calculated by internalizing the external costs associated with each mode, using carbon taxes and distance-based fees.

Aim of the thesis

By studying a wide range of adoption mechanisms for carbon pricing, this thesis aims to provide insights into the effects of carbon pricing, the factors that may limit its effectiveness, and how to design effective emissions reduction policies in the international shipping and freight transport sector. Moreover, the thesis aims to highlight the importance of analyzing carbon pricing and other emissions reduction policies from several angles, including sector-specific effects.

The four studies included in the thesis are:

I. Effects of fuel prices on sailing speeds in short-sea shipping
II. What can we expect from the climate agreements in the international shipping sector?
III. Unilateral emissions reduction policies and endogenous technological change
IV. Optimal pricing and modal shares for freight transport within Sweden

The first study estimates a fuel price elasticity of speed examining to what extent shipping companies respond to increased fuel prices by decreasing speed. The second study analyzes the level of carbon pricing and its effects in the international shipping sector considering countries' varying preferences for implementing emission reduction policies and incentives to free-ride. The third study explores the long-run effects of carbon pricing and how unilateral emissions reduction policies impact firms and other countries' innovation incentives. The fourth study computed the welfare-optimal freight allocation and discusses the effectiveness of modal shift as a tool to reduce emissions.

Concepts and theoretical framework

Studied policies

The design and effects of carbon pricing are the main focus of this thesis. In addition, the thesis examines the impact of complementary policy instruments, including technology standards (FuelEU Maritime) and R&D subsidies.

Carbon pricing, including a carbon tax and tradable permit systems (i.e., EU ETS), is regarded as the most cost-effective instrument for reducing emissions (e.g., Jenkins, 2014; Nordhaus, 1993). Carbon pricing leads to emissions reductions until the marginal cost of an additional unit of reduced emissions equals the carbon price. The cost-effectiveness of carbon pricing arises from technology neutrality: it allows firms and consumers to choose the least costly way to reduce emissions, whether by adopting cleaner technologies, reducing production or consumption, or paying the carbon price when other options are more expensive. Furthermore, carbon pricing creates incentives for investment in low-carbon technologies (Aghion et al., 2016; Popp, 2006).

Although carbon pricing is regarded as a preferable policy instrument to mitigate emissions, market failures and political resistance can lead to a combination of multiple policy instruments to perform better (Bennear and Stavins, 2007; Fischer and Newell, 2008; Jenkins, 2014; Lehmann, 2012). For example, Acemoglu et al. (2012) and Fischer and Newell (2008) show that combining carbon pricing with R&D subsidies, which correct a market failure from technology spillovers between firms, reduces emissions at lower costs than implementing carbon pricing alone. Lehmann (2012) further reviews how subsidies and technology standards can correct market failures arising from asymmetric information, heterogeneous abatement costs, and difficulties in supervising policy compliance. Jenkins (2014) discusses political constraints on carbon pricing, including uneven distribution of costs and benefits across generations and countries, preferences for revenue-neutral instruments, and industry opposition, particularly in carbon-intensive sectors. With less than half of global emissions currently priced (OECD, 2024), the willingness to implement carbon pricing across countries seems indeed to be limited.

The two other policy instruments covered by the thesis are R&D subsidies and technology standards (FuelEU Maritime). R&D subsidies aim to lower the future costs of clean technologies by reducing firms' innovation expenses. They can also enhance policy credibility by signaling government commitment to future climate policies (Ulph and Ulph, 2013) and promote domestic industry (Clausing and Wolfram, 2023; Fischer, 2017). The third study investigates whether unilateral carbon pricing (EU ETS) and technology standards (FuelEU Maritime), which raise transport costs, induces other regions to introduce R&D subsidies to mitigate adverse trade effects.

