Government of Canada Gouvernement du Canada

Canada

Research Portal

Application - Insight Development Grants

Identification

Applicant

Family Name: Kasahara **First Name:** Hiroyuki

Middle Names:

Current Position: Professor

Primary Affiliation: The University of British Columbia

Department/Division: Vancouver School of Economics

Application

Application Title Quantifying the response of maritime shipping CO_2 emissions to trade shocks and policy regulations

Language of the Application (•) English ( ) French

Committee 07 - Economics

Joint or Special Initiative Select

Is this a research-creation project? ( ) Yes (•) No

Does your proposal involve Indigenous research as defined by SSHRC? ( ) Yes (•) No

Scholar Type

Are you an Emerging Scholar or Established Scholar? Established

Confirmed Scholar Type Established

Established Scholars: Proposed Versus Ongoing Research

Established Scholars: Proposed Versus Ongoing Research

My previous and ongoing research mainly involves identifying, estimating, and testing finite mixture models and their applications in econometrics. My previous research also involves estimating the impact of import and export on firm productivity in the context of international trade. I am currently developing a computationally attractive method of estimating dynamic structural models. Recently, I also worked on empirically examining the impact of various policies (mask mandates, school closures, stay-at-home orders, business closures, etc.) on COVID cases, hospitalization, and deaths during the early period of COVID-19 pandemic. Another ongoing research (for which I received funding from SSHRC Insight Grant in 2021) is to investigate the identification issue and develop an estimation procedure of production function, TFP, and markup when researchers have only access to revenue data (without price and quantity data).

The proposed research is very different from my previous or other ongoing research in the late stages of the research process. None of my previous publications, as well as none of my working papers, involve CO2 emissions or other environmental issues. None of my previous or other ongoing research investigates environmental issues or does not use satellite shipment data. The proposed project that tries to measure the CO2 emission from international shipping is a new area of my research and the proposed project is in the early stages of the research process. To understand the feasibility of the project, in the last three months, we have obtained the satellite shipping data as well as the data on fleet characteristics to start investigating a method of measuring CO2 emissions. However, we have only done the preliminary descriptive analysis, visualization, and elementary regression analysis.

During the COVID pandemic, as a researcher who has empirical knowledge of analyzing observational data, I felt that it was important to tackle imminent issues by doing empirical research --- that's how I started working on the impact of various policies on the spread of COVID during the COVID pandemic. I believe environmental issues are one of the most important issues humankind faces now. Therefore, I would like to start working on some related environmental projects. In a broader context, the proposed research is my first attempt to understand how international trade is related to CO2 emissions. I hope that the SSHRC Insight Development Fund will help me transition my research toward the environment and international trade area. While transitioning toward a new area of research is not necessarily easy, I have conducted many empirical projects which successfully led to publications across different areas (firm productivity, investment, export and import, entry and exit, the effect of famine, the effect of mask mandates and school closure on COVID cases and deaths, etc.).

Administering Organization

Organization The University of British Columbia

Department/Division Economics

Invitations

Role	Last Name	First Name	Organization	Department

Activity Details

Certification Requirements

Does the proposed research involve humans as research participants? ○ Yes ◉ No

Does the proposed research involve animals? ○ Yes ◉ No

Impact Assessment

Will any phase of the proposed research take place outdoors? ○ Yes ◉ No

Keywords

List up to 10 keywords that best describe the proposal.

CO2 emission, maritime shipping, international trade, COVID-19 pandemic, environment, fuel efficiency, shipping speed regulation

Disciplines

Indicate and rank each entry relevant to your proposal, with Entry 1 as the most relevant and the last entry the least relevant.

1. Economics Economics
2. Urban and Regional Studies, Environmental Studies Urban and Regional Studies, Environmental Studies
3. Geography Geography

Areas of Research

Indicate and rank each entry relevant to your proposal, with Entry 1 as the most relevant and the last entry the least relevant. If you select Not Subject to Research Classification in Entry 1, the system will automatically remove any other areas of research when you save this page.

1. Environment and Sustainability
2.
3.

Temporal Periods

Indicate and rank each entry relevant to your proposal, with Entry 1 as the most relevant and the last entry the least relevant.

	From		To	
	Year	Period	Year	Period
1.	2000	AD	2023	AD
2.				

Geographical Regions

Indicate and rank each entry relevant to your proposal, with Entry 1 as the most relevant and the last entry the least relevant.

1. International
2.
3.

Countries

Indicate and rank each entry relevant to your proposal, with Entry 1 as the most relevant and the last entry the least relevant.

1.
2.
3.
4.
5.

