DETERMINANTS OF THE EXPANSION IN CONTAINER USE IN U.S. TRADE

by

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Abstract

This dissertation investigates empirically and quantitatively the determinants of containerization in the United States. Although containers were introduced in international trade in 1966, not all exports that could be containerized are containerized. The containerized share of containerizable exports grew from 61 percent in 2010 to 69 percent in 2018. The majority of this growth is driven by increase in the share of each product that is containerized, rather than a shift from exports of products that are less containerized towards exports of products that are highly containerized. This finding is consistent with supply shocks, such as declining container transport costs, as the driver of growth in containerization. Product-level regressions show that changes in containerized export shares respond negatively to changes in container transport costs caused by technological improvement in the container transport industry. I also find the effects are heterogeneous across products. Finally, to quantify the welfare gains associated with containerization, I develop a multi-country general equilibrium trade model with endogenous transport costs in which heterogeneous firms make both export and transport decisions.

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Chapter 1

Introduction

Maritime transport is the backbone of international trade and the global economy. Around 80 percent of international trade by volume and over 70 percent of international trade by value are carried by sea and are handled by seaports worldwide (UNCTAD (2017)). The use of containers in ocean shipping was one of the great technological and commercial innovations of the twentieth century. Containers can be handled interchangeably on vessels, in terminals, and via inland transport modes.

Even though containers are now over 50 years old, as of 2010 only 46 percent of total U.S. seaborne exports by value was containerized.[1] Even when I exclude bulk goods such as crude oil, grain or iron ore, only 61 percent of U.S. exports used containers in 2010, suggesting that the container revolution is still taking place. Since 2010 the containerized share of U.S. non-bulk exports to the rest of the world increased by 8 percentage points from 61 percent to 69 percent.[2]

There are three principal contributions in this dissertation. First, I conduct an accounting decomposition to investigate the sources of the recent growth in the use of containerization for U.S. exports using disaggregated product-level data. Second, I study econometrically how this growth is related to transport costs. Third, to quantify the productivity or welfare gains associated with containers, I develop a trade model with endogenous

[1] Containerization adopted first by the United States in 1956 and served the transport of domestic trade within the United States. Ten years later, on 23 April 1966, the first transatlantic service was started from the port of New Jersey to the port of Rotterdam.

[2] The containerized share of U.S. non-bulk imports is around 80 percent since 2010.

transport costs consistent with data facts and empirical findings.

To understand the sources of the overall growth in the U.S. container use since 2010 I decompose this growth into within- and between-product components. By focusing only on non-bulk products, this decomposition indicates whether it was individual products using containers more intensely (within-product effect), or if it was a shift to products that had heavy container use to begin with (between-product effect). I conduct the accounting decomposition using disaggregated and aggregated product-level data from the U.S. Census Bureau. The decomposition reveals that the within-product effect accounts for nearly all of the growth in the use of containers for U.S. exports since 2010. This result suggests that supply shocks such as improvements in container transport technology that reduce container transport costs relative to other transport modes are the likely driver of growth in the share of exports using containers.

Given that finding, I empirically estimate the role of container transport costs in explaining the growth in the use of containers. To do this, I combine two different data sets. I employ a port-level data set on transport cost per 20-foot container from 2010 to the present collected by Drewry Maritime Research (Drewry). I combine that with port-level export data at aggregated 2-digit Harmonized System product-level over the period 2010-2018 from the U.S. Census Bureau.[3] To identify the effect of container transport costs on the containerized share of U.S. exports I need a shifter of transport supply that is independent of the demand determinants. I construct a Bartik-type instrument that approximates this transport supply shift. I find that a 1,000 dollars decrease in transport costs per container is associated with a 9 percentage point increase in the containerized share of U.S. exports. In addition, the effects are heterogeneous across products. Non-bulk products that are less containerized are affected more by declines in container transport costs than non-bulk products that are highly containerized.

The data suggests that supply shocks drove the containerized export share growth. However, that data does not reveal the productivity or welfare gains associated with containerization. To quantify those, I use a multi-country general equilibrium trade model in

[3]To the best of my knowledge, the US is the only country for which containerized trade data by value is available.

which heterogeneous firms make both export and transport decisions. Conditional on exporting, a firm endogenously chooses whether to containerize or use break-bulk shipping to transport its exports.[4] However, there is a trade-off between the fixed export cost and the variable transport cost. Although containers involve lower variable transport costs than break-bulk shipping, they require a high fixed cost. Containerization decreased transport costs by lowering cargo-handling costs and port time, but firms that wanted to containerize their exports incurred high fixed export costs as they had to develop advanced logistics and inventory management systems and adjust their production design to take container dimensions into account. The theoretical model in this dissertation builds on the monopolistic competition framework with heterogeneous firms introduced by Melitz (2003) and used by Rua (2014). I augment Rua's model to allow for endogenous transport costs, which are determined in equilibrium by the interaction of demand and supply of sea transport. I endogenize transport costs by introducing a competitive sea transportation sector that provides transport services for exporting firms using labor as input. My model's innovation is that changes in transport costs reflect both changes in transportation sector productivity and wages.

In a symmetric two-country version of the model I assess quantitatively the effects of lower container costs on firms' productivity, trade flows and wages. This qualitative analysis reveals that an improvement in transport productivity increases wages, total exports, and the average productivity of exporting firms. Labor will be allocated from the least productive break-bulk exporters, who exit the export market, toward the more productive break-bulk exporters, who in turn adopt containers.

Related Literature This dissertation is related to three strands of literature. First, it is related to a literature that has considered the role and features of the container shipping industry. Bernhofen, El-Sahli and Kneller (2016) provide quantitative evidence of the effects of containerization on bilateral trade flows using a fixed effect panel approach. They identify the effect of containerization by exploiting the cross-sectional and time series variation in country adoption of container infrastructure. However, they do not provide a com-

[4]Break-bulk refers to transporting goods loose in the vessel's hold instead of in standardized containers.

prehensive general equilibrium analysis of the effect of containerization on trade. In this dissertation, I assess the effects of containerization on trade costs and flows by examining a general equilibrium framework that captures the effects of containerization.

