The Impact of Oil Prices on World Trade

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In this paper we investigate the importance of fuel costs in shaping world trade. We use AIS data on ship locations and transaction-level shipping prices, along with a dynamic model describing the world shipping industry, to measure the elasticity of trade with respect to ship fuel costs. We find that the average estimated elasticity is 0.35, but ranges from 0.1 to about 1.2 depending on the level of the fuel cost. The pass-through of fuel costs to transport costs is low, at 0.17. Strikingly, the trade elasticity features a pronounced asymmetry in low vs. high oil prices. As fuel costs decline, the elasticity plateaus and further declines have little impact on trade. This "flattening out" of the elasticity is attributed to the equilibrium of the transportation sector and in particular the changes in the relative bargaining positions of ships and exporters. Finally, we use the estimated elasticity to assess the importance of ship design on trade flows: if the large fuel efficiency gains achieved in the 1980s had not been realized, trade would be 12% lower today.

Keywords: fuel costs, shipping, world trade, trade elasticity, oil prices, fuel efficiency, fuel cost pass-through

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1 Introduction

How significant an effect do oil prices have on trade flows? Many have claimed that oil price spikes have the potential to put a break on world trade by increasing transport costs.[1] Indeed, oil prices determine ship fuel costs, which constitute the core (variable) cost component of the transportation sector. In this paper, we compute the world trade elasticity with respect to oil prices. We are able to isolate the impact of oil shocks on transportation costs (vs. other channels such as production input costs or income effects) through the use of a simple structural trade model that explicitly incorporates the transportation sector. We show that modeling the transport sector is crucial in understanding the mechanism behind the oil price pass-through to exporters and the patterns of the estimated elasticity.

We focus on oceanic shipping, which accounts for the large majority of international trade, and in particular on trade in bulk commodities, such as minerals, grain, and chemicals, which in turn accounts for about half of all seaborne trade in tonnage (UNCTAD, 2015). Bulk ships are often thought of as the "ocean taxis", as the industry's structure and operation resembles that of taxicabs. We use data on shipping contracts between shipowners and exporters that correspond to specific trips; we also obtain AIS ship movement data that inform us on ships' sequences of loaded and empty trips. This dataset was first used in our prior work, Brancaccio et al. (2020a), henceforth BKP.

We employ the dynamic spatial search model built in BKP, that centers on the behavior of ships and exporters. Ships are homogeneous and contract with exporters for individual trips, setting shipping prices through Nash Bargaining. After delivering the cargo for a price, a ship searches for new cargo in their current location. If unable to find an exporter, the ship can either wait at its current location, or ballast (i.e. travel empty) to a chosen destination. Fuel costs are the main variable cost of ships and they are captured through ships' cost of sailing. Exporters have one cargo to ship. Potential exporters decide whether to export or not, as well as which destination to export to. Once this entry decision is made, they wait at port until they match with a ship that will transport their cargo.

We leverage the model to compute the trade elasticity with respect to fuel costs as well as the pass-through of fuel costs to shipping prices. Our estimated trade elasticity is 0.35 at the average observed fuel cost level. In practice however, the baseline number is unlikely to be sufficient for policymakers. Indeed, we find that the elasticity depends crucially on the level of the oil price and ranges between 0.1 and 1.2.

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[1] For instance, a report by The Economist (Wood, 2008) states "For the countries of Asia, where the price of transporting goods to the West has a significant impact on their attractiveness as a manufacturing location, [the rising oil prices] are serious issues. In an era of high and volatile oil prices, is the world not as flat as has been suggested?". In his book "Why your world is about to get a whole lot smaller: oil and the end of globalization", Rubin (2009) argues that spiking oil prices will curtail long-distance shipping and traveling.

The pass-through of fuel costs to exporters is low, as the elasticity of prices with respect to fuel costs equals 0.17 at the average observed fuel cost. This suggests that fuel costs are not a good approximation of transport costs, and that modeling the transportation sector is crucial to understand the trade costs that countries are facing and the ensuing trade flows.

A striking feature of the estimated trade elasticity is its pronounced asymmetry in low and high levels of fuel costs. Indeed, the elasticity gets steeper as the fuel cost increases, while it plateaus as the fuel cost decreases. This asymmetry is generated by the equilibrium of the transportation sector and in particular, the changes in the relative bargaining positions of ships and exporters. Naturally, as the fuel cost declines, trade increases, since fuel costs are a key input in transportation costs. In addition, however, as the fuel cost declines, the world becomes more "flat", since distance matters less, and ships can reallocate cheaply across different regions. Therefore, they are less "tied" to their current location and are able to extract higher prices, as they have the option of ballasting to more attractive locations. This dampens the price decline and mutes the increase in trade disproportionally at low fuel costs. In contrast, when fuel costs are high, it is costlier for ships to change locations and exporters at their current location have a stronger bargaining position, leading to large increases in trade. This effect is particularly pronounced in net exporting regions, where the high likelihood of finding a load makes ships almost certain to stay put when oil prices are high. As a result, as the world becomes flat under low fuel costs, the increase in trade is muted because of ships' strong bargaining position.