Revisions Since Previous Application

Summary of Proposal

CO_2 emissions are a primary driver of global warming and present one of humankind's most pressing challenges. Maritime shipping contributes a third of CO_2 emissions from all trade-related activities, which corresponds to roughly 3% of global CO_2 emissions. The International Maritime Organization has set a target of a 50% reduction of CO_2 emissions from maritime shipping by 2050. The stringency of abatement actions required to meet this goal depends on how trade will evolve over the coming decades, and a thorough understanding of how an increase in trade affects CO_2 emissions from maritime shipping is essential for effective policy.

In this project, we measure the change in shipping CO_2 emissions over recent years using high-frequency data of ships' movements (hourly AIS tracking data for the global merchant fleet). By exploiting the large variation in shipping during the COVID pandemic, we estimate the short- to medium-run elasticity of CO_2 emissions from maritime shipping with respect to international trade. Using the estimated elasticities, we assess the impact of policy regulations on worldwide CO_2 emissions.

We combine three datasets. First, hourly AIS tracking data includes information on speed, location, and draft (the vertical distance between the waterline and the bottom of the hull), which can be used to determine whether a ship is carrying cargo or not. We match this data to a fleet register, which includes built year, size, type, and technical characteristics such as hull dimensions, engine power, propeller, etc.. Finally, we link this to data from the EU's Monitoring, Reporting, and Verification program, which provides annual fuel consumption and emissions for trips into and out of the EU.

From the AIS data, we identify all trips between a pair of ports for each ship. We estimate how fuel efficiency, accounting for operating conditions (speed, draft, weather), is determined by ship characteristics (age, size, etc.) using the fuel consumption data for EU trips from the MRV dataset. We then extrapolate these efficiencies to non-reporting ships—ships that did not stop at an EU port—based on their ship characteristics and operating conditions. Based on estimated fuel efficiencies for all trips across all ships, we estimate fuel consumption and the associated CO_2 emissions for all trips of any ship.

We compute the worldwide CO_2 emissions within each month by aggregating fuel consumption across all trips. Fuel consumption for each port pair is estimated by aggregating all trips taken from the origin to the destination port. By aggregating them to origin-destination country pair levels, we decompose a change in worldwide CO_2 emissions as the sum of a change in directional bilateral trade flows across different countries and directions. Directionality is important because many carriers travel without cargo due to trade imbalances, and we account for it by identifying ship loading and unloading at each port using the draft from AIS data, while using monthly product-level bilateral trade data from UN Comtrade, Eurostat, and the

US census as supplementary information.

We estimate the elasticity of CO_2 emissions specific to each ship category and origin-destination pair and then compute the elasticity of CO_2 emissions with respect to trade volume from each origin country to each destination country by aggregating the elasticities across different ship categories using their observed empirical shipping weights, where route-specific draft is used to adjust for the capacity utilization to account for trade imbalances. Using the estimated elasticities, we evaluate the impact of two potential policies on CO_2 emissions: regulating the maximum speed and regulating unladen trips.

Roles and Responsibilities

Hiroyuki Kasahara (principal investigator; PI hereafter) is responsible for organizing and managing a research team that consists of the PI, one Ph.D. student (Allen Peters), and one undergraduate research assistant (Oliver Xu). The PI will play a major role in all parts of the project: reviewing the literature, establishing the research framework and empirical methods, collecting and analyzing the data, doing counterfactual analysis, writing the manuscript, and presenting at seminars and conferences.

The PI's knowledge and previous experience in managing a research team, successfully implementing a project, writing empirical papers, and publishing scientific articles are essential to this project. One of the main tasks in the project is to estimate how fuel efficiency is related to various ship characteristics (age, ship types, ship sizes) as well as other time-varying operating conditions (capacity utilization, weather) using semi-parametric methods as well as machine learning tools (e.g., random forest and deep neural network). We also plan to conduct out-of-sample validation of the estimated models extensively. Therefore, the PI's extensive knowledge of econometrics and empirical methods will be essential for choosing appropriate estimation methods and implementing them. The PI will spend 50 percent of his time on this project relative to other ongoing research projects.

The PI also supervises Allen Peters (fifth-year Ph.D. student) for his dissertation, and the proposed project is a joint project with Allen Peters. This project will be a third chapter of Allen Peters' Ph.D. dissertation. Allen Peters is an exceptional Ph.D. student with extensive knowledge of computational programming and analyzing a large data set. The main area of research of Allen Peters is an intersection of empirical IO and environment, and his knowledge of empirical IO and environment helps formulate a practical framework for the proposed research and conducting regression analysis.

Purchasing and updating the data sets (AIS tracking data, the World Fleet Register, the MRV data, and bilateral trade data) is another key step for successfully implementing the project. To investigate the feasibility of the proposed project, Allen Peters contacted the seller of the data. He obtained a limited amount of data for preliminary investigation using the internal fund from the Vancouver School of Economics at the University of British Columbia. Allen Peters also attended a conference that is held for the shipping industry and made a connection with people who are working in the shipping industry. Allen Peters' working knowledge of the shipping sector will be indispensable for obtaining the relevant dataset and specifying an empirical model with relevant factors without ignoring essential variables. Allen Peters will also maintain a GitHub repository for this project so that the reproducible code becomes publicly available in the future (although we cannot post proprietary data) once the paper has been published. Allen Peters will spend 50 percent of his available time on this project in relation to other ongoing research projects.