Rua (2014) investigates the diffusion of containerization across countries and over time in the context of a Melitz (2003) single-product, heterogeneous firm model of trade in which firms choose between containerization and break-bulk shipping. She identifies the main forces that led to the adoption of containerization by countries and the use of containers by exporting firms. Then, using country-level data from early years of containerization, she tests empirically the contribution of these forces to the adoption and use of containers. However, my dissertation investigates the diffusion of containerization across products and over time by focusing on recent data on containerization. Using Rua (2014)'s extension, Coşar and Demir (2018) study the effects of containerization on transport by looking at the choice between containers and break-bulk shipping. However, this literature relies on exogenous transport costs which are modeled as iceberg trade costs theoretically and are approximated by distance empirically. My dissertation extends this literature both theoretically and empirically. First, the theoretical part of my dissertation allows endogenous transport costs by introducing into the existing trade model a transportation sector that uses labor as input into the production of transportation services. My model's innovation is that changes in transport costs reflect both changes in transportation sector productivity and wages. Second, the empirical part of my dissertation uses a direct measure of transport costs, such as container transport costs, rather than the commonly used proxies of trade costs.

Second, this dissertation is related to the literature on endogenous transport costs. Brancaccio, Kalouptsidi and Papageorgiou (2017) study endogenous transport costs in the presence of search frictions between exporters and ships, by focusing on dry bulk ships. Asturias (2018) studies how welfare effects of a trade reform differ when the trade model includes an oligopolistic transportation industry. He explores the impact of the number of shipping firms on transport prices and trade. Wong (2017) builds a trade model that focuses on trade imbalances and how they affect transportation costs using container shipping prices. Container vessels operate on fixed itineraries (round trips) between ports at published prices. Due to the round-trip effect, if demand is affected by protectionist policies like tariffs, this will cause spillovers to the other direction. Exploiting this round trip insight, the author estimates the containerized trade elasticity with respect to container shipping prices. However, the empirical part of my dissertation, which is most closely related to Wong (2017), investigates the role of container shipping prices in explaining the observed increase in the use of containerization since 2010.

Third, in contrast to the international trade literature that studies the effects of trade policy liberalization on trade, my dissertation relates to the growing literature on changes in transportation technology. Donaldson (2018) provides an empirical understanding of the extent to which transportation infrastructure projects actually reduce trade costs, and how the resulting trade cost reductions affect welfare. He uses a multi-region and multi-commodity Ricardian trade model to study the effects of the expansion of India's railroad network during 1853-1930. He finds that railroads reduced the cost of trading, narrowed inter-regional price gaps, and increased trade volumes. Moreover, Adamopoulos (2011) provides a quantitative assessment of the contribution of transport productivity disparities to cross-country income gaps. He studies the role of transportation for development by introducing regional trade and a transportation sector into the standard two-sector model of agriculture and non-agriculture. I contribute to this literature by analyzing the effects of containerization which is considered as the main technological change in ocean transport in the postwar era that affect the supply of transportation services.

Background Information about Container Industry As noted above, around 80 percent of world trade by volume and over 70 percent of world trade by value are carried by sea and are handled by seaports worldwide (UNCTAD (2017)). Goods that are carried by sea can be shipped in a number of different ways, depending on their characteristics. Different cargo types require different vessels, terminal configurations, and handling equipment. Bulk goods include unpacked homogeneous commodities that are loaded directly onto specialized carriers. They can be further divided into liquid bulk, such as crude oil, refined products (e.g. gasoline, diesel, and fuel oil) and a variety of chemicals, and dry bulk, such as iron ore, coal or grain. The remaining goods are considered as general cargo.

General cargo comprises a large variety of goods, including both manufactured and semi-manufactured goods, such as consumer products and primary commodities. It can either be containerized, placed in large standardized boxes (containers) which are loaded by cranes, or break-bulk, loaded into ships manually.

Until the mid-1960s all general cargo, called "break-bulk" cargo, was transported loose by cargo liners or general cargo ships and was loaded and unloaded manually in the vessel's hold by crews of dockworkers. As a result of this labor intensive operation, the cost of loading and unloading loose cargo was high, increasing the total transport cost. Levinson (2016) documents that in 1954 cargo-handling costs escalated to more than one-third of the total transport cost. A radical change in the transport system was needed to reduce these costs and provide fast, cheap and regular cargo transport services. This change came with an attempt to automate the transport process and increase productivity. The solution was to pack goods in standard shipping containers that can be handled interchangeably on vessels, in terminals, and via inland transport modes.[5, 6]

In terms of the container service infrastructure, three are the vital components of the new system: container-ships, container terminal and developments in communications and information technology. First, container-ships are ships designed to carry containers and have box-shaped holds and cell guides so that containers can be lowered securely into place below deck without the need for locking devices, reducing loading times to a matter of minutes. Second, container terminals are equipped with large gantry cranes that are used for loading and unloading intermodal containers from container-ships. Handling speeds vary from port to port, ranging from 15 to 30 lifts an hour from ship to dock, but averaging about 20 lifts per crane hour. In an adjacent storage area the containers are stored to await collection. Third, to run a container service, computer control systems were needed for controlling the movement of containers and taking bookings.

Today containerized cargo is the principal form of general cargo transport. Rua (2014) documents that the percent of world general cargo trade by weight that is containerized

[5]Containers are usually 8 feet wide, often 8 feet 6 inches high and mostly 20 or 40 feet long.

[6]Containerization was adopted first by the United States in 1956 and served the transport of domestic trade. Ten years later, on 23 April 1966, the first transatlantic container service was started from US East Coast (port of New Jersey) to Europe (port of Rotterdam).

increases from 0 in 1966 to 70 percent by the mid-2000s.[7] Break-bulk shipping is now generally reserved for cargo that is too heavy or large to fit in a container.[8] It is more time-intensive, and thus more expensive, than container shipping because each piece must be loaded and unloaded individually, often with special equipment.

Although the development of intermodal container shipping is impacting other transport modes, this dissertation is limited to sea transport. Figures 1.1 and 1.2 show the growing pattern of world containerized trade (by weight) and world container port traffic between 1990 and 2017. They both grew by 8 percent per year, with the sole downturn occurring during the Great Recession in 2009. In 2016 containerized trade accounted for about 52 percent of the value of all goods shipped by sea and containers dominated the transport of general cargo by carrying 72 percent of the general cargo trade by value.[9] Moreover, due to data limitations on containerized trade by value, this dissertation focuses on U.S. trade. To the best of my knowledge, the United States is the only country that reports containerized trade by value. International trade accounted for 27 percent of U.S. GDP in 2017. While almost one-third of U.S. trade by value is with Canada and Mexico, the remaining majority requires seaborne shipping or air cargo service to reach foreign countries. In 2017 containers carried 51 percent of U.S. seaborne exports and 72 percent of U.S. seaborne imports.[10]

The rest of the dissertation is organized as follows. Chapter 2 performs the accounting decomposition and investigates empirically the role of container transport costs in explaining the observed increase in the use of containerization. Chapter 3 outlines a model consistent with the empirical findings, derives its equilibrium, and illustrates the impact of containerization on welfare, trade costs and flows. Chapter 4 concludes.

