Endogenous Transportation Costs*

Jose Asturias
Georgetown University Qatar

September 25, 2019

Abstract

Quantitative trade models used to evaluate the effects of policy changes have largely abstracted away from modeling the transportation industry. This paper extends a standard Armington trade model to incorporate an oligopolistically competitive transportation industry in which shippers endogenously choose a transportation technology. I collect detailed data on the containerized maritime transportation industry to calibrate the parameters of the model. I then conduct quantitative experiments in which there is a symmetric increase in tariffs. On average, changes in transportation costs account for almost half of the changes in welfare. These findings suggest that the endogeneity of transportation costs is an important mechanism determining the welfare effects of such a policy change.

JEL classifications: F13, F15, D43

Keywords: Trade costs, transportation costs, trade liberalization

*Email: jga35@georgetown.edu. Tibor Besedes, Kerem Cosar, and Kensuke Teshima for thoughtful discussions of this paper as well as two anonymous referees who gave detailed feedback to help improve the paper. I would also like to thank the following individuals for suggestions and comments: Cristina Arellano, Thomas Holmes, Timothy Kehoe, Bernabe Lopez-Martin, Thierry Mayer, Dennis McCornac, Fabrizio Perri, Scott Petty, Terry Roe, Jack Rossbach, and Chunying Xie. Many thanks to the participants of the International Trade and Development Workshop at the University of Minnesota, Society for Economic Dynamics (Cyprus), Workshop on Dynamic Macroeconomics (Vigo, Spain), Congressional Budget Office, U.S. Government Accountability Office, Drexel University, University of Missouri (Columbia), Davidson College, Georgetown University in Qatar, NEUDC (Harvard University), Rocky Mountain Empirical Trade Conference (FREIT), North American Meeting of the Econometric Society, Spanish Economics Association Symposium, and the European Winter Meeting of the Econometric Society. I would also like to thank David Hummels and Douglas McDonald at the U.S. Army Corp of Engineers for their help in acquiring data.

1 Introduction

Quantitative trade models have been used to study significant issues in international trade, such as determining the welfare effects of enacting policy changes. These models have largely simplified the modeling of the transportation industry through the use of iceberg costs. This notion dates back to Samuelson (1954), in which the rationale is stated as: "The simplest assumption is the following: To carry each good across the ocean you must pay some of the good itself. Rather than set up elaborate models of a merchant marine,... we can achieve our purpose by assuming that... only a fraction of ice exported reaches its destination as unmelted ice." Since then, little work has been done to quantify the welfare predictions of policy changes using models that match micro-level facts about the transportation industry (e.g., the market structure of the transportation industry or economies of scale in the transportation technology). This issue matters all the more as transportation costs are a major barrier that firms face when exporting their products.[1]

To address this issue, the goal of this paper is twofold. First, this paper aims to build a general equilibrium trade model with a transportation industry that matches micro-level facts. The second goal is to calibrate the model to measure welfare changes as a result of an increase in tariffs.

To achieve these goals, I first collected detailed data on the containerized maritime transportation industry. Focusing on one form of transportation allows for the collection of detailed data on that industry. This particular form of transportation has two advantages. First, it is an important mode of transportation in international trade. Second, this form of transportation uses standardized shipping containers. The standardization of shipping containers provides a clean form in which to compare transportation costs across destinations.

I collected data on the cost to ship a standardized container from U.S. to foreign ports. I also collected data on the number of shippers that operate between these ports, the value of containerized trade flows, and distance. I define a route to be a U.S.-foreign port pair (e.g., Los Angeles to Callao, Peru). I find that routes with larger trade flows consistently have lower costs. Some evidence suggests that the market structure of the transportation industry and the scale of shippers play a role in explaining this relationship: routes with larger trade flows tend to have more shipping firms, and these shipping firms tend to be significantly larger.

It is important to keep in mind that shippers, such as A.P. Møller-Maersk, operate transportation networks that jointly service multiple ports at the same time. Thus, two types of economies of scale are in operation. First, as trade flows between regions increase, the transportation network becomes larger and lowers the average cost for the entire network.[2] For example, an increase in trade between the United States and Latin America would lower the transportation costs for all ports that are serviced on that network. A second source is that as trade flows increase between two ports, shippers

[1] Anderson and van Wincoop (2004) indicate that the ad valorem all-commodities arithmetic average is 10.7 percent for the United States. Furthermore, the transportation costs I have collected exhibit significant variation, implying that this number is significantly larger in some locations.

[2] See Hummels and Skiba (2004b) for a discussion of these regional scale economies.

find it worthwhile to utilize technologies that lower their average cost at the route-level. For example, a shipper may use larger ships within their transportation network to service the two ports. The focus of this paper is on the latter source of scale. Thus, my measure of shipper size is the value of port-to-port containerized trade flows divided by the number of shippers on that route, which is the average trade flows per shipper on a route. I will refer to this term as the average shipper size. Furthermore, entry into a route is when a shipper begins to service two ports using its transportation network (e.g. A.P. Møller-Maersk, uses its transportation network to connect Los Angeles to Callao, Peru).

I build a two-country Armington (1969) trade model with a transportation industry. The transportation industry has two key features. The first feature is that the industry is characterized by oligopolistic competition among shippers. The second feature, which is novel to the literature, is that shippers face a technological trade-off whereby they can choose a lower marginal cost in exchange for a higher fixed cost.[3] This feature of the model is consistent with the transportation industry in which shippers can adopt larger ships to lower the average cost per container.[4] The result is that, as trade flows increase, transportation costs may decline for two reasons. First, more shippers enter, which lowers the markups that firms charge. Second, firms find it optimal to invest in a technology that has a lower marginal cost.

I derive analytical expressions that characterize the transportation industry equilibrium. Markups are a function of the number of shippers that operate between two ports as well as a function of the importance of the trade flows between these two ports. For example, all else equal, if a port pair accounts for a small fraction of overall trade between two countries, then markups are lower than for a port pair that accounts for a large fraction of overall trade.

Next, the model is taken to the data. I use the analytical expressions to infer the marginal and fixed costs in each route, which yields two immediate results. First, routes with larger trade flows consistently have higher fixed costs and lower marginal costs relative to routes with small trade flows. Second, the differences in marginal costs account for the lower transportation costs in routes with larger trade flows (and not markups). These results provide initial evidence that shippers face a technological trade-off and that this trade-off is a key driver of the empirical results.

The two-country model is calibrated separately for each U.S.-foreign country pair. I use the calibrated model to simulate a symmetric 1 percent increase in tariffs in both the United States and the foreign country. Changing transportation costs due to the smaller trade flows account for

[3]This feature in which firms can choose a technology with a higher fixed cost in exchange for a lower marginal cost is similar to the models used by Bustos (2011) and Yeaple (2005). Similarly, in Steinwender (2015), managers are allowed to lower the marginal cost through increased effort, and in Ahn, Khandelwal, and Wei (2011), an exporting firm can choose to export through an intermediary (with a low fixed cost but a high marginal cost) or to export directly (with a high fixed cost but a lower marginal cost).

[4]An interview with Nils Anderson, the CEO of shipping firm A.P. Møller-Maersk, reveals that the company has invested in larger ships, such as the Triple E-class container ship, as a way of lowering the average cost per container. He cites that fuel costs on these larger ships are \$300-\$400 lower per 40-foot container for a round trip between Asia and Europe (see Milne (2013)).

almost half of the welfare losses due to higher tariffs: the increases in transportation costs account for 46 percent of the losses in real income in the United States on average; in the foreign country, transportation costs account for 43 percent of the losses in real income on average. Thus, endogenously changing transportation costs are almost as important as the effects arising directly from tariffs within my accounting exercise.

Furthermore, the increase in transportation costs is due entirely to increases in the marginal cost. The results indicate that the markups decline and mitigate the effects of the change in the marginal cost. To explain this result, consider two opposing forces that affect markups. First, the increase in tariffs reduces the number of shippers, which increases markups. Second, shippers also choose a technology with a lower fixed cost and a higher marginal cost. The increase in the marginal cost lowers the markups of shippers due to imperfect pass-through: only a fraction of the increase in the marginal cost is reflected in the change in transportation costs. The latter effect dominates, and shippers have lower markups after the increase in tariffs.

2 Related Literature

This paper contributes to various strands of literature in international trade. First, there is a large literature that uses quantitative trade models to study the welfare effects of policy changes, such as tariffs. This literature includes Eaton and Kortum (2002) and Alvarez and Lucas (2007), and is also related to the workhorse models considered by Arkolakis, Costinot, and Rodriguez-Clare (2012) since these models can be used to perform quantitative experiments on policy changes. In contrast to the existing literature, this is the first paper to study how welfare predictions change if a model of the transportation industry is incorporated into a quantitative trade model. The quantitative results show that, on average, changes in transportation costs account for almost half of the changes in real income when tariffs change. Thus, these results show that the inclusion of a transportation industry can have quantitatively relevant effects on the estimated welfare effects of a policy change.

This paper also contributes to the literature that studies the determinants of transportation costs.[5] Hummels and Skiba (2004b) and Skiba (forthcoming) focus on "scale economies" in the maritime transportation industry. They find empirical evidence that transportation costs decline as trade flows increase. Another set of papers study the market power of shippers. Hummels, Lugovskyy, and Skiba (2009) study the quantitative importance of market power among shippers and its effect on trade flows. Francois and Wooton (2001) study theoretically how the market structure of the transportation industry affects the estimated welfare effects of tariff changes. Fink, Mattoo, and Neagu (2002) and Moreira, Volpe, and Blyde (2008) find evidence consistent with oligopolistic competition in the

[5]Other papers, including Bougheas, Demetriades, and Morgenroth (1999), Clark, Dollar, and Micco (2004), and Wilmsmeier, Hoffmann, and Sanchez (2006), focus on how port quality affects transportation costs. Holmes and Singer (2018) study the indivisibility constraint that firms face, which is that they must typically ship entire containers, and consolidation strategies that they can implement. Cosar and Demir (2018) estimate the modal choice between containerization and breakbulk shipping.

shipping industry.

This paper contributes to this literature along two dimensions. This is the first paper that models the technological choice of shippers in which there is a trade-off between the fixed cost and the marginal cost. This technological choice plays an important role in explaining the negative relationship between transportation costs and the size of trade flows. A second contribution is that this paper extends the existing literature by allowing for goods to be transported between countries using different ports, which alters the competition shippers face. In this model, the level of competition that shippers face when operating between a given port pair (e.g., Los Angeles to Callao, Peru) is determined by the shippers that operate between these two ports, as well as by the shippers that operate along other port pairs (e.g., Oakland to Callao). The markups of shippers are characterized under this new framework.

Other contemporaneous works have built trade models in which transportation costs and trade flows are jointly determined.[6] For example, Wong (2018) builds a model that focuses on trade imbalances and how they affect transportation costs using data from containerized maritime shipping.[7] Trade imbalances can play a role in determining transportation costs: if two countries have imbalanced trade, then shippers face the problem that ships are at full capacity in one direction but not in the opposite direction. In Appendix B, I show that the empirical results relating to the size of trade flows are robust to including measures of trade imbalances. In another paper, Brancaccio, Kalouptsidi, and Papageorgiou (2017) develop a model based on dry bulk shipping, which is the shipping of non-containerized goods, with an emphasis on search costs between exporters and shippers. In both of these works, transportation costs are endogenously determined and respond to changes in trade flows. In contrast to these papers, I aim to understand the quantitative importance of modeling the transportation industry when evaluating the welfare effects of a change in tariffs. Since a change in tariffs affects the size of trade flows, my work emphasizes the relationship between the size of trade flows and transportation costs. I build a model with the aim of capturing this relationship, so as to conduct quantitative experiments.

This paper also contributes to the literature in international trade that identifies transportation costs. Indeed, as Anderson and van Wincoop (2004) state in their survey paper on trade costs: "An important theme is the many difficulties faced in obtaining accurate measures of trade costs." Few papers in the literature use a direct measure of transportation costs as I do, such as a price quote to ship a container. One exception is the work of Wong (2018), who uses similar data in this paper on transportation costs. Another exception is Limao and Venables (2001), who obtain the price to ship a standard container from Baltimore to 64 destinations. Most commonly, the literature has relied on

[6]There is a set of papers in economic geography that incorporates a transportation industry in which transportation costs are endogenously determined. These papers include Behrens, Gaigné, Ottaviano, and Thisse (2006), Behrens, Gaigne, and Thisse (2009), Behrens and Picard (2011), and Mori and Nishikimi (2002). Their goal is to theoretically understand how the inclusion of a transportation industry into a model of economic geography affects the concentration and location of economic activity.

[7]Ishikawa and Tarui (2018) and Jonkeren, Demirel, van Ommeren, and Rietveld (2011) also study how trade imbalances affect transportation costs.

differences in the price of a good across locations (e.g., differences in salt prices across locations in India), including Asturias, García-Santana, and Ramos (Forthcoming), Atkin and Donaldson (2015), and Donaldson (2018). The work of Atkin and Donaldson (2015) points to three shortcomings in using price differences: 1) there may be unobserved product differences across locations (such as quality), 2) it is necessary to know which locations trade in order for price differences to be informative, and 3) price differences contain both transportation costs and markups, which may vary across locations.[8] The price quotes that I use allow me to circumvent all of the issues faced by the literature that uses price differences across locations.[9]

3 Data

I collected detailed data on the containerized maritime transportation industry at the port-to-port level. The data include transportation costs, number of shippers, value of trade flows, and distance.

I focus on maritime transportation since it is a leading mode of transportation in international trade. Maritime shipping is used most intensively when countries do not rely on land trade (non-contiguous countries). For example, when excluding land trade, approximately 60 percent of U.S. manufacturing imports by value are transported via maritime shipping and 40 percent by air, which is calculated using the Census data used by Hummels (2007). The reliance on maritime shipping for manufacturing imports is stronger in Latin American countries. Excluding land trade, maritime shipping accounts for 74 percent of trade in Argentina, 66 percent in Colombia, 64 percent in Mexico, 82 percent in Peru, and 75 percent in Venezuela by value, according to trade data from the INTrade database from the Inter-American Development Bank. It is important to note that by weight, maritime shipping accounts for 98 percent of U.S. manufacturing imports which is calculated using the Census data used by Hummels (2007).

Finally, containerization is a key method for transporting these manufactured goods. Containerized shipping makes use of the shipping container, which is a standardized metal box that can easily be transported across multiple modes of transportation including ships, trains, and trucks.[10] The fact that it is standardized lowers the cost of loading and unloading. In the case of the United States, 72 percent of manufactured goods using maritime transportation are containerized (by value) according to the Waterborne Databank issued by the U.S. Maritime Administration.

[8]The idea that higher-quality products tend to be shipped farther is known as the Alchian-Allen conjecture, first found in Alchian and Allen (1964). If this is indeed the case, the use of pricing data would tend to bias the measurement of transportation costs. Hummels and Skiba (2004a) find empirical evidence for this conjecture.

[9]Other papers have used CIF/FOB (Cost, Insurance, Freight / Free on Board) measures from the International Monetary Fund and United Nations, which has been criticized by Hummels and Lugovskyy (2006).

[10]Levinson (2008) provides an introduction to the invention and diffusion of the use of shipping containers in international trade.

3.1 Transportation Costs

Data on transportation costs are obtained from the freight forwarder Air Parcel Express (APX). A freight forwarder is a third-party logistics provider that helps to arrange shipments and related paperwork for exporters. Freight forwarders advise exporters on transportation costs and other fees (port charges, consular fees, costs of special documentation, insurance costs, and handling fees), as well as on import rules and regulations, methods of shipping, and the necessary documents.

The transportation costs are for transporting a 20-foot container from major U.S. ports to over 300 destinations abroad in October 2014. I use data from the top 10 U.S. ports in terms of number of containers loaded in the port. These ports account for approximately 85 percent of U.S. container traffic each year and include Charleston, Houston, Los Angeles/Long Beach, New York/Newark, Norfolk, Oakland, Savannah, Seattle, and Tacoma.[11]

3.2 Number of Shippers

I acquired data collected in October 2014 on the number of shippers operating between ports from the *Journal of Commerce* (JOC), a respected trade publication in the transportation/logistics industry. The data come from the JOC Global Sailings Schedule, which includes information on shipping schedules for containerized shippers.[12] For example, the shipping schedules indicate that A.P. Møller-Maersk, the largest shipping firm in the world, operates the ship *Maersk Wolfsburg*. This ship picked up cargo in Los Angeles on October 16, 2014, and delivered it to Puerto Quetzal, Guatemala, on October 23, 2014.

Much like a bus system in a city, shippers have lines that make multiple sequential stops. This is due to the economies of scope in containerized shipping. In this case, after Los Angeles, the *Maersk Wolfsburg* stopped in Lazaro Cardenas, Mexico (October 21) to pick up and drop off cargo before arriving in Puerto Quetzal. After Puerto Quetzal, the ship stopped in Acajutla, El Salvador (October 23), Corinto, Nicaragua (October 25), and finally Balboa, Panama (October 28). The data also contain schedules that make use of regional shipping hubs in transporting shipping containers to their final destination. This is analogous to transferring to another bus to reach a final destination.

3.3 Containerized Trade Flows

Data on port-to-port containerized trade flows come from the Waterborne Databank issued by the U.S. Maritime Administration for the years 2000-2005. The dataset contains information about U.S. international maritime trade on a port-to-port level. The data are broken down into the Harmonized System (HS) six-digit product level, and include the cost of transportation and insurance, weight, and

[11] See U.S. Department of Transportation (2011), Table 3.

[12] When determining the number of shippers, I combine shippers that operate in the same alliance. See Appendix A for more details.

whether the shipment is containerized.[13]

The Waterborne Databank was discontinued in 2005, and there are no other available sources that report containerized trade at the port-to-port level. For this reason, I use the reported value of containerized trade in 2005 between ports and adjust it for the percentage increase in bilateral trade over the 2005-2014 period between the United States and the countries where the ports are located. This measure of trade flows is expected to be highly correlated to the true value of trade flows if data were available for 2014. To illustrate this point, I compute the correlation of the value of containerized trade flows in 2000 and 2005, and find it to be 0.85.

3.4 Port-to-Port Distance

I use the geospatial information system (GIS) to construct the distance between U.S. ports and foreign ports. I calculate the shortest navigable distance between the ports. For example, the distance between Los Angeles and Rotterdam incorporates the fact that ships can use the Panama Canal to minimize distance.

To do so, I combine two separate sets of geospatial data. First, I use the Global Shipping Lane Network shapefile provided by the Oak Ridge National Labs CTA Transportation Network Group. The shapefile contains information on global trading lanes used by maritime shippers. Second, I use the World Port Index provided by the National Geospatial Intelligence Agency to provide information on the location of ports. After combining these two sets of geospatial data, I use Network Analyst on ArcGIS to calculate the shortest path from the origin to destination port along the commonly used trading lanes. The final distance measure is given in nautical miles.[14]

3.5 Summary Statistics

Table 1 shows summary statistics for the assembled data. Each observation is a U.S.-foreign port pair. In the analysis, I only use observations for which all four data sources are available. Finally, each observation is referred to as a route.