To further document this mechanism, we explore a relevant testable prediction of our model. When fuel costs decline and distance is of less importance, ship values tend to equalize over space. A ship in an unloading region is now not much worse off than a ship in a loading region, as ballasting from the former to the latter is cheaper. As the dispersion in ship value functions declines, so does the dispersion in shipping prices which depend on the ship's value at the destination. We test this using the observed shipping prices and external data on fuel costs and find that indeed as oil prices fall, shipping prices equalize across space.

Finally, we use our estimates to assess how much recent trends in fuel efficiency of ship design have affected trade flows. Ship design is affected by a number of factors over time, such as long-term trends in the shipbuilding industry, technological improvements and environmental policies. We compute that the efficiency gains achieved in the 1980s by world shipyards led to a decline in shipping prices of 5.5% and an increase in trade by 12%. On the other hand, the recent deterioration in fuel efficiency design resulted in a 5.6% reduction in world trade. These calculations showcase the policy relevance of our estimated trade elasticity with respect to fuel costs, as a number of environmental regulations imposing fuel efficiency targets are currently discussed by international organizations.

Related Literature The literature quantifying the impact of oil prices on trade, as well as transport costs, is relatively thin. Hummels (2007) measures the elasticity of freight rates with respect to fuel costs and estimates it to about 0.2 to 0.3, while Mirza and Zitouna (2009) estimate it at 0.1; Beverelli et al. (2010) estimates a unitary elasticity. A few recent papers have explored the elasticity of trade with respect to freight rates, as well as the role of the transportation sector overall (e.g. Hummels (2007); Asturias (2020); Wong (2020), BKP). For instance, Wong (2020) estimates the trade elasticity with respect to shipping prices to about -3 and Limao and Venables (2001) report a similar estimate.[2] BKP examines how endogenous trade costs affect the level and the composition of trade, with a particular interest in how endogenous trade costs distort countries' comparative advantages.[3] von Below and Vezina (2016) find that the distance elasticity of trade significantly increases with the oil prices, so that fuel costs disproportionally affect trade between distant trading partners. Bridgman (2008) considers a trade model with an energy-using transportation sector to investigate the 1970-80s oil shocks and finds that they had a significant impact on world trade. Rubin (2009) argues that a shortage in oil and increasing oil prices will limit globalization.

The approach adopted here to measure the trade elasticity is different from most of the existing literature; we employ our structural model to isolate the impact of oil shocks only through the transportation sector rather than other channels (e.g. higher input costs, income effects, or correlated changes in demand).[4] In addition, our model guides us in understanding the shape of the elasticity, as well as the mechanism of the oil price pass-through to exporters.

In Section 2 we discuss the oceanic bulk shipping industry and the data. In Section 3 we present the model. In Section 4 we present the trade elasticity with respect to fuel costs and the oil price pass-through to exporters, while in Section 5 we investigate the relationship between price dispersion and oil prices. In Section 6 we ask how much the recent improvements in ship fuel efficiency have contributed to trade growth. Section 7 concludes.

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[2] North (1958) and Estevadeordal et al. (2003) also find that changes in transportation prices have been historically important determinants of world trade.

[3] In BKP we illustrate the impact of endogenous trade costs through several empirical exercises, one of which is a fuel cost decline which leads to disproportionally larger trade increases for net exporters. Given the importance of oil shocks, in the present paper we study further the trade elasticity with respect to fuel costs and explore the mechanisms through which they affect world trade. By investigating its shape, we demonstrate that the elasticity varies significantly with the level of oil shocks, suggesting that a scalar estimate for the elasticity is unlikely to be useful in most applications.

[4] The general model presented here follows BKP and has been used fairly widely for different transport modes in the literature; e.g. Lagos (2000, 2003); Brancaccio et al. (2020b); Buchholz (2020); Rosaia (2020).

2 Industry and Data

Bulk shipping involves large oceanic carrier vessels (larger than 10,000 DWT capacity) that carry mostly commodities and raw materials, such as grain, iron ore, steel, coal, chemicals, etc. The industry is unconcentrated with a large number of small firms. These ships operate much like taxi cabs: a shipowner contracts with a cargo owner for a specific trip; the ship is filled up with this exporter's load and it delivers the cargo at the agreed upon destination. The ship then restarts in that destination by looking for a new contract. Similar to taxi cabs, bulk shipping services are considered fairly homogeneous. Prices are negotiated between the shipowner and the exporter, and mediated by one or multiple shipbrokers.