[7] See Rua (2014) figure I.

[8] Examples of break-bulk cargo include construction and mining equipment, agricultural machinery, manufacturing materials, oversized vehicles, boats, cranes, turbine blades, ship propellers, generators and large engines.

[9] Wold Shipping Council

[10] U.S. Census Bureau (2017)

Chapter 2

Accounting Decomposition and Empirical Estimation of the Effect of Container Transport Cost on Containerization

2.1 Accounting Decomposition

In this section, I decompose changes in U.S. containerized exports as a fraction of U.S. "containerizable" - which I define below - exports to the rest of the world. The decomposition categorizes the changes into within-, between-, cross-, entry- and exit-product effects. I use both 6-digit and 2-digit Harmonized System (HS) product-level trade data. I then discuss the accounting decomposition results.

2.1.1 Measure of Containerizable Exports

My definition of containerizable exports excludes bulk products that are unlikely ever to be containerized, such as crude oil and wheat. I define a product as containerizable if in some year starting from 2002 its share of containerized exports in total seaborne exports is greater than or equal to 10 percent.[1] This positive threshold is inspired by the fact that for some bulk products the fraction of their seaborne exports that is containerized is too low (almost zero).[2] The majority of these products is transported bulk because of the high costs of packing and unpacking them into containers. These products are shipped in containers only when the quantity transported is limited. Therefore, I drop the products for which the share of containerized exports in total seaborne exports is less than 10 percent.[3] Moreover, to account for the technological change associated with containerization, as long as a product is containerizable in some year, it is considered containerizable in subsequent years. Then, the value of containerizable exports in each year equals the sum of value of seaborne exports across all containerizable products.

Figure 2.1 shows the product distribution of the share of containerized exports in total containerizable exports over the period 2010-2018. HS6 products exported by sea have large variation in terms of their containerized shares of containerizable exports. In 2010, only 16 percent of the products had shares between [0.9,1], while in 2018 the percentage increased to 52 percent. Clearly, the number of products that are effectively fully containerized has increased substantially in the past decade.

Figure 2.2 shows the fraction of U.S. containerizable exports to the rest of the world that is containerized over the period 2010-2018. The containerized share is broadly increasing over time. In 2010, 61 percent of U.S. containerizable exports was containerized and since then the share increased by 8 percentage points to 69 percent in 2018. Despite the perception that containerizable exports are highly containerized, this figure reveals that the container revolution is still taking place in the United States and there is still an important margin of transport mode choice between container and break-bulk shipping for U.S. exporters.

[1] My definition uses 2002 as the initial year because seaborne and containerized product-level export data is available from 2002 to the present.

[2] Examples of these products include wheat, grain, soybeans, iron ore, coal, crude oil, petroleum oils, natural gas, fertilizers, and wood.

[3] My results are robust to alternative thresholds.

2.1.2 Accounting Decomposition Framework

To understand the sources of the recent growth in containerization, following Foster, Haltiwanger and Krizan (2001), I decompose the aggregate change of U.S. containerized exports to the the rest of the world (X^c) as a share of U.S. containerizable exports (X^{c+b}) into within-, between-, cross-, entry- and exit-product effects as equation 2.1 shows below

$$\begin{aligned}\Delta\frac{X^c_t}{X^{c+b}_t} = & \underbrace{\sum_{g\in C}\omega_{g,t-1}\Delta\frac{X^c_{g,t}}{X^{c+b}_{g,t}}}_{\text{"Within" Effect}} + \underbrace{\sum_{g\in C}\Delta\omega_{g,t}\left(\frac{X^c_{g,t-1}}{X^{c+b}_{g,t-1}} - \frac{X^c_{t-1}}{X^{c+b}_{t-1}}\right)}_{\text{"Between" Effect}} + \underbrace{\sum_{g\in C}\Delta\omega_{g,t}\Delta\frac{X^c_{g,t}}{X^{c+b}_{g,t}}}_{\text{"Cross" Effect}} + \\ & \underbrace{\sum_{g\in N}\omega_{g,t}\left(\frac{X^c_{g,t}}{X^{c+b}_{g,t}} - \frac{X^c_{t-1}}{X^{c+b}_{t-1}}\right)}_{\text{"Entry" Effect}} - \underbrace{\sum_{g\in X}\omega_{g,t-1}\left(\frac{X^c_{g,t-1}}{X^{c+b}_{g,t-1}} - \frac{X^c_{t-1}}{X^{c+b}_{t-1}}\right)}_{\text{"Exit" Effect}},\end{aligned} \tag{2.1}$$

where $\omega_{g,t} = \frac{X^{c+b}_{g,t}}{\sum_{g\in G} X^{c+b}_{g,t}}$ is product g's share of total containerizable exports at time t. $X^c_{g,t}$ and $X^{c+b}_{g,t}$ are the value of U.S. containerized exports to the the rest of the world of product g at time t and the value of U.S. containerizable (containerized+breakbulk) exports to the the rest of the world of product g at time t, respectively. Moreover, C denotes continuing products, N denotes entering products, and X denotes exiting products.

The first term in this decomposition represents a within-product component based on product-level changes in containerized shares, weighted by initial product shares of containerizable exports (i.e. holding product shares fixed). The other terms reflect the reallocation of product shares of containerizable exports across products. The second term represents a between-product component that reflects changing product shares of containerizable exports, weighted by the deviation of initial product-specific containerized share from the initial containerized share across all products. The third term represents covariance between changes in containerized export shares and changes in product shares of containerizable exports. The last two terms represent the contribution of entering and exiting products, respectively. Positive (negative) entry and exit terms mean that entering and exiting products exhibit containerized shares greater (lower) than average initial containerized shares (across all products).

In this decomposition, the between-product, entry and exit terms involve deviations of the product-level containerized share from the initial containerized share across all products instead of the time-averaged containerized share that is used in the standard within/between decomposition. In contrast to the standard within/between decomposition, this alternative decomposition first offers an integrated treatment of entry/exit and continuing products, and second separates out within and between effects from cross/ covariance effects.

2.1.3 Data for Accounting Decomposition

To measure the value of containerizable exports and conduct the above decomposition, I use HS6 and HS2 product-level export data. Annual product-level seaborne and containerized export data by value is obtained from the U.S. Census Bureau's USA Trade Online (see data Appendix A.1 for further information).[4] I use the HS6 product-level data to define containerizable products and then I measure the annual value of containerizable exports by summing the value of seaborne exports across all containerizable HS6 products in each year. The time period of the final data set covers years from 2010 to 2018.