Another vital member of the team is Oliver Xu, who is a third-year undergraduate student at the Vancouver School of Economics (doing a double major in economics and statistics). While Oliver is only a third-year undergraduate student, he has exceptionally strong programming skills. Oliver Xu has been involved in the preliminary investigation of the project, including writing an initial code on estimating how fuel efficiency is determined by ship characteristics and operating conditions using machine learning tools. Oliver Xu plans to pursue his Ph.D. and will be an important team member for the next two years and, possibly, beyond.

Roles and Training of Students

The PI has supervised student research in the past and has written six papers together with four former students (Bingjing Li, Joel Rodrigue, Yawen Liang, Michio Suzuki, Jasmine Hao). The PI had hired eight undergraduate students (Chiyoung Ahn, Jasmine Yang, Pietro Montanarella, Chris Yu, Yiran Song, Alex Dong, Bessie Bao, Joanna Wang), one master student (Lavanda Chen), and five PhD students (Denis Kojevnikov, Yawen Liang, Dongxiao Zhang, Anton Laptiev, Jasmine Hao) as research assistants (RA, hereafter) over the past eight years while he currently hires one undergraduate student (Oliver Xu) and two PhD students (Kisho Hoshi, Allen Peters) and provide training to them.

It is anticipated that our research agenda will generate substantial opportunities for students to develop the research skills necessary for their own dissertation and beyond graduate school. The PI trains students to develop three types of skills: theoretical skills, computation skills, and data skills. First, the student will become familiar with theoretical econometrics and estimation methods in estimating how fuel efficiency is related to ship characteristics and operating conditions, where we plan to use semi-parametric estimation methods as well as machine learning toods. Second, the student will develop their skills in R and Python. This includes descriptive analysis, visualization, and regression analysis with R and using machine learning tools in Python. Students are also trained in using Rmarkdown for reproducibility. The student will also learn how to use Git and Github for collaboration. Third, the student will be an integral part of the basic empirical analysis. The student will learn how to organize the data sets and how to run semi-parametric regressions using Stata.

As a concrete example of my training strategies, I describe how I trained two students in the past: Chiyoung Ahn and Jasmine Hao.
Chiyoung Ahn worked as my full-time RA (35 hours per week) five years ago. Every weekday between May and August of 2016, I met him at 10am to discuss what he plans to do and again at 5pm to discuss his progress. To facilitate communication, I prepared a document that describes the list of things to do every week. In turn, I asked Chiyoung to prepare a weekly report on what he has done using Rmarkdown. Chiyoung and I worked together to develop an R package by using Git so that we can simultaneously work on R codes while using GitHub for file sharing. Example codes are given. After three months, Chiyoung has learned the following skills: (i) R-programming, (ii) how to use Git and Github, (iii) how to use Rmarkdown, (iv) how to create R-package. Chiyoung is now a Ph.D. student at the UPenn. Jasmine Hao has been working as my RA since September of 2017. Jasmine has excellent programming skills and is interested in econometrics. The training strategy for computational skills is similar to that for Chiyoung—I give a list of things to do and frequently meet to discuss her progress. I also trained her in theoretical econometrics. I am currently writing papers together with Jasmine and Chiyoung.

The PI has successfully applied the proposed training strategies in the past. In fact, after adopting these training strategies, three of Ph.D. students whom the PI has supervised become data scientists at Facebook, Amazon, and NuData Security. Another student (Jasmine Hao) got an assistant profesor job at the University of Hong Kong. This has been possible not only through the RA work but also through active collaboration with Ph.D. students. As in the past, the PI will encourage Ph.D students to develop their own thesis projects and/or to develop a joint project with the PI.

Knowledge Mobilization Plan

Overall Plan: We plan to write two academic papers based on the proposed project, which will be made available as working papers on UBC, SSRN, RePEc, and Arxiv websites and circulated through the CESifo Working Paper series. The papers will be presented at academic seminars and conferences in Canada and internationally. The papers will be submitted for publication to leading peer-reviewed journals in Economics. We also make our programming code (for estimating how ship characteristics and operation conditions determine fuel efficiency) publicly available via a GitHub repository so that researchers interested in this issue can examine our estimation procedure and, possibly, re-use or modify our code for future research.

Engaging Audiences: The academic audience will be engaged through formal presentations at academic seminars, conferences, and academic publications. Furthermore, we plan to present at conferences for practitioners in the shipping industry (e.g., Green Shipping Conference: https://vmcclimate.ca/green-ship-2022) so that our research results will be communicated with practitioners.

