# Reducing Emissions in International Trade: A Supply Chain Perspective

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November 26, 2019

**Abstract**

The acceleration of climate change has raised a difficult question among policy makers as to the tradeoff between economic growth and emission reduction. In this paper we propose a new approach for reducing Sulphur emissions in international trade at a lower cost, than imposing content fuel standards. Using bilateral panel data $(2009 - 2016)$ on trade, vessels, and maritime connectivity for countries located in Europe, America, Pacific Asia and Africa, and country-level data on logistics performance, we show that improvement in the supply chain upstream or downstream from the shipping activity may lead to a sufficient growth in trade that the average vessel size used to transport the goods will increase. As larger vessels are more fuel efficient per twenty-foot equivalent unit (TEU), they have the effect of reducing emissions per TEU. In terms of mechanisms, firstly, we show that there exists a significant positive relationship between trade, logistic performance and connectivity variables, using an augmented gravity equation. Then, we demonstrate that the increased trade can be accommodated by larger vessels, resulting in a reduction of Sulphur emissions per unit of output. The connectivity variables are used as measures of the network structure established for trade along the supply chains, and logistic performance index (LPI) as an operational measure. To deal with potential measurement errors, we use a few alternative measures of supply chain performance, including the average time and cost required to process a typical export/import transaction along the supply chains, as well as the number of documents required. We also apply several econometric models for panel data, including Pooled OLS, Fixed and Random-effects models, Instrumental Variables and regression with lagged explanatory variables to identify the correct model specification and for robustness checks.

**Keywords**: Bilateral trade; Logistics performance; Maritime connectivity; Supply chains; Sulphur emissions reduction; Vessel size.

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# 1 Introduction

The current apprehension with climate change has added a greater sense of urgency to curbing fossil fuel emissions than had been true in the past. The (apparent) acceleration of climate change has raised a difficult challenge among the policy-makers as to the tradeoff between economic growth and emission reduction. Each of the primary modes of transport has introduced policies and/or specified the means of reducing emissions. Road transport introduced catalytic converters to reduce air pollution in California in 1961, elsewhere in the U.S by 1974, and in Europe in the early 1990s; the EU was more focused on safety, fuel economy and member state harmonization than curbing emissions prior to 1992 (Hooftman et al., 2018). Aviation has organized its emission reduction strategies through International Civil Aviation Organization (ICAO), and the maritime sector through the International Maritime Organization (IMO). This paper focuses on the policy debates that have dominated the transport field for the past years (Eyring et al., 2005b), namely the strategies for reducing Sulphur emissions in the maritime sector.

Recently the IMO Maritime Pollution (MARPOL) convention sets a new directive limiting Sulphur content of marine fuels used on all vessels to 0.5% mass on mass (m/m) by January 1, 2020.[1] The vessel owners have a number of alternatives to comply with this more stringent limit, including burning higher quality fuel, investing in devices that clean exhaust gases (closed or open looped scrubbers), installing engines with a capability to burn a variety of low or zero Sulphur fuels, or scrapping the vessel. These options, however, require a certain amount of investment by the ship owners, and therefore adding up to the costs. Furthermore, this new regulation will affect the dynamics of the fuel market in an uncertain way. For example, if the number of vessels choosing to burn higher quality fuel goes up, the demand for cleaner fuels would increase, leading to an increase in prices at least in the short run.[2] As for the scrubbers, the open loop removes the Sulphur emissions from the exhaust gases, but the vessel discharges the stored emissions into the ocean. Consequently, several countries have banned the use of open loop scrubbers in their territorial waters and specifically the discharge of the wash water.[3] The hybrid and closed loop scrubbers are able to clean the exhaust gases with sea-

[1]Under the current regulations, vessels operating outside Emission Control Zones (ECZ) which include Baltic Sea, North Sea, North American and the United States Caribbean Sea Areas are allowed to emit 3.5% m/m, and those operating inside the zones are limited to 0.1% m/m.

[2]Fuel prices may somewhat moderate if refineries make investment in capacity to meet the new demand, though it is not clear that the longer-term trend would be steadily increasing fuel prices.

[3]Ten countries have banned the use of open loop scrubbers to discharge wash water, the most important are China (banned discharge in port waters of coaster ECZ, and Bohai Bay waters) and Singapore. In addition, countries with outright bans or restrictions include India, Abu Dhabi in UAE, Belgium, Germany, Lithuania, Latvia, Dublin in Ireland, Norway, and Hawaii, Connecticut and California in the United States.

water, but such closed loop systems use a portion of the vessel's carrying capacity. In sum, any choice may entail additional costs, which in turn affect international trade and lead to reductions in economic growth to some extent. On the other hand, the economic benefits from setting the target emissions level at 0.5% remain unclear, i.e., it is unclear whether this target value represents the threshold to achieve an absolute emission reduction or was established as an economically efficient level of emissions.[4] More importantly, the IMO directive appears to focus on reducing Sulphur emissions from the shipping activities only, without considering the other components of the supply chains that may influence trade and related emissions.[5]

This paper explores a new approach for reducing Sulphur emissions in international trade, by considering the role of maritime connectivity, performance of supply chains and the demand for vessels. Specifically, this research looks for ways to incentivize the use of larger vessels to accommodate international trade, as they are more fuel efficient per TEU than the smaller ones (Cullinane and Khanna (2000); Sys et al. (2008); Notteboom and Vernimmen (2009); Svindland (2018). Our argument is that improvements in the supply chain upstream or downstream from the shipping activity may lead to a sufficient growth in trade that the average vessel size used to transport the goods from one country to another one will increase. In our view, connectivity measures the nature and size of the network established for trade along the supply chains, and logistics performance captures how well the network works given the network has been established. In other words, connectivity variables measure the network structure, while the logistic performance indicators represent an operational measure. Besides, there has been a trend towards the use of large vessels over the past years, most notably because of the need to obtain realizable economies of scale with cost savings coming from lower investment, fuel and crew costs per TEU (Malchow, 2017). In some cases, these cost savings are offset (to some degree) by the increased investment in port facilities to handle larger vessels and the longer dwell times resulting from unloading of a large number of containers (Sys et al., 2008). Therefore, investments in other parts of the supply chain, besides the reduction in transportation costs, are needed to lower overall supply chain costs. Investments upstream or downstream from shipping may facilitate and incentivize the use of larger vessels.

[4]It is noted that the change from the current allowed value of 3.5% mm outside ECZ and from the value of 0.1% inside the zone is substantial. Thus, two salient features arise from this approach - if it makes a significant difference in terms of coverage, and if the marginal benefit of moving to 0.5 compared to another allowable amount for vessels operating outside the ECZ is substantially different (i.e., if it is expected that the marginal benefit from moving to 0.5% is different from moving to 1.0% m/m).

[5] The economic rationale behind is the following: if another sector along the supply chains is more efficient in reducing emissions than shipping, the latter can pay a more efficient economic agent to reduce the selected emissions and do it more cheaply. As such, fewer resources are used up to achieve the desired amount of emission reduction in the maritime sector.

Using an original dataset consisting of country pairs located in Europe, America, Pacific Asia and Africa for the $2009-2016$ period, we first build an augmented gravity model to investigate the impacts of performance of supply chains on bilateral trade. The empirical gravity equations are estimated using Pooled OLS and econometric models for panel data with fixed and random effects. Then, we evaluate the relationship between growth of trade and the demand for vessels between country pairs in terms of vessel size, and analyze the implications for Sulphur emission reduction. To our knowledge, this is the first study that looks into the issues of emission reduction in the transport sector from a broader, supply chain and economics, perspective. We provide an empirical evidence of the link between the performance of supply chains, international trade, and the demand for vessels, while deriving policy and economic implications for Sulphur emission reduction. In this analysis, we use the Logistics Performance Index (LPI) and several indicators of maritime connectivity, such as the number of operators on routes between country pairs, the number of common connections, and the number of transshipment, and the characteristics of vessels serving the country pairs, as measures of performance of supply chains. For robustness checks, we also consider alternative measures of performance of supply chains, such as the time and cost to import/export along the supply chains, as well as the number of documents required for import/export shipment. Finally, we investigate potential causality and endogeneity issues using Instrumental Variables (IV) estimation.

We find a strong relationship between logistics performance, bilateral trade, and size of vessels serving country pairs. The empirical results suggest that 1% change in bilateral trade (in terms of value) leads to an 0.003% increase in average size of container vessels. The growth of bilateral trade can be achieved not only by reducing the transportation costs and through economic growth, but also by enhancing the performance of logistics along the supply chains. We find that an improvement of the LPI index in the export country by one unit can lead to about 11.8% increase in trade in terms of value. Better connectivity between the origin and destination country can also influence bilateral trade. In particular, adding one operator to the shortest leg of the route between the country pairs results in 0.5% increase in trade, while an additional common connection (i.e., an additional country that is directly connected to both the origin and destination country) leads to a 0.2% increase. By using different measures of logistics performance that focus on the time and cost along the supply chain (i.e., through the stage of document preparation, customs clearance and inspections, inland transport and handling, and port and terminal handling), we find that reducing the time to export by one day reduces the cost of trade by 1.5%, while reducing the number of documents required for import shipment in the destination country goods by one improves bilateral trade by 8.1%.

The rest of the paper is organized as follows. Section 2 reviews the existing literature on Sulphur emissions from international trade and shipping industry, along with the importance of performance of supply chains in affecting trade. Section 3 specifies the methodology used in the paper. Subsection 3.1 provides the theoretical framework, which is the basis of the empirical analysis and Subsection 3.2 discusses the empirical strategies. Section 4 introduces the data and variables. Section 5 presents the empirical results, with robustness checks provided in Section 6. Section 7 discusses the implications of our empirical results for Sulphur emission reduction from international trade, and Section 8 concludes.

## 2 Literature Review

The amount of Sulphur emissions and their concentrations to a limited amount at major sea ports have become a major environmental challenge in maritime supply chains (Hilmola, 2018). Over the past decades, researchers have attempted to assess Sulphur emissions from international maritime at the regional and global level (see, among others, Corbett et al. (1999); Eyring et al. (2005a,b); Endresen et al. (2007); Smith et al. (2011), and concluded that fuel consumption and Sulphur emissions from international shipping have substantially increased. For example, Eyring et al. (2005b) evaluated the historical global emissions before 2000, and found that Sulphur emissions grew from 2.77 teragrams (Tg) to 12.03Tg between 1950 and 2000. Endresen et al. (2007) also computed the fuel-based Sulphur ship emissions from 1925 and 2002, and found that global emissions grew from 2.5Tg to about 8.5Tg during the period of scrutiny. Eyring et al. (2005a) even estimated a range of global future emissions to be between 6.9Tg and 14.6 Tg in 2000, and between 3.6Tg and 25.9 Tg in 2050, depending on the future traffic and technology available. Klimont et al. (2013) estimated that Sulphur dioxide from international shipping increased from 9800 Gg in 2000 to 13600 in 2010, closely following a 40% increase in goods loaded over this period. Emissions from the Northern Hemisphere, particularly along heavily traded routes and for transport vessels (bulk cargo, general cargo, and passenger) appear to be the largest, accounting for about 85% and 70% of global emissions, respectively (Corbett et al., 1999).