2.1.4 Accounting Decomposition Results

Accounting Decomposition Results Using HS6 Product-level Data

The decomposition results are shown in Table 2.1. The first row shows the accounting decomposition results for all containerizable HS6 products. Between 2010 and 2018, the containerized export share increased by 8 percentage points. The within effect accounts for more than 100 percent of the containerized export share growth while the between effect is smaller, accounting for 14 percent of the total growth. Decomposing the between effect of HS6 products with the highest between effects into its components reveals that there is fall in demand for exports of HS6 products that originally had lower container use than the initial average container use across all products. Therefore, the increase in containerized export shares within products accounts for most of the overall growth in containerized export shares from 2010 to 2018. Because this decomposition involves only containerizable

[4] Seaborne exports is defined as the sum of containerized exports and non-containerized exports.

products, this result means that a significant fraction of individual products experienced increase in their containerized export shares.

The cross term is negative indicating a negative covariance between changes in containerized export shares and changes in product shares of containerizable exports. More specifically, containerized export shares increase for most continuing products while their shares of containerizable exports decrease. In other words, between 2010 and 2018 there is fall in demand for exports of HS6 products that have higher containerized share than the initial one. The negative entry term means that entering products exhibit containerized shares lower than average initial containerized shares (across all products). The positive exit term means that exiting products exhibit containerized shares greater than average initial containerized shares (across all products). Thus, both entering and exiting products contribute negatively to the overall growth in containerized shares.

Given that the within effect dominates, I also show in the upper part of Table 2.2 the top ten HS6 products in terms of within effects. Between 2010 and 2018, passenger vehicles, pharmaceutical products, electric machinery and machinery parts are the individual HS6 products with the highest within effect, indicating that a greater share of their exports is containerized. These are also the products that account for most of the growth in the containerized export share over the period 2010-2018 (Table D.1).

However, two changes in the classification of HS products occurred during my sample period. The first occurred in 2012 and the second occurred in 2017. Therefore, if I do not take into account these code changes, entry and exit effects will not accurately reflect entry and exit of products as they will capture the effects of products that changed codes. The 2010 HS6 codes are based on the 2007 HS classification, while the 2018 HS6 codes are based on the 2017 HS classification. To address this issue, I consolidated the 2007 and 2017 HS classifications into a single HS classification. My methodology is based on the condition that most of the correlated codes in the HS 2007 and 2017 classifications are replaced by a single code. The unchanged and renumbered codes do not need consolidation. The 2007 codes that were merged in 2017 were assigned to a single 2017 code, while the 2007 codes that were split in 2017 were assigned to a single 2007 code, given that the multiple 2017 codes are not correlated with other 2017 codes. However, for simplicity, I deleted all the products for which multiple codes in 2007 were mapped to multiple codes in 2017. Then, I repeat the previous decomposition using this adjusted product sample. The results are shown in the second row of Table 2.1 and the lower part of Table 2.2. Accounting for the changes in the classification of HS products does not change the decomposition results. The within effect is still dominant, while pharmaceutical products, meat and electric machinery are the HS6 products for which a larger fraction of their containerizable exports was containerized in 2018 compared to 2010.

Accounting Decomposition Results Using HS2 Product-level Data

Next, using aggregated HS2 product-level data, I decompose the aggregate change of U.S. containerized exports to the the rest of the world (X^c) as a share of U.S. containerizable exports (X^{c+b}) into within-product and between-product effects as the standard within/between decomposition equation (2.2) shows below

$$\Delta \frac{X_t^c}{X_t^{c+b}} = \underbrace{\sum_{g \in G} \Delta \frac{X_{g,t}^c}{X_{g,t}^{c+b}} \frac{1}{2}(\omega_{g,t} + \omega_{g,t-1})}_{\text{"Within" Effect}} + \underbrace{\sum_{g \in G} \Delta \omega_{g,t} \frac{1}{2}\Big(\frac{X_{g,t}^c}{X_{g,t}^{c+b}} + \frac{X_{g,t-1}^c}{X_{g,t-1}^{c+b}} \Big)}_{\text{"Between" Effect}} \tag{2.2}$$

To do so, I aggregate for each year the containerizable HS6 product-level data into HS2 product-level data. The decomposition results are shown in Table 2.3. Evidently, using aggregated product-level data, the within effect is dominant and accounts for more than 100 percent of the overall growth in containerized export shares from 2010 to 2018. This means that a larger fraction of containerizable products exported from the United States to the rest of the world is containerized. On the other hand, the between effects are negative, indicating that there is a shift towards containerizable products that are less containerized. Table 2.4 presents the top ten HS2 products in terms of within effects. Between 2010 and 2018, machinery, electric machinery and vehicles are the individual HS2 products with the highest within effect, indicating that a greater share of their exports is containerized. However, vehicles and pharmaceutical products are the two HS2 products that account for most of the growth in containerized export shares (Table D.2).

Summary and Discussion

To summarize, in this section I decompose the growth in the containerized export share into within- and between-product effects using disaggregated HS6 and aggregated HS2 product-level data. The decomposition results show that the within-product contribution is positive and dominant during the 2010-2018 period of growth in containerized export share, indicating that a significant fraction of containerizable products, such as vehicles, machinery and pharmaceutical products, experienced increase in their containerized export shares. On the other hand, the fact that the between-product effect is small suggests that the growth in the containerized export share is not driven by changes in the product composition of U.S. exports, i.e. the data reveals that there is no shift from exports of containerizable products that are less containerized towards exports of containerizable products that are highly containerized. Thus, there is little reason to believe that demand effects in containerizable product markets, such as those in response to changes in relative product prices, have contributed to the recent growth in containerized export shares. However, the data suggests that supply shocks, such as improvements in container transport technology that reduce container transport costs relative to other transport modes and in turn reduce exporting firms' costs, are possible drivers of containerized export share growth. For this reason, in the next section, I test this hypothesis by investigating the role of container transport cost in explaining the growth of U.S. containerized export share.

2.2 Empirical Effect of Container Transport Cost on Containerization

This section first lays out my empirical strategy for estimating the effect of container transport costs on the containerized share of U.S. containerizable exports. Then, I describe the data I use. Finally, I present both ordinary least squares (OLS) and two-stage least squares (2SLS) estimation results.