First, transportation costs display significant dispersion: the ratio between the 90th and 10th percentiles is 2.59 (2,749/1,063). Second, the industry is characterized by a high degree of concentration among shippers. For example, the median route has only two shippers present. In fact, 46

[13] I use the Waterborne Databank to find a measure of ad valorem transportation costs by accessing information about the CIF and FOB value of shipments. The CIF value of a shipment includes the costs of transportation and insurance; the FOB value of the good does not contain transportation costs and insurance. Thus, dividing the CIF value by the FOB value yields an ad valorem transportation cost. I find that the correlation between the log ad valorem transportation costs for all imports and the log transportation costs that I collected is 0.18. These results must be treated with caution, however, because of three factors. First, issues related to the composition of goods traded across locations may reduce the reliability of ad valorem transportation costs. Second, the data for the Waterborne Databank are for the year 2005, whereas the quotes from APX are for the year 2013. Third, the information for transportation costs in the Waterborne Databank is only available for imports, whereas the APX quotes are transportation costs to export from the United States.

[14] A nautical mile is equivalent to 1,852 meters and is a widely used unit in marine navigation.

percent of routes are serviced by monopolists, and even the routes in the 90th percentile have only four shippers. This finding is consistent with the work of Hummels, Lugovskyy, and Skiba (2009), who also document high levels of concentration in the containerized maritime transportation industry. Third, the size of trade flows exhibit large variation across routes: the ratio between the 90th and 10th percentiles is 295 (1,769/6).

Fourth, I define the average shipper size as the value of port-to-port containerized trade flows divided by the number of shippers, which is the average trade flows per shipper on a route. I will refer to this term as the average shipper size. I use this measure because the focus of this paper is the scale of shippers at the route level.[15] For example, a shipper such as A.P. Møller-Maersk may use larger ships within their transportation network to service the two ports. The data show significant variation in the average size of shippers: the ratio between the 90th and 10th percentiles is 199 (795/4).

3.6 How Are Transportation Costs Related to Distance and the Size of Trade Flows?

In this section, I document correlations that I find in the assembled data, which motivate the model that I build in Section 4. When I calibrate the model in Section 6, I will calculate the same statistics using the model-generated data to see whether the model can account for these correlations.

I first study how transportation costs are related to the size of trade flows and the distance between the two ports. I estimate the following regression:

$$\log TransportationCost_{lm} = \delta_0 + \delta_1 \log GDP_{C(m)} + \delta_2 \log Dist_{lm} + \epsilon_{lm}, \tag{1}$$

where $TransportationCost_{lm}$ is the transportation cost from U.S. port l to foreign port m, $GDP_{C(m)}$ is the GDP of country C, $C(m)$ indicates the country where port m is located, and $Dist_{lm}$ denotes the distance between ports l and m. Since all routes in the dataset originate in the United States, I use the GDP of the destination country where the port is located. As a first step, I do not use the value of containerized trade flows in this specification since I mechanically expect lower transportation costs to be correlated with higher trade flows. The correlation of GDP and containerized trade flows is 0.93, so countries with larger GDPs also have larger trade flows in the dataset. The results of this estimation can be seen in column 1 of Table 2. The results show that a larger GDP is associated with lower transportation costs, and a longer distance is associated with higher transportation costs.

One feature of the data that is useful to understand is the relative importance of GDP and distance in explaining transportation costs. Thus, I calculate the partial correlations of these variables. The partial correlation, unlike a pairwise correlation, measures the strength of the relationship between two variables while controlling for the other variable. I find that the partial correlation between log

[15]This definition of average shipper size does not include information about scale at the level of the entire transportation network. The issue of changes in the scale of the transportation network is an additional channel not considered by the model presented in Section 4. In Section 8, I discuss that this additional mechanism would likely amplify the results of the model.

transportation costs and log GDP given the effect of log distance is -0.45. Furthermore, I find that the partial correlation between log transportation costs and log distance given the effect of GDP is 0.27. These correlations suggest that a larger fraction of the observed dispersion in transportation costs can be explained by the GDP of the destination country.

I also investigate the relationship between the number of shippers and the average shipper size with respect to the GDP of the destination country. I estimate equation 1 except that log $NumberShippers_{lm}$, the log number of shippers operating between U.S. port l and foreign port m, is the dependent variable. I similarly estimate the same equation except that log $AverageShipperSize_{lm}$, the log average shipper size between U.S. port l and foreign port m, is the dependent variable. The average shipper size is defined as $TradeFlows_{lm}/NumberShippers_{lm}$ where $TradeFlows_{lm}$ is the total trade flows between ports l and m. The results can be found in columns 2 and 3 of Table 2. Countries with larger GDPs have routes with more shippers, and the average shipper size is larger.

The recent works of Brancaccio, Kalouptsidi, and Papageorgiou (2017), Ishikawa and Tarui (2018), and Wong (2018) have studied how unbalanced trade can affect transportation costs. In particular, if the United States has a trade deficit with another country, then transportation costs tend to be lower from the United States to that country (and higher in the opposite direction) because of the capacity constraints of shippers. Routes with larger trade flows may tend to have larger trade deficits, which could explain these empirical relationships, especially those related to transportation costs. In Appendix B, I show that the findings are robust to including measures of bilateral trade imbalances in containerized trade between the United States and the foreign country.

Using trade flows as an independent variable To further understand the relationship between transportation costs and the size of trade flows, I estimate the following regression:

$$\log TransportationCost_{lm} = \phi_0 + \phi_1 \log TradeFlows_{lm} + \epsilon_{lm}. \tag{2}$$

As before, the estimated relationship from this regression is not intended to be causal. Instead, I aim to document correlations in the data which I will later compare with the calibrated model. The first column of Table 3 reports the estimated elasticity of trade flows to be -0.10, indicating that routes with larger trade flows have lower transportation costs.[16] The inclusion of distance as an independent variable does not significantly change the estimated coefficient on the trade flows.

Next, I study how the average shipper size and the number of shippers change with the size of

[16]As a robustness exercise, I estimate the regression in equation 2 using the GDP of the destination country as an instrumental variable (IV) and including distance as a control in the regression. The strategy is similar to the one employed by Hummels and Skiba (2004b) and Skiba (forthcoming). In particular, this specification gives an estimate of how transportation costs change as exogenous changes take place in the demand for transportation. The reason is that the GDP of the destination country affects transportation costs only through the size of trade flows. I find that this specification gives an elasticity of -0.17, which is the same to the second significant digit as in the baseline case. The results of the first stage of the IV estimation are in Appendix J.

trade flows in the cross section. To do so, I consider the following equation:

$$tradeflows = \frac{tradeflows}{shippers} * shippers. \tag{3}$$

This equation shows that increases in trade flows can be associated with an increase in the average shipper size, the number of shippers, or some combination of the two. For example, suppose that a 1 percent increase in trade flows is observed and that this increase is accompanied by a 1 percent increase in the trade flows per shipper. This result implies that the number of shippers remains constant. Conversely, if a 1 percent increase in trade flows is accompanied by a 1 percent increase in the number of shippers, then the value of trade flows per shipper remains constant.

I estimate equation 2 except that the dependent variable is the log number of shippers. I find that the elasticity of the number of shippers with respect to trade flows is 0.10, as reported in column 2 of Table 3. I similarly estimate equation 2 except that the dependent variable is the log average shipper size. I find an elasticity of average shipper size with respect to trade flows of 0.90, as reported in column 3. It can be shown that the coefficients on trade flows in columns 2 and 3 in Table 3 sum to 1.

These results show that increases in trade flows are associated with increases in both the average shipper size and the number of shippers. Quantitatively, however, larger trade flows are primarily accompanied by increases in the average shipper size.

A concern may be that the measure of average shipper size does not accurately reflect the size of shippers because of heterogeneity in shipper size within routes. For that reason, I reestimate equation 2 except that the dependent variable is a measure of the size of each shipper. I do not have data on the share of each shipper by route. However, I have information about the size of ships used by each shipper in deadweight tons (DWT). I define the size of a shipper to be the value of trade flows multiplied by a shipper's share in terms of total DWT that it operates on that route. The results can be found in Table A3 in Appendix J. The results are very similar to the baseline specification. Thus, although the focus of this paper is on the average size of shippers, the results show that routes with larger trade flows tend to have larger shippers even when accounting for shipper heterogeneity.

4 Model

I build a two-country Armington (1969) trade model that incorporates an oligopolistically competitive transportation industry. The simple demand structure of the model allows for deriving analytical characterizations of the solution of the transportation industry. This simple model structure also implies that trade from one port to another consists of a homogeneous good. In the transportation industry, shippers pay a sunk entry cost, and I focus on the symmetric equilibrium in which all shippers are identical in equilibrium.[17]

4.1 Consumer

There are two countries, i and j. Country j is populated by identical consumers of measure L_j. Each agent inelastically supplies one unit of labor and spends her income on goods from both countries. The representative consumer of country j chooses the quantity of the good purchased from country j, c_{jj}, and from country i, c_{ij}, to solve

$$\max_{c_{jj},c_{ij}} \left(c_{jj}^{\frac{\sigma-1}{\sigma}} + \zeta^{\frac{1}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{4}$$

$$\text{subject to } p_{jj}c_{jj} + \tau_{ij}p_{ij}c_{ij} = w_jL_j + R_j, \tag{5}$$

where $\zeta \in [0,1]$ is a home bias parameter; σ is the elasticity of substitution of goods across countries; τ_{ij} is the ad valorem tariff on goods from country i traveling to j; p_{jj} is the price of the country j good paid by country j and similarly for p_{ij}; w_j is the wage in country j; and R_j is tariff revenue that is rebated to the household lump sum. Consumers in j have the following demand for goods from i:

$$c_{ij} = \frac{\zeta\left(w_jL_j + R_j\right)}{\tau_{ij}^{\sigma}p_{ij}^{\sigma}P_j^{1-\sigma}}, \tag{6}$$

and similarly for c_{jj}:

$$c_{jj} = \frac{w_jL_j + R_j}{p_{jj}^{\sigma}P_j^{1-\sigma}}. \tag{7}$$

The price index, P_j, is

$$P_j = \left(p_{jj}^{1-\sigma} + \zeta\tau_{ij}^{1-\sigma}p_{ij}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}. \tag{8}$$

I now allow for the possibility that a country has multiple ports. Suppose that country i has Ω_i ports indexed by i' and country j has Ω_j ports indexed by j'. The composite good from i to j, c_{ij}, is defined to be

$$c_{ij} = \left(\sum_{i'=1}^{\Omega_i}\sum_{j'=1}^{\Omega_j} \mathbb{I}_{i'j'}\beta_{i'}^{\frac{1}{\gamma}}\beta_{j'}^{\frac{1}{\gamma}}c_{i'j'}^{\frac{\gamma-1}{\gamma}}\right)^{\frac{\gamma}{\gamma-1}}, \tag{9}$$

where $\mathbb{I}_{i'j'}$ is an indicator function that equals 1 if there is trade between ports i' and j'; $\beta_{i'}$ is an expenditure weight that is characterized by the importance of port i' in bilateral trade and similarly for $\beta_{j'}$; $c_{i'j'}$ is the consumption good transported from port i' to port j'; and γ is the elasticity of

[17] In the model, shipping firms compete oligopolistically against each other instead of coordinating as a cartel. In the past, shipping firms have been organized in conferences, which were exempt from antitrust regulations and operated as cartels. Shipping conferences, however, are no longer relevant in determining shipping prices. The Ocean Shipping Reform Act of 1998 greatly reduced the importance of conferences for container traffic entering and leaving the United States. For example, the last major shipping conference that operated in the United States was the Trans-Atlantic Conference Agreement (TACA), which disappeared in 2008. See Premti (2016) for a discussion of the regulation of shippers through time.

substitution across port pairs.[18,19] Goods shipped from Los Angeles to Callao and Oakland to Callao are differentiated products, with γ governing their substitutability. This setup is useful when we take the model to the data in Sections 5 and 6 because it is not uncommon to find trade flows from two U.S. ports (Los Angeles and Oakland) to the same foreign port (Callao). With the demand structure characterized above, the model will be able to generate positive trade flows from Los Angeles to Callo and Oakland to Callao just as in the data.[20]

The demand for goods from port i' going to port j', $c_{i'j'}$, is

$$c_{i'j'} = \mathbb{I}_{i'j'} \frac{\beta_{i'}\beta_{j'}c_{ij}}{p_{i'j'}^{\gamma}p_{ij}^{-\gamma}}, \tag{10}$$

where $p_{i'j'}$ is the price of $c_{i'j'}$, and the price index, p_{ij}, is defined as

$$p_{ij} = \left(\sum_{i'=1}^{\Omega_i} \sum_{j'=1}^{\Omega_j} \mathbb{I}_{i'j'}\beta_{i'}\beta_{,j'}p_{i'j'}^{1-\gamma} \right)^{\frac{1}{1-\gamma}}. \tag{11}$$

Combining equations 10 and 6 yields demand for $c_{i'j'}$:

$$c_{i'j'} = \mathbb{I}_{i'j'} \frac{\beta_{i'}\beta_{j'}\zeta\left(w_j L_j + R_j\right)}{\tau_{ij}^{\sigma}p_{i'j'}^{\gamma}p_{ij}^{\sigma-\gamma}P_j^{1-\sigma}}, \tag{12}$$

Defining c_{jj} using an expression similar to 9 is not necessary since consumers are assumed to receive the consumption good from the domestic producer with no transportation costs.

[18]Notice that $\mathbb{I}_{i'j'}$ is exogenous in the model. When going to the data, I will let this indicator function be 1 if trade between the two ports is observed and the data needed to carry out the analysis are available.

[19]A model of economic geography in which the location of economic activity is endogenous could provide a natural theory for the expenditure weights. In this case, cities of varying sizes would emerge, and firms located in those cities would tend to utilize nearby ports in order to minimize transportation costs. Thus, ports would also have varying sizes even if faced with the same transportation costs. In my setup, the model uses the expenditure weights to match the large differences in trade flows across ports that are not accounted for by transportation costs and leaves them fixed after the change in tariffs.

[20]The structure of demand with expenditure weights can capture some of the patterns that emerge when there are internal trade frictions within a country. For example, to reduce internal transportation costs, countries can have multiple ports where each port serves a nearby region. The transportation literature refers to this concept as the "hinterland" of a port. Thus, ports that have hinterlands with large populations will tend to be larger, which will be captured by the expenditure weights. Another aspect that results from internal trade frictions is that there are trade-offs between transportation costs and time. For example, goods that travel from East Asia to the East Coast of the United States can travel by a ship that passes through the Panama Canal. Goods can alternatively arrive in Los Angeles and then be transported to the East Coast via rail. The trade-off is that the route that uses the Panama Canal is less expensive, and the route that uses rail is faster (see Talley (2017) for a description of the North American land bridge). The model has the intuitive property that if transportation costs rise in one pair (e.g., East Asia to Los Angeles), then we would expect that some shipments would go to other ports (e.g., East Asia to New York).

4.2 Production Firm

Country i has a representative production firm that operates under perfect competition. The firm has a linear production technology with a constant unit labor requirement, $1/x_i$, where x_i is the productivity parameter. Since there are no domestic transportation costs, the firm in country i charges domestic consumers the factory-gate price, $p_{ii} = w_i/x_i$. To sell in the foreign country, the firm must pay $T_{i'j'}$ per unit of good to the shipper for goods transported from port i' to port j'. Thus, the firm charges $p_{i'j'} = w_i/x_i + T_{i'j'}$ for the product shipped from port i' to j'. The conditions are similar for goods produced by country j.

4.3 Transportation Industry

The transportation industry is characterized by a three-stage entry game, which is a similar setup to what is used by Sutton (1991) in which sunk costs are endogenous.[21] Here I briefly sketch out the stages of this entry game. In the first stage, N identical shippers enter the route to transport goods back and forth between ports i' and j' by paying a fixed cost, f, which is denominated in units of labor. Paying the fixed cost gives shippers access to a transportation technology with a labor requirement of $1/\phi$ to ship one unit of consumption good. In the second stage, shippers choose an optimal technology that has a lower unit labor requirement, $1/\Phi < 1/\phi$, and higher fixed cost, $F > f$.[22] In the third stage, shippers compete à la Cournot in each direction: the quantity to transport from i' to j' and from j' to i'. I consider the pure strategy Nash equilibrium in which, in a given route, all shippers choose the same technology in the second stage and are symmetric in the third stage.

The motivation for having a three-stage entry game is that the third stage, in which shippers choose quantity, corresponds to the short-run decisions of shippers; the second stage, in which shippers make their technological choice, corresponds to the medium-run decision of shippers; and the first stage, in which shippers decide whether or not to enter, is the long-run decision.

In this section, I characterize the problem of the transportation industry between two ports. For ease of exposition, the notation for these two ports is omitted unless it is necessary to indicate the direction of trade. I also assume that there is a continuous number of shippers that satisfies a zero-

[21] A solution to the three-stage entry game may not be a solution to a two-stage entry game in which the first and second stages are combined. Sutton (1991) discusses that the solution to the three-stage entry game often coincides with the two-stage formulation except that for some parameters, the two-stage entry game may not have a symmetric pure strategy Nash equilibrium. These differences arise because in the two-stage entry game, a shipper that enters takes as given the entry and technology decision of all shippers, whereas in the three-stage entry game, a shipper that enters takes into account that other shippers can adjust their technology in the second stage based on who has entered.

[22] The decision to purchase a ship has important dynamic considerations because the life of a ship spans over multiple decades (for detailed studies of these considerations, see Kalouptsidi (2014) and Kalouptsidi (2018)). However, shipping firms have the ability to charter containerships over short periods of time, and it is a common practice among shipping firms. For example, according to Alphaliner, an intelligence firm that collects data on containerized maritime transportation, over 53 percent of the worldwide capacity of containerships was from chartered ships, as reported in the September 2016 *Monthly Monitor*. This market reduces the dynamic considerations that firms face when making capital decisions.

profit condition.[23]

4.3.1 Third Stage for Shipper's Problem

I work backward through the entry game. In the third stage, shipping firm n takes the following as given: the total quantity supplied by competitors, $c_{i'j'}^{-n}$ and $c_{j'i'}^{-n}$; the nominal income of the representative consumer in each country, characterized by the right-hand side of the budget constraint in equation 5; wages in both countries; the factory-gate prices of the goods in each country, p_{ii} and p_{jj}; and price $p_{i'j'}$ of all other port pairs. Shippers use labor from country i to pay both the marginal cost and the fixed cost. The shipper with productivity Φ chooses $c_{i'j'}^{n}$ and $c_{j'i'}^{n}$ to maximize profits in the third stage:

$$\pi(\Phi; c_{i'j'}^{-n}, c_{j'i'}^{-n}) = \max_{c_{i'j'}^{n}, c_{j'i'}^{n}} \quad c_{i'j'}^{n}\left[T_{i'j'}\left(c_{i'j'}^{n} + c_{i'j'}^{-n}\right) - \frac{w_i}{\Phi}\right] + c_{j'i'}^{n}\left[T_{j'i'}\left(c_{j'i'}^{n} + c_{j'i'}^{-n}\right) - \frac{w_i}{\Phi}\right], \tag{13}$$

where $c_{i'j'}^{n} + c_{i'j'}^{-n}$ is the total quantity supplied by shippers from i' to j' and similarly from j' to i'. In equilibrium, it must be that $c_{i'j'}^{n} + c_{i'j'}^{-n} = c_{i'j'}$ where $c_{i'j'}$ is demand for transportation and is defined in equation 12. Furthermore, $T_{i'j'}\left(c_{i'j'}^{n} + c_{i'j'}^{-n}\right)$ is the inverse demand function for transportation. We write the solution to this problem as $c_{i'j'}^{n}\left(\Phi; c_{i'j'}^{-n}\right)$ and $c_{j'i'}^{n}\left(\Phi; c_{j'i'}^{-n}\right)$.