Given this significant increase, possible strategies for reducing Sulphur emissions have been largely discussed in the literature, particularly in the scientific and transportation literature. For example, Eyring et al. (2005a) discussed the possible reduction strategies for existing diesel engines, and found that using fuel with 2% Sulphur instead of 4% will halve Sulphur emissions, but at the penalty of an increased fuel price. They also suggested that aggressive Sulphur reduction can be achieved by strict international and national legislations, as the total Sulphur emissions rely only on the Sulphur content in the fuel burned not on technology. Lindstad et al. (2017) compared the compliance options based on ship type and operational patterns, and suggested that distillates would be an attractive option for smaller vessels, and scrubbers for larger vessels. But most of the existing studies, including documents and reports produced by IMO (e.g., Skjølsvik et al. (2000)) have examined the alternatives through the technical and operational perspective. Furthermore, they are mainly focused on strategies for reducing emissions within the maritime sector, abstracting away the possibility that the other activities in supply chains may be efficient in emission reduction, and therefore can contribute significantly in reducing emissions at the global level. The few studies (see, among others, (Psaraftis and Kontovas, 2009; Kontovas and Psaraftis, 2011) that have looked at this issue from the supply chain perspective investigated the impact of speed reduction option on the cost-effectiveness of the maritime logistics chain and emission reduction. Specifically, Psaraftis and Kontovas (2009) showed that speed reduction may not be the best alternative in Sulphur Control Emission Areas (SECAs) because it may cause a net increase of total emissions along a ship's route if the transit time remains the same. Cleaner fuels may also result in a reverse cargo shift from sea to land, therefore has the potential to produce more emissions on land than those saved at sea.Kontovas and Psaraftis (2011), however, found that speed reduction can be beneficial under certain conditions, though the real effectiveness of such a scheme depends on the possibility of reducing port time.

This paper contributes to the existing the literature by providing a new supply chain perspective for analysing Sulphur emission reduction. It highlights the role of the components of supply chains, from the efficiency of logistics and maritime connectivity (upstream) to the use of larger vessels (downstream). Specifically, this research provides an empirical evidence supporting that significant Sulphur emission reduction can be achieved (i) by investing in other parts of the supply chain, such as performance of logistics and maritime connectivity, to lower the overall supply chain cost, and therefore increasing international trade, and (ii) by using larger vessels to accommodate the increase in international trade. With the recent developments in the ship market, larger container vessels have becoming increasingly attractive for shippers. This has been motivated by the need to obtain realizable economies of scale with cost savings coming from lower investment, fuel and crew costs per TEU (Cullinane and Khanna, 2000; Malchow, 2017). Interestingly, evidence shows that the growth in the fleet size is not necessarily followed by increased fuel consumption because of the complex interaction among the key influencing variables, such as demand for sea transport, technical improvements and operational characteristics (average operating speed, average sailing distance) that determines the fuel consumption. For the $1925 - 2002$ period, for instance, Endresen et al. (2007) observed that the growth in sea borne trade during the $1925 - 2002$ period was not reflected by a corresponding growth in the fleet by vessel numbers, suggesting the influence of modern, larger and more efficient cargo ships, with improved cargo handling in ports on emission reduction. Furthermore, large vessels are more fuel efficiency per TEU, and thus have effect of reducing emissions per TEU. In some cases, the cost savings from economy of scale (Malchow, 2017) may be offset to some degree by the increased investment in port facilities to handle larger vessels and longer dwell times (Sys et al., 2008), especially in a competitive environment. Therefore, investments in other parts of the supply chains are needed to lower overall supply chain costs. Investments upstream or downstream from shipping may facilitate and incentivize the use of larger vessels, which are more fuel efficient per TEU, and thus have the effect of reducing emissions per TEU.

A number of studies have investigated the impacts of different components of the supply chain on trade (see, among others, Anderson and Van Wincoop (2003); Sánchez et al. (2003); Clark et al. (2004); Martí et al. (2014); Wilmsmeier and Hoffmann (2008); Limao and Venables (2001); Fugazza and Hoffmann (2017); Çelebi (2019)). For example, Anderson and Van Wincoop (2003) found that transport costs, measured in terms of a generalized price, add the same as an ad valorum tax of 21%. Limao and Venables (2001) showed that increasing trade costs by 10% reduces trade volumes by more than 20%. Clark et al. (2004) confirmed the highly significant negative impact of transport costs on bilateral trade. The other determinants of trade include port efficiency (Clark et al., 2004), shipping time (Hummels and Schaur, 2012), the quality of institutions (De Groot et al., 2004),[6] the quality of infrastructures (Limao and Venables, 2001), maritime connectivity (Fugazza and Hoffmann, 2017; Hoffmann et al., 2019), and different indicators of logistics efficiency, such as hinterland transport to and from the main ports, cost of the product and the shipping, total costs of trade document procedures and border control, inventory cost, along with indicators of complexity of customs documents and the frequency of services between ports (Hausman et al., 2005), and logistics performance (see, among others, (Martí et al., 2014; Çelebi, 2019).[7]This study contributes to this strand of literature by providing an empirical evidence on the impact of both logistics performance and maritime connectivity on

[6]In their model, the quality of institutions is captured by such as voice and accountability, political stability, government effectiveness, regulatory quality, rule of law and control of corruption.

[7](Martí et al., 2014) studied the impacts of LPI and its components (custom procedures, logistic cost, and quality of land and maritime infrastructures) on trade in emerging economies. He found substantial improvements in trade for Africa and South America, and showed that exporters benefit more than importers from improved logistics. Çelebi (2019) also used the LPI to show the impact of changing logistics on trade, but she focused on the differences between low, middle-and high-income countries.

bilateral trade, using a rich dataset compiled from various sources, consisting of 115 exporter and 123 partner countries located in 4 regions, including America, Europe, Pacific Asia and Africa for the period $2009-2016$. This study uses both subjective and quantitative measure of logistics performance. We demonstrate that improvements in the supply chain upstream or downstream from the shipping activity may lead to a sufficient growth in trade that the average vessel size used to transport the goods from one country to another one will increase.

# 3 Methodology

## 3.1 Theoretical Framework

This section describes the theoretical framework used for our empirical estimation. The gravity equation has been the workhorse of empirical models on international trade. Anderson (1979) demonstrated that the gravity models have solid theoretical foundations and allow researchers to study the relationship between bilateral trade, their costs, and the economic size of the country pairs, along with aggregate measures of the trade frictions for importers and exporters. The Armington-CES, which is the most popular gravity model, is based on several assumptions, such as, Cobb-Douglas utility functions for the representative agent in each country over each country's distinct goods, and constant elasticity of substitution. Many extensions of the Armington-CES model have delivered the structural gravity systems, and therefore have been used as the basis of many empirical models. Our empirical model is based on the framework proposed by Anderson and Van Wincoop (2003), which is a modified version of the Armington-CES model. The main assumptions of the model are the following: (i) constant elasticity of substitution (CES) utility function for the preferences of consumers, (ii) iceberg trade costs as in Samuelson (1952), (iii) total consumption equals total production, and (iv) labour is the only input in the production process.

The (reduced form) structural gravity system of Anderson and Van Wincoop (2003)' model is presented as follows:

$$\begin{aligned}
X_{ij} &= \left(\frac{t_{ij}}{\Pi_i P_j}\right)^{1-\sigma} Y_i Y_j, \quad \forall i,j, \quad \text{where} \\
\Pi_i &= \left[\sum_j \left(\frac{t_{ij}}{P_j}\right)^{1-\sigma} Y_j\right]^{\frac{1}{1-\sigma}} \forall i, \quad \text{and} \quad P_j = \left[\sum_i \left(\frac{t_{ij}}{\Pi_i}\right)^{1-\sigma} Y_i\right]^{\frac{1}{1-\sigma}} \forall j, \\
W_i &= B_A \left(\frac{A_i}{\Pi_i}\right)^{\frac{\sigma-1}{\sigma}} \quad \forall i,
\end{aligned}$$

where $X_{ij}$ denotes bilateral exports from country $i$ to country $j$, $\sigma$ is the elasticity of substitution across varieties from different countries, with $\sigma > 1$. Variable $Y_i$ and $Y_j$ represent the income in country $i$ and $j$, respectively, and $t_{ij}$ captures the bilateral trade costs. Terms $\Pi_i$ and $P_j$ are price indexes, referred by Anderson and Van Wincoop (2003) as *Inward Multilateral Resistances (IMRs)* and *Outward Multilateral Resistances (OMRs)*, respectively. In particular, the multilateral trade costs $\Pi_i(P_j)$ are GDP-weighed average of the relative trade frictions that producers (importers) in country $i$ ($j$) face when they export (imports) goods from country $i(j)$ to country $j(i)$ (for example, see Larch and Yotov (2016)). Larch and Yotov (2016) describe IMRs and OMRs as trade costs that consistently aggregate all bilateral costs into country-specific indexes and decompose the incidence of trade costs and their changes on the consumers and the producers in each country. $W_i$ is the wage in country $i$, $A_i$ is the technology available and $B_A$ is a parameter related to population $L_i$, with $B_A = L_i^{-\frac{1}{\sigma}}$. While Eq. (1) provides a link between bilateral trade flows, the size of the exporter and of the importer, and a generalized trade cost, Eq. (3) restates a link between trade costs and the factor prices.

Equations (1)-(2) are used as the basis of our empirical analysis. We will focus on the bilateral trade costs ($t_i j$) and its components, in particular the performance of logistics in the supply chain and maritime connectivity, and how they affect bilateral trade. Next, we extend the existing framework of Anderson and Van Wincoop (2003) to consider the link between the demand for vessels and bilateral trade flows. It is clear that the demand for ships is closely related to the demand for transport services. Therefore, it can be expected that developments in the shipping market depend on the conditions in international trade and in the world economy.[8] Nevertheless, the demand for ships can also be influenced by the activities of investors who may enter the market and demand ships when they see a potential rise in ship values (Strandenes, 2013).[9] The relationship between the demand for vessels

[8] Literature has also shown that economic shocks lead to change the demand for sea transport (Stopford, 2013).