Schedule: We plan to write two academic papers based on the project. The first paper provides estimates of CO_2 emissions during the COVID pandemic, and provide a descriptive analysis of how a change in CO_2

emissions before and during the pandemic is related to a change in trade volume across different regions. The second paper provides an estimate of heterogenous elasticities of CO_2 emission with respect to trade volumes across (directional) bilateral trade relationships; based on the estimated elasticities, we evaluate the impact of regulating the maximum speed of ships and the minimum capacity utilization, where the latter addresses the issue of excess CO_2 emissions related to trade imbalance between two countries (e.g., some vessel from China to Australia are near empty).

Expected Outcomes

Scholarly Benefits

Indicate up to three scholarly benefits of the proposed project. **(required)**

1. Knowledge creation/intellectual outcomes
2. Student training/skill development
3. Enhanced research methods

Summary of Expected Scholarly Outcomes

The proposed research estimates worldwide CO_2 emissions before and during the COVID pandemic at the monthly level. It reveals how a change in international trade affected CO_2 emissions during the COVID pandemic. The decomposition analysis allows us to understand how and why CO_2 emissions from international shipping change during the COVID pandemic in terms of regions or bilateral trade relationships. The estimated elasticities of CO_2 emissions with respect to trade volumes will allow us to conduct counterfactual experiments on how a change in policy regulations (e.g., speed regulations) affects CO_2 emissions, helping us to evaluate the proposed policy regulations of international shipping to reduce CO_2 emissions.

Social Benefits

Indicate up to three social benefits of the proposed project.

1. Environmental outcomes
2. Enhanced policy
3.

Summary of Expected Social Outcomes

The result of proposed counterfactual experiments may help in understanding better policy regulations to reduce CO_2 emissions from international shipping. The advice to policy makers as well as practitioners in international shipping industry will help reduce CO_2 emissions from international shipping, achieving a better future environment. We also make the programming code publicly available so that researchers who are interested in this issue re-do or modify our research to examine related issues in the future to further produce environmental knowledge related to international shipping and CO_2 emissions.

Audiences

Indicate up to five potential target audiences for the proposed project.

1. Academic sector/peers
2. International not-for-profit organizations
   Specify:
   IMO
3. Practitioner/professional/industrial associations
4. Canadian government
   Federal
5.

Summary of Benefits to Potential Target Audiences

The academic researchers working on the area of intersection between environment and trade will benefit from our research because our project will provide a benchmark measure of CO_2 emissions from international shipping during the COVID pandemic and also provide decomposition analysis to identify the source of a change in CO_2 emissions in terms of different regions / bilateral trade relationships. International organizations such as IMO will also benefit from our research because we employ different methods of estimating CO_2 emissions and contrast our estimates with their estimates. International shipping industry practitioners will benefit from our research results to better understand how to reduce CO_2 emissions. Finally, our research results have important policy implications for the Canadian government to reduce CO_2 emissions from international shipping.

Funds Requested from SSHRC

Year 1

Personnel Costs			
Student Salaries and Benefits / Stipends	**Number**	**Amount**	**Justification**
Undergraduate	1	$9,600.00	One undergraduate research assistant (Oliver Xu) is hired to do literature reviews, descriptive data analysis, and regression analysis.
Masters			
Doctoral	1	$14,400.00	One doctoral student (Allen Peters) is hired to do data analysis, programming for semi-parametric regression and counterfactual simulations.
Subtotal		**$24,000.00**	
Non-Student Salaries	**Number**	**Amount**	**Justification**
Postdoctoral			
Professional/Technical Services			
Other			
Subtotal		**$0.00**	
Travel and Subsistence Costs	**Number**	**Amount**	**Justification**

for Research			
Applicant / Team Members			
Student(s)			
Subtotal		**$0.00**	

Travel and Subsistence Costs for Dissemination	Number	Amount	Justification
Applicant / Team Members			
Student(s)			
Subtotal		**$0.00**	

Other Expenses	Amount	Justification
Supplies		
Non-disposable equipment		
AIS data	$20,000.00	AIS data for containerships and dry bulk for 2018, 2021 2022. Previously, we purchased 2019-2020 data for containerships and dry bulk (but without tankers) at 10000 USD. Given the previous purchasing cost, we estimate the cost of updating AIS data to be 15000 USD, which is approximately 20000 CAD.
Subtotal	**$20,000.00**	
Grand Total Year 1	**$44,000.00**	

Year 2

Personnel Costs

Student Salaries and Benefits / Stipends	Number	Amount	Justification
Undergraduate	1	$9,600.00	One undergraduate research assistant (Oliver Xu) is hired to do literature reviews, descriptive data analysis, and regression analysis.
Masters			
Doctoral	1	$14,400.00	One doctoral student (Allen Peters) is hired to do data analysis, programming for semi-parametric regression and counterfactual simulations.
Subtotal		**$24,000.00**	