2.2.1 Estimation Framework

Do container transport costs have an impact on containerized share of U.S. containerizable exports? To answer this question I use the following empirical framework:

$$\Delta \frac{X^{c}_{ijgt}}{X^{c+b}_{ijgt}} = \beta \Delta CFR_{ijt} + \mu_g + \mu_{ij} + \mu_t + e_{ijgt}, \tag{2.3}$$

where $\Delta \frac{X^{c}_{ijgt}}{X^{c+b}_{ijgt}}$ is the change in containerized share of total containerizable exports (in value) from U.S. port i to foreign country j of product g from year $t-1$ to t and ΔCFR_{ijt} is the change in the Container Freight Rate (transport cost per 20-foot container) from origin i to destination j from year $t-1$ to t. The rate at which products tend to become transported in containers is likely to vary across products for reasons other than cost. To control for this, I include product fixed effects, denoted by μ_g. The suitability of individual ports for container traffic changes over time, as some ports focus relatively more on building container terminals than others. In order to control for this, I include origin-destination fixed effects, denoted by μ_{ij}. Moreover, conditions that affect all products and origin-destination pairs change over time, such as container transport technology and break-bulk shipping price. In order to control for this, I include time fixed effects, denoted by μ_t. e_{ijgt} denotes the error term.

In contrast to the empirical gravity approach that uses physical distance, common language, and common colonial history as a proxy for the unobservable component of bilateral trade costs, this dissertation is one of the few papers in the literature that uses a direct measure of transport costs, such as the container freight rate, measured as the price to transport a 20-foot container.[5]

The time varying change in the bilateral container freight rate is the key explanatory variable. The coefficient on this variable, β, is interpreted as the effect of increasing the bilateral container freight rate by 1,000 dollars on the bilateral product-specific containerized share of U.S. containerizable exports.[6]

[5]Exceptions are Wong (2017), Asturias (2018), and Limão and Venables (2001).

[6]Ideally, I would use a relative price measure, e.g., the container freight rate relative to the break-bulk freight rate. The latter is product-specific because it depends on volume and weight of cargo transported. However, I control for the break-bulk shipping price by including time fixed effects.

Estimating equation (2.3) by ordinary least squares (OLS) is problematic, because container freight rates are endogenous. Hence, OLS estimates are biased. For example, an unobserved reduction in the fixed cost of containerization relative to fixed cost of break-bulk will simultaneously increase demand for container transport relative to break-bulk by exporters and container freight rates. Thus, to be able to consistently estimate β, an instrument is required that is uncorrelated with the error of equation (2.3) but is correlated with the container freight rate.

To identify the effect of container transport cost on the containerized share of U.S. containerizable exports, I need a shifter of transport supply that is independent of the determinants of demand for containers. My transport supply shifter is a Bartik-style instrument and is given by the annual growth rate in the average container freight rate across origin-destination pairs from year $t-1$ to t weighted by the initial (time-invariant) origin-destination specific container freight rate

$$Z_{ijt} = \left(log\overline{CFR_t} - log\overline{CFR_{t-1}}\right)CFR_{ijt_0}, \tag{2.4}$$

where $\overline{CFR_t} = \frac{1}{N_{ij}}\sum_i \sum_j CFR_{ijt}$ is the average container freight rate across all origin-destination pairs at year t.

In particular, the Bartik instrument ensures that any aggregate change in growth rates will be proportional to the initial origin-destination specific container freight rate. That is, in case of a decline in the average container freight rate due to technological improvements in container shipping, port-pairs with high initial bilateral container freight rate will be affected more than port-pairs with low initial bilateral container freight rate. For example, it is intuitive that lower freight rate has larger effect on long distance transportation than on short distance transportation. Thus, the identifying assumption is that container transport supply shocks have greater effects on port-pairs with high initial bilateral container freight rate than port-pairs with low initial bilateral container freight rate. One potential weakness of the instrument is that the growth rates of average freight rates may be endogenous to aggregate growth in containerized quantities. However, time fixed effects remove time series variation and make the instrument capture differences on the impact of aggregate changes between ports pairs that originally had low or high container freight rate. This can be seen as a difference-in-difference setting.

The above framework yields a single estimated slope coefficient that applies to all HS2 categories. I also estimate the following regression:

$$\Delta \frac{X^{c}_{ijgt}}{X^{c+b}_{ijgt}} = \sum_{g=1}^{G} \beta_g [\Delta CFR_{ijt} * \mu_g] + \mu_{ij} + \mu_t + e_{ijgt} \tag{2.5}$$

where μ_g are product dummy variables and $g = 1, ..., G$ are containerizable HS2 products. In the above regression, there is a separate slope coefficient for each HS2 product, β_g, which is interpreted as the product-specific effect of container freight rate on containerized export shares. I am expecting negative coefficients for most products and larger negative effects for products that are less containerized than products that are highly containerized.

2.2.2 Data

To estimate equation (2.3), I combine two different data sets. I employ a data set of bilateral container freight rates collected by Drewry Maritime Research (Drewry). The container freight rate is the average price in dollars that is paid by freight forwarders to ocean carriers for the transport of a fully loaded 20-foot container from an origin port to a destination port, and vice versa, in a given month (see data Appendix A.2 for further information). Freight forwarders arrange freight shipments on behalf of suppliers or importers, depending on who is responsible for freight arrangements, and ocean carriers are companies that own ships and arrange freight movements from port to port. In addition, I aggregate the monthly container freight rate to obtain annual data by calculating for each port pair the average container freight rate.

The time frame of my analysis is dictated by the availability of bilateral container freight rate data.[7] The port pairs in my data set are the three U.S. ports (Houston, Los Angeles, and New York) and the foreign ports located in 10 OECD countries together with China and India from 2010 to 2018.[8] These are the top 3 U.S. ports as measured by twenty-foot

[7] Drewry reports data on container freight rates from 2006 to the present but data coverage is limited over the period 2006-2009.

[8] The OECD countries are Australia, Chile, Italy, Japan, Korea, Mexico, New Zealand, Netherlands, Turkey,

equivalent units (TEU) of container cargo. Unlike dry bulk ports, which usually handle solely imports or exports, container ports handle both imports and exports. The ports analyzed handle on average around 50 percent of total U.S. containerized exports by value.

I combine the container freight rate data set with product-level seaborne and containerized export data over the period 2010-2018 from the U.S. Census Bureau's USA Trade Online. USA Trade Online reports annual value of total seaborne and containerized exports of products between US ports and foreign countries with products disaggregated to the 6-digit Harmonized System (HS) level. Using my previously defined measure of containerizable exports, I aggregate for each year the containerizable HS6 product-level data into HS2 product-level data. Since Drewry provides port-level freight rate data, while USA Trade Online provides U.S. port-foreign country export data, I combine freight rates from a U.S. port to a foreign port provided by Drewry with seaborne and containerized export data from the U.S. port to the foreign country in which the foreign port is located.