[9] It has been argued that these activities ensure better allocation of vessels among ship owners servicing international trade by bringing liquidity in the ship market.

and trade is captured by the following equation:

$$V_{ij} = g(X_{ij}, \mathbf{Z_{ij}}), \tag{4}$$

where $V_{ij}$ denotes the demand for vessels for transporting goods between country i and country j, and $\mathbf{Z_{ij}}$ is a set of control variables that affect the demand for ship, as discussed above. Function $g(.)$ is assumed to be increasing in $X_{ij}$ such that an increase in bilateral trade flows leads to a large demand for vessels or vessel capacity for a pair of country.

The next section discusses the empirical strategies.

## 3.2 Empirical strategies

The objective of this section is to describe the strategies for the empirical estimations. The first step consists of translating the structural gravity systems and the demand for vessel equation in (1)-(4) into empirical equations. Therefore, the system of equations related to bilateral trade can be rewritten as follows:[10]

$$X_{ijt} \quad = \quad x_{ijt} + e_{ijt}, \quad \text{where} \quad x_{ijt} = \left(\frac{t_{ij}}{\Pi_i P_j}\right)^{1-\sigma} Y_{it} Y_{jt}, \quad \forall i, j,$$

where $e_{ijt}$ is the error term and $(1-\sigma)$ is the trade elasticity of trade costs. In the literature of empirical trade, it is common to specify the bilateral trade costs $x_{ijt}$, as follows:

$$x_{ijt} = exp\{\mathbf{z_{it}^N}\beta^N + \mathbf{z_{it}^H}\beta^H + \delta_{it}^X + \delta_{jt}^M\},$$

where $z_{it}^N$ is a vector of variables capturing natural trade barriers, such as distance and contiguity dummy variable, $z_{it}^H$ is a vector of dummy variables that represent the historical and cultural linkages commonly known to affect the costs of bilateral trade. It includes common official language, whether the language is spoken by at least a significant proportion of the population in both countries, if the country pairs are or were ever in colonial relationship, and if the pairs are in colonial relationship post 1945. Terms $\delta_{it}^X$ and $\delta_{it}^M$ are variables that represent the multilateral resistance terms for the exporter and the importer, respectively, discussed in Section 3.1. It is common to use importer and exporter fixed effects in cross-section settings and importer-time and exporter-time fixed effects with

[10]For details, see Bayer, Kerr and Yotov (2018). Gravity, distance, and international trade in "*Handbook of International Trade and Transportation (Chapter 2), Edition 2018*" by Blonigen, B.A. and Wilson, W.W.

panel data to account for the (unobservable) multilateral resistance terms (see for e.g., Anderson and Van Wincoop (2003)). Most empirical estimations in international trade are based on Eq. (6) in its logarithmic form. In other words, the common functional form of gravity equation is derived from the following equation:

$$log\ x_{ijt} = \mathbf{z_{it}^N}\beta^N + \mathbf{z_{it}^H}\beta^H + \delta_{it}^X + \delta_{jt}^M + e_{it},$$

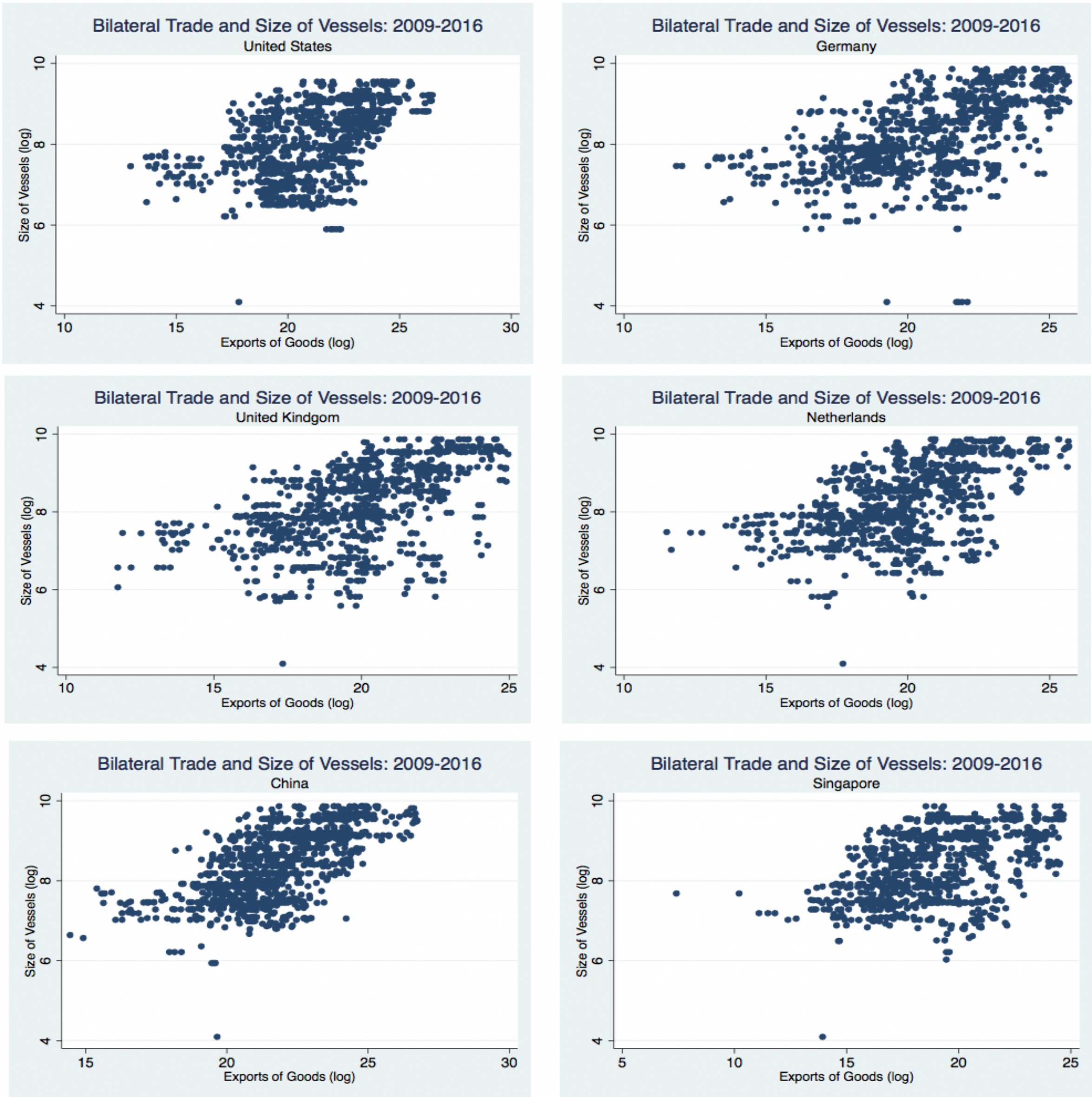
where $e_{it}$ is an error term. In this analysis, the gravity equation in we extend Eq.(7) is extended to consider the key components of supply chains, including (i) indicators of logistics performance in the exporter country and in the destination, and (ii) indicators of maritime connectivity. As control variables, we include Gross Domestic Product per capita, denoted by GDP$_{it}$ and GDP$_{jt}$, for both the exporter and the importer, respectively, to account for time- and country-varying characteristics that may influence bilateral trade flows. The empirical equation reads:

$$log\ x_{ijt} = \mathbf{z_{it}^N}\beta^N + \mathbf{z_{it}^H}\beta^H + \mathbf{I_{ijt}}\beta^{\mathbf{I}} + \mathbf{Z}_{ijt}\beta^X + \delta_{it}^X + \delta_{jt}^M + e_{ijt}.$$

where $\mathbf{I_{ijt}}$ represents a vector of indicators capturing the performance of supply chains, $\mathbf{Z}_{ijt}$ is a vector of control variables. As discussed previously, better connection between the country pairs, and/or improvement in logistics performance in the origin and destination country are expected to reduce the bilateral trade costs, and therefore increasing the value of trade. Thus, the coefficients for the indicators are expected to be positive (i.e., $\beta^I > 0$).

The next step consists of defining the functional form of function $g(.)$ in Eq.(4). We assume a linear relationship between the size of vessels and bilateral trade. This specification is motivated by the existing literature, as discussed in Section 2. Moreover, we observe a positive linear correlation between size of ships and value of trade in our sampled countries during the period of scrutiny. Figure 1 shows the correlation between size of container vessels and exports of goods for selected countries during the $2009 - 2016$ period.

Figure 1: Size of (container) vessels and bilateral exports of goods for selected countries during 2009–2016 time period




Source: Compiled by the authors from UNCTAD and UNCOMTRADE Statistics Data. Note: The unit of vessel size is TEU and Exports of Goods are expressed in terms of value in millions of US Dollar.

Therefore, $g(.)$ is assumed to be a linear function of bilateral trade flows and of a set of control variables that would affect the demand for vessels. The size of (container) vessels serving the country pair is used as the dependent variable and bilateral exports as the key explanatory variable. Thus, the equation for the demand for vessels becomes:

$$V_{ijt} = X_{ijt}\alpha^x + \mathbf{Z_{ijt}}\alpha^z + \delta_{it}^X + \delta_{jt}^M + \mu_{ijt}, \tag{9}$$

where $\mu_{ijt}$ is the error term. The rationale behind Eq. (9) is the following: ship owners can respond to a change in trade in two ways; either by increasing the size of vessels transporting the goods from the origin to the destination country ($\alpha^x > 0$), or by keeping (even reducing) the current vessel size but increase their number instead ($\alpha^x \leq 0$). The former would result in emission reduction per unit of output, while the later lead to the opposite results. Like the previous specification, a set of control variables, such as distance, GDP per capita for the exporter and for the importer countries, time- and country- fixed effects are included into the estimation model.