Our analysis is based on two databases. First, a sample of contracts between shipowners and exporters obtained from Clarksons Research. Each observation is a contract for a trip and it specifies the origin and destination of the trip, the loading and signing dates the ship and the price between 2010-2016. Second, we use AIS data reporting ship locations, as well as the ship's draft (i.e. the distance between the bottom of the ship's hull and the waterline) which allows us to distinguish loaded from empty movements. We obtain data for 5,000 ships (about half the world fleet) between 2010-2016 from ExactEarth Ltd. For a more detailed description of the industry and the data we refer the reader to Kalouptsidi (2014) and BKP respectively; BKP also provides summary statistics and data patterns.

For example, a prevailing feature of the data is the large trade imbalances and their impact on shipping prices. Indeed, most countries are either large net importers or large net exporters of the commodities carried in bulk vessels. China and India are the biggest importers, while Brazil, Australia and North America are the biggest exporters. These trade imbalances translate into asymmetric ship hiring rates at different regions of the world: although a ship in Brazil is very likely to find a cargo, a ship in China is much less so. As a result, a ship would much rather unload a cargo in Brazil than China, as her options are much better in Brazil and this is reflected in the prices the ship agrees upon. Indeed, the price to unload in China is substantially higher than the price to unload in Brazil. Shipping prices exhibit pronounced asymmetries, reflecting the world's natural geography (distances and natural inheritance) and its impact on ship profitability at different regions of the world.

3 Model

We next provide a description of the dynamic spatial search model of the global shipping industry.

3.1 Environment

Time is discrete. There are I regions in the world and two types of agents: exporters (or freights) and ships. Every period, at each location i, $\mathcal{E}_i$ potential exporters decide whether and where to export. If they decide to export, they pay production and export costs, κ_{ij} and draw their revenue (or valuation) r from shipping the good, from a distribution F^r_{ij} with mean $\bar{r}_{ij}$. Let e_i denote the exporters awaiting transportation in region i.

Ships are homogeneous and carry at most one freight at a time. Every period a ship is either sailing towards destination j, full or empty, at a per-period sailing cost c^s_{ij}, which is primarily the fuel cost; or it is waiting in port i at cost c^w_i. A ship sailing from i to j arrives at its destination with probability d_{ij}, so that the average trip duration equals $1/d_{ij}$.

Ships at port i meet exporters originating from port i randomly. Every period the number of matches in location i is determined by a matching function $m_i(s_i, e_i)$, where s_i is the number of unmatched ships in location i, and e_i is the number of unmatched exporters. Let $\lambda_i = m_i/s_i$ denote the probability that a ship meets an exporter and $\lambda^e_i = m_i/e_i$ the probability that an exporter meets a ship.

The surplus of a meeting is split via generalized Nash bargaining. This determines the price τ_{ijr} that an exporter with valuation r pays the ship in order to be transported from i to j. Let $\gamma \in (0,1)$ denote the exporter's bargaining power.

Ships that remain unmatched decide whether to remain in their current region or ballast elsewhere subject to i.i.d. logit shocks, ϵ_{ij}. Exporters that remain unmatched survive with probability $\delta > 0$ and wait in their current region.

3.2 Equilibrium

We focus on the steady state equilibrium of this framework.

Ships The value of a ship traveling from i to j, V_{ij}, is given by,

$$V_{ij} = -c^s_{ij} + d_{ij}\beta V_j + (1 - d_{ij})\beta V_{ij} \tag{1}$$

where β is the discount factor. In words, the ship pays the per period travel cost, c^s_{ij}, then with probability d_{ij} it arrives at its destination and begins the following period unmatched at j, and with the complement probability the following period it is still traveling. V_j is the value of a ship that is unmatched in port j

at the start of the period and is given by,

$$V_i = -c_i^w + \lambda_i E_{j,r} \left(\tau_{ijr} + V_{ij}\right) + \left(1 - \lambda_i\right) U_i \tag{2}$$

i.e. the ship pays the port cost, c_i^w, and with probability λ_i it meets some exporter with destination j and value r. In this case, the ship receives the shipping price, τ_{ijr}, which is the outcome of Nash bargaining, and immediately begins its trip towards j, obtaining value V_{ij}, defined in (1) above. Instead, if the ship cannot find an exporter, which happens with probability $(1 - \lambda_i)$, it receives the value U_i from being unmatched in i.