An attractive feature of my panel specification is that it allows me to examine the dynamic aspects of U.S. containerized exports over time. My final data set is an unbalanced panel because the United States is not trading all HS2 products with all foreign countries in all years and also freight rate data between U.S. ports and some countries is not available for all years. Each annual observation is at a U.S. port-foreign country and HS2 product-level. Table 2.5 presents summary statistics for the combined data set. The average bilateral container freight rate is 1,592 dollars per container, with substantial variation. Additionally, the data provides evidence for the decline in container transport cost since 2010. Figure 2.3 shows for each year in the data set, the average real container freight rate across port pairs, which is declining. On the other hand, the containerized share of containerizable exports is increasing on average during the sample period.

2.2.3 Results

Table 2.6 presents OLS and 2SLS estimated coefficients of equation (2.3). Column (1) reports the OLS estimate of the effect of container transport cost on the containerized share of U.S. containerizable exports, which is generally inconsistent. The estimate is almost

and United Kingdom.

zero and is not statistically significant. Of course, because the container freight rates are endogenous, the OLS estimates are a biased measure of the demand response to container freight rates. In particular, shifts in the demand curve owing to forces that are independent of improvements in transportation technology will bias the coefficient upwards.

Column (2) reports the 2SLS estimate of the effect of container transport cost on the containerized share of U.S. containerizable exports using the Bartik instrument. The 2SLS estimate is much larger in magnitude than the OLS estimate. The 2SLS estimate is negative and statistically significant, after controlling for product, origin-destination, and time fixed effects. A 1,000 dollars decrease in container freight rates is associated with a 9 percentage point increase in the containerized share of U.S. exports. To put this in a broader perspective, a one standard deviation decrease in container freight rate increases containerized export shares by 2 percentage points. Thus, the result suggests that declines in container freight rates are associated with statistically significant and economically large increases of bilateral containerized export shares.

In terms of magnitudes, the average container freight rate across port pairs has declined by 1,015 dollars from 2010 to 2018. The estimated coefficient implies that for a port pair with that decline, all else equal, the containerized share of containerizable exports should have risen by 9 percentage points. This rise is equivalent to 130 percent of the average increase in the containerized share of containerizable exports from 2010 to 2018.

The first stage results are shown in Table 2.7 and Figure 2.4. Controlling for time-invariant differences across products and port-pairs, as well as aggregate time-varying shocks, a 1,000 dollars increase in my constructed instrument corresponds to a significant and positive 2.5 dollar increase in container freight rate. Finally, the F-statistic of the first stage regression suggests that I do not have a weak instrument problem.

Moreover, the effects of container freight rates on the containerized share of U.S. containerizable exports are heterogeneous across products. In appendix Table D.3 I report the HS2 product-specific effects of container freight rate on the containerized export share of each HS2 product.[9] As expected and shown in Figure 2.5 the estimated coefficients for more than nine-tenths of the HS2 products are negative. Furthermore, the coefficients

[9] HS2 product-specific first stage regression results are shown in appendix Tables D.4.

on most HS2 products with low average containerized export shares are higher on absolute value than the coefficients on HS2 products with higher average containerized export shares. For example, works of art (HS97) have an 85 percent containerized export share, while tobacco (HS24) have a 91 percent containerized export share; the regression results indicate that, in response to a 1,000 dollars decline in the container freight rate, works of art have the highest increase in their containerized export share (22 percentage points), while tobacco have the lowest increase (0.5 percentage point).

Next, I test the simultaneous hypotheses that the product-specific effects (coefficients of interaction term in equation (2.5)) are equal for HS2 products within aggregated HS2 product categories. A list of aggregated HS2 product categories is given in appendix Table D.5. I fail to reject the null hypotheses that the effects are identical within aggregated HS2 products. This result suggests equating the HS2 product-specific effects within aggregated HS2 products will not substantially harm the fit of the model. Table 2.8 shows the aggregated HS2 product-specific effects of container freight rate on the containerized export share.[10] Changes in containerized export shares for all aggregated HS2 products respond negatively to changes in container freight rates. On average, decreasing the container freight rate by 1,000 dollars increases the containerized export share by 9 percentage points. However, the effects vary across products. Decreasing the container freight rate by 1,000 dollars increases the containerized export share of metals by 13 percentage points while it increases the containerized export share of footwear by only 4 percentage points. The average containerized export share of metals is 74 percent while the average containerized export share of footwear is 82 percent. Evidently, as shown in Figure 2.6, products with low average containerized export share experience larger increases in their containerized export share in response to a decline in container freight rates than products with high average containerized export share.

Finally, to investigate the effects of origin-destination- and year-specific factors unrelated to container freight rates on containerized export shares, I test whether origin-destination- and year-specific intercepts of equation (2.5) are simultaneously identical for all origin-destination pairs and years, respectively. The results show that origin-destination-

[10] Aggregated HS2 product-specific first stage regression results are shown in appendix Table D.6.

and year-specific factors unrelated to container freight rates have heterogeneous effects on the containerized export shares across origin-destination pairs and over time, respectively.[11] Figure 2.7 plots the relationship between the estimated coefficients on origin-destination fixed effects when Houston (USA)-Veracruz (MEX) is the omitted port pair and port distance. The relationship is positive indicating that the effect of origin-destination-specific factors unrelated to container freight rates on containerized export shares is higher for more distant port pairs than less distant port pairs. Figure 2.8 plots the estimated coefficients on year fixed effects when the omitted year is 2018. The effects of year-specific factors unrelated to container freight rates on containerized export shares are lower over the period from 2011 to 2017 than in 2018.

To summarize, in this section I investigate the role of container transport cost in explaining the growth of U.S. containerized export share. There is empirical evidence supporting the responsiveness of containerization to changes in container freight rates caused by technological improvement in the container transport industry. However, the data does not reveal the productivity or welfare gains associated with containerization. To quantify those, I develop in the next chapter a multi-country general equilibrium trade model with endogenous transport costs consistent with the data facts and empirical findings.

[11] I reject the null hypothesis that the coefficients of the origin-destination and year fixed effects in regression (2.5) are simultaneously identical.

Chapter 3

Model of Exporters with Endogenous Transport Costs

This chapter develops the theoretical model, solves for its general equilibrium and illustrates qualitatively the impact of productivity gains due to containerization on firms' productivity, trade flows and welfare in a symmetric two-country version of the model.

3.1 Model Set-up

The trade model in this dissertation builds on the monopolistic competition framework with heterogeneous firms introduced by Melitz (2003) and used by Rua (2014), where firms make export and transport decisions. I augment Rua (2014)'s model to allow for endogenous transport costs, which are determined in equilibrium by the interaction of demand and supply of sea transport.