In sum, Eq.(9) establishes the link between the size of vessels and bilateral trade, while Eq.(8) characterizes the role of logistics performance and maritime connectivity, among others, in affecting trade. As it is common in empirical estimation of panel data, pooled OLS and Generalized Linear Model (GLM) with random and fixed effects are applied on each equation. The results of statistical tests, model goodness-of-fit, and the consistency of the estimates are used to select the most appropriate specification. In all estimations, robust standard errors are applied to correct for heteroskedasticity and autocorrelation. For robustness checks, we conduct an analysis using lagged values of logistics performance and maritime connectivity indicators, alternative measures of performance of the supply chain, and instrumental variables (IV) approach to control for potential causality and endogeneity problems. While including country- and year- fixed effects into the model helps capture the effects of potential (unobserved) omitted variables, the instrumental variables (IV) techniques appear to be an effective tool to deal with such endogeneity issue. According to the preliminary statistical tests, the lagged values of exports appear to be valid instruments for bilateral trade in the IV analysis.

In the next section, we discuss the source of data and the variables used in the empirical estimation in detail.

# 4 Data and Variables

We start with a discussion of the variables of interest, logistics performance and maritime connectivity indicators in Subsection 4.1. Then, the dataset and the variables used in the empirical estimations are described in Subsection 4.2.

### 4.1 Indicators of logistics performance and maritime connectivity

The *Logistics Performance Index (LPI)* produced by the World Bank is used as the main indicator of the performance of supply chains. The LPI attempts to provide a measure of the reliability and resilience of service delivery of supply chains, therefore it can be used to represent the time and costs of transacting. The LPI, a composite index drawn from web-based surveys, aggregates the views of the logistics and freight forwarding community. More specifically, the LPI is the weighted average of six indicators; (1) the efficiency of customs and border management, (2) quality of trade and transport infrastructure, (3) ease of arranging competitively prices international shipments, (4) quality of logistics services, (5) ability to track and trace consignments, and (6) frequency of service delivery in scheduled or expected delivery time (Arvis et al., 2018). Technically, for each of the six core competencies, the respondents are asked to rate eight export and import markets based on how important they are to the country of location of the respondent (see Arvis et al. (2018), Appendix 5 for more details). Each of the survey questions are scored on a scale from 1 to 5, with 1 indicating very low to 5 denoting high. The weightings of each of the six components are established using principal component analysis. For example, the loadings for 2016 are customs (0.41), infrastructure (0.41), international shipments (0.41), logistics quality and competence (0.41), tracking and tracing (0.41) and timeliness (0.40). Table 1 shows the LPI scores of the top performers in our sample of countries in 2010, 2012, 2014 and 2016.

The average LPI score for the exporters included in the sample is 3.12, with Germany showing the highest value (4.12) in 2016, followed by Sweden, Netherlands, Singapore, Belgium, Hong Kong and United Kingdom. These countries remain the top performer during the period of scrutiny. It is noted that the LPI scores are only available for the year 2007, 2010, 2012, 2014 and 2016. In our analysis, the missing data for the corresponding year is filled with the mean of two consecutive years.[11] Over the past years, the performance of logistics and infrastructures in leading countries in international trade has also significantly improved during the 2009-2015, as shown in Figure 2. While the average LPI is 3.07 in 2009, it reaches 3.21 in 2015, before slight decreasing to 3.19 in 2016.

The subjective LPI scores are widely used in the literature because they are derived from fully convincing methodology and provide high degree of comparability across countries and over time. To address potential issues related to the validity and precision of subjective indices, we consider alternative quantitative measures of logistics performance as robustness checks. These concrete metrics

[11] This is equivalent to assume a linear growth of LPI between two years. Therefore, the LPI score for the missing year (t) is computed using the equation: $LPI_{it}^{m} = \frac{LPI_i(t-1)+LPI_i(t+1)}{2}$, where superscript m denotes missing value.

Table 1: LPI scores for the selected leading countries between 2010 and 2016

| 2016 Ranking | Country | 2010 | 2012 | 2014 | 2016 | Average 2010 − 2016 |
|---|---|---|---|---|---|---|
| 1 | Germany | 4.11 | 4.03 | 4.12 | 4.23 | 4.12 |
| 2 | Sweden | 4.08 | 3.85 | 3.96 | 4.2 | 4.02 |
| 3 | Netherlands | 4.07 | 4.02 | 4.05 | 4.19 | 4.08 |
| 4 | Singapore | 4.09 | 4.13 | 4 | 4.14 | 4.09 |
| 5 | Belgium | 3.94 | 3.98 | 4.04 | 4.11 | 4.02 |
| 6 | Hong Kong | 3.88 | 4.12 | 3.83 | 4.07 | 3.98 |
| 7 | United Kingdom | 3.95 | 3.9 | 4.01 | 4.07 | 3.98 |
| 8 | United States | 3.86 | 3.93 | 3.92 | 3.99 | 3.93 |
| 9 | Japan | 3.97 | 3.93 | 3.91 | 3.97 | 3.95 |
| 10 | United Arab Emirates | 3.63 | 3.78 | 3.54 | 3.94 | 3.72 |
| 11 | Canada | 3.87 | 3.85 | 3.86 | 3.93 | 3.88 |
| 12 | Finland | 3.89 | 4.05 | 3.62 | 3.92 | 3.87 |
| 13 | France | 3.84 | 3.85 | 3.85 | 3.9 | 3.86 |
| 14 | Denmark | 3.85 | 4.02 | 3.78 | 3.82 | 3.87 |
| 15 | Australia | 3.84 | 3.73 | 3.81 | 3.79 | 3.79 |
| 16 | Ireland | 3.89 | 3.52 | 3.87 | 3.79 | 3.77 |
| 17 | South Africa | 3.46 | 3.67 | 3.43 | 3.78 | 3.59 |
| 18 | Italy | 3.64 | 3.67 | 3.69 | 3.76 | 3.69 |
| 19 | Norway | 3.93 | 3.68 | 3.96 | 3.73 | 3.83 |
| 20 | Spain | 3.63 | 3.7 | 3.72 | 3.73 | 3.70 |
| 21 | Republic of Korea | 3.64 | 3.7 | 3.67 | 3.72 | 3.68 |
| 22 | China | 3.49 | 3.52 | 3.53 | 3.66 | 3.55 |
| 23 | Israel | 3.41 | - | 3.26 | 3.66 | 2.58 |
| 24 | Lithuania | 3.13 | 2.95 | 3.18 | 3.63 | 3.22 |
| 25 | Qatar | 2.95 | 3.32 | 3.52 | 3.6 | 3.35 |
| 26 | Malaysia | 3.44 | 3.49 | 3.59 | 3.43 | 3.49 |
| 27 | Poland | 3.44 | 3.43 | 3.49 | 3.43 | 3.45 |
| 28 | Turkey | 3.22 | 3.51 | 3.5 | 3.42 | 3.41 |
| 29 | India | 3.12 | 3.08 | 3.08 | 3.42 | 3.18 |
| 30 | Portugal | 3.34 | 3.5 | 3.56 | 3.41 | 3.45 |

compiled by the World Bank since 2005 include the time and cost of exporting and importing a typical 20-foot FCL container with medium-value products from the port of entry to a firm in the most populous or commercially active city in the country, or to the port of exit from a firm in that city (see, Hausman et al. (2005) for more details on the metrics and the survey).[12]

Regarding the indicators of maritime connectivity, we consider the number of operators between country pairs, the number of connections, and the number of transshipments, as measures of connectivity. The number of operators represents the level of competition on the route along the origin and

[12]The survey excluded ocean freight time and cost, since that would have involved an extremely large number of bilateral trade partners for each country. It included distance, however, used as a surrogate for shipping cost. Details on the data are given in the Robustness checks section.

destination country. The number of connections gives the total number of countries that have a direct connection to both the origin and the destination country. It is noted that the number of transshipments can be zero, which indicates a direct connection. These indicators are highly correlated with the "Liner Shipping Bilateral Connectivity Index (LSBCI)", constructed by UNCTAD to measure maritime connectivity between country pairs. For example, according to LSBCI scores, the pair, United Kingdom-Netherlands, is the most connected countries in 2016, followed by Belgium- United Kingdom, Belgium-Netherlands, and Netherlands-Germany. But these country pairs also had the highest number of common direct connections, and the highest number of carriers on the thinnest segment in 2016. In fact, the number of carriers serving the routes between Belgium and Netherlands was 77, while the one serving routes between Belgium and Germany is 76. In Asia, the routes between Korea and China, and those between Malaysia and Singapore are the best served, with an average maximum number of carriers of 72 and 70, respectively.[13]

### 4.2 Description of the dataset and variables

The dataset is composed of 12, 089 pairs of countries (with 115 exporter countries and 123 partner countries) located in 4 regions, including America, Europe, Pacific Asia and Africa, for the period 2009-2016. The exports data comes from United Nations Commodity Trade (UN Comtrade) Statistics Database, which is the most commonly used database in empirical research in international trade. UN Comtrade reports the most recent detailed statistics on exports in terms of volume and value (current US Dollars) for almost 200 countries worldwide. In the empirical literature of international trade, it is very common to use of export values instead of volumes of exports, i.e., the gravity equation is known to represent the nominal trade rather than real trade or trade volume. Moreover, as Fugazza and Hoffmann (2017) argued, defining trade volumes at the country level could be tricky, as in most cases, trade volumes are de facto nominal values deflated by some price indices, and that is real values. Table 2 lists the variables used in the model.

[13] Other indicators of maritime connectivity used in the literature are the country-level "Liner Shipping Connectivity Index LSCI" and "Liner Shipping Bilateral Connectivity Index LSBCIÓ for country pairs, constructed by UNCTAD. The LSCI is drawn from data on the worldÕs container ship deployment, the number of vessels, their container carrying capacity, the number of services and companies, and the size of the largest ship, whereas LSBCI looks at the connectivity between two trading countries and accounts for both direct and indirect connections between the country pairs.