Non-Student Salaries	Number	Amount	Justification
Postdoctoral			
Professional/Technical Services			
Other			
Subtotal		**$0.00**	

Travel and Subsistence Costs for Research	Number	Amount	Justification
Applicant / Team Members			
Student(s)			
Subtotal		**$0.00**	

Travel and Subsistence Costs for Dissemination	Number	Amount	Justification
Applicant / Team Members	1	$1,500.00	The applicant plans to attend one domestic conference to present the paper.
Student(s)	1	$1,500.00	One doctoral student plans to attend one domestic conference to present the paper. This will provide an excellent experience for the student.
Subtotal		**$3,000.00**	

Other Expenses	Amount	Justification
Supplies		
Non-disposable equipment		
Subtotal	**$0.00**	
Grand Total Year 2	**$27,000.00**	

Grand Total	**$71,000.00**	

Funds from Other Sources

List all contributors (e.g., host institution or organization, individuals, not-for-profit organizations, philanthropic foundations and private sector organizations), that are providing cash and/or in-kind contributions for the proposal. Indicate whether or not these funds have been confirmed.

If a funding source is not listed, you must:

- type the source name in Funding Source
- identify the contribution type
- enter an amount.

If you have received more than one contribution of the same type from a single funding source (i.e., cash or in-kind) and same confirmation status, you must combine these into one entry (e.g., two confirmed $20,000 cash contributions from a university become one confirmed $40,000 cash contribution). Enter amounts rounded off to the nearest dollar—in Canadian currency—without spaces or commas (e.g., 40000). For blank entries, leave in the "0" value.

For examples of Canadian and international sources of eligible cash and/or in-kind support, see SSHRC's Guidelines for Cash and In-Kind Contributions.

Note: All contributions must be indicated in Canadian currency.

Funding Source	Contribution Type	Confirmed	Year 1	Year 2	Total
					$0.00
Details					
					$0.00
Details					
					$0.00
Details					
Grand Total					$0.00

Reviewer Exclusion

Excluded Reviewers

Exclusion Type	Family Name / Collaboration	First Name	Initials	Organization	Department	Email
No records to display.						

Detailed Description of Proposed Research:

Project: Quantifying the response of maritime shipping CO_2 emissions to trade shocks and policy regulations

Objective: First, we quantify monthly, fleet-level CO_2 emissions from worldwide maritime shipping activity before and during the COVID pandemic. Second, we examine the change in CO_2 emissions from maritime shipping during the COVID pandemic in terms of changes in bilateral trade volumes and provide a decomposition analysis. Third, we model the heterogenous elasticities of CO_2 emissions from maritime shipping with respect to international trade, which in turn are used to conduct a counterfactual analysis of potential emissions policies.

Context: Global trade is intricately linked with maritime shipping, which transports over 80% of the volume of all traded goods and around 70% of their value (UNCTAD, 2017). At the same time, maritime shipping contributes a third of CO_2 emissions from all trade-related activities (Shapiro, 2016), which corresponds to about 3% of global CO_2 emissions, roughly equal to the total emissions of Germany (Faber et al., 2020). The International Maritime Organization (IMO) has set a target of a 50% reduction by 2050 and introduced a minimum efficiency requirement for new ships in 2013, with stringency increasing over time and future levels yet to be determined. The stringency of abatement actions required to meet this goal clearly depends on how trade will evolve over the coming decades, and a thorough understanding of this relationship is essential for effective policy.

While trade volumes typically vary slowly, the COVID pandemic induced substantial variation over a short period: World merchandise trade decreased by more than 10 percent in the first three months of the pandemic before recovering over the following two years (Arriola et al., 2021). We first measure the change in shipping emissions before and during this period using high-frequency data of ships' movements, which we then relate to the change in bilateral trade volumes between country pairs. By exploiting the large variation in shipping, we estimate the short- to medium-run elasticity of CO_2 emissions from maritime shipping with respect to international trade.

Quantifying the elasticity of shipping emissions to trade is challenging for a number of reasons. A ship's fuel consumption depends on many factors, including its size and age, with newer and larger ships typically more efficient. The existing fleet is extremely heterogeneous: Figure 1 illustrates the large variation across both dimensions in just a subset of ships, namely small to medium bulk carriers (This excludes