The value of a ship that remains unmatched in i at the end of the period is

$$U_i\left(\epsilon\right) = \max\left\{\beta V_i + \sigma\epsilon_{ii}, \max_{j \neq i} V_{ij} + \sigma\epsilon_{ij}\right\}$$

i.e. the ship can either remain in i and obtain value V_i the following period, defined in (2) or it can choose a destination j and ballast there, obtaining value V_{ij}. Finally, let $U_i \equiv E_\epsilon U_i(\epsilon)$ denote the "ex ante" value of an unmatched ship, i.e. *before* drawing the logit shocks ϵ_{ij}.

Exporters The value of an unmatched exporter in market i with destination j and valuation r at the end of the period is

$$U_{ijr}^e = \beta\delta\left[\lambda_i^e\left(r - \tau_{ijr}\right) + \left(1 - \lambda_i^e\right) U_{ijr}^e\right] \tag{3}$$

i.e. conditional on surviving (which occurs with probability δ), with probability λ_i^e the exporter meets a ship, in which case it receives value r from being transported to its desired destination and pays the shipping price τ_{ijr}. With probability $1 - \lambda_i^e$ it remains unmatched and obtains the corresponding value U_{ij}^e.

Finally, every period there are $\mathcal{E}_i$ potential exporters and the value of each is

$$U_i^e = \max\left\{\epsilon_0^e, \max_{j \neq i}\left\{E_r U_{ijr}^e - \kappa_{ij} + \epsilon_j^e\right\}\right\} \tag{4}$$

where ϵ^e are i.i.d. logit shocks. In words, each one chooses between its outside option of not exporting (with a payoff normalized to zero), and exporting to one of the $j \neq i$ destinations. If it chooses to export, it pays the entry cost, κ_{ij}, draws value, r, and obtains the value U_{ijr}^e given by (3).

Shipping Price It is straightforward to show that Nash bargaining implies that the shipping price is,

$$\tau_{ijr} = (1-\mu_i)(U_i - V_{ij}) + \mu_i r \tag{5}$$

where $\mu_i = (1-\gamma)(1-\beta\delta) / (1-\beta\delta(1-\gamma\lambda_i^e))$.

The equilibrium price depends positively on r, so that more valuable freights pay higher prices. Moreover, the price depends on the value of traveling from i to j, V_{ij} (which in turn depends on V_j), as well as the value of the ships' outside option, U_i. These objects capture the attractiveness of both the origin i, as well as the destination j. Destinations where the probability of ballasting afterwards is high are unattractive to ships, who then command higher prices to travel there. The same holds for destinations that are more distant (low d_{ij}), have low value exporters, or low matching probabilities. Moreover, V_j controls for conditions at all possible ballast and export destinations from j. Similarly, U_i controls for the attractiveness of the origin (e.g. exporter revenues, nearby ballast opportunities, matching probability).

4 Fuel Cost and Trade Elasticity

We now study how a change in the cost of fuel affects maritime trade. We can think of this as the impact of an oil price shock on trade through transport costs. To perform this analysis we use the estimates obtained in BKP. We refer the interested reader there for a description of the estimation procedure.[5]

The overall effect is shown in Figure 1. The left panel plots the percent change in world exports, defined as the sum of realized matches between exporters and ships over all ports, against the percent change in fuel costs captured by c_{ij}^s in our setup. The right panel plots the corresponding elasticity. The change in trade is substantial: the elasticity is estimated at 0.35 at the average fuel cost in our data and ranges from 0.1 to 1.2.

A striking feature of the estimated trade elasticity, is its pronounced asymmetry in low and high levels of fuel costs. Indeed, the elasticity gets steeper as the fuel cost increases, while it plateaus at low fuel cost levels, whereby declines have little impact on trade. For instance, consider a symmetric decline and

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[5] Importantly, fuel costs enter the model through the travel costs, c_{ij}^s, which consist primarily of the cost of fuel (Stopford, 2009). We thus calibrate their level using the average weekly price of fuel in our sample. Over our sample period ships face an average fuel price of 470$ per meter ton. Assuming ships travel at an average speed of 13mph, the average daily consumption of fuel is around 20 tons per day (Stopford (2009)). This adds up to a total expenditure for fuel of $69,100 per week.

We allow travel costs to differ for each pair (i, j) as follows: c_{ij}^s takes one of seven values based on the continent and coast of the origin; we set one of the c_{ij}^s (East Coast of North and South America) to equal to the average fuel cost of 69,100$ and estimate the rest. Our results suggest that the fuel cost, c_{ij}^s, exhibits relatively low variation over space, consistent with the empirical observation that fuel price dispersion is low.