Table 2: List of variables in the model

| Variable | Definition | Unit |
|---|---|---|
| Bilateral trade | Value of exports of goods | Current US$ |
| Vessel size | Size of the largest container vessel on the weakest route | TEU |
| Logistics performance index (LPI) | Aggregate score computed by the World Bank | 1 to 5 |
| Transshipment | Min. number of transshipments required to get from the exporter to the importer country | 0 to 3 |
| Number of operators | Nb. of carriers operating along the route between the pair of country | 1 to 82 |
| Number of connections | Total nb. of countries that have a direct connection to both the exporter and the importer country | 0 to 95 |
| Control variables | | |
| Distance (D) | Simple distance between the most populated cities in the origin and destination country | Kilometre |
| GDP per capita | Gross Domestic Product per capita | Current US$ |
| Standard gravity dummy variables | | |
| Contiguity | Geographical location close to each other | 0 or 1 |
| Common official language | Common official or primary language | 0 or 1 |
| Spoken language | Language spoken by at least 9% of the pop. in both countries | 0 or 1 |
| Colonial relationship | Pairs in colonial relationship post 1945 | 0 or 1 |
| Common colonizer | Pairs having common colonizer post 1945 | 0 or 1 |

Information on vessel size for container at the country-pair level and the number of carriers serving the country pairs are obtained from United Nations Conference on Trade and Development (UNCTAD). The original data contains a measure of the size of the largest ship on the weakest (thinnest) route for country pairs. To compute the variable, UNCTAD uses the Max-Min method, which identifies the maximum size of vessels on the best connection between two countries. To illustrate, assume that two options are available for exporting goods from country i to country j, but both options require one transhipment, say, either via country A or via country B. If the maximum size of vessels serving the segment (i-A) is 3,000 TEU and that of (A-j) is 2,000 TEU, then the minimum vessel size for the option via country A is 2,000 TEU. Similarly, if the maximum vessel size for the segment (i-B) is 3,000 TEU and that for (B-j) is 1,000 TEU, the minimum for the option via country B is 1,000 TEU. The function Max-Min takes the maximum of the two options (or two minimums), which is the min (2000; 1000) =2,000 TEU. The same reasoning applies when the available alternatives require multiple transhipments. Therefore, it is possible that some observations are related to the maximum size of ships used to transport goods from the origin to the country of shipment (instead of country of destination). The number of carriers was computed using the same Max-Min approach.[14] It is noted that this variable captures the level of competition on services that connect country pairs.

The aggregate LPI, its components and GDPs per capita are from the World Bank's World Development Indicators (WDI) website. The quantitative measures of the time and cost of exporting and importing goods for countries are also compiled from the World Bank database.[15] The metrics are drawn from surveys of freight forwarders located in different countries on freight time and costs from the factory gate until the cargo is loaded on a ship, including administrative procedures such as acquiring an export or import licence, customs clearance, inspection of goods and several other indicators (Nordås et al., 2006). Data on distance between country pairs, common language and colonies comes from the CEPII GeoDist database.[16] Table 3 shows the descriptive statistics of the variables used in the empirical estimation.

[14]To illustrate, assume that there are two options to export goods from country i to country j, with both requiring one transhipment. The first option is via country A and the second option via B. If (i-A) is served by 3 companies and (A-j) by 5 companies, the minimum number of carriers for this option is 3. Similarly, if (i-B) is served by 2 companies and (B-j) by 5 companies, competition on the thinnest route is 2. The function Max-Min gives the maximum of the two options, which is 3.

[15]World Bank Doing Business Database, http://www.doingbusiness.org/.

[16]See http://www.cepii.fr/anglaisgraph/bdd/distances.html/. CEPII make available a "square" gravity dataset for all world pairs of countries, for the period 1948 to 2016. This dataset was originally generated to be used in the following paper: Head, K., T. Mayer and J. Ries, 2010, "The erosion of colonial trade linkages after independence", *Journal of International Economics*, 81(1):1-14. (formerly CEPII discussion paper, 2008-27).

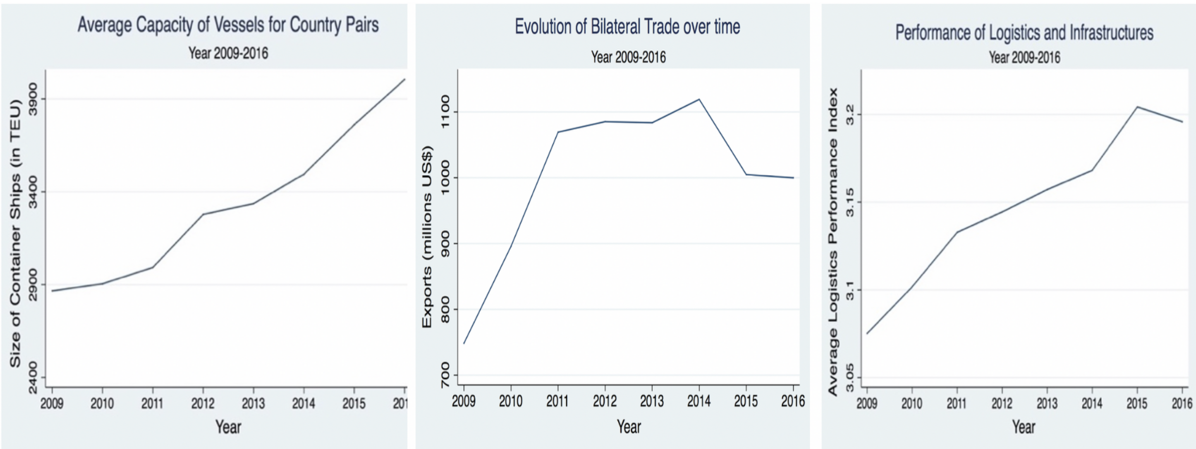
Table 3: Descriptive Statistics

| **Variable** | Average | Std. Deviation | Min | Max |
|---|---|---|---|---|
| Exports of goods (in millions of US$) | 1 450 | 10 000 | 1 | 410 000 |
| Vessel size | 3 895.67 3 | 311.466 | 0 | 19 224 |
| Logistics performance index for exporter | 3.12 | 0.549 | 1.87 | 4.23 |
| Logistics performance index for importer | 3.12 | 0.549 | 1.7 | 4.23 |
| Indicators of connectivity | | | | |
| Number of transhipment | 0.667 | 0.478 | 0 | 2 |
| Number of operators | 6.368 | 6.201 | 1 | 82 |
| Number of common connections | 15.253 | 12.788 | 1 | 95 |
| Distance (in km) | 7 558.521 | 4 464.338 | 114.637 | 19 650.13 |
| GDP per capita exporter | 19 064.39 | 19 972.69 | 391.553 | 103 059.2 |
| GDP per capita importer | 16 883.97 | 19 378.74 | 391.201 | 103 059.2 |
| Standard gravity dummy variables | | | | |
| Contiguity | 0.0231 | 0.150 | 0 | 1 |
| Common official language | 0.143 | 0.350 | 0 | 1 |
| Spoken language | 0.160 | 0.367 | 0 | 1 |
| Colonial relationship | 0.023 | 0.148 | 0 | 1 |
| Common colonizer | 0.077 | 0.267 | 0 | 1 |
| Number of observation | 80 091 | | | |

For the period $2009 - 2016$, bilateral exports are valued at 1,450 million $US, on average, while average size of container ship running on the thinnest segment of the route is 3,896 TEU. Though country pairs like Canada -United States, China - Hong Kong, and Mexico-United States have the most important trade relationship, with value of bilateral exports almost exceeding 300,000 million $US in a particular year, the largest ship (which reaches a size of 19,224 TEU in 2016) serves countries like Belgium, China, Germany, Denmark, Spain, France, UK, Korea, Morocco, Malaysia, Netherlands, Singapore, and Sweden. This is not surprising because these countries were also the most connected countries during this period. For example, the United Kingdom - Netherlands pair displays the highest bilateral connectivity index (LSBCI) in 2016, followed by Belgium- United Kingdom, Belgium-Netherlands, and Netherlands-Germany. The number of common direct connections, along with the number of carriers on the thinnest segment for these country pairs are also amongst the highest. For instance, the number of carriers serving the routes between Belgium and Netherlands was 77 in 2016, while the one serving routes between Belgium and Germany is 76. In Asia, the routes between Korea and China, and those between Malaysia and Singapore are the best served, with an average maximum number of carriers of 72 and 70, respectively.

In terms of trend over time, we observe a steady increase in all types of vessels for the period of scrutiny (2009-2016), especially in container ships. But while average capacity of (container) vessels has increased tremendously between 2009 and 2016, the exports of goods do not show a steady increase during the same period, at least in terms of value, as shown in Figure 2.

Figure 2: Evolution of size of vessels, bilateral trade and logistics performance between 2009 and 2016 - Average of selected country pairs




Source: Compiled by the authors from UNCTAD and World Bank Statistics, $2009-2016$.

The next section presents the empirical results.

# 5 Empirical Results

## 5.1 Logistics performance and bilateral trade

The estimation results for Eq.(8) are reported in Table 4. Column 1 shows the coefficients for Pooled OLS estimators, and Columns 2 and 3 the coeffcients for the RE and FE models. Since the models display strong heteroskedasticity and autocorrelation in the residuals, the standard errors are clustered at the country-pair level. The dependent variable is the natural log of export values between country i and j at time t (log $x_{ijt}$). And the key explanatory variables are the indicators of logistic performance, LPI scores for the exporter ($\text{LPI}_{it}$) and the partner ($\text{LPI}_{jt}$) country, and the indicators of maritime connectivity that include: (i) the number of carriers serving the thinnest routes serving the country pairs, (ii) the number of common direct connections, and (iii) the number of transshipments. We also control for the natural log of distance (log $\text{Dist}_{ij}$), the natural log of GDP of the origin (log $\text{GDP}_{it}$) and destination (log $\text{GDP}_{jt}$) country, and the set of historical and colonial dummy variables. All specifications include time-, exporter- and importer- fixed effects, which are represented by year and country dummies.[17]

We run a number of statistical tests to identify the most appropriate model for our empirical estimation. In terms of goodness-of-fit, the FE model appears to be the best fit for our data with an Adjusted $R^2$ of 0.9261, compared with 0.7192 for the RE model and 0.7865 for the Pooled OLS. The Breusch and Pagan Lagrange Multiplier (LM) test for comparing Pooled OLS and Random Effects model shows a very large Chi-square statistic ($\chi^2$=80,339.22 and associated p-value=0.000), strongly rejecting the null hypothesis of non-existence of random effects. Therefore, the RE model is preferred to Pooled OLS. By comparing the RE model with the fixed effects, the Hausman test rejects the null hypothesis that the difference in FE and RE coefficients is not systematic, with Chi-square equal to 394.92 (and associated p-value=0.000). It is noted that rejection of the null hypothesis implies that the random effects model estimator is likely to be inconsistent. Therefore, the FE model is expected to provide better performance than its RE counterpart.[18] The Mundlak (1978) test, which is the alternative to Hausman test but controls for heteroskedasticity and multicollinearity in the errors, also confirms that the fixed-effects assumptions are satisfied.[19] Therefore, we can conclude that the FE model is the most appropriate model, and is used as the basis of our interpretation. The results are reported in Column 1 of Table 4. To get some insights into the impacts of the time-invariant regressors, which cannot be identified in the FE model, the estimation results from the Pooled OLS and RE models are reported in Column 2 and 3 of Table 4.