4.3.2 Second Stage for Shipper's Problem

In the first stage, N shippers have entered and have access to a technology with a marginal cost of w_i/ϕ to transport a unit of consumption good. In the second stage, shippers choose a lower marginal cost by investing in a more productive technology, $\Phi \geq \phi$, which is associated with a higher fixed cost of

$$\log F\left(\Phi\right) = \alpha_1 \log \Phi + \alpha_0. \tag{14}$$

The cost F is the total cost of a particular technology. Given that the shipper already paid f in the first stage, a fixed cost F only requires an additional cost of $F - f$. It must be that $\log f = \alpha_1 \log \phi + \alpha_0$ so that if the shipper chooses technology ϕ, there would be no additional cost incurred in the second period. The parameter α_1, which is an important parameter for the quantitative results, governs how costly it is in terms of the fixed cost to lower the marginal cost.

Firm n takes $c_{i'j'}^{-n}$ and $c_{j'i'}^{-n}$ as given and chooses the technology that maximizes its profitability in

[23]Notice that a model with a discrete number of shippers and my model give the same answer when my model predicts a whole number of shippers (e.g., 1, 2, 3, ...). My model tends to *overpredict* the welfare effects relative to a model with discrete shippers if there is *no entry* in the latter model. Similarly, my model tends to *underpredict* the welfare effects relative to a model with discrete shippers if there is *entry* in the latter model. Thus, I consider the quantitative results to be an average effect of a change in tariffs.

the third stage, which must satisfy

$$\frac{d\pi(\Phi; c_{i'j'}^{-n}, c_{j'i'}^{-n})}{d\Phi} = w_i \frac{dF\left(\Phi\right)}{d\Phi}. \tag{15}$$

The solution to the second-stage problem can be expressed as $\Phi\left(c_{i'j'}^{-n}, c_{j'i'}^{-n}\right)$.

4.3.3 First Stage for Shipper's Problem

We focus on the equilibrium with a continuous number of N symmetric shippers, which is endogenously determined by the zero profit condition. Because of the symmetry condition, we can rewrite all of the solutions as a function of N. In the first stage, the free entry condition must be satisfied such that the profits in the third stage, $\pi(N)$, equal the total fixed cost from the second stage, $F(N)$. Notice that even though the shipper must only pay f in the first stage, the shipper takes into account that there may be an additional cost incurred in the second stage.

4.4 Government

The government gives consumers a lump-sum rebate on all tariff revenue. The tariff revenue in country j is

$$R_j = \left(\tau_{ij} - 1\right) p_{ij} c_{ij}. \tag{16}$$

There is a similar condition for country i.

4.5 Labor Market Clearing Conditions

Finally, the labor market clearing conditions if only labor from country i is used to operate the transportation industry is

$$\underbrace{\frac{c_{ii}}{x_i} + \sum_{i'=1}^{\Omega_i}\sum_{j'=1}^{\Omega_j} \mathbb{I}_{i'j'} \frac{c_{i'j'}}{x_i}}_{\text{Labor used by production firm}} + \underbrace{\sum_{i'=1}^{\Omega_i}\sum_{j'=1}^{\Omega_j} \mathbb{I}_{i'j'} \frac{c_{i'j'}}{\Phi_{i'j'}} + \sum_{i'=1}^{\Omega_i}\sum_{j'=1}^{\Omega_j} \mathbb{I}_{j'i'} \frac{c_{j'i'}}{\Phi_{i'j'}} + N_{i'j'} F_{i'j'}}_{\text{Labor used by transportation industry}} = \underbrace{L_i}_{\text{Labor endowment}}, \tag{17}$$

where $\Phi_{i'j'}$ is the productivity chosen by shippers that operate between i' and j' in the second second stage, $N_{i'j'}$ is the number of shippers that operate, and $F_{i'j'}$ is the fixed cost that they choose in the second stage. In country j, the condition is

$$\underbrace{\frac{c_{jj}}{x_j} + \sum_{i'=1}^{\Omega_i}\sum_{j'=1}^{\Omega_j} \mathbb{I}_{j'i'} \frac{c_{j'i'}}{x_j}}_{\text{Labor used by production firm}} = \underbrace{L_j}_{\text{Labor endowment}}. \tag{18}$$

In equilibrium, the balanced trade condition between the two countries is redundant because of Walras's law.

4.6 Characterizing the Solution for Transportation Industry

I now characterize the solution for the transportation industry. These characterizations will allow a better understanding of the determinants of the variables, such as markups, in the model. I also use these expressions when calibrating the model parameters.

Proposition 1. *Consider the route to ship consumption goods from i' to j'. Equilibrium transportation costs in the third stage must satisfy*

$$T_{i'j'} = \underbrace{\frac{\epsilon_{i'j'}}{\epsilon_{i'j'} - 1}}_{Markup} \underbrace{\frac{w_i}{\Phi_{i'j'}}}_{Marginal\ Cost}, \tag{19}$$

where $\epsilon_{i'j'}$ is the perceived price elasticity of demand of individual shippers. The perceived price elasticity of a shipper is

$$\epsilon_{i'j'} = N_{i'j'} \frac{T_{i'j'}}{p_{i'j'}} \kappa_{i'j'}, \tag{20}$$

where $\kappa_{i'j'}$ is determined as follows:

$$\kappa_{i'j'} = \gamma - [\gamma - \sigma] \frac{p_{i'j'} c_{i'j'}}{p_{ij} c_{ij}} - (\sigma - 1) \frac{\tau_{ij} p_{i'j'} c_{i'j'}}{w_j L_j + R_j}. \tag{21}$$

We have a similar set of conditions characterizing transportation costs from j' to i'.

Proof. See Appendix C for the full proof. □

Equation 19 shows that transportation costs can be expressed as a markup over marginal cost, where the markup is a function of the perceived price elasticity. The first term of the perceived price elasticity in equation 20 is the total number of shippers. As this number increases, the perceived price elasticity of shippers increases. In the case that the number of shippers approaches infinity, the market structure becomes perfectly competitive, and markups approach 1. The second term, $T_{i'j'}/p_{i'j'}$, is the relative size of transportation costs in the final delivery price of the consumption good. As this number declines, transportation costs account for a smaller fraction of the delivery price, and the perceived price elasticity declines.

The last term, $\kappa_{i'j'}$, is determined by the importance of trade flows between ports. To understand this term, consider the following three cases:

$$\kappa_{i'j'} = \begin{cases} \gamma & \text{if } \frac{p_{i'j'}c_{i'j'}}{p_{ij}c_{ij}} = 0 \text{ and } \frac{\tau_{ij}p_{i'j'}c_{i'j'}}{w_jL_j+R_j} = 0 \\ \sigma & \text{if } \frac{p_{i'j'}c_{i'j'}}{p_{ij}c_{ij}} = 1 \text{ and } \frac{\tau_{ij}p_{i'j'}c_{i'j'}}{w_jL_j+R_j} = 0 \\ 1 & \text{if } \frac{p_{i'j'}c_{i'j'}}{p_{ij}c_{ij}} = 1 \text{ and } \frac{\tau_{ij}p_{i'j'}c_{i'j'}}{w_jL_j+R_j} = 1 \end{cases} \tag{22}$$

Notice that $(p_{i'j'}c_{i'j'}) / (p_{ij}c_{ij})$ is the fraction of trade from country i to j that transits from port i' to j'. Thus, this term considers the importance of a port pair in accounting for total bilateral trade from i to j. The term $(\tau_{ij}p_{i'j'}c_{i'j'}) / (w_jL_j + R_j)$ is the fraction of country j's total expenditure of goods that transit from port i' to j'.

The first case is one in which trade from port i' to j' accounts for a negligible portion of trade from country i to j or $(p_{i'j'}c_{i'j'}) / (p_{ij}c_{ij}) = 0$. Equation 22 shows that in this case, $\kappa_{i'j'}$ is solely determined by γ. Thus, the γ parameter affects the market power of shippers operating between port pairs that are not important in accounting for bilateral trade between the two countries: as γ increases, then $\kappa_{i'j'}$ and $\epsilon_{i'j'}$ increase, and the markup in equation 19 for these shippers declines. The second case is one in which trade from port i' to j' accounts for all of the trade from country i to j or $(p_{i'j'}c_{i'j'}) / (p_{ij}c_{ij}) = 1$. In this case, $\kappa_{i'j'}$ is solely determined by σ. Thus, the σ parameter determines the level of the market power of shippers that operate between port pairs that are important in accounting for bilateral trade. In Section 5, the calibration indicates that $\gamma > \sigma$. Thus, as trade from i' to j' becomes more important, shippers that operate between these ports charge higher markups. This result arises from shippers internalizing their ability to influence the p_{ij} price index in expression 12.

For example, consider the trade from the United States to Peru. Suppose that a very small fraction of the goods purchased by Peru are transported from Los Angeles to Callao. Then γ will affect the market power of the shippers that operate between these two ports. On the other hand, suppose that all goods purchased by Peru are transported from Los Angeles to Callao. Then σ will affect the market power of the shippers that operate between these two ports. Because $\sigma < \gamma$, the markup will be higher in the latter case. The model also allows for intermediate cases: as two ports account for a larger fraction of bilateral trade between two countries, then $\kappa_{i'j'}$ decreases from γ to σ and markups increase.

Consider again the case in which shippers operate between port pairs that are important in accounting for bilateral trade. Furthermore, in the third case, trade from i' to j' accounts for a large fraction of country j's total expenditure or $(\tau_{ij}p_{i'j'}c_{i'j'}) / (w_jL_j + R_j) = 1$. In this case, $\kappa_{i'j'} = 1$. In Section 5, the calibration indicates that $1 < \sigma$. Thus, as country j's expenditures on goods from i' to j' increase as a fraction of its total expenditures, the markups of shippers that operate between these two ports increase. This result arises from shippers understanding that they can influence country j's aggregate price index, P_j.

The results from the model are consistent with other models of oligopolistic competition with

CES industry demand in which the market share of a firm is sufficient information to infer markups, as in Atkeson and Burstein (2008). In my methodology, three different market shares are needed to determine the markup. The first is the market share of a shipper among the firms that operate between two ports, which in this case is the same as knowing the number of firms. The second, for total bilateral trade, is the market share of trade accounted for by two ports. The third, for a country's total expenditure, is the market share accounted for by trade between two ports. Furthermore, a model with competition arising across ports is useful because otherwise there would be two stark choices in defining the relevant market. The first would be to define the relevant market as all the shippers that operate between the same port pair. Thus, a shipper that operates between Oakland and Callao would not consider the potential competition from shippers operating between Los Angeles and Callao. The second choice would be to define the relevant market as all the shippers that operate between two countries. In that case, a shipper would consider competitors operating from Los Angeles to Callao as exactly identical to those operating from Oakland to Callao.

In Proposition 2, I derive a condition that characterizes the profitability of shipping firms as a function of the value of bilateral trade and the number of shippers.

Proposition 2. *The equilibrium profits for shippers in equation 13 can be rewritten as*

$$\pi_{i'j'} = \frac{c_{i'j'}p_{i'j'}}{N^2\kappa_{i'j'}} + \frac{c_{j'i'}p_{j'i'}}{N^2\kappa_{j'i'}}, \tag{23}$$

where $\pi_{i'j'}$ is the total profit of shippers (before payment of the fixed cost) that operate between ports i' and j'.

Proof. See Appendix C for the full proof. □

Equation 23 shows that profitability is increasing in the equilibrium trade flows between ports and decreasing in the number of shippers. The profitability of shippers is also decreasing in $\kappa_{i'j'}$ and $\kappa_{j'i'}$.

Notice that Proposition 1 is consistent with the zero profit and the free entry condition. The reason is that the number of shippers in the model is pinned down such that $\pi_{i'j'}$ equals the total fixed costs paid. Furthermore, the derivation for $\pi_{i'j'}$ uses the condition for the transportation costs and markups derived in Proposition 1.

4.7 An Alternative Model in Which Shippers Use Labor from Both Countries

Notice that shippers use labor from country i to operate in the transportation industry. In Appendix D, I present an extended model in which shippers use a combination of labor from both countries to pay the marginal and fixed costs. I show that Propositions 1 and 2 continue to hold under this new setup.

The concern may be that using labor from only one country for the transportation industry may affect the estimated welfare results in the quantitative exercise in Section 7. In particular, an increase in the transportation industry's labor demand may raise wages, thereby affecting that country's real income. The quantitative results in Section 7.1, however, suggest that the demand for labor from the transportation industry is not the main driver of changes in real income. The reason is that wages account for only a small portion of the changes in real income after the tariff change. Finally, the ownership of the transportation industry (i.e., which countries receive its profits) does not matter because there are zero profits.

5 Transportation Technology

In this section, I use conditions from the model in Section 4 to infer the marginal and fixed costs for each U.S.-foreign port pair in the data. I then study how this transportation technology is related to the size of trade flows.

5.1 Elasticities of the Model

As a first step, I describe the values used for the two elasticities of the model: the elasticity of substitution across port pairs, γ, and the elasticity of substitution across country-level goods, σ. These elasticities are needed to calculate the marginal and fixed costs for each U.S.-foreign port pair.

5.1.1 Elasticity of Substitution across Port Pairs, γ

To estimate γ, I derive a gravity equation from the model of port-to-port trade flows, which is a result of the CES demand structure for the final good. I combine equations 6 and 10 to derive the following condition that characterizes the port-to-port value of trade:

$$\log p_{i'j'}c_{i'j'} = (1-\gamma)\log p_{i'j'} + \log \beta_{i'} + \log \beta_{j'} + \log\left(p_{ij}^{\gamma-\sigma}\tau_{ij}^{-\sigma}P_j^{\sigma-1}\zeta\left(w_jL_j + R_j\right)\right). \tag{24}$$

I then estimate the following regression using all of the observations in the dataset:

$$\log TradeFlows_{i'j'} = \eta_0 + \eta_1 \log Price_{i'j'} + I_{i'} + I_{j'} + \epsilon_{i'j'}, \tag{25}$$

where $TradeFlows_{i'j'}$ is the value of trade flows from port i' in the United States to j' abroad, $Price_{i'j'}$ is the delivery price of the good at the destination, $I_{i'}$ is a U.S. port fixed effect, and $I_{j'}$ is a foreign port fixed effect. The intuition behind the identification strategy is that I want to compare the changes in trade flows with differences in the delivery price of the good. If small changes in prices are associated with large changes in trade flows, then I infer that γ is relatively high. In the estimation, an origin U.S. port dummy is included to control for $\beta_{i'}$, and a foreign destination port dummy to control for $\beta_{j'}$, which are the last two terms in equation 24. These expenditure weights account for differences in the size of ports that are not related to transportation costs. For example, a particular port may be larger because it services an area of the country that has a larger population.

The delivery price, $Price_{i'j'}$, is the factory-gate price of the good plus the transportation cost. Notice that the relative importance of transportation costs in the overall price of the good will affect the estimation of γ. For example, suppose that the transportation costs are a relatively small part of the delivery price of the good. Then the delivery price will not vary significantly across destinations. Consequently, γ would need to be large in order to rationalize the observed variation in trade flows. In Appendix E, I solve for the factory-gate price that is consistent with the ad valorem transportation cost of 10.7 percent for the average commodity entering the United States, as documented by Anderson and van Wincoop (2004), as well as the observed trade flows and transportation costs. I arrive at a factory-gate price of \$12,265. Thus, when estimating equation 25, I use the delivery price $Price_{i'j'} = \$12,265 + TransportationCost_{i'j'}$.

Table 4 reports the results of the estimation of equation 25. Across all specifications, there is a negative correlation between trade flows and the delivery price of the good. In the first specification, fixed effects are not included. In the second and third specifications, only U.S. port or destination port dummies are included. The fourth specification includes both U.S. and destination port dummies and is the preferred specification since it is consistent with the model. The coefficient on the delivery price of the good is $\eta_1 = -12.89$, indicating that $\gamma = 13.89$.

Even though equation 25 was derived from the model, we may have concerns about the estimation strategy for γ.[24] As I will discuss in Section 6, one concern is that I am calibrating a separate model for each foreign country, and each of these models has its own set of expenditure weights. As a result, I should include a separate set of U.S. port dummies for each foreign country when estimating equation 25. For example, there would be one set of U.S. port dummies when considering trade with Peru and another set of U.S. port dummies when considering trade with Japan. However, when I estimate this regression, the coefficient on the delivery price is statistically insignificant. Thus, there is a tension between accurately capturing the bilateral trade flows between countries (i.e., each two-country model having its own set of expenditure weights) and the estimation of γ. There is also the concern about measurement error in the explanatory variable. Measurement error in the delivery price (e.g., from unobserved costs) will result in attenuation bias and lower the estimate of γ.

Because of these concerns, in Section 7.4, I conduct a sensitivity analysis by varying γ. The sensitivity analysis shows that the main results of the paper hold even when considering these alternative γ's. Furthermore, in Section 6.4, I report the distribution of markups in the calibrated model and compare them with existing empirical studies that estimate markups. This comparison is useful because γ is an important parameter in determining shippers' markups.

[24] We may also be concerned that both demand and cost differences across routes may confound the estimation of γ. The intuition for how the model overcomes this challenge is that for each U.S. port, there are multiple observations, so the estimation can control for size with a fixed effect ($\beta_{i'}$ in equation 25) and likewise for each foreign port (fixed effect $\beta_{j'}$). Thus, the estimation holds fixed these demand factors and compares how the changes in the delivery price are related to changes in trade flows. Note that because I only have a single origin country in my data, the foreign port fixed effects will additionally absorb the country-level terms at the end of equation 24.

5.1.2 Elasticity of Substitution across Country-Level Goods, σ

I use a value of σ that generates trade elasticities similar to those reported in the international trade literature.[25] Notice that as σ increases, trade flows become more responsive to changes in tariffs. In the calibrated model, I use $\sigma = 5$. In the quantitative exercise in Section 7, a 1 percent bilateral increase in tariffs trade leads to a decline of 5.42 percent in total bilateral trade flows in the median U.S.-foreign port pair. This trade elasticity is in line with estimates from empirical studies. For example, Head and Mayer (2014) carry out a meta-analysis of empirical estimates of trade elasticity using variation in tariff rates and find a median estimate of 5.03. Thus, the trade elasticity implied by the model is similar to the findings in the international trade literature.

5.2 Inferring a Transportation Technology

As a next step, I infer the marginal cost and fixed cost for each U.S.-foreign port pair in my data.[26]

5.2.1 Inferring Marginal Cost

As can be seen in equation 19, transportation costs depend on both the marginal cost and the markup. The markup depends on factors related to competition, such as the number of shippers, as well as on the importance of the trading route in accounting for bilateral trade between the two countries. Thus, I adjust for these factors when using transportation costs to determine the marginal cost. To understand the identification strategy, suppose that there are two routes in which shippers have the same perceived price elasticity. However, if one route has a higher transportation cost, then the model interprets that route as having a higher marginal cost.

I first calculate the perceived price elasticity characterized in equation 20. Once the perceived price elasticity is calculated, I use equation 19 to infer the marginal cost.

5.2.2 Inferring Fixed Cost

I use the condition in equation 23, along with the zero profit condition, to determine the fixed cost of entry for each route. The zero profit condition implies that the fixed cost can be determined using information about the size of trade flows, the number of shippers, and $\kappa_{i'j'}$. The intuition behind the identification strategy is that profits are an increasing function of the trade flows between two ports.