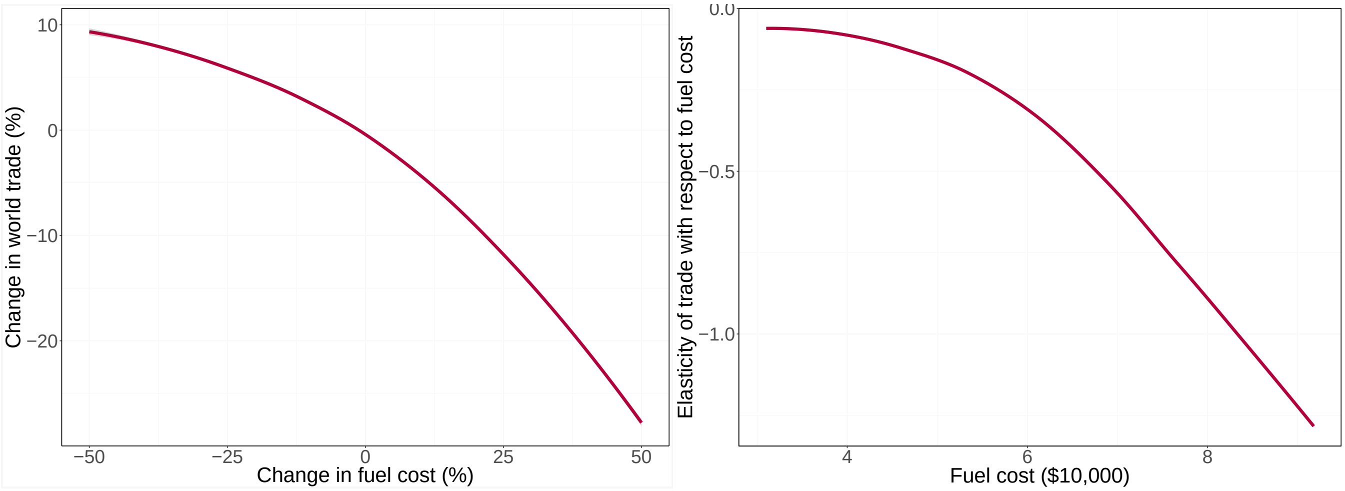

Figure 1: This figure uses the estimated model to compute changes in total trade in reaction to changes in the fuel cost. The left panel shows the total change in world trade for different shocks to fuel costs, while the right panel plots the corresponding elasticity. The average weekly fuel expenditure within our sample period is around $69,100. To produce the figure above, we use the model to simulate the equilibrium level of exports associated with different counterfactual values of fuel expenditure c^s_{ij}.

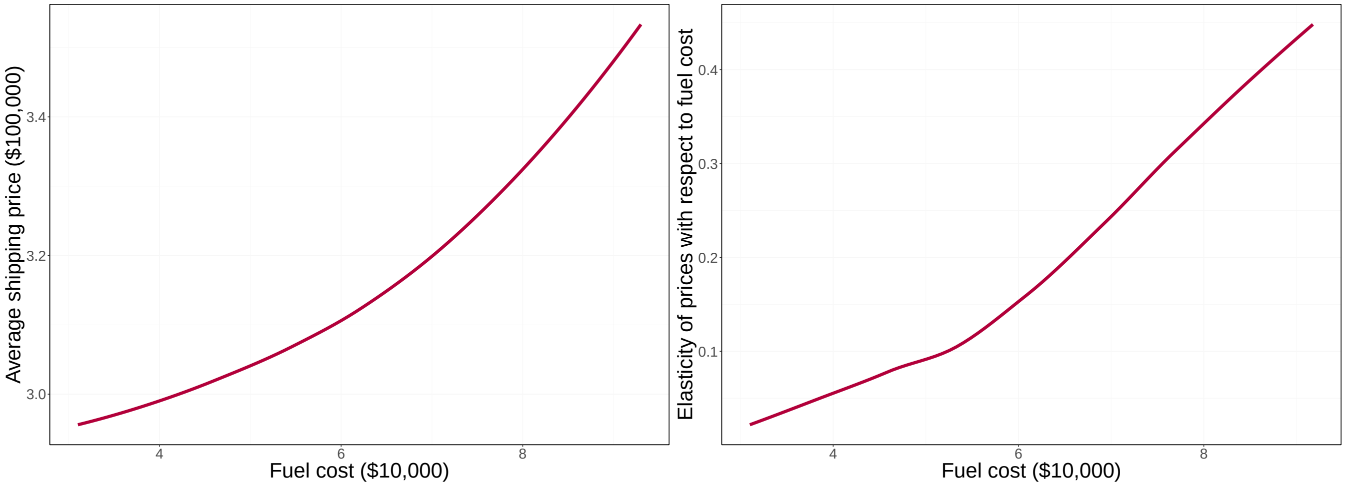

Figure 2: This figure uses the estimated model to compute shipping prices as a function of the fuel price. The left panel shows the average shipping prices for different fuel costs, while the right panel plots the corresponding elasticity. In our baseline estimation we calibrate c^s_{ij} to be equal to the average weekly fuel expenditure within our sample period, which is around $69,100. To produce the figure above, we use our model to simulate the equilibrium value of shipping prices (τ_{ij}) associated with different counterfactual values of fuel expenditure c^s_{ij}.

increase of 30% from the weekly fuel expenditure in our sample of about 69,100$. When the fuel cost increases by 30%, total trade falls by about 15%; in contrast, when the fuel cost declines by 30%, total trade grows by about 8%. As we argue below, this asymmetry is generated by the equilibrium of the transportation sector and in particular, the relative bargaining position of ships and exporters.