The results indicate that other regions respond more strongly to technology standards (FuelEU Maritime) than to carbon pricing (EU ETS), largely due to the high cost of clean technology in the shipping sector. Because technology costs far exceed the carbon price, carbon pricing alone does not ensure sufficient future demand to incentivize private investment in clean technology. Thus, although technology standards such as FuelEU Maritime are less effective than carbon pricing per se (Anderson et al., 2010; Fischer and Newell, 2008), they can help ensure demand for clean technologies and thereby increase investment. Moreover, the political acceptance of technology standards tends to be higher (Dimanchev and Knittel, 2020).

Measuring social cost of carbon emissions

There are two main approaches to analyze the effectiveness of carbon pricing and other policy instruments: cost-effectiveness and cost-benefit criterion (Goulder and Mathai, 2000). Cost-effectiveness criterion asks what the cheapest way is to achieve a given emissions reduction target, and from this derives a shadow price of carbon emissions. Cost-benefit criterion, on the other hand, takes the social cost of carbon emissions as given and compares the cost of the policy with the monetary valuation of achieved emissions reductions. In this thesis, the costs and benefits of carbon pricing and other policies are evaluated using cost-benefit criterion, taking the social cost of carbon emissions as given.

The social cost of carbon emissions (SCC) define a monetary valuation of emitting one additional tonne of carbon dioxide (Rennert et al., 2025). Under a global government maximising world welfare, the SCC should equal the global marginal damage cost of an additional tonne of carbon emissions (Nordhaus, 2014). Empirical estimates of SCC exhibit significant variation both at global and regional level (Aerts et al., 2024; Ricke et al., 2018).[1]

In this thesis, the SCC is taken to equal the implemented or planned carbon pricing and referred as *revealed carbon price*. This may not be equal to the global marginal damage cost for many reasons. First, a country does not experience the full global cost of more emissions. Second, free-riding as well as political factors and incomplete information on actual climate damage are likely to make the implemented carbon pricing to deviate from SCC. Using the implemented carbon pricing to represent the SCC has both advantages and disadvantages. The downside is that the implemented carbon pricing does not necessarily reflect the global or country-specific damage cost, which means the costs and benefits of analyzed policies may deviate from their "true" effects. On the other hand, implemented carbon pricing incorporates political aspects, which, especially when analyzing potential climate agreements in the second paper, provide more realistic estimates of what countries are actually willing to agree upon.

[1] For example, Rennert et al. (2022) estimate a global SCC of 185 USD per tonne of CO2, while Bilal and Känzig (2024) find a substantially higher global estimate of 1065 USD per tonne of CO2. Ricke et al. (2018) provide country-specific SCC estimates that range from negative for Northern Europe, Russia, and Canada up to 80 USD per tonne of CO2 for India.

Shipping, international trade, and climate agreements

Shipping accounts for over 80% of international trade of goods (UNCTAD, 2025). Consequently, emissions reduction policies in the shipping sector can impact trade or conversely, trade may impact on the types of emissions reduction policies countries are willing to adopt. An example of interdependency between emissions reduction policies in the shipping sector, trade, and wider economic impacts was provided in October 2025, when IMO member countries voted to postpone the adoption of global emissions reduction policies. The delay followed threats from the Trump administration to impose additional trade tariffs and other retaliatory measures on countries supporting the agreement, motivated by concerns over adverse economic effects from increased shipping costs (Financial Times, 2025; U.S. Department of State, 2025). The second and third studies incorporate international trade in the analysis of effects and design of carbon pricing by applying a partial equilibrium model for shipping trade.