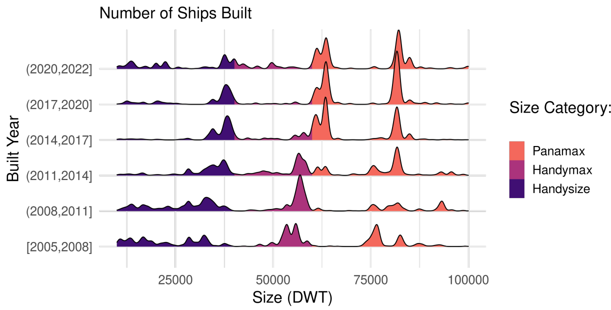

Figure 1: Existing fleet of bulk carriers

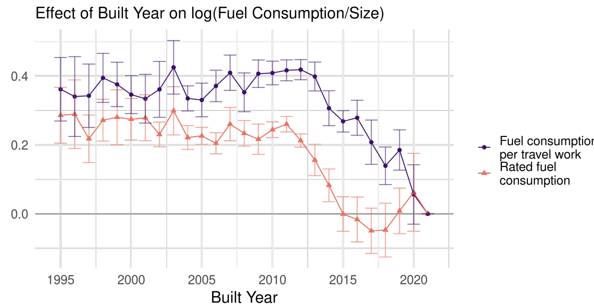

Figure 2: Built-year fixed effects from efficiency regression (1) with 95% CI

the largest class up to 400'000 deadweight tonnes (DWT)). Furthermore, new ships have become larger over time. Ship size is related to the volume of trade, the type of products shipped, and port and canal infrastructure. As such, different bilateral trade relationships involve different sizes of ships and hence different fuel efficiency, leading to heterogenous emissions–trade elasticities across country pairs. In addition, the presence of trade imbalances means ships often travel without cargo on certain routes. Finally, fuel consumption depends roughly cubicly on speed, meaning that the short-run elasticity of emissions to shipping demand may be quite large and may fluctuate over time with the price of fuel.

The Fourth IMO GHG Study 2020 (Faber et al., 2020) details both bottom-up and top-down methodologies for calculating emissions. Their bottom-up approach employs data collected from ships' automatic identification systems (AIS) which transmit the location and speed of each ship every few minutes (c.f., Jalkanen et al., 2009; Olmer et al., 2017; Johansson et al., 2017). In order to estimate CO_2 emissions, they combine AIS data with ship fuel consumption ratings and aggregate. Our approach is similar, but leverages actual emissions reports to estimate fuel efficiencies.

A small number of authors have explored the relation between trade and shipping. Cristea et al. (2013) and Shapiro (2016) take macroeconomic approaches to look broadly at emissions from all transportation modes involved in trade. Focusing on maritime shipping, van der Loeff et al. (2018) and Liu et al. (2019) link AIS data with granular indicators of trade volumes to create region-specific estimates. Most closely related to our work, Wang et al. (2021) calculate bilateral seaborne trade volumes and link them with shipping emissions estimated from AIS data. They provide a snapshot of values for the year 2018 and develop a model based on nominal efficiencies for exploring counterfactuals. With a more empirical approach, Brancaccio et al.

(2018) explore the elasticity of trade with respect to ship fuel costs. Our work will be among the first to seriously explore the relationship in the opposite direction — from trade to emissions — on a global scale. We propose a novel empirical method to estimate efficiencies using reported fuel consumption from the European Union's (EU) Monitoring, Reporting, and Verification (MRV) program. Furthermore, we leverage COVID-related variations to calibrate and validate our model. The use of actual reported emissions allows us to capture more of the previously discussed adjustment channels, and the large cross-sectional/time-series variation in shipping activity during the COVID pandemic aids identification.

Methodology: We first estimate how a ship's fuel consumption efficiency, accounting for its speed and draft, is determined by its observed technical characteristics. Then we compute high-frequency emissions estimates for each ship's trips between ports. This first stage relies on three key datasets that we have obtained: (i) AIS tracking data, (ii) the World Fleet Register, and (iii) the MRV data.

Hourly AIS tracking data for the entire registered fleets in the world includes information on speed, location, and draft (the vertical distance between the waterline and the bottom of the hull), which can be used to determine whether a ship is carrying cargo or not. We match this data to the World Fleet Register from Clarksons Research that includes basic information on each ship, including built year, size, and type as well as other detailed technical characteristics such as hull dimensions, engine power, propeller details, etcetera. Finally, we further link this to publicly available data from the EU's MRV regulation, which provides annual fuel consumption and emissions for trips into and out of the EU ("EU trips," hereafter).

Our methodology for estimating fuel efficiency builds on that of the IMO as detailed in Faber et al. (2020). However, whereas they use theoretical fuel consumption values corresponding to rather coarse ship size- and age-bins, we empirically estimate ship-specific fuel efficiencies using actual fuel consumption data and all available ship characteristics. Our procedure is as follows. First, we identify trips from the AIS data as between two stops of a sufficient length in proximity to land, and flag EU trips as those with at least one stop within the EU. Next, we estimate how fuel efficiency is determined by ship characteristics (age, size, etc.) and operating conditions (speed, draft) using the fuel consumption data for EU trips from the MRV dataset. Then, we extrapolate these efficiencies to non-reporting ships—ships that did not stop at an EU port–based on their ship characteristics and operating conditions. These estimates can be aggregated at any desired level. To our knowledge, this will be the first work to employ the MRV data to estimate fuel efficiency.