Since fuel costs are ships' main variable cost, higher fuel costs naturally lead to higher shipping prices, all else equal. Fuel costs, however, do not act just as inputs for ships; they also determine their relative bargaining position. When fuel costs increase, ships become "captive" to their current location: as it is costly to ballast elsewhere, ships are constrained in their ability to exploit opportunities in other regions. This limits the competition for ships between exporters across different regions and allows exporters to pay lower shipping prices than otherwise. In contrast, when fuel costs decrease, it is cheaper for ships to reallocate in space. Ships are less "tied" to their current region and it is now the exporters that are in a weaker bargaining position and thus forced to agree to higher prices than otherwise. This indirect effect of fuel price shocks, coupled with the direct effect of fuel costs on the cost of transporting a cargo, determines the level and shape of the elasticity plotted in Figure 1.

Formally, from the price equation (5), a decline in the fuel cost c^s_{ij}, directly reduces the value of a traveling ship, V_{ij}, by reducing its cost (see equation (1)). At the same time however it affects ships' outside options, captured by the U_i term (see equation (3)). This effect tends to "dampen" the overall reduction in prices, and exporter entry, when fuel costs fall.

In order to understand the asymmetry in Figure 1 note that the effect of fuel cost shocks on the ships' bargaining position is different for different levels of the fuel cost, c^s_{ij}. In a world with high fuel costs, ships' bargaining position reacts less to changes in the fuel cost. Indeed, at high fuel costs, the ship is likely to stay put rather than ballast, especially when in loading regions (net exporters). As a result, the price decline is not dampened as above and the increase in trade is sharper. Formally, when fuel costs are high, the outside option of ships U_i, is roughly equal to value of remaining in the current region, V_i, especially in exporting countries. A change in c^s_{ij} has little direct effect on V_i and therefore U_i, and the dampening impact of c^s_{ij} on prices is very small: most of the reduction in c^s_{ij} shows up directly in prices which leads to a correspondingly large increase in exporter entry in net exporting countries.

Consider now a world with low fuel costs. In contrast to the situation above, it is now relatively cheap for ships to reallocate in space. In this "flat" world, a ship is likely to choose the ballasting rather than the waiting option, and as a result, declines in the fuel cost have a large impact on its outside option. This mutes substantially the increase in trade and the elasticity of trade shrinks substantially. Formally, the

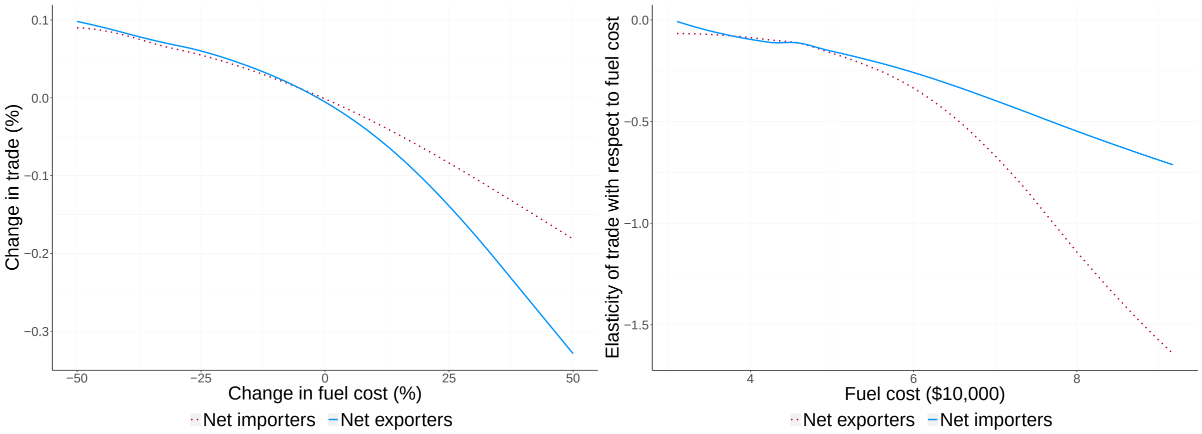

Figure 3: This figure uses the estimated model to compute changes in trade in reaction to changes in fuel price for net importers and net exporters. The left panel shows the total change in trade for different shocks to fuel costs, while the right panel plots the corresponding elasticity. We classify a region as a net importer if the number of incoming cargoes is higher than the number of outgoing cargoes and vice versa.

outside option of ships, U_i, is more likely to equal to one of the traveler values, V_{ij}, and a reduction in c^s_{ij}, can now have a sizable increase in U_i, leading to a dampening in the price decline and a smaller increase in exporter entry.