Trade costs comprise transport costs, tariffs, border-related costs, and distribution costs (Anderson and Van Wincoop, 2004). Carbon pricing in the shipping sector affects international trade primarily through transport costs, which account for around 20% of total trade costs but vary significantly by commodity type, trading distance, infrastructure access, and the relative share of other trade components (Anderson and Van Wincoop, 2004), and thus, the costs and benefits from global emissions reduction policies in the shipping sector are not equally divided between the countries. The unequally divided costs and benefits together with free-riding incentives hinder implementation of global emissions reduction policies. The second study in this thesis examines the effects of carbon pricing in international shipping, considering that countries are likely to join an emissions reduction agreement only if it leaves them better off (Nordhaus, 2015). In the study, the countries agree on bilateral carbon pricing based on Nash bargaining (Nash, 1953)[2] and the

[2] Nash bargaining belongs to cooperative game theory, which provides one framework for analysis of international emissions reduction agreements.

outcome of bargaining process depends on countries' trade relations, costs of clean technology, as well as the countries' revealed carbon price.

An argument against bilateral agreements is the fragmentation of emission regulation (European Parliamentary Research Service, 2024), which can for example increase operational costs of shipping companies (Ship & Bunker, 2025) and hinder the implementation of larger agreements (Karatayev et al., 2021). Moreover, the fundamental finding in economics is that uniform carbon pricing leads to largest welfare gains globally. However, there are no global, uniform, emissions reduction policies in place, mainly due to free-riding. Also in international trade, bilateral and regional trade agreements are more common, largely due to the heterogeneity of countries (Yilmazkuday and Yilmazkuday, 2014). Moreover, Saggi and Yildiz (2011) show that when countries are highly heterogenous bilateral agreements can be preferrable also from the global welfare perspective since achieving large multinational agreements is unlikely. Moreover, bilateral or regional climate agreements can support the formation of larger agreements by lowering the cost of clean technologies, through increased R&D and learning-by-doing (Acemoglu et al., 2014; Golombek and Hoel, 2004.; Hale and Urpelainen, 2015; Mideksa, 2025).

The impact of carbon pricing on production in the shipping sector lies beyond the scope of this thesis. However, findings from the second and third studies indicate that carbon pricing reduces demand for shipping trade. This raises an important question: how do reductions in shipping trade affect goods production and total emissions from shipping?

Ludwig (2024) and Shapiro (2016) address this question by examining the effects of carbon pricing in the shipping sector accounting for effects on production. Ludwig (2024) finds that the EU ETS reduces emissions by about 10%, primarily through decreased production. Yet, the policy also shifts production to countries with less efficient technologies, increasing emissions per unit of output. Shapiro (2016) studies the welfare effects of global and regional carbon pricing and also finds that regional carbon pricing redirects trade to unregulated routes. Moreover, a moderate global and regional carbon pricing increases global welfare but the costs and benefits from the policies are not equally distributed between countries (Shapiro, 2016). A main conclusion from both studies is that the gains from international trade far exceed the climate costs. Moreover, since shipping emissions represent only about 3% of emissions related to production (Shapiro, 2016), production effects should be considered when evaluating the costs and benefits of carbon pricing in international shipping.

Adaptation mechanisms for carbon pricing

In this thesis, emissions can be reduced through reductions in trade, efficiency improvements, and switching to cleaner technologies. This section reviews the emissions reduction channels considered in this thesis.

Efficiency improvements: speed reduction and modal shift

The first and fourth studies examine emission reductions from efficiency improvements, specifically reductions in sailing speed and changes in modal shares and shipment sizes.

The first study explores how shipping companies respond to increased fuel prices by reducing sailing speed. Fuel consumption increases exponentially with sailing speed, and a common approximation is that this relationship follows a cubic law (third-power) (Psaraftis and Kontovas, 2013; Psaraftis and Lagouvardou, 2023; Ronen, 1982; Ryder and Chappell, 1980). Thus, a 10% reduction in speed would yield a 27% reduction in fuel consumption, ceteris paribus, making a speed reduction a cost-effective way to reduce emissions.

The first study uses Automated Identification System (AIS) data from the Baltic Sea to estimate the fuel price elasticity of speed, finding an elasticity of –0.08. A 10% fuel price increase reduces speed by 0.8%, which applying the cubic relationship between speed and fuel consumption, implies that the same price increase would lower hourly fuel consumption by approximately 2.4%. The results suggest that shipping companies do respond to higher fuel prices by reducing speed, although the effect is modest.