As a preliminary investigation, we have estimated fuel efficiencies for bulk carriers, regressing fuel efficiency on a set of ship characteristics (using logs of all variables) as well as built-year fixed effects.

$$\log\left(\frac{fuel\ consumption}{size \cdot \sum_{x \in X} \cdot s_x^2 \cdot x}\right)_{it} = built\ year_i + \boldsymbol{\beta} f(Z_i) + \varepsilon_{it}, \tag{1}$$

where $fuel\ consumption$ is reported annual consumption, $size$ is the ship's capacity in deadweight tonnage, x is the distance traveled at each speed s_x, Z_i is a vector of ship characteristics (including $size$), and $f(\cdot)$ is an unknown function, which we use semi-parametric sieve methods using B-splines as well as machine learning tools (e.g., random forest, deep neural network) to estimate.

Figure 2 plots the built-year fixed effects for our preliminary estimation based on a log-linear specification. Efficiency is surprisingly flat for ships built before roughly 2013, after which it improved sharply. This agrees well with the analysis of evolution of new ship efficiency from Faber et al. (2015, Figure 15). The current specification does not include the effects of laden status or weather but we plan to include the draft in the AIS data as well as wind/wave speeds using detailed weather data.

A limitation of our proposed approach is that the fuel consumption data is annual and there may be significant error in calculating the travel work over such a long time period. We partially mitigate this by using only observations for which reported distance traveled closely matches the distance from tracking data. On the other hand, the advantage with regards to the approach of Faber et al. (2020) is that it relies less on theoretical assumptions. Figure 2 provides a preliminary indication of the difference between using nominal versus actual fuel efficiencies. For CO_2 emissions estimates, we plan to compare our estimate with that of Faber et al. (2020).

Using the estimated fuel efficiency for each ship and its travel history, it is straightforward to compute the worldwide CO_2 emissions within each month of the years from 2018 to 2022 by aggregating fuel consumptions across all ships. Fuel consumption for each origin–destination port pair is estimated by aggregating all trips taken from the origin port to the destination port. Aggregating at each country pair gives an estimate of the monthly CO_2 emissions associated with maritime shipping for each origin-destination country pair. We analyze the source of a change in the worldwide CO_2 emission by decomposing it as the sum of a change in directional bilateral trade flows across different countries and directions. Directionality is important—around

42% of bulk carriers travel without cargo due to trade imbalances (Brancaccio et al., 2020)—and we account for it by identifying ship loading and unloading at each port using the draft from AIS data while using monthly product-level bilateral trade data from UN Comtrade, Eurostat, and the US census as supplementary information.

Finally, we model the elasticity of CO_2 emissions from maritime shipping with respect to the trade volume from origin to destination for any country pair. The idea is that we estimate the elasticity of CO_2 emissions specific to each ship category and origin-destination pair and compute the elasticity of CO_2 emissions with respect to trade volume for each origin-destination country pair by aggregating the elasticities across different ship categories using their observed empirical shipping weights.

Specifically, we create multiple categories of ships based on ship type (containerships, bulk carriers, and tankers), size, and age. For each category, we estimate a version of the fuel efficiency equation (1). As a benchmark, we evaluate the equation at the observed average speed and the average draft for each category of ships traveling from each origin country to each destination country. This will allow us to compute the elasticity of fuel consumption (and CO_2 emissions) with respect to an increase in trade volume shipped from an origin country to a destination country. Note that these elasticities are different across ship categories; furthermore, they depend on the average speed and the average draft. The route-specific draft is also used to indicate the utilization of ship capacity to account for trade imbalances. For example, the flow of dry bulk goods between Australia and China is highly directional so that using solely ship movements from China to Australia would vastly overestimate the flow of dry bulk goods in that direction.

The elasticity of CO_2 emissions with respect to trade volume depends on shipping speed, capacity utilization, and ship size. The fuel consumed and, hence, the CO_2 emitted is less if the speed is slower, ships are more fully loaded, and larger ships are used. Using the estimated elasticities, we plan to evaluate the impact of two policy regulations on CO_2 emissions: First, we evaluate the effect of regulating the maximum speed of ships on CO_2 emissions. Second, we evaluate the effect of regulating unloaded trips in the context of trade imbalance. The proposed analysis has two important limitations. First, our analysis abstracts away from the general equilibrium effect (e.g., Shapiro, 2016). Second, our project has limited scope in that we don't analyze the CO_2 emission from production of trade goods (e.g., Cristea et al., 2013). Nonetheless, we hope that our analysis will provide an important stepping stone for future, more comprehensive quantitative analyses.