We also examine the pass-through of fuel cost shocks to shipping prices. Figure 2 displays shipping prices as a function of fuel costs, as well as the elasticity of shipping prices with respect to fuel costs. The elasticity is equal to 0.17 at the average fuel cost level and ranges from 0.03 to 0.43. Naturally, it features the same asymmetry. The level of the elasticity suggests that the pass-through of fuel costs to exporters is relatively low. Our estimates are similar to those found in Hummels (2007). The low pass-through, as well as the varying range of the elasticity suggests that transport costs are not well approximated by fuel costs and that modeling the equilibrium of the transportation sector is important in understanding the nature of trade costs.

We explore further our proposed mechanism by investigating separately the behavior of net exporters vs. net importers. Figure 3 plot exports and trade elasticities for different fuel cost levels for net exporting and net importing regions separately. The graphs are telling: at high levels of the fuel cost, for net exporters decreases in fuel costs are associated with substantially steeper increases in trade than for net importers. Indeed, ships in net exporting countries almost always prefer to stay put rather than ballast away when the fuel costs are high. Therefore, ships benefit less from decreases in fuel prices – their bargaining position does not improve substantially and any decline in fuel costs leads to large reductions in shipping prices and thus large increases in trade. Therefore, a decline in fuel costs when the fuel cost is high, disproportionally benefits net exporters, widening the trade gap between countries. As fuel costs further decline, however, the world becomes flat, as ships can costlessly reallocate.

Finally, it is worth noting that we find that as fuel costs decline ships do ballast more and there is a reallocation across space from net importers to net exporters. However at low levels of fuel costs, further declines lead to small changes in reallocation: at these levels most opportunities are taken up and there are considerably fewer ships waiting at net importers that are able to take advantage of the reduction in fuel cost to ballast to net exporters. This also implies a much lower trade elasticity to oil shocks, as shown in Figure 1. The world fleet utilization is close to full capacity.

5 Oil Shocks and Price Dispersion

In this section we search for descriptive evidence that the equilibrium in the transportation sector and the relative bargaining position of ships and exporters are important determinants of world trade elasticities with respect to oil shocks. To do so, we consider a prediction of our setup regarding the correlation between fuel oil prices and the cross-sectional dispersion of shipping prices.

Consistent with the narrative of the previous section, as fuel costs decline, ship values tend to equalize over space. For instance, a ship in China is now not much worse off than a ship in Australia, as ballasting from China to Australia is cheaper. As the dispersion in ship value functions declines, so does the dispersion in shipping prices.

To make this argument more precise, consider again the price equation, (5), for a given origin i: differences in prices across different destinations j are driven by differences in the value function of a traveling ship, V_{ij} (holding constant the distribution of exporter valuations). As c^s_{ij} falls, V_{ij} tend to equalize across *destinations*, j, both because differences in distance are less costly, but also because differences in the ship's value, V_j, across different destinations matter less. As discussed above, ending a trip in a destination that is attractive to ships is less important than it used to be due to the cheaper ballasting. Similarly, since differences in U_i across i are now lower, differences in the shipping price across *origins*, i, also shrink.[6] This convergence in ship valuations across space drives a decline in the dispersion of prices *per-day* both across destinations and origins.[7]

Therefore, a testable implication of our framework is that shipping price dispersion should be increasing

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[6] Indeed, holding constant differences in exporter valuations and matching probabilities, any difference in the shipping price across *origins*, i, is driven by differences in the value of an unmatched ship, U_i.

[7] It is worth emphasizing that in a model where prices depend exclusively on distances and ships' outside options do not affect them, the dispersion of prices *per-day* do not depend on the level of fuel costs.

the fuel cost. To test this prediction we use time-series data on fuel costs between 2012 and 2016 (from Clarksons Research) and regress the dispersion in per-day shipping prices on contemporary fuel cost. Importantly, the focus on per-day prices allows us to control for the differential exposure to oil shocks of routes covering different distances. Table 1 reports the results from a regression of the dispersion of shipping prices on fuel costs and shows that as fuel prices increase, the dispersion of per-day shipping prices for trips with different origins or different destinations increases. The coefficient of the fuel cost is positive and significant, and robust to the inclusion of different time fixed effects.