Previous studies estimating abatement costs for reduced speed from shipping companies' cost and profit functions find that the abatement costs range from negative values up to 420 USD per tonne of reduced CO_2 (Corbett et al., 2009; Eide et al., 2009; Lindstad et al., 2011; Nepomuceno de Oliveira et al., 2022). While particularly negative abatement costs suggest that higher fuel prices should incentivize speed reductions, the low fuel price elasticities of speed indicate potential barriers to implementing speed reduction (Jia et al., 2017; Poulsen and Sampson, 2019; Rehmatulla and Smith, 2020, 2015) or that existing cost-based estimates underestimate the true abatement cost of speed reduction. Moreover, ship speed impacts the fleet supply and thus the profitability of speed reduction is also affected by the market conditions. Consequently, the results from the first study emphasize the importance of studying the observed responses to potential policies, since the results can reveal behavioral and institutional constraints that limit the actual emissions reductions.

In the fourth study, emissions can be reduced by switching from road to rail and waterborne transport, which produce fewer emissions per transported tonne, as long as road transport is not electrified. The results from the fourth study, aligned with the previous research (Björk et al., 2023; Johansson et al., 2024; Pinchasik et al., 2020), indicate that shifting freight from road to rail and waterborne transport is an expensive and inefficient way to reduce emissions. Moreover, under optimal pricing, which internalizes all external costs in the freight transport sector, freight is shifted from road and waterborne transport to rail. Therefore, policies should focus on decarbonizing each mode and improving the overall efficiency of the freight transport system rather than aiming to reduce emissions through modal shift. The fourth study finds that a carbon price of 1000 €/tCO_2 reduces tonne-kilometers for road and waterborne transport by approximately 1% and 2.5%, respectively, illustrating the high cost of modal shift as an emissions reduction policy.

Alternative fuels and other emissions reduction technologies

In the second study, an abatement cost curve is constructed to evaluate the adoption of clean technologies resulting from carbon pricing. The abatement cost curve pins together costs of reducing emissions through operational measures, such as speed reduction and voyage optimization, improved ship design, and switching to alternative fuels. The third study allows emissions reductions from near-zero fuels, focusing on the long-run effects.

Currently, there is no dominant near-zero technology for shipping (Brynolf et al., 2022; Laskar et al., 2025). Batteries are a potential technology for short-distance ferry and passenger transport, but for large ocean-going ships, alternative fuels provide a more feasible solution (Korberg et al., 2021; Malik Kanchiralla et al., 2024). Alternative fuels can be categorized into biofuels, produced from biomass, and electrofuels, produced by combining hydrogen with carbon or nitrogen (Korberg et al., 2021). While biofuels are currently a more cost-effective solution, electrofuels derived from renewable energy sources are needed to decarbonize the shipping sector.

Since there is no dominant technology, the abatement cost estimates in the second and third study relies on approximated average costs. In the second study, we assume that the abatement costs are quadratic, implying that the marginal cost of an additional unit of abatement increases with the amount of reduced emissions. The quadratic relationship captures the fact that reducing emissions through operational measures is cheaper than switching to alternative fuels. In the third study, we approximate the cost of near-zero technology using the abatement costs of electricity-based alternative fuels from Lagouvardou et al. (2023). The modelling approaches in the second and third studies exclude a potential heterogeneity in costs across ship types and geography, which can impact the estimated costs and emissions reductions.

Summary of studies

Effect of fuel prices on sailing speeds in short-sea shipping

The study estimates the effect of fuel prices on sailing speeds using Automated Identification System (AIS) data covering the Baltic Sea and Norwegian coastal areas from the years 2007-2018. The fuel price elasticities of sailing speed are estimated using a fixed effects model, treating route-specific factors as fixed effects. The contribution of the study is twofold. First, the study estimates the effects of fuel prices on sailing speed for short-sea shipping and second, it proposes an instrument variable approach to disentangle a correlation between fuel prices and freight rates. By instrumenting fuel prices on oil supply shocks, the study aims to estimate the causal effect of fuel prices on sailing speeds.