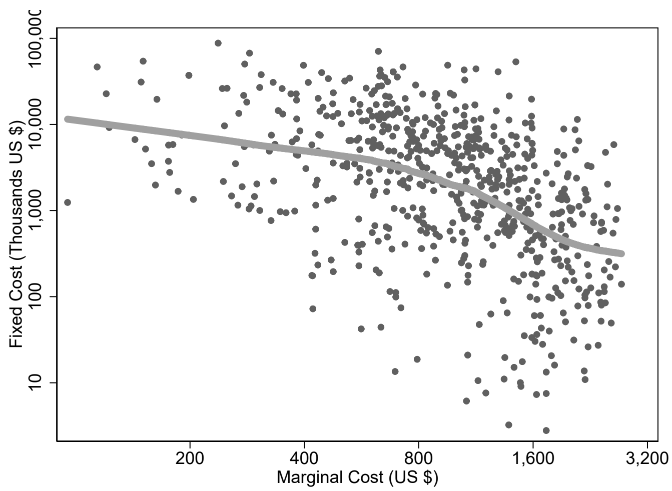
[25] Because I assume that only one good is traded and calibrate my model to match the total trade flow, the model's predictions capture both the intensive and extensive margin. Furthermore, I calibrate the elasticity of substitution between the country-level goods, σ, so that the model closely matches the sensitivity of total trade flows with respect to tariffs that is consistent with empirical studies.

[26] The strategies used to infer the marginal cost and fixed cost have been previously used in the literature of industrial organization. For example, De Loecker, Goldberg, Khandelwal, and Pavcnik (2016) use markups implied by a system of demand along with prices to determine the marginal cost of firms (see Ackerberg, Benkard, Berry, and Pakes (2007) for a detailed survey). The use of market size along with the number of producers to measure entry costs has also been previously used in the literature (Bresnahan and Reiss (1990) and Bresnahan and Reiss (1991) are early examples of this methodology).

Thus, if two routes are the same except that one has larger trade flows, I interpret the latter route as having a higher fixed cost.

Since the number of shippers is continuous in the model and not in the data, I make an adjustment to the number of shippers used to infer the fixed cost. For example, if there are 2 shippers that operate between two ports, then there is information about the bounds on the fixed costs: the fixed costs are low enough for two shippers to enter but high enough to prevent a third shipper from entering. To capture a middle range of the possible fixed costs, if there are 2 shippers in the data, I use 2.5 shippers to infer the fixed cost.

FIGURE 1
FIXED COST VERSUS MARGINAL COST



5.3 Results

I now report two results that emerge from the marginal and fixed costs that I found in Section 5.2.

5.3.1 Result 1: Routes with Larger Trade Flows Have Higher Fixed Costs and Lower Marginal Costs

Figure 1 shows a scatterplot of the fixed cost versus marginal cost found. The data were fitted with a LOWESS regression function, which is non-parametric in order to flexibly characterize the data. The figure shows a robust pattern in which higher fixed costs are associated with lower marginal costs. To better understand how these relationships relate to the size of trade flows, panel A of Figure 2 shows a scatterplot of the fixed cost versus port-to-port trade flows; panel B shows a scatterplot of the marginal cost versus port-to-port trade flows. Routes with larger trade flows have both higher fixed cost and lower marginal cost.[27]

[27] Similarly, the GDP of the destination country is associated with a lower marginal cost and a higher fixed cost.

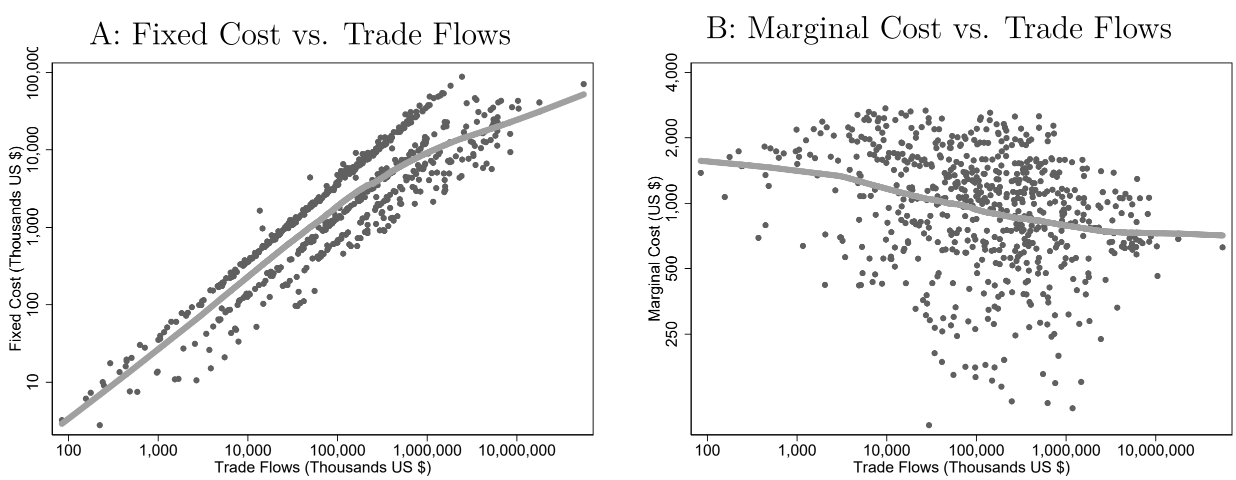
The relationship between fixed and marginal costs relative to the size of trade flows emerges intuitively from the results in Section 3. The data show that there are only small increases in the number of shippers as trade flows increase. The model interprets this relationship as increasing fixed costs in routes with larger trade flows. At the same time, routes with larger trade flows also tend to have lower transportation costs, which cannot be fully accounted for by differences in markups.

5.3.2 Result 2: High Transportation Costs Are Due to High Marginal Costs (and Not Markups)

As can be seen in equation 19, high transportation costs can be driven by either high marginal costs or high markups. Thus, the model has two potential forces that can explain why routes with larger trade flows have lower transportation costs. The first is related to the technological choice of shippers. As trade flows increase, shippers find it worthwhile to adopt a technology with a lower marginal cost and a higher fixed cost. The second is related to the fact that routes with larger trade flows tend to also have more shippers, which lowers markups.

Figure 2

Fixed Cost and Marginal Cost vs. Trade Flows



To better understand these two forces, I calculate the correlation between transportation costs and marginal costs to be 0.87, which indicates that differences in marginal costs are the main driver of differences in transportation costs. As a second step, I calculate the correlation between transportation costs and markups to be -0.20. Thus, differences in markups are quantitatively much less important than differences in marginal costs. Furthermore, markups tend to mitigate the effects of a high marginal cost on transportation costs. This fact is consistent with models in which there is imperfect pass-through of changes in marginal cost: increases in marginal cost are not fully reflected in transportation costs, and as a result, markups decline.

6 Calibration

In this section, I calibrate the two-country model presented in Section 4 for each foreign country in the dataset. Thus, the focus is on a bilateral reduction in tariffs as opposed to a multilateral reduction. In Section 5.1, I have already determined the elasticities of the model, γ and σ. I have also determined the equilibrium fixed cost and marginal cost expressed in dollar terms for each U.S.-foreign port pair.

The α_1 is a key parameter in governing the mechanism pertaining to why routes with larger trade flows tend to have lower transportation costs. First, suppose that α_1 is high. In this case, as trade flows increase, shippers do not find it favorable to lower their marginal cost and raise their fixed cost. On the other hand, the entry of new shippers will lower the markups. Thus, if α_1 is relatively high, then differences in markups account for differences in transportation costs between routes with large and small trade flows. Second, suppose that α_1 is relatively low. As trade flows increase, firms find it worthwhile to raise their fixed cost, which deters entry. On the other hand, marginal cost declines, which lowers transportation costs. Thus, if α_1 is relatively low, then the differences in marginal cost primarily account for the differences in transportation costs. The previous empirical results suggest that α_1 is relatively low. For example, the results in Section 3 show that increases in trade flows tend to be primarily accompanied by larger shippers as opposed to more shippers. Furthermore, the results in Section 5 suggest that the differences in marginal cost drive the differences in transportation costs.

Table 5 shows a summary of each parameter and how they are pinned down. In each calibration, the following parameters are normalized to 1 without loss of generality: the labor endowment of the United States, the productivity of the production firms, x_i, in each country, and wages in the United States. I also use the labor of the United States as the input for the shippers, which implies that the United States is country i.

Here, it is useful to make a point about how the number of shippers is mapped from the data to the model. The number of shippers in this model corresponds to the number of firms that transport goods between a U.S. and a foreign port. For example, if A.P. Møller-Maersk and Evergreen Shipping operate between Los Angeles and a foreign port, then there are two shippers in the model that have entered that route.

6.1 Calibrating Port-Level Expenditure Weights, $\beta_{i'}$ and $\beta_{j'}$

Equation 9 shows that there are port-level expenditure weights $\beta_{i'}$ and $\beta_{j'}$ in the determination of the composite good c_{ij}. To better understand how these port-level expenditure weights operate, it is useful to refer to equation 10, which is the demand for $c_{i'j'}$. The equation shows that as $\beta_{i'}$ increases, then port i' becomes increasingly important relative to other ports in i in accounting for the goods that country j purchases. Furthermore, as $\beta_{j'}$ increases, then port j' becomes increasingly important relative to other ports in j in accounting for the goods that country j purchases. These port-level expenditure weights are useful because they allow the model to more flexibly match the trade flows observed in the data. In particular, the expenditure weights enable the model to better capture differences in the trade flows across ports that are not accounted for by transportation costs. In the counterfactual exercise, I hold fixed these unobserved factors after the change in tariffs.

To determine port-level expenditure weights $\beta_{i'}$ and $\beta_{j'}$, I reestimate equation 25 for each U.S.-foreign country pair to pin down the port-level expenditure weights.[28] Notice that each U.S.-foreign country pair has its own calibrated model with its own set of expenditure weights. This setup allows for more flexibility in matching the data and the market shares of ports in accounting for bilateral trade. Once I estimate the regression in equation 25, we have that $\log \beta_{i'} = I_{i'}$ and $\log \beta_{j'} = I_{j'}$. Notice that the intuition for identification is that, holding fixed transportation costs, the coefficients $\beta_{i'}$ and $\beta_{j'}$ are chosen to best match the importance of ports i' and j'.

In order to check that the calibrated model gives reasonable predictions of trade flows relative to the data, I compute the fraction of total bilateral trade accounted for by each route. For example, one observation is that trade between Los Angeles and Callao, Peru, accounts for 20.2 percent of total bilateral trade between the United States and Peru. I compute the same statistic in the fully calibrated model. The log correlation between these two variables is 0.85, indicating that the model is capturing the differences in the size of trade flows across routes.

6.2 Calibrating Labor Endowments, L_i, and Home Bias Parameters, ζ

The next step is to calibrate the labor endowments and home bias parameters. The labor endowment determines the size of the foreign economy relative to the United States. Equation 6 shows that the home bias parameter determines the level of trade between the two countries. To calibrate these two parameters, I feed into the model the number of shippers and the transportation costs observed in the data; I use the elasticities, marginal cost, and fixed costs previously found in Section 5; and I use the port-level expenditure weights from Section 6.1.[29] I then simulate the model and infer the labor endowment of the foreign country so that the model matches the relative GDP of the two countries. The home bias parameter, ζ, is also set so that the model matches the ratio of imports to GDP for both countries.[30]

Notice that when the model is calibrated, the shippers are not allowed to reoptimize in terms of number of shippers, technological choice, and transportation costs charged. This calibration, however, is a model-consistent way of identifying the labor endowments and the home bias parameters. For example, suppose that a set of labor endowments and home bias parameters are chosen, and data is simulated from the model, allowing for the decision of shippers to be endogenous. These model

[28] The omitted variable of the regression implies that the expenditure weight for one U.S. port and one foreign port is normalized to 1. This is a normalization because the expenditure weights determine the relative importance of each port.

[29] In Appendix F, I discuss how I map transportation costs, marginal cost, and fixed cost, all of which are expressed in dollars, into comparable moments in the model.

[30] Note that since the GDP of each country is a calibration target, once the home bias parameter is calibrated, the model matches the import penetration of both countries.

parameters can be recovered using this methodology on the model-simulated data.

6.3 Calibrating the Relationship between the Fixed and Marginal Cost, α_1

The next step is to pin down the technological choices available to shippers. Figure 3 shows an example of two menu of choices, a high and low cost menu. The menu of choices is characterized by the slope of the line, governed by α_1 in equation 14, and the level, governed by α_0.[31]

To calibrate α_1, we use the following procedure. First, I solve for the α_0 for each U.S.-foreign port observation that is consistent with the marginal and fixed cost that I found in Section 5.2 by rearranging equation 14. Having a different α_0 for each U.S.-foreign port pair aims at capturing the heterogeneous costs across routes, which, as shown in Appendix G shows, reflects a mixture of technological and non–technological costs. The marginal and fixed costs that I backed out using the data in Section 5.2, which are in dollars, are mapped to those in the model, as described in Appendix F.

In equilibrium, a higher α_1 is associated with a higher average number of shippers.[32] The reason is that as α_1 increases, shippers do not find it worthwhile to choose a low marginal cost and high fixed cost technology, which deters entry. If $\alpha_1 = 2.60$, then there are 2.5 shippers in the median route, which matches the data, as can be seen in Table 1.

6.4 Distribution of Markups in Calibrated Model

I now discuss the distribution of markups implied by the model. I focus on the markups charged by shippers from U.S. ports to foreign ports. The markups are weighted by the number of firms in each route, in order to calculate the average markup charged by shippers. First, the distribution is normally distributed with a mean of 1.49. The distribution has a standard deviation of 0.06, and the 90th and 10th percentiles of the distribution are 1.55 and 1.40, respectively. The distribution is similar for the markups from foreign ports to U.S. ports.

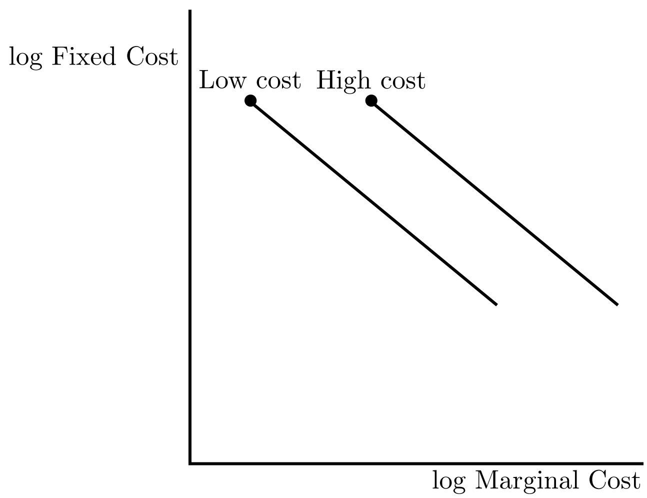
I have not found other studies that calculate the markups of firms in the containerized maritime transportation industry with which I could compare my results. The only study that I could find was De Loecker and Eeckhout (2017), which reports weighted markups for broad two-digit NAICS industry codes in the United States. The closest industry is the transportation industry, which

[31] In Appendix G, I show how regulatory costs can be incorporated into the existing framework and remain consistent with the model.

[32] I use the following algorithm to solve the model given α_0 and α_1. First, the model is solved holding fixed the technological choice of firms in the case that all firms choose a very low fixed cost and high marginal cost. Here, I choose a marginal cost of $2,000. Given the low fixed cost, there is positive entry in all routes. However, the condition that characterizes the optimal technology, characterized in equation 15, is not satisfied. Thus, I raise the fixed costs across routes until the optimal technology condition is satisfied. Furthermore, I drop any routes for which the number of shippers drops below 1 as the fixed cost is raised. In the final calibration, I drop 19 percent of the routes in the original sample. However, these routes tend to be small and for the average country constitute 1 percent of total bilateral trade flows in the data.

Figure 3

Simple Example of Fixed Cost versus Marginal Cost



is code 48. This broad industry category includes diverse modes of transportation including air, rail, trucking, taxis, and pipelines (transporting oil and natural gas); this industry also includes the transport of both passengers and goods. For this industry, they report a weighted markup of a little under 1.25 (see Figure B.6 therein). Thus, the markups in my model are higher than those found in the transportation industry in the United States. Obviously, the transportation industry includes many modes of transportation that are not related to containerized maritime transportation. Thus, it is also useful to compare my markups with the weighted markups for the entire economy, which the authors report to be 1.67. Overall, the markups from the model are within a plausible range relative to those found by De Loecker and Eeckhout (2017).

6.5 Comparing the Calibrated Model and Data

In Tables 6, 7, and 8, I regenerate Tables 1, 2, and 3 respectively and include the same statistics for the model-generated data. In order to compare model output and data, I convert the transportation costs and value of trade flows from the model into dollars using the strategy outlined in Appendix F.

The model captures the key features of the data summarized in Section 3 reasonably well.[33] Table 6 reports the unconditional distribution of transportation costs for shipping from the United States to foreign ports, the number of shippers, and trade flows. The distribution of transportation costs and the number of shippers are of special interest, given the goal of the quantitative exercise. The model matches the unconditional distribution well for both of these variables. Notice that the median number of shippers in the model is 2.5, which is a calibrated target. The other distribution moments,

[33] As an additional robustness exercise, I compare the quantitative results from my model with a detailed study from the transportation literature of the cost savings associated with adopting larger ships. See Appendix I for details.

however, were not targeted in the calibration.

Table 7 shows that in the model and data, countries with larger GDPs have lower transportation costs. The model is also consistent with the data in that countries with larger GDP also have larger shippers. For both of these statistics, the model generates quantitatively similar cross-sectional relationships as in the data. The model does not generate as strong of a positive relationship between the number of shippers and GDP.

Table 8 shows that the model accurately captures the cross-sectional relationship between transportation costs, number of shippers, and average shipper size relative to the size of the trade flows. These relationships are quantitatively similar in both the model and data.

Figure 4 shows the relationship between transportation costs and distance in both the data and the model. A LOWESS regression function is also included for both cases. Neither case exhibits a strong relationship between transportation costs and distance. Next, Panel A of Figure 5 shows the relationship between transportation costs and the GDP of the destination country in both the data and the model; Panel B shows the relationship between transportation costs and the size of trade flows. Both Panels A and B show a similar negative relationship in both the model-generated data and actual data, as shown by the LOWESS regression function.

Panel A of Figure 6 shows the relationship between the number of shippers and the size of the trade flows. In this case, the patterns between the model-generated data and actual data are a little different: the number of shippers increases monotonically with trade flows in the model, whereas the data show some small non-monotonicities. Panel B shows the relationship between average shipper size and the size of the trade flows. In this case, the model and data are very similar because the cross-sectional differences in the average shipper size are driven by differences in trade flows, not by the differences in the number of shippers. Note that in order to construct Figure 6, I adjusted the number of shippers in the data to be consistent with the model. In particular, if there are 2 shippers in the data, then I adjusted the number of shippers in the data to be 2.5.

7 Quantitative Exercise

In this section, I raise tariffs by 1 percent for both the United States and the foreign country. I decompose these changes in real income into what can be accounted for by changes in tariffs, transportation costs, and wages.