[17]To save space, the coefficients for the country (exporter and importer) dummies are not reported in Table 3. But it is noted that most of the coefficients are statistically significant.

[18]See Wooldridge (2002) for details on the tests.

[19]The key to the Mundlak (1978) approach is to determine if the time-invariant unobservable and the covariates are correlated. If the test suggests the existence of such correlation, the fixed-effects assumptions are satisfied. But without evidence of any correlation, the random effects assumptions are satisfied. To implement the test, the panel-level average of the time-varying covariates are firstly computed and included into the regression. Then, the regression equation is estimated with robust standard errors. The decision is based on the result of the hypothesis test of whether the coefficients of the average time-varying variables are jointly equal to zero or not. The test rejects the null hypothesis with a statistic of Chi-square of 3941.66 (and p-value=0.000), suggesting that the time-invariant unobservable and covariates are correlated, thus the fixed-effects assumptions are satisfied.

Table 4: Estimation results for the gravity equation

| **Dependent variable: Exports of goods (log)** | **FE Model** | **Pooled OLS** | **RE Model** |
|---|---|---|---|
| **Explanatory variable** | **coeff.** | **coeff.** | **coeff.** |
| Aggregate LPI of Exporter | 0.118*** | 0.126*** | 0.176*** |
| | (0.042) | (0.042) | (0.048) |
| Aggregate LPI of Importer | 0.055 | 0.054 | 0.042 |
| | (0.035) | (0.035) | (0.042) |
| Nb. of operators | 0.005** | 0.002 | -0.008** |
| | (0.002) | (0.002) | (0.003) |
| Nb. of common connections | 0.002* | -0.00001 | -0.008*** |
| | (0.001) | (0.001) | (0.002) |
| Nb. of transshipments | -0.043 | -0.131*** | -0.620*** |
| | (0.026) | (0.025) | (0.041) |
| GDP of Exporter (log) | 0.316*** | 0.323*** | 0.362*** |
| | (0.040) | (0.040) | (0.046) |
| GDP of Importer (log) | 0.527*** | 0.525*** | 0.524*** |
| | (0.038) | (0.038) | (0.045) |
| Year Dummies | Base: 2008 | | |
| 2009 | -0.104*** | -0.107 *** | -0.110*** |
| | (0.015) | (0.016) | (0.018) |
| 2010 | 0.030* | 0.026* | 0.012 |
| | (0.016) | (0.016) | (0.018) |
| 2011 | 0.128*** | 0.127 *** | 0.136*** |
| | (0.018) | (0.018) | (0.020) |
| 2012 | 0.142 *** | 0.142*** | 0.152*** |
| | (0.019) | (0.019) | (0.022) |
| 2013 | 0.156*** | 0.158*** | 0.167*** |
| | (0.020) | (0.020) | (0.023) |
| 2014 | 0.187*** | 0.187*** | 0.183*** |
| | (0.021) | (0.021) | (0.023) |
| 2015 | 0.162*** | 0.180*** | 0.237 |
| | (0.022) | (0.021) | (0.024) |
| 2016 | 0.116*** | 0.119*** | 0.121*** |
| | (0.020) | (0.020) | (0.023) |
| Distance (log) | - | -1.624*** | -1.468*** |
| | - | (0.029) | (0.027) |

Table 4: Estimation results for the gravity equation (cont'd)

| **Dependent variable: Exports of goods (log)** | **FE Model** | **Pooled OLS** | **RE Model** |
|---|---|---|---|
| **Explanatory variable (cont'd)** | **coeff.** | **coeff.** | **coeff.** |
| Standard gravity model dummies | | | |
| Continguity | - | 0.119 | 0.159 |
| | - | (0.145) | (0.122) |
| Common official language | - | 0.874*** | 0.731*** |
| | - | (0.092) | (0.079) |
| Language spoken by 9% of pop. | - | 0.138 | 0.178** |
| | - | (0.091) | (0.078) |
| Colonial relationship | - | 0.791*** | 0.628*** |
| | - | (0.113) | (0.100) |
| Common colonizer | - | 0.319*** | 0.289*** |
| | - | (0.071) | (0.068) |
| Intercept | 8.582*** | 14.233*** | 13.523*** |
| | (0.502) | (0.579) | (0.628) |
| Nb. of observations | 80 091 | 80 091 | 80 091 |
| Goodness-of-fit (Adj. $R^2$) | 0.9261 | 0.7192 | 0.7865 |

Note: Superscripts $(***)$, $(**)$, $(*)$ indicate statistical significance at the 1%, 5% and 10% level, respectively.
The model includes exporter- and importer- specific fixed effects. Robust standard errors are in brackets.

We start with the impacts of our key variables, namely LPI and maritime connectivity. In our view the variables measuring connectivity provide a measure of the nature and size of the network established for trade. On the other hand, the LPI measures how well the network works given the network has been established. The connectivity variables are measures of network structure. The LPI and its constituent variables represent an operational measure. Turning to Table 3, the coefficient of the LPI for the exporter country is positive and statistically significant at the 1% level, whereas the LPI for the importer is not statistically significant. This suggests a positive relationship between logistics performance and trade. The coefficient represents a semi-elasticity, and indicates that a unit increase in the average LPI score for the exporter country increases the value of bilateral exports by 11.8%. This result is consistent with the previous findings (see for example, Martí et al. (2014); Çelebi (2019)). By improving logistics performance, the fluidity of goods and people movement is facilitated. This, in turn, reduces the time and costs of transacting, and thus increases the value of exports. As the change in LPI score for the importer country has no significant effects, it is therefore important to focus on the reliability and resilience of service delivery of supply chains in the exporter country rather than that in the importer country.

Maritime connectivity is captured by three variables, namely the number of operators serving the thinnest routes, the number of common direct connections and the number of transshipment.[20] The number of carriers operating on any segment of the maritime routes can be interpreted as the level competition between shipping companies on services offered in this market as well as the amount of available capacity (or inventory of capacity). Therefore, a positive coefficient for this variable is expected to increase the value of exports, as more competition and more capacity are associated with cost reduction and/or better service quality. In the FE model, the coefficient for the number of carriers is positive and statistically significant at the 5% level, confirming the positive relationship between competition and bilateral trade. In terms of magnitude, the coefficient of 0.005 indicates that adding one carrier on the least competitive segment (or leg) of a maritime route would increase the value of exports by 0.5%.

The number of common direct connections between any two countries has also a significant influence on bilateral trade. Its positive and statistically significant coefficient (at the 10% level) indicates that the value of exports would increase by 0.2% if the shippers have an additional option to get their goods transported from the origin to the destination with one shipment. The number of transshipment, however, appears to have no significant effects on trade. Though the coefficient for variable is statistically significant in the RE and Pooled OLS, it loses its significance in the FE model. This result can be explained by the way this variable enters into the equation. In the FE estimation, we consider the number of transshipment as a discrete variable, though the descriptive statistics show that the latter variable only takes three different values, namely 0 (no transshipment or directly connected), 1(one connection) and 2 (2 connections). Moreover, 33.64% of the observed country pairs are directly connected, 66.05% are connected with one transshipment, and only 0.31% requires 2 transshipments. When this variable enters into the estimation as a categorical variable where direct connection is the category of reference, we observe a significant difference between the coefficients of direct and indirect shipment. The negative coefficient for one transshipment is negative (-0.052) and becomes statistically significant at the 5% level. This suggests that the value of exports between

[20]It is noted that the impacts of these variables are not consistent across specifications. For example, the coefficient of the number of operators is negative and significant at the 5% level in the Pooled OLS, it becomes positive in RE and FE model, but then loses significance in the RE model. Reversely, the number of common connections shows a negative coefficient in the RE and Pooled OLS, but the coefficient becomes positive in the FE model. While the number of transshipment keeps its negative sign across models, its effect loses significance in the FE model. Based on the results of the statistical tests, and since the results for the Pooled OLS and RE model are not always intuitive, we focus on the coefficients of the FE model.

countries that are directly connected are 5.2% higher than the value of bilateral exports that require one transshipment. To conclude, both logistics performance and maritime connectivity appear to play a significant role in reducing the costs of trade, by improving either the access and opportunity or the quality of connections, therefore increasing the value of trade.

The impacts of the control variables are as expected. The coefficients of GDP per capita in the exporter and importer country are both positive and statistically significant at the 1% level, with a coefficient slightly higher for the GDP of the country of destination. This suggests that the richer the (origin or destination) country, the higher the value of bilateral trade is. The elasticities are 0.316 for the country of origin and 0.527 for the country of destination, suggesting that 1% increase in GDP per capita of the origin (destination) country would increase the value of exports by 0.316% (0.527%). The coefficients for year dummies are all statistically significant, at least at the 10% level, and all positive except for year 2009, indicating higher values of exports for later years as compared to 2008. The decrease in value in 2009 may owe to the effects of the 2008 financial crisis that affected the world economy and therefore international trade.

For other control variables, such as distance and standard gravity model dummies, their effects could not be identified in the FE model. Therefore, we refer to the results of the RE model in Column 2 of Table 4 to get insights into their influence. The coefficient associated with distance is negative and significant at the 1% level in the Pooled OLS and RE models. In the empirical estimation of the gravity models, it is common to use distance to capture the cost of trade between two countries. Therefore, the negative coefficient is consistent with the expectations in the sense that an increase in the transportation cost lowers the value of trade. The large magnitude of the coefficient (1.624) confirms the importance of transportation costs in affecting trade. We find that 1% increase in transportation costs would lower the value of exports by 1.624%. As for the standard gravity model dummies, the variables representing common official language, colonial relationship and common colonizer are positive and statistically significant at the 1% level. These results are consistent with the literature, supporting that country pairs that share common language and common history tend to have a strong permanent trade link than country pairs that are not historically or/and culturally related.

## 5.2 Bilateral trade and size of vessels

Like in the previous section, we conduct a number of specification tests to identify the best model for Eq.(9). The result of the Maximum Likelihood test suggests that RE model is more appropriate than Pooled OLS (with $\chi^2$=56591.36 and p-value=0.000), while the Hausman test rejects the null hypothesis that the difference in RE and FE coefficients is not systematic (with $\chi^2$=226.30 and p-value=0.000), implying that the FE model provides a better fit than the RE model. This result remains valid while heteroskedasticity and multicollinearity in errors are controlled for.[21] Therefore, we only report the results of the FE model in Column 1 of Table 5. Standard errors are clustered at the country-pair level and are displayed in brackets.