Applying oil supply shocks as an instrument increases the estimated elasticity from -0.012 to -0.08, suggesting that ignoring correlation between fuel prices and freight rates can lead to biased estimates. The results further suggest that shipping companies respond to increased fuel prices by reducing speed, but the effect is modest. Consequently, increases in fuel prices due to EU ETS are likely to lead to small reductions in sailing speeds.

The standard errors used in the study control for correlation over time within the routes and across routes given the same time unit. However, shipping is formed as a network, and thus the speeds may correlate over time also across routes. If this is the case, the standard errors in the current study are underestimated, which can lead to incorrect inference of the results. The future studies should account for the network structure of the shipping sector.

What can we expect from the climate agreements in the international shipping sector?

Agreeing on global emissions reduction policies is difficult due to incentives to free-ride and countries' varying preferences of implementing emissions reduction policies. Previous literature on carbon pricing in the international shipping sector has primarily examined its effects on trade demand and abatement decisions. However, the literature has not addressed what levels of carbon pricing are feasible and what kind of effects such carbon pricing would have on trade and abatement decisions. The second study contributes to the literature by exploring both the effects and the design of carbon pricing in international shipping, taking into account that the benefits of shipping trade and willingness to price carbon emissions vary across countries.

The design and effects of carbon pricing in the international shipping sector is studied in the context of bilateral agreements. In the model, countries agree on carbon pricing and allocation of tax revenues or tradable permits in Nash bargaining. The emissions reductions occur either through reduced trade demand or by switching to cleaner technologies. The carbon pricing and its effects are illustrated in a numerical example using data from eight trading blocs.

The results suggest that bilateral agreements could reduce emissions by between 3% and 14%, depending on the abatement costs and the allocation of tax revenues or tradable permits. The emissions reductions are larger when countries can also agree on allocation of tax revenues or tradable permits since flexible allocation allows higher levels of carbon pricing. However, the emissions reductions are limited due to high abatement costs.

Unilateral emissions reduction policies and endogenous technological change

The results from the second study indicate that abatement costs in the shipping sector are too high and that most countries' willingness to implement emission-reduction policies is too low to achieve significant global emissions reductions. Building on this, the third study examines what countries with greater willingness to implement emissions reduction policies can do to reduce emissions in the global shipping sector.

The third study builds on the second study by accounting for reductions in abatement costs from investments in research and development (R&D) and learning-by-doing induced by unilateral emissions reduction policies. Using EU policies as a case study, the analysis explores how carbon pricing (EU ETS) and a carbon-intensity limit on fuels (FuelEU Maritime) affect firms' R&D and learning-by-doing investments, as well as other regions' incentives to adopt R&D subsidies to offset higher transport costs to and from the EU.

The results indicate that FuelEU Maritime drives most private investment due to its high compliance costs. In contrast, the EU ETS carbon price is too low to induce significant abatement. Consequently, FuelEU Maritime is the primary driver of both investment and emissions reductions. The findings also show that EU unilateral policies increase other regions' incentives to introduce R&D subsidies. However, returns to R&D spending are diminishing: while subsidies increase private investments, the additional cost reductions are minor compared to those achieved through demand-side policies.

Optimal pricing and modal shares for freight transport within Sweden

The fourth study examines the welfare-optimal freight allocation in Sweden. Shifting freight from road to rail and waterborne transport is a common policy target since the latter two produce less emissions per tonne-kilometer. By developing a simple freight network model for Sweden, the study aims to explore the welfare effects of modal shift policy targets.

The developed freight network model derives from the inventory theory, according to which the freight transport mode and shipment size are decided simultaneously by minimizing generalized costs. The generalized costs comprise transport costs, in-transit capital costs, and costs of warehousing (wait costs). We extend the previous literature by allowing a stochastic demand for freight transport derived from a multinominal logit model.