	Dispersion of per-day shipping price, log					
	Across destinations			Across origins		
	I	II	III	IV	V	VI
Fuel Price (log)	0.228**	0.812***	0.766***	0.288***	0.741***	0.597**
	(0.091)	(0.200)	(0.229)	(0.090)	(0.194)	(0.236)
FE	None	Year	Quarter × year	None	Year	Quarter × year
Observations	175	175	175	175	175	175
R^2	0.035	0.718	0.923	0.056	0.735	0.917

$^{**}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Table 1: This table reports the estimates from a regression of the dispersion of shipping prices across trip destinations on fuel costs. For all the regressions, we compute the average shipping price per-day that different exporting countries face within a month. The dependent variable in all regressions is the standard deviation of this average shipping price across destinations (in logs). The main independent variable is the monthly fuel price (in logs). In column I we report the raw correlation, while in columns II and III we add year and quarter-year fixed effects respectively.

6 Fleet Fuel Efficiency and World Trade

In this section, we compute how much recent trends in the fleet's fuel efficiency have affected trade flows.[8] In recent work, Faber and Hoen (2015), compute an index of energy efficiency over the last 50 years, for

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[8] Several papers in the field of maritime economics have explored energy efficiency in different ship segments (e.g. Adland and Jia (2016a), Adland and Jia (2016b), Adland et al. (2017) and Adland et al. (2017)).

different types of ships (see Figure 7 therein specifically for bulk ships).[9] They find that energy efficiency for bulk carriers improved dramatically (by about 25%) in the 1980s and after a short stable period began deteriorating. This observed reversion in energy efficiency is striking.

Ship design is determined endogenously by the "long-run" market equilibrium in the shipping and shipbuilding markets; as such it is affected by market conditions (world trade), fuel costs, and environmental policies. For instance, the improvements in efficiency in the 1980s follow the oil crisis of the 1970s. The lag in the shipyards' reaction is also consistent with the time required to produce novel ship designs (Faber and Hoen, 2015). The later deterioration in ship efficiency may originally have been due to the massive increase in trade starting in the 1990s-2000s: at the time, shipyards faced severe capacity constraints and opted for simple and quick to build designs (Kalouptsidi (2014), Kalouptsidi (2018), Faber and Hoen (2015)), while high freight rates made high fuel costs less painful for shipowners.

Overall, the combination of (i) long-term trends in the shipbuilding industry; (ii) technological improvements; and (iii) environmental policies lead to time-varying ship designs in terms of fuel efficiency. Here, we use our estimates for the trade elasticity to calculate (i) the gains in trade because of the improvement in design fuel efficiency since the early 1980s; and (ii) the reduction in trade brought about by the more recent deterioration in fuel efficiency. Our estimated elasticities suggest that the 25% improvement in fuel efficiency since the 1980s have led to a decline in shipping prices by 5.5% and a corresponding increase in trade by 11.8%. On the other hand, since the 1990s efficiency has deteriorated by 13%, resulting in a 5.6% reduction in world trade, and a 2.5% increase in shipping prices. Note that these estimates vary from the back-of-the-envelope calculation one would obtain using the mean estimated elasticity.

In summary, consistent with the trade elasticities estimated above, we find that ship design is an important determinant of trade. As global institutions are currently considering the phasing in of substantial environmental policies (e.g. the International Maritime Organization (IMO) is currently phasing in limits on sulphur in ship fuel) it is our hope that our methodology and estimates can be of use in the cost-benefit analysis of determining the optimal levels of environmental standards.

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[9] In order to assess design fuel efficiency, Faber and Hoen (2015) use data from the IHS Maritime World Register of Ships and from Clarksons World Fleet Register to compute each ship's Estimated Index Value (EIV). The EIV computation takes into account the ship's capacity (deadweight tonnage), main engine power, auxiliary power and design speed.

	Impact on	
	Shipping Prices	International Trade
Fuel efficiency gains, 1980-1990	-5.5%	11.8%
Fuel efficiency decline, 2000-2015	2.5%	-5.6%

Table 2: Impact of changes in ships' fuel efficiency in 1980s and 2000s on international trade and shipping prices.

7 Conclusion

In this paper, we quantify how world trade reacts in response to changes in oil prices. We show that the trade elasticity with respect to oil prices is substantially asymmetric with respect to high and low fuel costs. In particular, as fuel costs decline, the elasticity becomes flatter and trade becomes less responsive to further declines in fuel costs.

Our approach is not free of caveats. We do not model all the margins along which ships can react to fuel costs. For instance, ships can adjust their speed (e.g. "slow-steaming" during oil price spikes). Moreover, we only consider our model in steady state, so firms do not form expectations about oil price fluctuations; as a result, our elasticity should be considered a short or medium-term one. Finally, we consider the impact of oil shocks solely via transportation costs.

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