The coefficient for the log of exports is positive and statistically significant at the 5% level, implying a positive link between vessel size and bilateral trade. This is consistent with the expectation that the vessels owners may accommodate the increase in trade by using larger vessels. According to the magnitude of the coefficient, an increase of 1% in the value of exports would be associated with 0.003% increase in the size of container vessels. The GDPs of the origin and destination country also appear to have strong positive influence on the size of container vessels, and that richer countries deploy larger vessels, at least for transporting containers. We find that 1% increase in GDP per capita of the exporter (importer) country would increase the size of container vessels by 0.082% (0.11.3%). The coefficients of the year dummies are also strongly significant and get larger over time, starting with 0.174 in 2009 to 0.410 in 2016. Indeed, if the average size of container vessels in 2009 is 0.174 larger than the average size in 2008, it has more than doubled in 2016. Since we include exporter- and importer- country fixed effects in the estimation, that would control for the impacts of time-unvarying effects we do not observe.

In the next section, we conduct a robustness check analysis to ensure that our results are robust to potential causality and endogeneity issues, and to other measures of logistics performance.

[21] The specification test based on Mundlak (1978) argument rejects the null hypothesis that the time-invariant unobservable and covariates are uncorrelated, implying that the FE assumptions are satisfied.

Table 5: Estimation results for the demand for vessels equation

| **Dep. variable: Vessel size for container (log)** | **Model with fixed effects** |
|---|---|
| **Explanatory variable** | **Coeff.** |
| Exports of goods (log) | 0.003** |
| | (0.002) |
| GDP of Exporter (log) | 0.082*** |
| | (0.013) |
| GDP of Importer (log) | 0.113*** |
| | (0.012) |
| Year Dummies | Base: 2008 |
| 2009 | 0.174*** |
| | (0.006) |
| 2010 | 0.201*** |
| | (0.006) |
| 2011 | 0.195*** |
| | (0.006) |
| 2012 | 0.213*** |
| | (0.007) |
| 2013 | 0.242*** |
| | (0.007) |
| 2014 | 0.292*** |
| | (0.007) |
| 2015 | 0.361*** |
| | (0.006) |
| 2016 | 0.410*** |
| | (0.006) |
| Intercept | 5.894*** |
| | (0.155) |
| Nb. of observations | 80 081 |
| Goodness-of-fit (Adj. R- squared) | 0.7784 |

Note: Superscripts $(***)$, $(**)$, $(*)$ indicate statistical significance at the 1%, 5% and 10% level, respectively.

The model includes exporter- and importer- specific fixed effects. Robust standard errors are used.

# 6 Robustness checks

## 6.1 Causality issue

We have shown in Section 5.1 that logistics performance and maritime connectivity influence trade flows, vessels. However, trade can also influence the performance of logistics and the quality of connectivity in a country. In other words, it can happen that the growth of trade has led to the improvement in logistics performance and maritime connectivity in the country. For example, service providers may adapt the number of carriers which active on any given route (supply) to the demand, which is the intensity of trade observed in that route Fugazza and Hoffmann (2017). Moreover, investment in logistics and infrastructures may take longer time to make effects. To deal with this potential issue, we estimate the gravity equation in Eq.(8) using the once-lagged values of LPIs, number of carriers, number of connections and number of transshipments. The estimation results with the once-lagged variables are reported in Table 6. The main findings hold, though the magnitude of the LPI coefficient is reduced from 0.118 to 0.064. The impacts of all other variables are also as expected. Furthermore, the coefficients for aggregate LPI for the destination country, and number become statistically significant, while the number of common connections loses its significance.

## 6.2 Use of alternative measure of logistics performance

In this section, we present the estimation results of the extended gravity equation with alternative measures of performance of logistics. Three quantitative metrics developed by the World Bank are considered, including, (i) the average time required to process a typical export/import transaction, (ii) the cost of processing a typical export/import transaction, and (iii) the complexity of transactions, as reflected by the number of documents required for export/import shipment. The variables are supposed to capture the time and cost along the supply chain, in particular through 4 predefined stages: document preparation; customs clearance and inspections; inland transport and handling; and port and terminal handling (from the moment the stage is initiated and runs until it is completed).

Table 6: Estimation results for the gravity equation with once-lagged variables

| **Dependent variable: Exports of goods (log)** | **FE model** |
|---|---|
| **Explanatory variable** | **coefficient** |
| Aggregate LPI of Exporter (t-1) | 0.064** |
| | (0.032) |
| Aggregate LPI of Importer (t-1) | 0.071** |
| | (0.031) |
| Nb. of operators (t-1) | 0.006*** |
| | (0.002) |
| Nb. of common connections (t-1) | 0.001 |
| | (0.001) |
| Nb. of transshipments (t-1) | -0.086*** |
| | (0.023) |
| GDP of Exporter (log) | 0.384*** |
| | (0.035) |
| GDP of Importer (log) | 0.496*** |
| | (0.033) |
| Year Dummies | Base: 2009 |
| 2010 | 0.133*** |
| | (0.015) |
| 2011 | 0.221*** |
| | (0.017) |
| 2012 | 0.237*** |
| | (0.018) |
| 2013 | 0.246*** |
| | (0.019) |
| 2014 | 0.270*** |
| | (0.020) |
| 2015 | 0.256*** |
| | (0.018) |
| 2016 | 0.212*** |
| | (0.019) |
| Intercept | 8.599 *** |
| | (0.442) |
| Nb. of observations | 64 488 |
| Goodness-of-fit (Adj. R2) | 0.9371 |

Note: Superscripts $(***)$, $(**)$, $(*)$ indicate statistical significance at the 1%, 5% and 10% level, respectively.

The model includes exporter- and importer- specific fixed effects. Robust standard errors are in brackets.

Information on these measures was collected from surveys of experienced logistics practitioners (freight forwarders) around the world conducted by the World Bank since 2005. Survey respondents were asked to focus on a manufactured product that is of medium value; is transportable in dry-cargo, 20-foot containers, and were asked to base their response on a medium-size firm with 200 or more employees. Furthermore, the firm was assumed to be located in the country's most populous city and to export at least 10% of its products internationally. Details on the surveys and methodologies are described in Hausman et al. (2005). Since 2015, the World Bank has changed the methodology to compute and collect these variables. For consistency, we focus on the 2009-2015 period. Similar indicators are used in, among others, Hausman (2004); Hausman et al. (2005); Nordås et al. (2006) and Hummels and Schaur (2012).

The time to export/import is the time associated with exporting a standardized goods by sea transport along the supply chain, excluding sea transport time. The cost to export/import is the cost associated with exporting a standardized cargo of goods by sea transport through the predefined stages, and is expressed in form of all charges and fees across all the procedures in US$, including costs for documents, administrative fees for customs clearance and inspections, customs broker fees, port-related charges and inland transport costs.[22] It is calculated in US dollars per container deflated, and measures the fees levied on the export of goods in a 20-foot container. The number of documents to export/import is the number of documents required by law or common practice by relevant agencies per export/import shipment, including government ministries, customs authorities, port authorities and other control agencies. Since export and import surveys are conducted separately, and the indicators related to exports are highly correlated with those related to imports, we run two separate regressions with the time and cost to export and the time and cost to import.

The time and cost to export/import vary largely across countries. The cost to export and import ranges between about $416 and $12,399, and between $398 and $13,730, respectively, with an average cost of $1,261 for exports and $1,453 for imports. The average time to export (to import) is 16 days (17 days), with a minimum of 6 days (4 days) and a maximum of 102 days (101 days) for export (import). For example, while exporting (importing) goods form Denmark, Singapore, and United States takes on average 6 days (5 days), it takes more that 30 days, on average to export/import goods from African countries like Angola, Congo, Guinea, or Venezuela. The average number of documents required to export (import) ranges from 2 and 11 (13) from (to) France or Ireland is 2 (2), whereas country like China, Egypt, Kenya or Ukraine requires 8 documents, on average. The average number

[22]Costs are adjusted for purchasing power parity.

of documents required to import to Nigeria and Ivory Coast is even higher, reaching 13. Finally, the average cost of related-trade transactions for a 20-foot container in Singapore ranges between 413$ and 430$, compared with a range of between \$8,672 and \$9,603 in Venezuela. Table 7 shows the estimation results with the time and cost to export and import along the supply chains, respectively.

Focusing on the impacts of the indicators of logistics performance, the estimated coefficients in Column 1 of Table 7 show that time to export is the most significant variable that influences bilateral trade. Its coefficient is negative and statistically significant at the 1% level, indicating that if the time required to export a standardized container along the supply chain is delayed by one day, the value of exports drops by 1.5%. This finding confirms the importance of time cost in affecting trade, consistent with earlier findings (Hausman et al., 2005; Hummels and Schaur, 2012), Hummels and Schaur, 2012). For example, Hummels and Schaur (2012) found that each additional day in transit is worth 0.6% to 2.3% of the value of the good, and that long transit delays significantly lower the probability that a country will successfully export a good. Regarding the performance of supply chains in the importer country, the number of documents required to import goods to the country is the key variable affecting bilateral trade. The coefficient suggests that one additional document would reduce the value of trade by 8.1%. This finding is particularly relevant for regions like Africa or Asia. In some regions, institutional issues, such as customs inspection and clearance, technical clearance, and document processing are among the most important factors in the cost and time shipments, even more important than the physical conditions of roads and rail (Subramanian and Arnold, 2001).

Table 7: Estimation results with time and cost of exporting/importing goods - FE Models

| **Dependent variable: Exports of goods (log)** | **With time and cost to export** | **With time and cost to import** |
|---|---|---|
| **Explanatory variable** | **coefficient** | **coefficient** |
| Time to export/import (days) | -0.015*** | -0.004 |
| | (0.005) | (0.003) |
| Cost to export/import (log) (US$ per container deflated) | 0.051 | -0.061 |
| | (0.065) | (0.065) |
| Nb. of documents required for export /import shipment | -0.038 | -0.081*** |
| | (0.030) | (0.016) |
| Nb. of operators | 0.003 | 0.002 |
| | (0.002) | (0.002) |
| Nb. of common connections | 0.001 | 0.000 |
| | (0.002) | (0.002) |
| Nb. of transshipments | -0.010 | -0.007 |
| | (0.030) | (0.030) |
| GDP of Exporter (log) | 0.414*** | 0.405*** |
| | (0.051) | (0.052) |
| GDP of Importer (log) | 0.452*** | 0.452*** |
| | (0.044) | (0.044) |
| Year Dummies | Base: 2009 | Base: 2009 |
| 2010 | 0.143*** | 0.135*** |
| | (0.015) | (0.015) |
| 2011 | 0.233*** | 0.226*** |
| | (0.020) | (0.021) |
| 2012 | 0.248*** | 0.239*** |
| | (0.022) | (0.022) |
| 2013 | 0.259*** | 0.251*** |
| | (0.023) | (0.024) |
| 2014 | 0.288*** | 0.278*** |
| | (0.024) | (0.025) |
| 2015 | 0.274*** | 0.264*** |
| | (0.025) | (0.025) |
| Intercept | 8.872*** | 9.907*** |
| | (0.809) | (0.826) |
| Nb. of observations | 61 888 | 61 888 |
| Goodness-of-fit (Adj. $R^2$) | 0.9319 | 0.9319 |

Note: Superscripts $(***)$, $(**)$, $(*)$ indicate statistical significance at the 1%, 5% and 10% level, respectively.