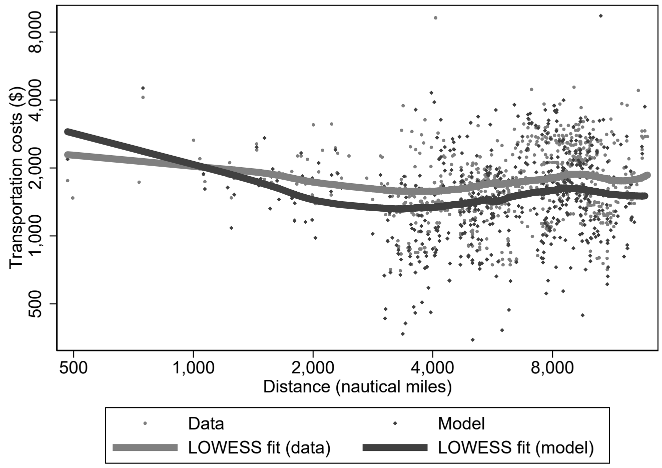
7.1 Changes in Real Income

The real income of country j before the change in tariffs, Y_j, is defined as

$$Y_j = \frac{w_j L_j + R_j}{P_j}. \tag{26}$$

Figure 4

Transportation costs vs. distance



The real income after the change in tariffs, Y_j', is similarly defined. The percentage change in real income, ΔY_j, is

$$\Delta Y_j = \frac{Y_j' - Y_j}{Y_j} * 100. \tag{27}$$

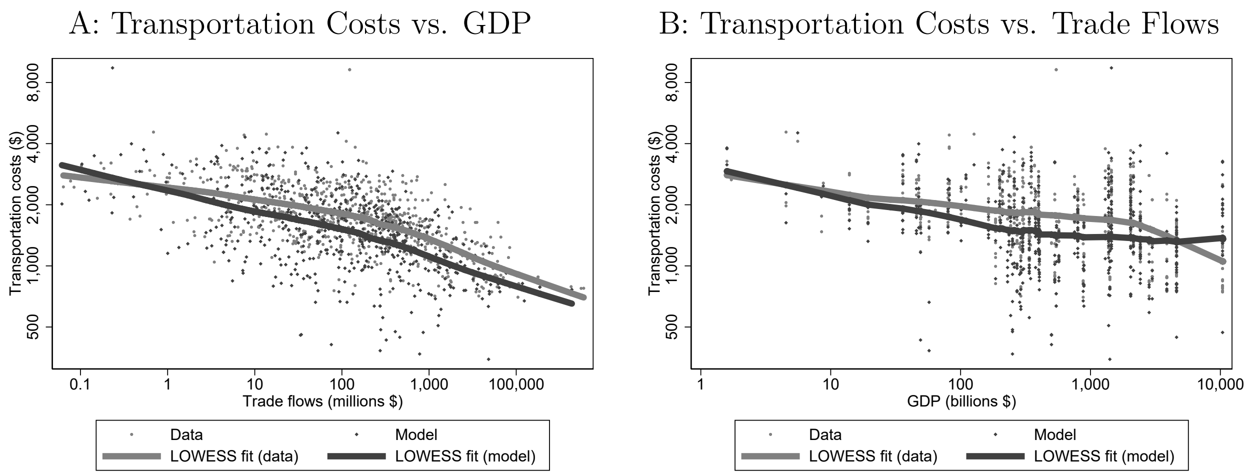
In all cases, there is a decline in real income for both the United States and the foreign country. On average, the United States loses -0.000037, percent and the foreign country loses -0.002637 percent. One concern when conducting the welfare analysis could be that the full cost of new transportation infrastructure is not taken into account. For example, suppose that two countries liberalize trade and, as a result, trade flows increase. In the quantitative exercise, more shippers enter, and shippers will choose a technology with a higher fixed cost and a lower marginal cost. These changes may require new or improved transportation infrastructure. I argue, however, that the cost associated with the new transportation infrastructure is considered in the welfare analysis. The reason is that shippers are usually charged fees to use the port, which in most cases is owned by the government or a related entity. If the shippers are charged for both the costs of operating the port and the capital costs, then the cost of infrastructure is captured by the marginal and fixed costs inferred.

The aim is to understand the importance of changing transportation costs in accounting for changes in real income. Thus, I decompose ΔY_j into the changes accounted for by transportation costs, tariffs, and wages. To decompose changes in real income, first define $Y_{j,Tariffs}'$ as

$$Y_{j,Tariffs}' = \frac{w_j L_j + R_j'}{P_{j,Tariffs}'}, \tag{28}$$

where $P_{j,Tariffs}'$ is the price index if all equilibrium variables are left the same when computing the

Figure 5



price index and only tariffs are changed. To compute $Y'_{j,Tariffs}$, I change the tariff revenue and adjust the price index to reflect the new tariff rates. In the case of an increase in tariffs, tariff revenue increases but the price index also increases. Notice that this is not an equilibrium outcome. For example, changes in tariffs would imply that wages and transportation costs would adjust, but if these variables are adjusted to the equilibrium outcome, the relative importance of the changes in tariffs versus transportation costs and wages cannot be understood. Similarly, let $Y'_{j,Transp}$ be

$$Y'_{j,Transp} = \frac{w_j L_j + R_j}{P'_{j,Transp}}, \tag{29}$$

where $P'_{j,Transp}$ is the price index if transportation costs are changed and everything else is left constant. Finally, let Y'_{Wages} be

$$Y'_{j,Wages} = \frac{w'_j L_j + R_j}{P'_{Wages}}, \tag{30}$$

where $P'_{j,Wages}$ is the price index if wages are changed and all other equilibrium variables are left the same. The full details of how equations 28-30 are calculated can be found in Appendix H.

The percentage change in real income accounted for by the change in tariffs is

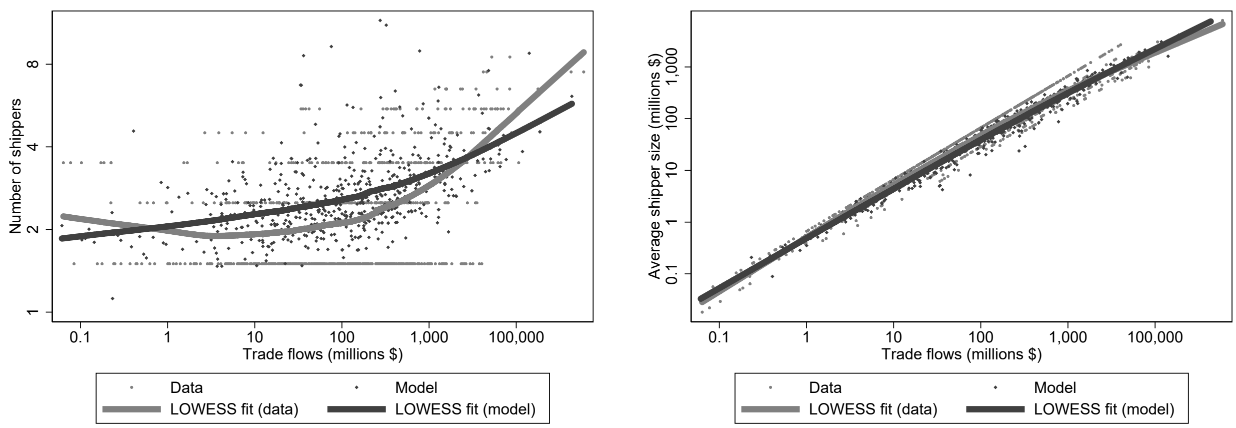
$$\Delta Y_{j,Tariffs} = \left(\frac{Y'_{j,Tariffs} - Y_j}{Y_j} \right) * 100, \tag{31}$$

and similarly for $\Delta Y_{j,Transp}$ and $\Delta Y_{j,Wages}$, which are the changes accounted for by transportation costs and wages, respectively. These changes do not necessarily sum to the percentage change in real income. Thus, a residual term is defined as follows

$$\Delta Y_{j,Residual} = \Delta Y_j - \Delta Y_{j,Tariffs} - \Delta Y_{j,Transp} - \Delta Y_{j,Wages}. \tag{32}$$

Figure 6

A: Number of Shippers vs. Trade Flows   B: Average Shipper Size vs. Trade Flows



Quantitatively, this residual term is small in all the simulations.

Transportation costs account for a significant portion of the changes in real income. On average, changing transportation costs account for 46 percent of the losses in real income for the United States. The 90th and 10th percentiles are 77 and 21, respectively. Tariffs account for 53 percent of the losses in real income for the United States. Thus, transportation costs are almost as important as tariffs in accounting for changes in real income. The changes in wages, on the other hand, are quantitatively less important. Wages account for 2 percent of the real income losses on average. The 90th and 10th percentiles are 11 and -3, respectively. This last result indicates that changes in wages are not the main driving factor of the results. Furthermore, we may be concerned that changes in the demand for transportation services may affect the wages of the United States and consequently affect the estimated welfare effects. In this particular case, the decline in the demand for labor in the transportation industry would lower wages in the United States and negatively affect its welfare. Finally, the distribution of these components for the foreign country is similar to that of the United States. For example, on average, 43 percent of the losses in the foreign country are accounted for by changes in transportation costs, which is similar to the losses in the United States.

In Section 7.4, I compare the changes in real income from the baseline model to a model in which the transportation industry is perfectly competitive. Notice that if the transportation industry is perfectly competitive, then transportation costs remained fixed after trade flows change. The results from the robustness exercise are similar to the baseline results.[34]

[34] It would be difficult to operationalize a welfare decomposition in which, as a first step, I hold fixed transportation costs, transportation technology, and the number of shippers, and then, as a second step, allow the transportation industry to adjust to the new equilibrium. To understand why this is the case, suppose that I first simulate an increase in tariffs while holding fixed transportation costs, transportation technology, and the number of shippers. The lower trade flows imply that shippers would have negative profits since shippers had zero profits before the fall in trade flows. These negative profits violate the zero profit condition of the model and also pose a problem for the interpretation of the decomposition. The welfare of countries would now be affected through two separate channels: first, through the

7.2 Changes in Transportation Costs

I now discuss the changes in transportation costs as a result of the reduction in tariffs. On average, the increase in tariffs results in a 1.49 percent increase in transportation costs from the United States to foreign ports. In equation 19, it can be seen that the percentage changes in transportation costs can be decomposed into the percentage change accounted for by the marginal cost and markups. The average percentage change in markups is -0.14, and the average percentage change in marginal cost is 1.64. Thus, the changes in transportation costs are driven entirely by the changes in marginal cost. Notice that two opposing forces affect markups. On the one hand, the decrease in the number of shippers raises markups. On the other hand, the increase in marginal cost lowers markups because of imperfect pass-through: the full increase in marginal cost is not fully reflected in the transportation costs. The latter force dominates, which explains why markups decline.

Next, I calculate the ratio of the percentage change in transportation costs and the percentage change in trade flows for each observation. Doing so yields an elasticity of the responsiveness of transportation costs to changes in trade flows through an increase in tariffs. In the mean case, a 1 percent decrease in trade flows is associated with an increase of 0.25 percent in transportation costs. This elasticity varies most consistently with the initial level of the marginal cost. Figure 7 shows the elasticity of transportation costs with respect to trade flows compared to the marginal cost before the change in tariffs. There is a negative relationship between these two variables. Thus, the routes with small trade flows that have a high marginal cost also tend to be those with the most responsive transportation costs. Next, the routes with high marginal costs also have the most responsive changes in technology. Figure 8 compares the percentage change in the marginal cost with the marginal cost before the change in tariffs.

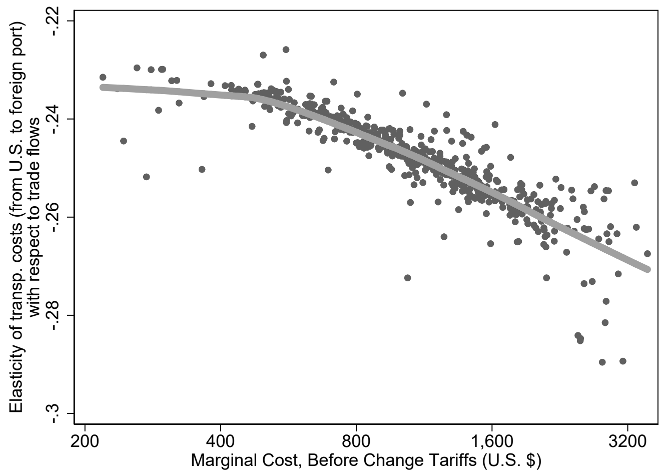
7.3 Does the Decline in Trade Flows Lead to Fewer Shippers or Lower Average Shipper Size?

Equation 3 shows that a decline in trade flows can lead to either fewer shippers or a decline in the average shipper size. On average, a 1 percent decrease in trade flows is associated with a 0.16 percent decrease in the number of shippers. Thus, the decline in trade flows primarily leads to a decline in the average shipper size and not in the number of shippers because the endogenous fixed cost slows the exit of shippers after the change in tariffs. Notice that these results are similar to the cross-sectional patterns found in Section 3.6. In the cross section, a 1 percent decline in trade flows is associated with a decline of 0.10 percent in the number of shippers and a 0.90 percent decrease in the average shipper size.

change in tariffs, and second, through the losses from the transportation industry. A similar argument can be made for the second step of this decomposition.

Figure 7

Elasticity of transportation costs (from U.S. to foreign port) with respect to trade flows vs. initial marginal cost



7.4 Sensitivity Analysis

7.4.1 Alternative Values of γ

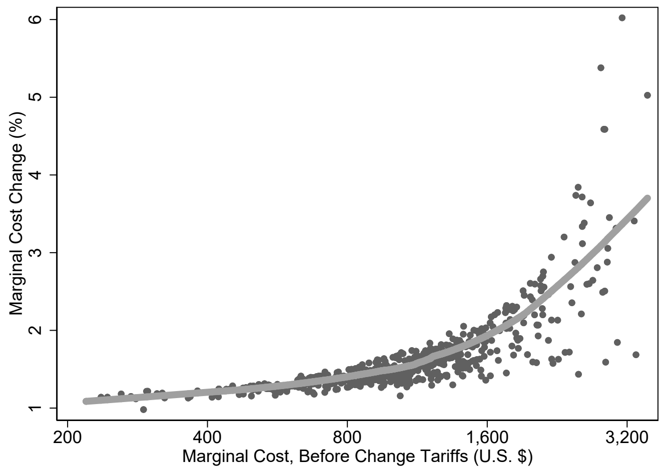
Given the concerns about the estimate of γ in Section 5.1.1, I perform a sensitivity analysis to see how varying this parameter affects the quantitative results. I do so for the cases of $\gamma = 10$ and 15, which is around the baseline estimate of 13.89. I redo the calibration exercises in Section 5.2 and Sections 6.1-6.3 for each γ. I subsequently increase tariffs in both countries by 1 percent and apply the decomposition found in Section 7.1.

The model indicates that when $\gamma = 10$, changes in transportation costs account for 55 percent of the losses in real income for the United States and 46 percent when $\gamma = 15$. In the baseline case, transportation costs account for 46 percent of the losses in real income for the United States. The results are similar for the foreign country.

Why do transportation costs account for a greater fraction of the losses in real income when γ is lower? The reason is that changes in γ imply a different α_1 parameter in the calibration. The α_1 parameter of the model is calibrated so that the model matches the number of shippers on the average route, which is 2.5. In the baseline calibration, the calibrated parameter was $\alpha_1 = 2.60$. When $\gamma = 10$, there is a large decline in the α_1 parameter to 1.56. The reason is that, as γ declines, shippers' markups increase, which increases profitability and induces entry. Lowering α_1 encourages the adoption of higher fixed cost technologies and lowers the number of shippers, which allows the model to once again match the data. This intuition is the same as in Section 6.3. Conversely, when $\gamma = 15$, meaning that shippers have lower markups than in the baseline case, the model sets the parameter α_1 to 2.91.

Figure 8

Percentage change marginal cost after increase in tariffs vs. initial marginal cost



Thus, marginal cost is more reactive to changes in trade flows when $\gamma = 10$ because adopting a lower marginal cost technology becomes less costly as trade flows increase. In the simulations, the elasticity of marginal cost with respect to trade flows on the average route is -0.39 percent when $\gamma = 10$, -0.28 when $\gamma = 13.89$, and -0.26 when $\gamma = 15$. These changes in marginal cost, due to imperfect pass-through, are reflected in transportation costs.[35]

Another interesting result is that the fraction of losses accounted for by changes in transportation costs vary little when γ increases from 13.89 to 15, as compared to when γ declines from 13.89 to 10. This is true even when considering the rate of change of this variable with respect to γ. The reason is that markups are more sensitive to changes in γ as this parameter declines. In the simulations, the average markup is 1.80 when $\gamma = 10$, 1.49 when $\gamma = 13.89$, and 1.44 when $\gamma = 15$. This result is important because changes in markups affect the entry decisions of shippers and affect the α_1 parameter when calibrating the model.

The sensitivity results imply that as γ declines, the fraction of losses accounted for by transportation costs increases. Furthermore, as γ increases, the fraction of losses accounted for by transportation costs declines even though these changes do not appear to be as important quamtitatively.

7.4.2 Alternative Real Income Decomposition

I perform a robustness exercise with an alternative decomposition for changes in real income. In particular, I begin with the calibrated model and change the market structure to one that is perfectly

[35]The elasticity of transportation costs with respect to trade flows is -0.34 percent when $\gamma = 10$, -0.25 when $\gamma = 13.89$, and -0.24 percent when $\gamma = 15$.

competitive. I set the fixed cost for each route equal to zero and set the marginal cost in each direction equal to the transportation cost from the calibrated model. Thus, this model under perfect competition exactly matches the transportation costs of the calibrated model. Furthermore, as tariffs change, transportation costs remain fixed at their marginal cost. I can then resolve this new model before and after the changes in tariffs.

I consider the changes in real income predicted by this model to be those that cannot be accounted for by changing transportation costs. In the average simulation, transportation costs account for 54 percent of the real income losses for the United States and 46 percent for the foreign country.

The sensitivity results show that the main result of the paper, that is, changing transportation costs account for a significant fraction of the change in real income after a change in tariffs, is robust to this alternative decomposition.

8 Conclusion

The study of how transportation costs are determined and their implications for international trade is a underexplored area of research. This paper points to two areas for future research. First, the analysis in this paper focused on the scale of shippers at the route level. However, strong complementarities are inherent in serving ports together, which results in shippers utilizing transportation networks that operate at regional levels. One implication of these transportation networks is that changes in trade policy would affect the scale of the shippers in terms of their transportation network. Thus, the effects of a change in trade policy would be further amplified by economies of scale at the regional level. Furthermore, the transportation costs charged by shippers would be a maximization problem that would consider the entire network. Another implication of modeling the transportation network is that the transportation costs of a country would be determined by the size of its own trade flows in addition to the trade flows of its neighbors. These spillovers across countries can have implications for trade policies that have not been explored in the literature. For example, a U.S.-Chile free trade agreement could lower the transportation costs for neighboring countries such as Peru. One exception is the work of Brancaccio, Kalouptsidi, and Papageorgiou (2017), who study these types of spillovers across countries.

Second, it would be useful to expand the analysis to include other modes of transportation. I have focused on the containerized maritime transportation industry, which allows for collecting detailed data about this one mode of transportation and conducting a careful analysis. Goods can, however, be transported in alternative ways, including by truck, rail, and plane. It would be useful to understand how sensitive changes in transportation costs are in other modes of transportation. Research suggests that trade costs decline when total bilateral trade, which includes all modes of transportation, increases. For example, Anderson, Vesselovsky, and Yotov (2016) use a gravity framework and determine that U.S.-Canada trade costs decline with increased trade flows. Breaking down these effects into different modes of transportation would be informative for policymakers in fully understanding the effects of changes in trade policy.

References

Ackerberg, D., C. L. Benkard, S. Berry, and A. Pakes (2007): "Econometric Tools for Analyzing Market Outcomes," in *The Handbook of Econometrics*, chap. 63.

Ahn, J., A. K. Khandelwal, and S.-J. Wei (2011): "The Role of Intermediaries in Facilitating Trade," *Journal of International Economics*, 84, 73–85.