I consider an open economy with a finite number of countries $i \in \{1, ..., N\}$. Each country has a continuum of firms and each firm in the world produces a distinct variety for final consumption $k \in M$. There is a continuum M of possible varieties that the world can produce and all varieties can be containerized.

3.1.1 Preferences and Optimal Demand

Each country is populated by L_i identical households, each of which supplies one unit of labor inelastically and earns wage w_i. Preferences of the representative household in county i are given by a constant elasticity of substitution (CES) over varieties available in county i:

$$U_i = \left[\sum_{j \in N} \int_{k \in \Omega_{ij}} c_{ij}(k)^{\frac{\sigma-1}{\sigma}} dk \right]^{\frac{\sigma}{\sigma-1}} \tag{3.1}$$

where $c_{ij}(k)$ is the quantity consumed in country i of variety k, which can be imported from j ($i \neq j$) or produced domestically ($i = j$), and $\sigma > 1$ is the elasticity of substitution between varieties. $\Omega_{ij} \in M$ is the exogenous mass of varieties available in county i, i.e. varieties that are produced by firms in i together with varieties produced by firms in each country j and are consumed in country i.

The representative household in country i maximizes her utility subject to her budget constraint:

$$\sum_{j \in N} \int_{k \in \Omega_{ij}} p_{ij}(k) c_{ij}(k) dk = Y_i \tag{3.2}$$

where $p_{ij}(k)$ is the price that consumers in i pay for the consumption of variety k and this price includes transportation costs when variety k is imported from j, and Y_i is aggregate expenditure allocated to imports from each exporting country j in country i. The first order condition with respect to $c_{ij}(k)$ that results from the utility maximization problem of the representative household in country i imply

$$c_{ij}(k) = p_{ij}(k)^{-\sigma} P_i^{\sigma-1} Y_i \tag{3.3}$$

which is optimal consumption and import demand in terms of the prices. The aggregate price index in country i is $P_i = \left[\sum_{j \in N} \int_{k \in \Omega_{ij}} p_{ij}(k)^{1-\sigma} dk \right]^{\frac{1}{1-\sigma}}$.

Hence, for a consumer in country i, total expenditure on variety k is

$$p_{ij}(k) c_{ij}(k) = p_{ij}(k)^{1-\sigma} P_i^{\sigma-1} Y_i \tag{3.4}$$

and total trade flows (trade value) from country j to country i are found by aggregating total expenditure over all firms in country j

$$X_{ij} = \int_{k \in \Omega_j} p_{ij}(k) c_{ij}(k) dk = P_i^{\sigma-1} Y_i \int_{k \in \Omega_j} p_{ij}(k)^{1-\sigma} dk \tag{3.5}$$

3.1.2 Technology and Optimal Supply

As in Melitz (2003) firms are heterogeneous in the production of varieties and all varieties can be containerized. Each firm in j has a productivity $\phi > 0$ drawn from a continuous distribution with cumulative distribution function $G(\phi)$ that does not vary across countries.

Trade between countries is not frictionless and exporting firms based in country j that want to export to country i face two additional export costs: variable transport costs p^t_{ij} and a fixed cost f_{ij} that does not vary with export volume. These costs are the same for all firms in country j. I endogenize transport costs (p^t_{ij}) by introducing a transportation sector that provides transport services for exporting firms. However, non-exporting firms in country j that produce only domestically do not face these costs, that is $p^t_{jj} = 0$ and $f_{jj} = 0$. The absence of fixed production cost ensures that all firms produce and sell domestically, because profits from selling in the domestic market are always positive, in contrast to the original Melitz model in which the presence of fixed production cost implies that not all firms will produce as firms with low productivity draw will earn negative profits and exit the industry.

Based on the productivity draw, a firm in addition to producing for its domestic market will choose whether to produce for the export market. Conditional on exporting, a firm endogenously chooses whether to containerize or use break-bulk shipping to transport its exports, $d \in \{b, c\}$, conditional on the exogenous adoption of the container service infrastructure by both the origin and the destination. This means that countries involved in trade have adopted the container service infrastructure. Thus, exporting firm's decision to use container or break-bulk shipping is not driven by the availability of the container service infrastructure in both the origin and the destination.

Although containerization involves lower transport costs than break-bulk shipping, it requires a higher fixed export cost, i.e. $p^{tb}_{ij} > p^{tc}_{ij} > 0$ and $f^c_{ij} > f^b_{ij} > 0$, where superscripts denote firm's choice of transport method $\{b, c\}$. Containerization decreased transport costs as it lowered cargo-handling costs and port time but "firms that wanted to use containerization had to keep sophisticated distribution, logistics, and inventory management systems that were more costly than their traditional systems, which had been created for working with break-bulk shipping" (Rua (2014)). Moreover, some exporting firms take container dimensions into account when they design their varieties so that varieties can be shipped fully assembled. If varieties cannot be shipped fully assembled, firms invest in finding practical ways to allow difficult varieties to be containerized by careful planning and some disassembly. For these reasons, firms that use containerization incur higher fixed exporting costs than firms that use break-bulk shipping.

Hence, based on this framework all firms produce domestically and can be partitioned by export and transport status into three groups: firms that do not export, firms that export using break-bulk shipping technology, and firms that export using containerization.

Prices, Revenue and Profits for a firm A firm with productivity ϕ can produce x_{ij} units of output with the amount of labor

$$l_{ij}(\phi) = \frac{1}{\phi} x_{ij}(\phi) + f_{ij} \tag{3.6}$$

where $x_{ij}(\phi)$ is the output of the variety produced by a firm in country j with productivity ϕ and sold to country i, $l_{ij}(\phi)$ is labor in j used to make this variety, f_{ij} is the fixed export cost measured in units of labor and $\frac{1}{\phi}$ is the production cost of one unit of output in units of labor by a firm with productivity ϕ. $\frac{1}{\phi} x_{ij}(\phi)$ units of labor are employed in country j that supplies $x_{ij}(\phi)$ units of output to country i. When the output of the variety produced by country j's firm is consumed only domestically, then $f_{jj} = 0$ and $x_{jj}(\phi) = c_{jj}(\phi)$ (production=consumption), and when the output of the variety produced by country j's firm is exported to country i, then $f_{ij} > 0$ and $x_{ij}(\phi) = c_{ij}(\phi)$ in case of endogenous transport costs.