The results indicate that the modal shares are close to the optimal despite the current tax levels being below the welfare-optimal levels. Moreover, the modal shares are rigid, implying low cross-elasticities between the modes, aligned with the previous literature. Still, there are some small changes in modal shares: optimal pricing increases shipment sizes and shifts freight from road and waterborne transport to rail. Overall, a significant shift from road to other modes is unlikely to be achieved or to be welfare-improving. Moreover, road electrification will further impact the profitability of modal shift as a policy target.

Discussion and future work

The four studies examine the impact of carbon pricing in the freight transport sector. The main conclusion from the studies is that substantial emissions reductions require technological change that lowers the cost of clean technologies. Therefore, policymakers should prioritize policies that strengthen technological development and the early adoption of new technologies in the shipping and freight transport sector.

Studies I, II, and IV focus on the short-run effects of carbon pricing and find that, given current abatement costs, emissions reductions remain limited. In contrast, Study III extends the analysis to the long run, and shows that EU emissions reduction policies reduce abatement costs over time, leading to significant emissions reductions. This highlights the importance of considering long-run effects when designing and evaluating policies for the shipping and freight transport sector. Furthermore, Study III emphasizes that future demand plays a critical role in incentivizing investment in clean technologies. Consequently, demand-side policies (i.e., EU ETS and FuelEU Maritime) are essential. These policies must operate in two ways: first, by announcing higher carbon prices well in advance so that firms (and other governments) have an incentive to invest in R&D; and second, by introducing a positive carbon price in the near term so that learning-by-doing can take place. Carbon pricing alone may not be fully effective, at least in the short run, because uncertainty about future policy weakens investment incentives. Moreover, the entire industry needs to transition simultaneously for clean technologies to scale up, and such coordination problems may justify additional policies beyond carbon pricing.

The study also underscores the need to account for dynamic effects when analyzing policies. Moreover, due to the international nature of freight transport, the emission regulation does not only impact the costs and welfare of the regulating country but also the costs and welfare of the exporting and importing countries. Thus, when designing and analyzing the emissions reduction policies in the freight transport sector, the effects of policies on export and import should be considered.

There are some limitations, which call for future research. First, the thesis does not consider risk of carbon leakage from bilateral and unilateral policies. The two main sources of the carbon leakage are rerouting and decline in price of conventional, dirty, technology. Ludwig, (2024) and Shapiro (2016) document rerouting of shipping trade and reallocation of ships resulting from regional or unilateral carbon pricing. The effect of declining prices of conventional ships and fuels can be mitigated by introducing technology standards, which does not leave room for other ways to reduce emissions.

Second, Ludwig (2024) and Shapiro (2016) show that unilateral carbon pricing and other emissions-reduction policies in the shipping sector can affect global trade patterns—both route choice and the volume and composition of trade (through impacts on global production). In the worst case, such shifts can even increase global carbon emissions. The route choice is important because the shipping and freight transport sector is formed as a network. The network effects can lead to carbon leakage as shown by Ludwig (2024) or positive spillover effects if retrofitted ships must be used also in unregulated routes. Thus, the recommendation for the policymakers is to conduct an impact assessment of effects of EU's policies on production and consumption to increase understanding of how policies impact the emissions from production and consumption but also how domestic production is affected.

Although the results indicate that pricing carbon emissions has modest effects in the short run, carbon pricing provides an important signal for the industry to reduce its emissions. The shipping sector has been characterized as "hard to abate" (Trosvik and Brynolf, 2024) due to the high abatement costs, which are also documented in this thesis. However, the high abatement costs partly result from lacking emissions regulation, and thus insufficient incentives for clean innovations. Consequently, introducing gradually tightening emissions regulation is urged to provide correct incentives for the industry and guarantee that firms benefit from switching to clean technologies.

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