Alchian, A. A., and W. R. Allen (1964): *University Economics*. Wadsworth.

Alvarez, F., and R. Lucas (2007): "General Equilibrium Analysis of the Eaton–Kortum Model of International Trade," *Journal of Monetary Economics*, 54(6), 1726–1768.

Anderson, J. E., and E. van Wincoop (2004): "Trade Costs," *Journal of Economic Literature*, 42(3), 691–751.

Anderson, J. E., M. Vesselovsky, and Y. V. Yotov (2016): "Gravity with Scale Effects," *Journal of International Economics*, 100, 174 – 193.

Arkolakis, C., A. Costinot, and A. Rodriguez-Clare (2012): "New Trade Models, Same Old Gains?," *American Economic Review*, 102(1), 94–130.

Armington, P. S. (1969): "A Theory of Demand for Products Distinguished by Place of Production," *Staff Papers (International Monetary Fund)*, 16(1), pp. 159–178.

Asturias, J., M. García-Santana, and R. Ramos (Forthcoming): "Competition and the Welfare Gains from Transportation Infrastructure: Evidence from the Golden Quadrilateral of India," *Journal of the European Economic Association*.

Atkeson, A., and A. Burstein (2008): "Pricing-to-Market, Trade Costs, and International Relative Prices," *American Economic Review*, 98(5), 1998–2031.

Atkin, D., and D. Donaldson (2015): "Who's Getting Globalized? The Size and Implications of Intranational Trade Costs," *Working Paper*.

Behrens, K., C. Gaigné, G. I. Ottaviano, and J.-F. Thisse (2006): "How Density Economies in International Transportation Link the Internal Geography of Trading Partners," *Journal of Urban Economics*, 60(2), 248 – 263.

Behrens, K., C. Gaigne, and J.-F. Thisse (2009): "Industry Location and Welfare when Transport Costs are Endogenous," *Journal of Urban Economics*, 65(2), 195 – 208.

Behrens, K., and P. M. Picard (2011): "Transportation, Freight Rates, and Economic Geography," *Journal of International Economics*, 85(2), 280 – 291.

Bougheas, S., P. O. Demetriades, and E. L. Morgenroth (1999): "Infrastructure, Transport Costs and Trade," *Journal of International Economics*, 47(1), 169 – 189.

Brancaccio, G., M. Kalouptsidi, and T. Papageorgiou (2017): "Geography, Search Frictions, and Endogenous Trade Costs," *NBER Working Paper No. 23581.*

Bresnahan, T. F., and P. C. Reiss (1990): "Entry in Monopoly Markets," *Review of Economic Studies*, 57(4), 531–553.

——— (1991): "Entry and Competition in Concentrated Markets," *Journal of Political Economy*, 99(5), 977–1009.

Bustos, P. (2011): "Trade Liberalization, Exports, and Technology Upgrading:: Evidence on the Impact of MERCOSUR on Argentinian Firms," *American Economic Review*, 101, 304–340.

Clark, X., D. Dollar, and A. Micco (2004): "Port Efficiency, Maritime Transport Costs, and Bilateral Trade," *Journal of Development Economics*, 75(2), 417–450, 15th Inter American Seminar on Economics.

Cosar, A. K., and B. Demir (2018): "Shipping Inside the Box: Containerization and Trade," *Working Paper.*

Cullinane, K., and M. Khanna (1999): "Economies of Scale in Large Container Ships," *Journal of Transport Economics and Policy*, 33(2), 185–207.

——— (2000): "Economies of Scale in Large Containerships: Optimal Size and Geographical Implications," *Journal of Transport Geography*, 8(3), 181–195.

De Loecker, J., and J. Eeckhout (2017): "The Rise of Market Power and the Macroeconomic Implications," *Working Paper.*

De Loecker, J., P. K. Goldberg, A. K. Khandelwal, and N. Pavcnik (2016): "Prices, Markups, and Trade Reform," *Econometrica*, 84(2), 445–510.

Donaldson, D. (2018): "Railroads of the Raj: the Economic Impact of Transportation Infrastructure," *American Economic Review*, 108(4-5), 899–934.

Eaton, J., and S. Kortum (2002): "Technology, Geography, and Trade," *Econometrica*, 70(5), 1741–1779.

Fink, C., A. Mattoo, and I. C. Neagu (2002): "Trade in International Maritime Services: How Much Does Policy Matter?," *The World Bank Economic Review*, 16(1), 81–108.

Francois, J. F., and I. Wooton (2001): "Trade in International Transport Services: The Role of Competition," *Review of International Economics*, 9(2), 249–261.

Head, K., and T. Mayer (2014): "Chapter 3 - Gravity Equations: Workhorse,Toolkit, and Cookbook," in *Handbook of International Economics*, ed. by E. H. Gita Gopinath, and K. Rogoff, vol. 4, pp. 131–195. Elsevier.

Holmes, T. J., and E. Singer (2018): "Indivisibilities in Distribution," *NBER Working Paper 24525*.

Hummels, D. (2007): "Transportation Costs and International Trade in the Second Era of Globalization," *The Journal of Economic Perspectives*, 21(3), 131–154.

Hummels, D., and V. Lugovskyy (2006): "Are Matched Partner Trade Statistics a Usable Measure of Transportation Costs?," *Review of International Economics*, 14(1), 69–86.

Hummels, D., V. Lugovskyy, and A. Skiba (2009): "The Trade Reducing Effects of Market Power in International Shipping," *Journal of Development Economics*, 89(1), 84–97.

Hummels, D., and A. Skiba (2004a): "Shipping the Good Apples Out? An Empirical Confirmation of the Alchian-Allen Conjecture," *Journal of Political Economy*, 112(6), 1384–1402.

——— (2004b): "A Virtuous Circle? Regional Tariff Liberalization and Scale Economies in Transport," in *FTAA and Beyond: Prospects for Integration in the America*, ed. by A. Estevadeordal, D. Rodrik, and A. V. Alan M. Taylor. Harvard University Press.

Ishikawa, J., and N. Tarui (2018): "Backfiring with Backhaul Problems: Trade and Industrial Policies with Endogenous Transport Costs," *Journal of International Economics*, 111, 81–98.

Jonkeren, O., E. Demirel, J. van Ommeren, and P. Rietveld (2011): "Endogenous Transport Prices and Trade Imbalances," *Journal of Economic Geography*, 11(3), 509–527.

Kalouptsidi, M. (2014): "Time to Build and Fluctuations in Bulk Shipping," *American Economic Review*, 104(2), 564–608.

——— (2018): "Detection and Impact of Industrial Subsidies: The Case of Chinese Shipbuilding," *Review of Economic Studies*, 85, 1111–1158.

Levinson, M. (2008): *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger*. Princeton University Press.

Limao, N., and A. Venables (2001): "Infrastructure, Geographical Disadvantage, Transport Costs, and Trade," *The World Bank Economic Review*, 15(3), 451–479.

Milne, R. (2013): "Nils Andersen, CEO, AP Møller-Maersk," *Financial Times*.

Moreira, M., C. Volpe, and J. Blyde (2008): *Unclogging the Arteries: the Impact of Transport Costs on Latin American and Caribbean Trade*. Inter-American Development Bank.

Mori, T., and K. Nishikimi (2002): "Economies of Transport Density and Industrial Agglomeration," *Regional Science and Urban Economics*, 32(2), 167–200.

Premti, A. (2016): "Liner Shipping: Is There a Way for More Competition?," *United Nations Conference on Trade and Development Discussion Paper No. 224*.

Samuelson, P. A. (1954): "The Transfer Problem and Transport Costs, II: Analysis of Effects of Trade Impediments," *The Economic Journal*, 64(254), 264–289.

Skiba, A. (forthcoming): "Economies of Scale in Transportation and Regional Welfare," *Review of International Economics*.

Steinwender, C. (2015): "The Roles of Import Competition and Export Opportunities for Technical Change," *Working Paper*.

Sutton, J. (1991): *Sunk Costs and Market Structure: Price Competition, Advertising, and the Evolution of Concentration*. MIT Press.

Talley, W. K. (2017): *Port Economics*. Routledge, London, 2nd edn.

U.S. Department of Transportation (2011): *America's Container Ports: Linking Markets at Home and Abroad*. U.S. Department of Transportation, Bureau of Transportation Statistics, Washington, DC.

Wilmsmeier, G., J. Hoffmann, and R. J. Sanchez (2006): "The Impact of Port Characteristics on International Maritime Transport Costs," *Research in Transportation Economics*, 16, 117 – 140, Port Economics.

Wong, W. F. (2018): "The Round Trip Effect: Endogenous Transport Costs and International Trade," *Working Paper*.

Yeaple, S. R. (2005): "A Simple Model of Firm Heterogeneity, International Trade, and Wages," *Journal of International Economics*, 65, 1–20.

Tables

Table 1

Summary Statistics

	St. dev.	Mean	Percentile 10	Percentile 50	Percentile 90
Transportation costs ($)	768	1,844	1,063	1,702	2,749
Number of shippers	1.4	2.1	1.0	2.0	4.0
Trade flows (million $)	3,830	923	6	142	1,769
Average shipper size (million $)	689	308	4	87	795
Distance (nautical miles)	2,944	6,893	3,313	6,920	10,686

Table 1 reports descriptive statistics for the assembled dataset, which is described in Section 3. It reports the standard deviation, mean, 10th percentile, 50th percentile, and 90th percentile for the following: transportation costs ($), number of shippers, total port-to-port containerized trade flows (million $), average shipper size (million $), and distance (nautical miles). The average shipper size is calculated as the total port-to-port containerized trade flows divided by the number of shippers.

Table 2
Transportation Industry vs. GDP and Distance

	(1) Log transportation costs	(2) Log number of shippers	(3) Log average shipper size
Log GDP	-0.106***	0.0911***	0.543***
	(0.00806)	(0.0141)	(0.0486)
Log distance	0.177***	-0.0632	-0.721***
	(0.0239)	(0.0417)	(0.144)
Observations	697	697	697
R-squared	0.216	0.0568	0.158

Column 1 of Table 2 reports the results of the estimation of equation 1. The dependent variable is the log transportation cost from a U.S. port to a foreign port, which is described in Section 3.1. The independent variables are the log GDP (U.S. dollars) of the destination country where the foreign port is located and the log distance, measured in nautical miles, between the two ports described in Section 3.4. The dependent variable in column 2 is the log number of shippers between a U.S.-foreign port pair, which is described in Section 3.2. The dependent variable in column 3 is the log average shipper size between a U.S.-foreign port pair. To construct average shipper size, the total value of containerized trade flows in U.S. dollars between two ports, which is described in Section 3.3, is divided by the number of shippers, which is described in Section 3.2. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3
Transportation Industry vs. Size of Trade Flows

	(1) Log transportation costs	(2) Log number of shippers	(3) Log average shipper size
Log trade flows	-0.0950***	0.0999***	0.900***
	(0.00489)	(0.00890)	(0.00890)
Observations	697	697	697
R-squared	0.353	0.153	0.936

Column 1 of Table 3 reports the results of the estimation of equation 2. The dependent variable is the log transportation cost from a U.S. port to a foreign port, which is described in Section 3.1. The independent variable is the total value of containerized trade flows (U.S. dollars), described in Section 3.3. The dependent variable in column 2 is the log number of shippers between a U.S.-foreign port pair, which is described in Section 3.2. The dependent variable in column 3 is the log average shipper size between a U.S.-foreign port pair. To construct average shipper size, the total value of containerized trade flows in U.S. dollars between two ports, which is described in Section 3.3, is divided by the number of shippers, which is described in Section 3.2. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 4
Estimation of Elasticity of Substitution across Port Pairs, γ

	Log trade flows from U.S. port to foreign port			
	(1)	(2)	(3)	(4)
Log price at destination	-19.89***	-18.06***	-20.16***	-12.89***
	(1.433)	(1.431)	(1.634)	(1.578)
Origin port FE	No	Yes	No	Yes
Destination port FE	No	No	Yes	Yes
Observations	697	697	697	697
R-squared	0.217	0.293	0.629	0.724

Table 4 reports the results of the estimation of equation 25. The dependent variable is the log value of containerized trade flows from the U.S. port to the foreign port (U.S. dollars), which is described in Section 3.3. The independent variable is the log delivery price of the U.S. good (U.S. dollars) at a destination port; the construction of this variable is described in Section 5.1. Column 1 reports the results without any fixed effects. Column 2 reports the results using only origin port fixed effects. Column 3 reports the results with only destination port fixed effects. Column 4 reports the results with both origin and destination port fixed effects. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 5
Summary of Calibration

Parameter	Interpretation	Calibration Target
	Parameters Not Common across Calibrations	
$\beta_{i'}$, $\beta_{j'}$	Expenditure weights of origin port i' in country i and destination port j' in country j	Estimation of equation 24. See Section 6.1 for more information.
L_i, L_j	Labor endowments of countries i and j	Foreign endowment is calibrated to match the relative GDP of U.S. and foreign country. U.S. labor endowment is normalized to 1. See Section 6.2 for more information.
ζ	Home bias parameter	Calibrated to match the import penetration. See Section 6.2 for more information.
α_0	Level of fixed cost and marginal cost relationship (one for each U.S.-foreign port pair)	Chosen such that the marginal and fixed costs are as found in Section 5.2. See Section 6.3 for more information.
	Parameters Common across Calibrations	
γ	Elasticity of substitution across port pairs	Estimation of equation 24. See Section 5.1 for more information.
σ	Elasticity of substitution across goods produced in different countries	Set $\sigma = 5$, which is standard in the international trade literature. This value results in a quantitatively reasonable trade elasticity when lowering tariffs in Section 7. See Section 5.1.2 for more information.
α_1	Trade-off between fixed cost and marginal cost of shippers	Calibrated to match the average number of shipping firms. See Section 6.3 for more information.
x_i, x_j	Productivity of production firm in country i and j	Normalized to 1.

Table 5 summarizes all of the parameters used in the calibrated model.

Table 6
Summary Statistics (Model vs. Data)

	St. dev.	Mean	Percentile 10	50	90
Transportation costs ($)	768	1,844	1,063	1,702	2,749
	798	**1,633**	**810**	**1,501**	**2,645**
Number of shippers	1.4	2.1	1.0	2.0	4.0
	1.2	**2.8**	**1.8**	**2.5**	**4.0**
Trade flows (million $)	3,830	923	6	142	1,769
	2,544	**733**	**5**	**119**	**1,516**
Average shipper size (million $)	689	308	4	87	795
	505	**197**	**2**	**47**	**479**

Table 6 reports descriptive statistics for the assembled dataset and the model-generated data. Statistics of the model are in bold. With the exception of distance, the summary statistics of the data are identical to those in Table 1. The assembled data are described in Section 3. The model and quantitative work are presented in Sections 4-7. The standard deviation, mean, 10th percentile, 50th percentile, and 90th percentile are reported for the following: transportation costs ($), number of shippers, total port-to-port containerized trade flows (million $), and average shipper size (million $). The average shipper size is calculated as the total port-to-port containerized trade flows divided by the number of shippers. The transportation costs, trade flows, and average shipper size from the model have been converted into dollars using the steps described in Appendix F.

Table 7
Transportation Industry vs. GDP and Distance (Model and Data)

	Log transportation costs		Log number of shippers		Log average shipper size	
	(1)	(2)	(3)	(4)	(5)	(6)
Log GDP	-0.106***	-0.0817***	0.0911***	0.00412	0.543***	0.461***
	(0.00806)	(0.0125)	(0.0141)	(0.00898)	(0.0486)	(0.0568)
Log distance	0.177***	0.159***	-0.0632	-0.150***	-0.721***	-0.383**
	(0.0239)	(0.0358)	(0.0417)	(0.0256)	(0.144)	(0.162)
Data/model	Data	Model	Data	Model	Data	Model
Observations	697	565	697	565	697	565
R-squared	0.216	0.0829	0.0568	0.0595	0.158	0.105

Columns 1 and 2 of Table 7 report the results of the estimation of equation 1 using both data and output from the model. The results using the data are identical to those in Table 2. The dependent variable is the log transportation cost from a U.S. port to a foreign port. The construction of transportation costs in the data is described in Section 3.1. The model and quantitative work are presented in Sections 4-7. The independent variables are the log GDP of the destination country where the foreign port is located, which in the case of the data is in U.S. dollars; and the log distance, measured in nautical miles, between the two ports described in Section 3.4. The dependent variable in columns 3 and 4 is the log number of shippers between a U.S.-foreign port pair, which is described in Section 3.2. The dependent variable in columns 5 and 6 is the log average shipper size between a U.S.-foreign port pair. To construct average shipper size, the total value of containerized trade flows in U.S. dollars between two ports, which is described in Section 3.3, is divided by the number of shippers, which is described in Section 3.2. The transportation costs, trade flows, and average shipper size from the model have been converted into dollars using the steps described in Appendix F. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 8
Transportation Industry vs. Size of Trade Flows (Model and Data)

	Log transportation costs		Log number of shippers		Log average shipper size	
	(1)	(2)	(3)	(4)	(5)	(6)
Log trade flows	-0.0950***	-0.110***	0.0999***	0.0729***	0.900***	0.927***
	(0.00489)	(0.00724)	(0.00890)	(0.00525)	(0.00890)	(0.00525)
Data/model	Data	Model	Data	Model	Data	Model
Observations	697	565	697	565	697	565
R-squared	0.353	0.291	0.153	0.255	0.936	0.982

Columns 1 and 2 of Table 8 report the results of the estimation of equation 2 using both data and output from the model. The results using the data are identical to those in Table 3. The dependent variable is the log transportation cost from a U.S. port to a foreign port. The construction of transportation costs in the data is described in Section 3.1. The model and quantitative work are presented in Sections 4-7. The independent variable is the total value of containerized trade flows (U.S. dollars), described in Section 3.3. The dependent variable in columns 3 and 4 is the log number of shippers between a U.S.-foreign port pair, which is described in Section 3.2. The dependent variable in columns 5 and 6 is the log average shipper size between a U.S.-foreign port pair. To construct average shipper size, the total value of containerized trade flows in U.S. dollars between two ports, which is described in Section 3.3, is divided by the number of shippers, which is described in Section 3.2. The transportation costs, trade flows, and average shipper size from the model have been converted into dollars using the steps described in Appendix F. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

A Appendix: Data

In this section, I discuss additional details in the preparation and usage of the assembled data.

A.1 Transportation costs

Transportation costs are collected from the freight forward APX. APX has a shipping rate "calculator" intended for users to receive immediate shipping quotes (http://www.apx-ocean-freight.com/get-quote.html). I use quotes for full container load (FCL) in which the exporter is purchasing the use of the entire container. APX has an option for less than container load (LCL) in which they combine shipments of various clients. I receive quotes to ship a 20 foot container of textiles from all available U.S. origins to all available destinations. Although I request the quotes to ship textiles, I tried various commodities and found that there were no differences in transportation costs to ship a 20 foot container depending on the product I intended to ship.

A.2 Number of shippers

The data on the number of shippers comes from the Journal of Commerce (JOC) Global Sailings Schedule. This information is used by exporters to determine voyage dates for ships. I download all of the data for October 15, 2014 to November 14, 2014. Within this date range, I use the "carrier" field to determine the shipping firm. Furthermore, I combine shippers that form part of the various alliances: CKYH (Hanjin, Yang Ming, K-Line, COSCO Container Lines), G6 (Hapag-Lloyd, APL, OOCL, NYK Container Line, Hyundai, Mitsui O.S.K. Lines), and Maresk-Safmarine (Maersk Line, Safmarine).