The model includes exporter- and importer- specific fixed effects. Robust standard errors are in brackets.

### 6.3 Endogeneity issue

In this section, we report the results of the IV estimation of Eq.(9) to control for potential endogeneity problems. The endogeneity issue arises when some variables excluded from the models are held responsible for the change in both the dependent variables and some of the regressors. For example, the increase in size of vessels can be the result of technology development, while it is likely that the growth of trade is linked to technology advancement. We have included year dummies and GDPs per capita variables in the FE estimation to control for these unobserved effects. For robustness checks, we also run an estimation with the IV approach, which is the most well-known method to control for potential endogeneity problems. We use the once (t-1)- and twice-lagged (t-2) values of exports of goods (log) as instruments for exports at period t. The Sargan-Hansen test for overidentifying restrictions confirm the validity of the instruments. Furthermore, the Stock and Yogo test rejects the hypothesis that the instruments are weak.[23] The estimation results are shown in Table 8. Unlike the other variables which remain statistically significant, the coefficient for exports of goods becomes negative while losing its significance. To explore the source of this change, we test the validity of our main hypothesis treating exports of goods as endogenous. The result cannot strongly reject the null hypothesis that exports is treated as exogenous, with $\chi^2$-square statistic of 0.615 (and p-value=0.433). Therefore, endogeneity issue is not present in our analysis, confirming the robustness of our main results.

[23]The $\chi^2$ statistic is 1.325 (with associated p-value= 0.2497), indicating that the null hypothesis that the orthogonality conditions are satisfied cannot be rejected. Therefore, the instruments are valid. Furthermore, the Stock and Yogo test for weak instruments show a Cragg-Donald Wald F statistic of 344.253 and Kleibergen-Paap Wald F statistic of 61.652, which are large enough to confirm the rejection of the null hypothesis that the instruments are weak. Hence, our additional instruments have an amount of explanatory power for the endogenous variables.

Table 8: Estimation results using IV estimation

| Dep. variable: Variable: Vessel size for container (log) | Model with fixed effects |
|---|---|
| **Explanatory variable** | **coefficient** |
| Exports of goods (log) | -0.012 |
| | (0.017) |
| GDP of Exporter (log) | 0.058*** |
| | (0.020) |
| GDP of Importer (log) | 0.131*** |
| | (0.018) |
| Year Dummies | Base: 2008 |
| 2009 | 0.174*** |
| | (0.006) |
| 2010 | -0.197*** |
| | (0.008) |
| 2011 | -0.193*** |
| | (0.006) |
| 2012 | -0.177*** |
| | (0.006) |
| 2013 | -0.162*** |
| | (0.005) |
| 2014 | -0.103*** |
| | (0.005) |
| 2015 | -0.048 *** |
| | (0.005) |
| Intercept | 5.894* |
| | (0.155) |
| Nb. of observations | 52 145 |

Note: Superscripts ($***$), ($**$), ($*$) indicate statistical significance at the 1%, 5% and 10% level, respectively.
The model includes exporter- and importer- specific fixed effects. Robust standard errors are in brackets.

# 7 Implications for Sulphur emission reduction from international trade

The findings regarding the positive relationship and increase in vessel size have important policy implications for emissions. It is commonly known that larger ships tend to be more energy efficient per freight unit (per ton mile of goods transported) than smaller ones (Cullinane and Khanna, 2000;

Sys et al., 2008; Notteboom and Vernimmen, 2009). Svindland (2018) calculated $SO_2$ emissions from short sea shipping services operating in Emissions Control Areas in Northern Europe using comprehensive data sets for two container feeder vessels operating in the North Sea over a full year in 2015, and showed that the levels of $SO_2$ emissions from smaller vessels under 500 TEU are higher, as expected.[24] In particular, he found that prior to the pre-ECA regulations of 1% Sulphur content, a small 4,544 dwt feeder vessel with a capacity of 323 TEU emits, on average, 4.243g per TEU-km $SO_2$ emissions (or 0.315g per tonne-km) for a full year of operation, while a medium 7,750 dwt feeder vessel of with a capacity of 458 TEU produces an average of 3.316g TEU-km (or 0.266g per tonne-km). The findings of Svindland (2018) suggest that a change of vessel capacity from 323 TEU to 458 TEU, which is equivalent to a 41.79% increase, lead to a decrease of $SO_2$ emissions per TEU-km from 4.243g per to 3.316g TEU-km, hence a decrease by 27.95%.

Using the findings of Svindland (2018) as reference, we can provide some insights into the $SO_2$ emission reduction resulting from improvement in the performance of supply chains. The results are summarized in Table 9.

Table 9: $SO_2$ emission reduction associated with improvement in performance of supply chains

| **Change in component of supply chains** | $\uparrow$ **trade** | $\uparrow$ **vessel size** | $\downarrow$ $SO_2$ **emissions (per TEU per km)** |
|---|---|---|---|
| $1-unit$ improvement in LPI score for exporter | 11.8% | 0.0345% | 0.02367% |
| Reduction of the time spent to export (by one day) | 1.5% | 0.0045% | 0.00301 % |
| Reduction of the number of documents required for import shipment (by one) | 8.1% | 0.0243% | 0.01625% |
| 1 additional number of operators | 0.5% | 0.0015% | 0.00100% |
| 1 additional common connection | 0.2% | 0.0006% | 0.00040% |
| 1% decrease in transportation cost (km) | 1.62% | 0.00487% | 0.00326% |

Note: The calculations are based on the findings from Svindland (2018).

The above calculations provide some insights into the contribution of logistics along the supply chains to Sulphur emission reduction. Maritime transportation costs, the time spent along the supply chains to export, and the number of documents required by the authorities for export/import shipment

[24] Hjelle and Fridell (2012) also estimated the $SO_2$ emissions under the SECA- regulations and found that a 13000dwt container vessel generates 0.233g $SO_2$ emissions per tonne-km. For a typical short sea shipping, a 6000dwt container vessel which serves the route Bremen (Germany) -Le Havre (France) emit 81kg $SO_2$ for one shipment of 1000 tonnes, while the same 6000 dwt container feeder discharges 77 Kg $SO_2$ emissions per one shipment from Gothenburg (Sweden) to Aberdeen (Scotland).

are particularly important. It is noted that the aim of this exercise is not to provide a complete scientific assessment of Sulphur emissions from international trade, depending on the size of vessels. However, this gives an idea of the potential emission reduction when different components of the supply chains are taken into consideration.

# 8 Conclusion

This paper explores a new approach to achieve a reduction in Sulphur emissions by focusing on improvement in performance of the supply chain upstream and downstream of the shipping activity, such that the average size of vessels transporting the goods from one country to another one increases. First, we establish the link between the performance of supply chains and international trade using a modified version of the gravity models. Then, we empirically estimate the relationship between trade, size of vessels, and discuss the implications for Sulphur emission reduction. We estimate the empirical equations on a unique dataset composed of countries located in America, Europe, Pacific Asia and Africa from the $2009 - 2016$ period. In particular, the dataset includes bilateral trade data, the characteristics of vessels transporting goods between country pairs, and several indicators of performance of supply chains, such as logistics performance index, indicators of maritime connectivity, and the operational cost and time to export and import along the supply chains,

We find that improving the maritime connectivity and the logistics performance lead to reductions in bilateral trade costs and therefore increase in international trade. Controlling for the general increase in trade due to demand side effects such as growth in GDP, we found that lowering costs in one part of the supply chain resulted in an additional growth in trade. This incremental growth was accommodated with larger vessels rather than simply more vessels. The larger vessels have a lower Sulphur emissions per unit output or, from a productivity perspective, a higher productivity per unit of emissions. In terms of magnitude, our results suggest that 1% change in bilateral trade (in terms of value) leads to an 0.003% increase in average size of container vessels. The growth of bilateral trade can be achieved not only by reducing the transportation costs and through economic growth, but also by enhancing the performance of logistics along the supply chains. In particular, an improvement of the LPI index in the export country by one unit can lead to about 11.8% increase in trade in terms of value. Regarding the influence of maritime connectivity, adding one operator to the shortest leg of the route between the country pairs results in 0.5% increase in trade, while an additional common connection (i.e., an additional country that is directly connected to both the origin and destination country) leads to a 0.2% increase. By using different measures of logistics performance that focus on the time and cost along the supply chain (i.e., through the stage of document preparation, customs clearance and inspections, inland transport and handling, and port and terminal handling), we are able to demonstrate that reducing the time to export by one day reduces the cost of trade by 1.5%, while reducing the number of documents required for import shipment in the destination country goods by one improves bilateral trade by 8.1%. Our results are robust to potential causality and endogeneity issues.

Our results have important implications for decision-makers, such as port authorities and governments, as well as international organizations when it comes to emission reduction in the maritime sector. Recently, the International Maritime Organization (IMO) sets a new directive limiting the Sulphur fuel content of all vessels operating in all areas to 0.5 m/m, effective in January 1, 2020. While the IMO approach appears to focus exclusively on the maritime component of the supply chain, and therefore ignores the outcome that some other point in the supply chain may undergo an increase in emissions, this study implies that there may be opportunities in the supply chain to augment the reduction in Sulphur emissions. Therefore, the authorities may want to invest in improving the performance of services and infrastructures along the supply chains and create incentives for shippers to use larger vessels. This study have some limitations. First, a hypothetical example was used to derive the insights into the potential emission Sulphur reductions from the use of larger vessels. The link between Sulphur emissions and characteristics of vessels can be established properly by future research. Second, this analysis focuses on container vessels. This research can be extended by considering other types of vessels, such as bulk, cargo and others. Avenue for future research also includes a consideration of other types of emissions, such as $NO_x$ and $CO_2$. Finally, future research may want to use different measures of performance of supply chains.

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