Timeline for conducting the proposed project (July 2023 – June 2025)

July-Sept 2023	Obtain the updated AIS data. Clean the data and provide descriptive analysis and visulalization for the relationship between fuel efficiency and ship characteristics. Preliminary regression analysis.
Oct-Dec 2023	Estimate how fuel efficiency is related to ship characteristics (size, ship types, ages) and operation conditions (draft, speed) using semi-parametric methods and machine learning tools.
Jan-Mar 2024	We conduct validation test for the predictive powers across different specifications and models to choose a specification and an estimation method that have good out-of-sample prediction performance.
Apr-June 2024	The estimated model is used to compute the worldwide CO2 emissions from international shipping. We provide decomposition analysis to understand a source of changes in the aggregate CO2 emissions from shipping in terms of bilateral trade relationships.
July-Sept 2024	The first draft of the first paper on the worldwide CO2 emissions from international shipping during the COVID pandemic is written. Present it at international workshop. Estimate the heterogenous elasticities of CO2 emissions from international shipping with respect to trade volume is estimated at each of bilateral trade relationship. Submission to conferences.
Oct-Dec 2024	The second draft of the first paper is written. We conduct counterfactual experiments of regulating ship speeds and regulation that prevent the travels with empty cargo and quantify the impact of such regulations on the worldwide CO2 emissions. The first draft of the second paper on the impact of policy regulations on CO2 emission is written.
Jan-Mar 2025	We will submit the first paper to a journal (e.g., AEJ: economic policy, Journal of International Economics). The second draft of a paper on the impact of policy regulations on CO2 emission. Submission to conferences.
Apr-June 2025	The third draft of a paper on the impact of policy regulations on CO2 emission. We will present the paper at internal workshops as well as external seminars.
July 2025-	The final draft of a paper on the impact of policy regulations on CO2 emission . Submission to a journal.

References

Arriola, C., Kowalski, P., and van Tongeren, F. (2021), "The impact of COVID-19 on directions and structure of international trade," *OECD Trade Policy Papers, No. 252, OECD Publishing, Paris.*

Brancaccio, G., Kalouptsidi, M., and Papageorgiou, T. (2018), "The impact of oil prices on world trade," *Review of International Economics.*

— (2020), "Geography, transportation, and endogenous trade costs," *Econometrica*, 88, 657–691.

Cristea, A., Hummels, D., Puzzello, L., and Avetisyan, M. (2013), "Trade and the greenhouse gas emissions from international freight transport," *Journal of Environmental Economics and Management*, 65, 153–173.

Faber, J., Hanayama, S., Zhang, S., Pereda, P., Comer, B., Hauerhof, E., and Yuan, H. (2020), "Fourth IMO greenhouse gas study," Online, accessed 11. Jul. 2021.

Faber, J., Hoen, M., Vergeer, R., and Calleya, J. (2015), "Historical trends in ship design efficiency," Tech. rep., CE Delft.

Jalkanen, J.-P., Brink, A., Kalli, J., Pettersson, H., Kukkonen, J., and Stipa, T. (2009), "A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area," *Atmospheric Chemistry and Physics*, 9, 9209–9223.

Johansson, L., Jalkanen, J.-P., and Kukkonen, J. (2017), "Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution," *Atmospheric Environment*, 167, 403–415.

Liu, H., Meng, Z.-H., Lv, Z.-F., Wang, X.-T., Deng, F.-Y., Liu, Y., Zhang, Y.-N., Shi, M.-S., Zhang, Q., and He, K.-B. (2019), "Emissions and health impacts from global shipping embodied in US–China bilateral trade," *Nature Sustainability*, 2, 1027–1033.

Olmer, N., Comer, B., Roy, B., Mao, X., and Rutherford, D. (2017), "Greenhouse gas emissions from global shipping, 2013–2015 Detailed Methodology," *International Council on Clean Transportation: Washington, DC, USA*, 1–38.

Shapiro, J. S. (2016), "Trade Costs, CO¡sub¿2¡/sub¿, and the Environment," *American Economic Journal: Economic Policy*, 8, 220–54.

Ugé, C., Scheidweiler, T., and Jahn, C. (2020), "Estimation of worldwide ship emissions using AIS signals," in *2020 European Navigation Conference (ENC)*, IEEE, pp. 1–10.

United Nations Conference on Trade and Development (2017), "Review of Maritime Transport 2017," United Nations Geneva.

van der Loeff, W. S., Godar, J., and Prakash, V. (2018), "A spatially explicit data-driven approach to calculating commodity-specific shipping emissions per vessel," *Journal of Cleaner Production*, 205, 895–908.

Wang, X.-T., Liu, H., Lv, Z.-F., Deng, F.-Y., Xu, H.-L., Qi, L.-J., Shi, M.-S., Zhao, J.-C., Zheng, S.-X., Man, H.-Y., et al. (2021), "Trade-linked shipping CO2 emissions," *Nature Climate Change*, 11, 945–951.