A.3 Port-to-Port Containerized Trade Flows

The port-to-port containerized trade flows are derived from the Waterborne Databanks issued by the U.S. Maritime Administration for the years 2000-2005. The data contains information on U.S. waterborne international trade. For exports, it contains information about the the U.S. port of origin, the foreign port where the shipment is headed next, the final destination country. Notice that the destination port where the shipment is headed next does not need to be located in the final destination country because a container can be transhipped at an intermediary port before reaching a final destination. For the same reason, I also have information about the country of origin and whether the shipment was transshipped in the United States on its way to a foreign destination. The data also contains HS 6 product code, SITC revision 3 industry code, value of shipment in U.S. dollars, weight of the shipment in kilograms, percent of shipment value that is containerized, and the percent of weight that is containerized. For imports, the data is similar except that the data also contains CIF charges (insurance and freight). I consider trade flows that are U.S. exports (the origin is a U.S. port) or U.S. imports (the final destination port is a U.S. port). Thus, I do not consider trans-shipments through the United States.

Because the Waterborne Databanks are the only source of port-to-port containerized trade flow data, I scale up the value of both imports and exports by the percent increase in total bilateral trade between the United States and the foreign country using trade data from the World Integrated Trade Solutions (WITS) by the World Bank.

I list here some additional notes regarding the trade flows used:

- Section 5.1.1: Notice that $TradeFlows_{i'j'}$ in equation 25 corresponds to $p_{i'j'}c_{i'j'}$ in the model, where $p_{i'j'} = w_i/x_i + T_{i'j'}$ includes transportation costs. To account for the transportation costs, I multiply the value of exports in the data by $\tau^T_{i'j'}$ that I found in equation A24 in Appendix E to solve for $TradeFlows_{i'j'}$.

- Section 5.2.1: From the United States to the foreign port, I use $TradeFlows_{i'j'}$ for the value of trade, just as I did in Section 5.1.1. This give us enough information to calculate $\epsilon_{i'j'}$, in equation 20, and $\kappa_{i'j'}$, in equation 21.

- Section 5.2.2: I have the information needed to calculate the profitability of shipping goods from the U.S. to the foreign port, found in equation 23. To calculate $\kappa_{i'j'}$ from the foreign port to the U.S. port, I need to use the value of trade flows that incorporate the transportation costs (as in the same manner as Section 5.1.1 and Section 5.2.1). To do so, I use the reported import values plus the CIF charges. With that information, I can calculate the profitability of shippers.

A.4 Shortest Navegable Distance Between Ports

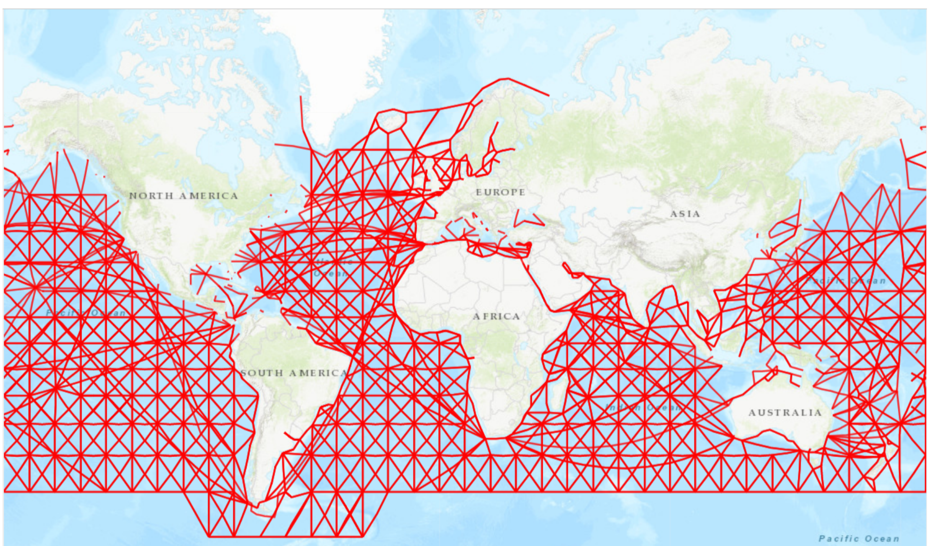
First, I use the Global Shipping Lane Network shapefile that is published by the Oak Ridge National Labs CTA Transportation Network Group. The shapefile contains geospatial information about the network of trading lanes used by maritime shippers. Figure A1 shows a map of this network. I also use the World Port Index provided by the National Geospatial-Intelligence Agency, which provides the location of each port. I then assign each port to the closest point on the network of shipping routes. Finally, there are many possible routes that a shipper can take. In order to solve for the least costly path, I use Dijkstra's algorithm to calculate the shortest path between an origin and destination. I implement this algorithm using the Network Analyst tool in ArcGIS.

A.5 Combining Contingous Ports

I combine the data for Los Angeles port (Census port codes 2704 and 2791) and Long Beach port (Census port code 2709). The reason is that these two ports, while technically independent, are adjacent to each other and are considered to be the same port in practice. I similarly combine data for Newark port (Census port code 4601) and New York port (Census port code 1001).

Figure A1

Global Shipping Lane Network



B Appendix: Trade Imbalances

Trade imbalances can play a role in determining transportation costs. For example, if two countries have imbalanced trade, then shippers face the problem that ships are at full capacity in one direction but not in the opposite direction. Wong (2018) studies how these trade imbalances affect transportation costs and finds that "[a] one percent deviation from the average container freight rates from [port] i to j is correlated across time with a negative deviation of 0.8 percent from the average container freight rates from j to i." The author finds that within port pairs, transportation costs move in opposite directions and that these changes are driven by imbalanced trade.

It may be a concern that the results from Section 3 are driven by these trade imbalances. Recall that the transportation costs used are to transport a container from a port in the United States to a foreign port. Thus, the results could be driven by the United States having large trade deficits in routes with larger trade flows, which implies that the ships arrive in the United States full but return with excess capacity.

To explore this possibility, I construct a measure of containerized trade imbalances using data from the USA Trade Online database from the U.S. Census Bureau.[36] I create a country-to-country measure of trade imbalances, which is the value of U.S. containerized imports divided by U.S. containerized exports in 2014. I include the log measure of trade imbalances in the regression, similar to the one estimated in equation 1. The dependent variable is the log transportation cost, and the independent variables are the log GDP of the destination country, the log distance between ports, and the log trade imbalance. The inclusion of the trade imbalance measure allows for an adjustment to the level of transportation costs, which depend on the size of the trade imbalances.

The results are reported in column 1 of Table A1. I find that, even with controls for the trade imbalances, the coefficient on the GDP of the destination country is negative and statistically significant. I also find that the coefficient on trade imbalances is negative and statistically significant. Notice that this is the sign that we expect: if the United States has a trade deficit relative to a particular country (the trade imbalance term is high), then transportation costs from the United States to the other country should be lower.

I similarly estimate equation 1 in which the dependent variable is the log number of shippers. The measure of trade imbalances used is different from the one used for transportation costs because I want to examine whether trade imbalances in either direction are correlated with the number of shippers. Thus, the measure of trade imbalances is the maximum of exports divided by imports and imports divided by exports. This trade imbalance measure is high if there is an imbalance in either direction. The results are reported in column 2 of Table A1. Column 3 reports the results of a similar regression except that the independent variable is the log of the average shipper size. The results

[36]The USA Trade Online database contains data on containerized trade flows from each U.S. port to a destination country. The advantage of this dataset relative to the Waterborne Databank is that it is regularly updated. The advantage of the Waterborne Databank is that it contains trade flows on port-to-port containerized trade flows; however, it was discontinued in 2005.

suggest that trade imbalances discourage entry of shippers. The coefficients on GDP and distance, however, do not change significantly relative to the baseline specification reported in Table 2.

Table A1

Transportation Industry and Size of Trade Flows (with Trade Imbalance Control)

	(1) Log transportation costs	(2) Log number of shippers	(3) Log average shipper size
Log GDP	-0.0891***	0.109***	0.431***
	(0.00894)	(0.0158)	(0.0538)
Log distance	0.177***	-0.0648	-0.720***
	(0.0236)	(0.0416)	(0.142)
Log trade imbalance	-0.0449***	-0.0466**	0.288***
	(0.0105)	(0.0184)	(0.0629)
Observations	696	696	696
R-squared	0.236	0.0648	0.182

Column 1 of Table A1 reports the results of the estimation of equation 1 with the addition of bilateral trade imbalances as independent variables. The dependent variable is the log transportation cost from a U.S. port to a foreign port, which is described in Section 3.1. The independent variables are the log GDP (U.S. dollars) of the destination country where the foreign port is located; the log distance, measured in nautical miles, between the two ports described in Section 3.4; and the log of the bilateral trade imbalance measure described in Appendix B. The dependent variable in column 2 is the log number of shippers between a U.S.-foreign port pair, which is described in Section 3.2. The dependent variable in column 3 is the log average shipper size between a U.S.-foreign port pair. To construct average shipper size, the total value of containerized trade flows in U.S. dollars between two ports, which is described in Section 3.3, is divided by the number of shippers, which is described in Section 3.2. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

C Appendix: Proofs

C.1 Proof of Proposition 1

Proof. I write the maximization problem in the third stage of a shipper operating from i' to j' that takes as given the quantity supplied by its competitors, $c_{i'j'}^{-n}$, as

$$\max_{c_{i'j'}^{n}} \; c_{i'j'}^{n}\left(T_{i'j'}\left(c_{i'j'}^{n}+c_{i'j'}^{-n}\right)-\frac{w_i}{\Phi}\right), \tag{A1}$$

where $c_{i'j'}^{n}+c_{i'j'}^{-n}=c_{i'j'}$. As in Section 4.3, I do not denote the i' and j' unless it is needed to denote the direction of trade. I can similarly write the maximization problem from j' to i'. Notice that I can separately solve the problem for each direction because the shippers have a constant returns to scale technology. The first order condition becomes

$$T_{i'j'}\left(c_{i'j'}^{n}+c_{i'j'}^{-n}\right)-\frac{w_i}{\Phi}+c_{i'j'}^{n}\left(\frac{dT_{i'j'}\left(c_{i'j'}^{n}+c_{i'j'}^{-n}\right)}{dc_{i'j'}^{n}}\right)^{-1}=0. \tag{A2}$$

In order to simplify the notation, I henceforth denote $T_{i'j'}\left(c_{i'j'}^{n}+c_{i'j'}^{-n}\right)$ simply as $T_{i'j'}$. I can show that this implies that the solution, $T_{i'j'}$, satisfies

$$T_{i'j'}=\frac{\epsilon_{i'j'}}{\epsilon_{i'j'}-1}\frac{w_i}{\Phi}, \tag{A3}$$

where

$$\epsilon_{i'j'}=-\frac{T_{i'j'}}{c_{i'j'}^{n}}\left(\frac{dT_{i'j'}}{dc_{i'j'}^{n}}\right)^{-1} \tag{A4}$$

Notice that equation A3 is the same as equation 19.

I now derive the condition in equation 20 for $\epsilon_{i'j'}$. I use equations 6 and 10, along with the fact that $c_{i'j'}^{n}+c_{i'j'}^{-n}=c_{i'j'}$, to find

$$c_{i'j'}^{n}+c_{i'j'}^{-n}=\beta_{i'}\beta_{j'}p_{i'j'}^{-\gamma}p_{ij}^{\gamma-\sigma}P_j^{\sigma-1}\zeta\left(w_jL_j+R_j\right)\tau_{ij}^{-\sigma}. \tag{A5}$$

Notice that for a given $c_{i'j'}^{n}$, $T_{i'j'}$ is the solution to a system of equations that characterize demand. Thus, I can use implicit differentiation to solve for $\frac{dT_{i'j'}}{dc_{i'j'}^{n}}$. I use equation A5 to find

$$\frac{1}{c_{i'j'}}=-\gamma\frac{\frac{dp_{i'j'}}{dc_{i'j'}^{n}}}{p_{i'j'}}+(\gamma-\sigma)\frac{\frac{dp_{ij}}{dc_{i'j'}^{n}}}{p_{ij}}+(\sigma-1)\frac{\frac{dP_j}{dc_{i'j'}^{n}}}{P_j}. \tag{A6}$$

To derive the first term on the right hand side of equation A6, I know that $p_{i'j'}=w_i/x_i+T_{i'j'}$, which implies that

$$\frac{dp_{i'j'}}{dc^n_{i'j'}} = \frac{dT_{i'j'}}{dc^n_{i'j'}}. \tag{A7}$$

For the second term, I re-write equation 11 so that shippers take as given the price index of other port-pairs

$$p_{ij} = \left(\beta_{i'}\beta_{,j'}p_{i'j'}^{1-\gamma} + \bar{p}_{i'j'}\right)^{\frac{1}{1-\gamma}}, \tag{A8}$$

where $\bar{p}_{i'j'}$ is taken as given by the shipper. I use equation A8 to find

$$\frac{\frac{dp_{ij}}{dc^n_{i'j'}}}{p_{ij}} = \frac{\beta_{i'}\beta_{,j'}p_{i'j'}^{1-\gamma}}{p_{ij}^{1-\gamma}} p_{i'j'}^{-1} \frac{dT_{i'j'}}{dc^n_{i'j'}}. \tag{A9}$$

I know that

$$\frac{p_{i'j'}c_{i'j'}}{p_{ij}c_{ij}} = \frac{\beta_{i'}\beta_{,j'}p_{i'j'}^{1-\gamma}}{p_{ij}^{1-\gamma}}, \tag{A10}$$

which I substitute into equation A9 to arrive at

$$\frac{\frac{dp_{ij}}{dc^n_{i'j'}}}{p_{ij}} = \frac{p_{i'j'}c_{i'j'}}{p_{ij}c_{ij}} p_{i'j'}^{-1} \frac{dT_{i'j'}}{dc^n_{i'j'}}. \tag{A11}$$

For the third term, I differentiate equation 8 with respect to $c^n_{i'j'}$ and then divide by P_j to find

$$\frac{\frac{dP_j}{dc^n_{i'j'}}}{P_j} = \frac{\zeta\tau_{ij}^{1-\sigma}p_{ij}^{1-\sigma}}{P_j^{1-\sigma}} p_{ij}^{-1} \frac{dp_{ij}}{dc^n_{i'j'}}. \tag{A12}$$

I can show that

$$\frac{\tau_{ij}p_{ij}c_{ij}}{w_jL_j + R_j} = \frac{\zeta\tau_{ij}^{1-\sigma}p_{ij}^{1-\sigma}}{P_j^{1-\sigma}}, \tag{A13}$$

which I substitute into equation A12 to arrive at

$$\frac{\frac{dP_j}{dc^n_{i'j'}}}{P_j} = \frac{\tau_{ij}p_{ij}c_{ij}}{w_jL_j + R_j} p_{ij}^{-1} \frac{dp_{ij}}{dc^n_{i'j'}}. \tag{A14}$$

I plug in the condition in equation A11 to find

$$\frac{\frac{dP_j}{dc^n_{i'j'}}}{P_j} = \frac{\tau_{ij}p_{i'j'}c_{i'j'}}{w_jL_j + R_j} p_{i'j'}^{-1} \frac{dT_{i'j'}}{dc^n_{i'j'}}. \tag{A15}$$

I use the conditions in equations A7, A11, and A15 in equation A6 and apply symmetry across shippers to arrive at equations 20 and 21. □

C.2 Proof of Proposition 2

Proof. I use the condition in equation 19 to find that

$$\frac{w_i}{\Phi} = \frac{\epsilon_{i'j'} - 1}{\epsilon_{i'j'}} T_{i'j'} \tag{A16}$$

As in Section 4.3, I do not denote the i' and j' unless it is needed to denote the direction of trade. I substitute into the profitability condition in equation 13 the solutions from Proposition 1 to derive the condition

$$\pi = c^n_{i'j'} T_{i'j'} \left(\frac{1}{\epsilon_{i'j'}} \right) + c^n_{j'i'} T_{j'i'} \left(\frac{1}{\epsilon_{j'i'}} \right). \tag{A17}$$

I then plug in for the expression of $\epsilon_{i'j'}$ and $\epsilon_{j'i'}$ characterized in equation 20 to find

$$\pi = \frac{p_{i'j'} c^n_{i'j'}}{N_{i'j'} \kappa_{i'j'},}. \tag{A18}$$

I use the fact that $c_{i'j'} = N c^n_{i'j'}$ to find the condition in equation 23. □

D Appendix: Model with Transportation Industry That Uses Labor from Both Countries

In this section, I extend the baseline model to allow the transportation industry to use labor from both countries. I also show that Propositions 1 and 2 continue to hold with minor adjustments.[37]

D.1 Setup of Extended Model

All of the conditions of the model in Section 4 remain the same except for those described below.

Labor Used by Transportation Industry Suppose that the transportation industry uses a fixed proportion of labor from countries i and j. In particular, suppose that for every unit of labor, the transportation industry uses a_i from country i and a_j from country j, where $a_i + a_j = 1$.

Third Stage for Shipper's Problem We now restate the shipper's problem in equation 13. A shipper with productivity Φ chooses $c^n_{i'j'}$ and $c^n_{j'i'}$ to maximize profits in the third stage:

$$\pi(\Phi; c^{-n}_{i'j'}, c^{-n}_{j'i'}) = \max_{c^n_{i'j'}, c^n_{j'i'}} \quad c^n_{i'j'} \left[T_{i'j'} \left(c^n_{i'j'} + c^{-n}_{i'j'} \right) - \frac{\tilde{w}}{\Phi} \right] + c^n_{j'i'} \left[T_{j'i'} \left(c^n_{j'i'} + c^{-n}_{j'i'} \right) - \frac{\tilde{w}}{\Phi} \right], \tag{A19}$$

where $\tilde{w} = a_i w_i + a_j w_j$ and the rest of the variables are defined as before.

Second Stage for Shipper's Problem The second stage remains the same as before except that 15 becomes

$$\frac{d\pi(\Phi; c^{-n}_{i'j'}, c^{-n}_{j'i'})}{d\Phi} = \tilde{w} \frac{dF\left(\Phi\right)}{d\Phi}. \tag{A20}$$

First Stage for Shipper's Problem The first stage remains the same as before where the zero profit condition pins down the number of shippers.

Labor Market Clearing Conditions The labor market clearing condition for country i in equation 17 becomes

$$\underbrace{\frac{c_{ii}}{x_i} + \sum_{i'=1}^{\Omega_i} \sum_{j'=1}^{\Omega_j} \mathbb{I}_{i'j'} \frac{c_{i'j'}}{x_i}}_{\text{Labor used by production firm}} + \underbrace{a_i \left[\sum_{i'=1}^{\Omega_i} \sum_{j'=1}^{\Omega_j} \mathbb{I}_{i'j'} \frac{c_{i'j'}}{\Phi_{i'j'}} + \sum_{i'=1}^{\Omega_i} \sum_{j'=1}^{\Omega_j} \mathbb{I}_{j'i'} \frac{c_{j'i'}}{\Phi_{i'j'}} + N_{i'j'} F_{i'j'} \right]}_{\text{Labor from country } i \text{ used by transportation industry}} = \underbrace{L_i}_{\text{Labor endowment}}, \tag{A21}$$

[37] Notice that shippers use an amalgam of labor from countries i and j, which ensures that all shippers face the same cost per unit of labor. However, if shippers use labor from different countries (e.g., some shippers use labor from country i, whereas other shippers use labor from country j), then shippers' costs per unit of labor would vary, and the symmetry of shippers would not hold.

and the labor market clearing condition for country j in equation 18 becomes

$$\underbrace{\frac{c_{jj}}{x_j} + \sum_{i'=1}^{\Omega_i} \sum_{j'=1}^{\Omega_j} \mathbb{I}_{j'i'} \frac{c_{j'i'}}{x_j}}_{\text{Labor used by production firm}} \underbrace{+ a_j \left[\sum_{i'=1}^{\Omega_i} \sum_{j'=1}^{\Omega_j} \mathbb{I}_{i'j'} \frac{c_{i'j'}}{\Phi_{i'j'}} + \sum_{i'=1}^{\Omega_i} \sum_{j'=1}^{\Omega_j} \mathbb{I}_{j'i'} \frac{c_{j'i'}}{\Phi_{i'j'}} + N_{i'j'} F_{i'j'} \right]}_{\text{Labor used from country } j \text{ by transportation industry}} = \underbrace{L_j}_{\text{Labor endowment}} . \quad \text{(A22)}$$

Notice that this model is more general than the baseline case since it is equivalent to the baseline model when $a_i = 1$ and $a_j = 0$.

D.2 Propositions 1 and 2 Hold in the New Model

Under the new setup, the transportation costs from i' to j' in equation 19 in Proposition 1 become

$$T_{i'j'} = \underbrace{\frac{\epsilon_{i'j'}}{\epsilon_{i'j'} - 1}}_{\text{Markup}} \underbrace{\frac{\tilde{w}}{\Phi_{i'j'}}}_{\text{Marginal Cost}} . \quad \text{(A23)}$$

The characterizations of $\epsilon_{i'j'}$ in equation 20 and $\kappa_{i'j'}$ in equation 21 remain the same. The intuition behind this result is that the shippers take the cost of labor as given. Thus, the proof is the same as before except that $\tilde{w}$ replaces w_i.

Furthermore, equation 23 in Proposition 2 holds with no changes. As with the results in Proposition 1, the proof is the same except that $\tilde{w}$ replaces w_i. However, $\tilde{w}$ does not appear in the final expression because it has been arranged to be in terms of observables.

E Appendix: Determining the Factory-Gate Price

As discussed in Section 4.2, the delivery price is equal to the factory-gate price, p_{ii}, plus transportation costs, $T_{i'j'}$. To determine the importance of transportation costs in the final delivery price, I use the fact that the ad valorem transportation cost is 10.7 percent for the average commodity entering the United States (see Anderson and van Wincoop (2004)). The ad valorem transportation cost from i' to j', $\tau^T_{i'j'}$, is defined as

$$\tau^T_{i'j'} = \frac{Price_{ii} + TransportationCost_{i'j'}}{Price_{ii}}, \tag{A24}$$

where $Price_{ii}$ is the value in dollars of the factory-gate good in country i. I solve for $Price_{ii}$ such that it satisfies

$$\sum_{i'=1}^{\Omega_i} \sum_{j'=1}^{\Omega_j} Share_{i'j'} \tau^T_{i'j'} = 1.107, \tag{A25}$$

where $Share_{i'j'}$ is the fraction of exports from country i that is accounted for by exports from i' to j' in the data. To solve for this value, I first guess $Price_{ii}$ and solve for the ad valorem transportation cost for each observation using equation A24 along with $TransportationCost_{i'j'}$ from the pricing data. I then use equation A25 to solve for the implied aggregate ad valorem transportation cost. The condition in equation A25 is satisfied when the factory-gate price in the United States is $Price_{ii} = \$12,265$. Thus, the destination price used in estimating equation 25 is $Price_{i'j'} = \$12,265 + TransportationCost_{i'j'}$.

F Appendix: Mapping Fixed Cost, Marginal Cost, and Transportation Costs, Which Are Denominated in Dollars, into Model Objects

It is necessary to map the transportation costs observed in the data, which are in dollars, to transportation costs in the model. The ad valorem transportation costs are set to be equal in the model and data. Goods shipped from a U.S. port to foreign port must satisfy

$$\frac{TransportationCost_{i'j'} + \$12,265}{\$12,265} = \frac{T_{i'j'} + p_{ii}}{p_{ii}}, \tag{A26}$$

where $TransportationCost_{i'j'}$ is the transportation costs in the data, as mentioned in Section 3. In equation A26, I use the formulation for ad valorem transportation costs from equation A24. Notice that the factory-gate price for the U.S. good, $p_{ii} = w_i/x_i$, is 1 since I normalize $w_i = x_i = 1$. I rearrange to arrive at

$$T_{i'j'} = \frac{TransportationCost_{i'j'}}{\$12,265}. \tag{A27}$$

Once $T_{i'j'}$ has been determined, the parameter that governs the efficiency of the shippers, Φ, can be backed out. This parameter is directly related to the marginal cost of shippers, as can be seen in equation 19. I rearrange this equation to find

$$\Phi = \frac{\epsilon_{i'j'}}{\epsilon_{i'j'} - 1} \frac{w_i}{T_{i'j'}}, \tag{A28}$$

where I use the perceived price elasticities previously found in Section 5.2.1. Notice that I have normalized $w_i = 1$, which allows determining Φ without the need for simulating the model.

There is a similar issue of mapping the backed-out fixed costs, which are in dollars, to the fixed costs in the model. The fixed costs are set in the model, F, to match the following condition:

$$\frac{w_i F}{GDP_i^{Model}} = \frac{FC^{Data}}{GDP_i^{Data}}, \tag{A29}$$

where GDP_i^{Model} and GDP_i^{Data} are the GDP of country i in the model and data, respectively, and FC^{Data} is the fixed cost inferred from the data. I rearrange equation A29 and solve for F.

G Appendix: How Do Regulatory Costs Map into Fixed and Marginal Costs?

Suppose that firms face the following technological trade-off between fixed and marginal costs:

$$\log FC^T = \alpha_0^T - \alpha_1^T \log MC^T, \tag{A30}$$

where FC^T is the technological component of the fixed cost, MC^T is the technological component of the marginal cost, and α_0^T and $\alpha_1^T > 0$ are technological in nature. For example, if two ports are very far away, then α_0^T is higher.

Shippers may also face non-technological costs. For example, there may be poor regulatory environments that increase costs for firms (e.g., red tape, delays at ports, or strong unions that attempt to extract rents). I suppose that there are additional costs that affect the total fixed cost, FC, and the total marginal cost, MC, in the following way:

$$FC = \xi_{FC}^R FC^T, \tag{A31}$$

$$MC = \xi_{MC}^R MC^T, \tag{A32}$$

where $\xi_{FC}^R \geq 1$ and $\xi_{MC}^R \geq 1$. Parameters ξ_{FC}^R and ξ_{MC}^R represent the non-technological costs that firms face. I substitute equations A31 and A32 into equation A30 and rearrange to find

$$\log FC = - \underbrace{\alpha_1^T}_{\alpha_1 \text{ in equation } 14} \log MC + \underbrace{\left[\alpha_0^T + \alpha_1^T \log \xi_{MC}^R + \log \xi_{FC}^R\right]}_{\alpha_0 \text{ in equation } 14}. \tag{A33}$$

Thus, the trade-off between the total fixed cost and the total marginal cost is determined by α_1^T, which is technological in nature. For a given marginal cost, the level of fixed costs is determined by a mixture of technological and non-technological costs. Figure 3 shows an example of the choice that shippers face in a high- versus low-cost scenario. Notice that the formulation in equation A33 is consistent with equation 14 in the model when $\alpha_1 = \alpha_1^T$ and $\alpha_0 = \alpha_0^T + \alpha_1^T \log \xi_{MC}^R + \log \xi_{FC}^R$.

H Appendix: More Information about Real Income Decomposition in Section 7.1

H.1 Simple Example with Two Countries, Each with One Port

Let us consider a simple example to better understand the decomposition described in equations 28-30. To that end, consider a case in which there are two countries, i and j. Furthermore, each country has one port: country i has port i', and country j has port j'.

We substitute the price index in equation 8 into the expression for real income in equation 26 to arrive at the following expression:

$$Y_j = \frac{w_j L_j + R_j}{\left(p_{jj}^{1-\sigma} + \zeta \tau_{ij}^{1-\sigma} p_{ij}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}. \tag{A34}$$

We can further substitute the expressions for p_{ii} and p_{ij} into this equation:

$$Y_j = \frac{w_j L_j + R_j}{\left(\left(\frac{w_j}{x_j}\right)^{1-\sigma} + \zeta \tau_{ij}^{1-\sigma} \left(\frac{w_i}{x_i} + T_{i'j'}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}. \tag{A35}$$

Notice that in this particular case, country j receives goods from only one port in i, which travels from i' to j'. Thus, the price for the composite good from country i to j, p_{ij}, is simply the delivery price of the good traveling from port i' to j', $p_{i'j'} = \frac{w_i}{x_i} + T_{i'j'}$.

We see from the above equation that the real income could change because of the following:

- Changes in transportation costs, which would be reflected in $T_{i'j'}$
- Changes in tariffs, which would be reflected in τ_{ij} and R_j
- Changes in wages, which would be reflected in w_j and w_i

For these variables, I have a set of them before, $\{T_{i'j'}, \tau_{ij}, R_j, w_i, w_j\}$, and after, $\{T'_{i'j'}, \tau'_{ij}, R'_j, w'_i, w'_j\}$, the change in tariffs.

The expression for $Y'_{j,Tariffs}$ in equation 28 can be expressed in this simple case as

$$Y'_{j,Tariffs} = \frac{w_j L_j + R'_j}{\left(\left(\frac{w_j}{x_j}\right)^{1-\sigma} + \zeta \left(\tau'_{ij}\right)^{1-\sigma} \left(\frac{w_i}{x_i} + T_{i'j'}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}. \tag{A36}$$

The expression for $Y'_{j,Transp}$ in equation 29 can be expressed as

$$Y'_{j,Transp} = \frac{w_j L_j + R_j}{\left(\left(\frac{w_j}{x_j}\right)^{1-\sigma} + \zeta \tau_{ij}^{1-\sigma} \left(\frac{w_i}{x_i} + T'_{i'j'}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}. \tag{A37}$$

The expression for $Y'_{j,Wages}$ in equation 30 can be expressed as

$$Y'_{j,Wages} = \frac{w'_j L_j + R_j}{\left(\left(\frac{w'_j}{x_j}\right)^{1-\sigma} + \zeta\tau_{ij}^{1-\sigma}\left(\frac{w'_i}{x_i} + T_{i'j'}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}. \tag{A38}$$

H.2 General Case with Two Countries, Each with an Arbitrary Number of Ports

The example in Section H.1 is a simplified example of the decomposition. We can now find a general expression for A35. We begin with equation A34 and plug the expression for p_{ij} into equation 11 to find

$$Y_j = \frac{w_j L_j + R_j}{\left(p_{jj}^{1-\sigma} + \zeta\tau_{ij}^{1-\sigma}\left(\left(\sum_{i'=1}^{\Omega_i}\sum_{j'=1}^{\Omega_j}\left[\mathbb{I}_{i'j'}\beta_{i'}\beta_{,j'}p_{i'j'}^{1-\gamma}\right]\right)^{\frac{1}{1-\gamma}}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}. \tag{A39}$$

We can further substitute the expressions for p_{ii} and p_{ji} into this equation:

$$Y_j = \frac{w_j L_j + R_j}{\left(\left(\frac{w_j}{x_j}\right)^{1-\sigma} + \zeta\tau_{ij}^{1-\sigma}\left(\left(\sum_{i'=1}^{\Omega_i}\sum_{j'=1}^{\Omega_j}\left[\mathbb{I}_{i'j'}\beta_{i'}\beta_{,j'}\left(\frac{w_i}{x_i} + T_{i'j'}\right)^{1-\gamma}\right]\right)^{\frac{1}{1-\gamma}}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}. \tag{A40}$$

We can define $Y'_{j,Tariffs}$, $Y'_{j,Transp}$, and $Y'_{j,Wages}$ in a similar manner as in equations A36, A37, and A38 respectively.

I Appendix: Examination of Transportation Technology

The technological choice that shippers face is modeled in a relatively simple manner as a tradeoff between fixed cost and marginal cost. This simple formulation, which abstracts from many of the intricacies of the transportation industry, is useful because it allows for a tractable model that can be embeded into a general equilibrium model. It is comforting to see that this model can quantitatively account for how changes in trade flows on a route affect the number of shippers and transportation costswithin the transportation industry as shown in Sections 7.2 and 7.3. However, given the complexities of the transportation industry, it is also useful to compare the results of this model with more detailed studies of the transportation technology. For that reason, I look to the transportation literature, which has studied in detail the cost savings associated with adopting larger ships. I rely on the work of Cullinane and Khanna (1999) and Cullinane and Khanna (2000), who calculated the average cost per container for various ship sizes. In the language of the authors, as ships become larger, shippers enjoy economies of scale at sea and diseconomies of scale at port. In particular, the economies of scale at sea arise from various forces: the average cost per container declines because of lower capital costs per container, lower operating costs per container (insurance, administration cost, crew cost, and maintenance), lower fuel costs per container, and faster speed, which allows the ship to spend fewer days at sea. On the other hand, the diseconomies of scale at port arise from larger ships spending a longer time in port. The authors' detailed calculations of average cost take all of these factors into account.

Table A2 shows the average cost per container as calculated by the authors for three voyages: trans-Atlantic (4,000 miles), trans-Pacific (8,000 miles), and Europe to East Asia (11,500 miles). The average cost per container is a function of the number of containers the ship holds. I also calculate the elasticity of the decline in average cost per container with respect to ship size.

A few important results emerge from the table. First, the table gives an approximate range for the elasticities: for the trans-Atlantic voyage, the average elasticity is 0.17; for the trans-Pacific voyage, the average elasticity is 0.26; for the Europe to East Asia voyage, the average elasticity is 0.30. Second, as capacity increases, there is a decline in the elasticities. Thus, as ships become larger, the decline in average cost with respect to ship size becomes smaller. Third, the elasticities tend to be larger for longer voyages. Thus, the cost savings from adopting larger ships are more important for longer voyages.

To compare these results with the quantitative results from the model, we need to suppose that the shipper size in the model, which is in terms of value of trade flows transported, is directly proportional to the ship size that the shipper uses. For example, if the shipper size in the quantitative exercises doubles, then that would correspond to the ship size used doubling as well. In the average simulation, the model predicts an elasticity of 0.30 for the decline in average cost with respect to shipper size. Notice that this elasticity is similar to the elasticities found in Table A2. As a second step, I estimate a regression using the model output in which the dependent variable is the log elasticity of average cost with respect to shipper size. The two dependent variables are the log of the value of trade flows before the change in tariffs and the log distance between the two ports. The coefficient on the size of initial trade flows is negative and statistically significant: controlling for distance, the routes in which the shippers were already large experienced smaller declines in average cost with respect to increases in trade flows. Notice that this result is consistent with the second result from the previous paragraph. Furthermore, the coefficient on distance is positive: controlling for the size of shippers, the routes that were farther away saw a larger decline in average cost with respect to increases in trade flows. Notice that this result is consistent with the third result from the previous paragraph.

The authors also provide details regarding their calculations of fixed cost. First, supposing that the fixed cost is only related to the cost of capital of the ship, the authors report an elasticity of 0.759 for the daily capital cost with respect to the capacity of the ship.[38] Second, supposing that the fixed cost includes capital costs as well as repair and maintenance, insurance, administrative, and crew costs, they report an elasticity of 0.82.[39] In the quantitative results, I calculate an elasticity of fixed cost with respect to shipper size of 0.85 on average.

The elasticity of the decline in average cost with respect to shipper size in the model is similar in magnitude to the estimates of the elasticity of the decline in average cost with respect to ship size found in the transportation literature. Furthermore, there are similarities between the elasticity of the increase in fixed cost with respect to trade flows in the model and the increase in capital costs with respect to ship size. We must be cautious of the results as the model abstracts from the transportation network and how ships of various sizes are allocated across this network. However, these correlations are suggestive that the size of ships play an important role in the technological choice that shippers face in the model.

[38]The authors suppose that the daily capital cost is proportional to the price of the ship. In particular, they apply a capital recovery factor in the case that the ship has a life of 20 years, a salvage value of zero, and an interest rate of 10 percent.

[39]The authors report the total daily fixed cost of ships with a capacity of 200 ($4,280) and 3,400 ($26,860) 20-foot containers. The midpoint method gives an elasticity of 0.82 ((22,580 / 15,570) / (3200 / 1800)). The authors also report that these numbers are similar to those reported in the charter markets, where container ships can be rented for short periods of time.

Table A2

Average Cost per 20-Foot Container vs. Ship Size as Calculated by Cullinane and Khanna (2000)

Capacity (20-foot containers)	Trans-Atlantic 4,000 miles Cost (US $)	Trans-Atlantic 4,000 miles Elasticity	Trans-Pacific 8,000 miles Cost (US $)	Trans-Pacific 8,000 miles Elasticity	Europe-East Asia 11,500 miles Cost (US $)	Europe-East Asia 11,500 miles Elasticity
1000	181		328		457	
2000	142	0.36	249	0.41	342	0.43
3000	129	0.24	219	0.32	297	0.35
4000	121	0.22	201	0.30	270	0.33
5000	117	0.15	190	0.25	254	0.27
6000	114	0.14	182	0.24	242	0.27
7000	113	0.06	177	0.18	233	0.25
8000	113	0.00	174	0.13	227	0.20
Average elasticity		**0.17**		**0.26**		**0.30**

Table A2 reports the average cost per 20-foot container as well as the elasticity of the average cost with respect to ship capacity. The first column shows the capacity of the ship in terms of 20-foot containers. Column 2 reports the average cost per container for a Trans-Atlantic voyage, as shown in Table 3 in Cullinane and Khanna (2000). Column 3 reports the elasticity of the average cost with respect to ship capacity. This elasticity is calculated by the author using the midpoint elasticity formula. For example, increasing capacity from 1,000 to 2,000 containers for a Trans-Atlantic voyage decreases the average cost from \$181 to \$142, yielding an elasticity of 0.36 $(-((142-181)/161.5)/((2000-1000)/1500))$. Columns 4 and 5 report similar information for a Trans-Pacific voyage. Columns 6 and 7 report similar information for a Europe to East Asia voyage. The final row calculates a simple average of the elasticities for each of the three voyages.

J Appendix: Additional Tables

Table A3

Shipper Size and Trade Flows

	(1) Log shipper size
Log trade flows	0.855***
	(0.00921)
Observations	1214
R-squared	0.877

Table A3 reports the results of the estimation of equation 2, except that each observation is a shipper and the dependent variable is the shipper size. The dependent variable is the log shipper size between a U.S.-foreign port pair. To construct shipper size, the total value of containerized trade flows in U.S. dollars between two ports, which is described in Section 3.3, is multiplied by the shipper's market share. To calculate the market share, I find the fraction of total deadweight tons (DWT) of the ships operated by the shipping firm. The independent variables are the total value of containerized trade flows (U.S. dollars), described in Section 3.3. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table A4

First-Stage Regression of Equation 2

	(1) Log trade flows
Log GDP	0.634***
	(0.0514)
Log distance	-0.784***
	(0.152)
Observations	697
R-squared	0.184
F-statistic	78.17

Table A4 reports the results of the first-stage regression of equation 2, which is described in footnote 16. The dependent variable is the log total containerized trade flows in U.S. dollars between two ports, which is described in Section 3.3. The independent variable is the log of the GDP of the destination country in 2014 as reported by the World Development Indicators and the log distance, measured in nautical miles, between the two ports described in Section 3.4. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.