In contrast to most trade models, which do not model the specific frictions that impede trade, and thus rely on iceberg costs, in this dissertation, I model trade as requiring transportation services t_{ij}. These services are produced by transportation firms, which employ labor. Thus, exporting firms in j who export to i demand transportation services t_{ij} which are offered by the transportation sector located in j. I assume that the exporting technology in each country is Leontieff; hence, this type of technology implies that one unit of transportation services is required for every unit of good transported regardless of location and thus distance.[1] Thus, $t_{ij} = x_{ij}(\phi) = c_{ij}(\phi)$ when $i \neq j$.

The optimization problem of a firm in country j with productivity ϕ is [2]

$$\max_{x_{ij}(\phi)} \sum_{i \in N} \left[p_{ij}(\phi)x_{ij}(\phi) - p^t_{ij}x_{ij}(\phi) - w_j l_{ij}(\phi) \right]$$

$$\max_{x_{ij}(\phi)} \sum_{i \in N} \left[p_{ij}(\phi)x_{ij}(\phi) - p^t_{ij}x_{ij}(\phi) - \frac{w_j}{\phi}x_{ij}(\phi) - w_j f_{ij} \right] \tag{3.7}$$

$$s.t. x_{ij}(\phi) = c_{ij}(\phi) = p_{ij}(\phi)^{-\sigma} P_i^{\sigma-1} Y_i$$

The first order condition implies that a firm in j with productivity ϕ will charge a price

$$p_{ij}(\phi) = \frac{\sigma}{\sigma - 1}\left(\frac{w_j}{\phi} + p^t_{ij}\right) \tag{3.8}$$

which is a gross markup over marginal cost - which includes both the marginal production cost and the transportation services - where the gross markup is $\frac{1}{\rho} = \frac{\sigma}{\sigma-1}$ and $0 < \rho < 1$.

The total revenue received by a firm in country j from supplying a variety to country i is given by combining the optimal price (3.8) and the optimal demand (C.4)

$$r_{ij}(\phi) = p_{ij}(\phi)c_{ij}(\phi) = \left[\frac{\sigma}{\sigma - 1}\left(\frac{w_j}{\phi} + p^t_{ij}\right)\right]^{1-\sigma} P_i^{\sigma-1} Y_i \tag{3.9}$$

The corresponding firm profits are

$$\pi_{ij}(\phi) = p_{ij}(\phi)x_{ij}(\phi) - p^t_{ij}x_{ij}(\phi) - \frac{w_j}{\phi}x_{ij}(\phi) - w_j f_{ij} = \frac{1}{\sigma}r_{ij}(\phi) - w_j f_{ij} \tag{3.10}$$

[1] Exporting firms combine transportation services with exports in order to produce imports into the other countries, i.e. $c_{ij}(\phi) = min[x_{ij}(\phi), t_{ij}]$, where c_{ij} is i's demand for imports from j, x_{ij} are j's exports to i and t_{ij} are the transportation services needed to transport goods from j to i.

[2] For a non-exporting firm in j, the objective function becomes $\max_{x_{jj}(\phi)} \left[p_{jj}(\phi)c_{jj}(\phi) - \frac{w_j}{\phi}c_{jj}(\phi) \right]$.

Both revenue and profit are increasing in a firm's productivity. The combined revenue and profit of a firm depend on its export and transport status

$$r_{ij}(\phi) = \begin{cases} \left(\frac{\sigma}{\sigma-1}\frac{w_j}{\phi}\right)^{1-\sigma} P_j^{\sigma-1} Y_j = r_{jj}(\phi) & \text{if firm does not export} \\ \left[\frac{\sigma}{\sigma-1}\left(\frac{w_j}{\phi} + p_{ij}^{tb}\right)\right]^{1-\sigma} P_i^{\sigma-1} Y_i = r_{ij}^{b}(\phi) & \text{if firm exports with b} \\ \left[\frac{\sigma}{\sigma-1}\left(\frac{w_j}{\phi} + p_{ij}^{tc}\right)\right]^{1-\sigma} P_i^{\sigma-1} Y_i = r_{ij}^{c}(\phi) & \text{if firm exports with c} \end{cases} \tag{3.11}$$

$$\pi_{ij}(\phi) = \begin{cases} \frac{1}{\sigma} r_{jj}(\phi) = \pi_{jj}(\phi) & \text{if firm does not export} \\ \frac{1}{\sigma} r_{ij}^{b}(\phi) - w_j f_{ij}^{b} = \pi_{ij}^{b}(\phi) & \text{if firm exports with b} \\ \frac{1}{\sigma} r_{ij}^{c}(\phi) - w_j f_{ij}^{c} = \pi_{ij}^{c}(\phi) & \text{if firm exports with c} \end{cases} \tag{3.12}$$

Because profit from selling in the domestic market ($\pi_{jj}(\phi)$) is always positive, because $f_{jj} = 0$, an exporting firm will always sell in the domestic market. Thus

$$\pi_{ij}(\phi) = \begin{cases} \frac{1}{\sigma} r_{jj}(\phi) = \pi_{jj}(\phi) & \text{if firm does not export} \\ \pi_{jj}(\phi) + \pi_{ij}^{b}(\phi) & \text{if firm sells in the domestic market and exports with b} \\ \pi_{jj}(\phi) + \pi_{ij}^{c}(\phi) & \text{if firm sells in the domestic market and exports with c} \end{cases} \tag{3.13}$$

Transportation Sector When transport costs are endogenous, cross-country trade in varieties requires the production of transportation services t_{ij} by a transportation firm located in each country. Transportation services t_{ij} are produced according to the following simple linear technology in labor:

$$t_{ij} = A_{ij} l_{ij}^{t} \tag{3.14}$$

where A_{ij} is transportation sector productivity and l_{ij}^{t} is labor employed in the transportation sector. I assume that each country j has a transportation firm that solves the following problem

$$\max_{l^t_{ij}} \sum_{i \in N} \left[p^t_{ij} t_{ij} - w_j l^t_{ij} \right] \\ s.t. t_{ij} = A_{ij} l^t_{ij} \tag{3.15}$$

The first order condition with respect to l^t_{ij} implies that the transport cost per unit of good transported is

$$p^t_{ij} = \frac{w_j}{A_{ij}} \tag{3.16}$$

My model's innovation is that changes in transport costs reflect both changes in transportation sector productivity and wages. Transporting a unit of a good within each country is costless $p^t_{jj} = 0$ while transporting a unit of a good across countries costs $p^t_{ij} > 0$ and this transport cost depends on wages and the transportation productivity of the exporting country. The productivity of the transportation sector using containerization is higher than the productivity of the transportation sector using break-bulk shipping $A^c_{ij} > A^b_{ij}$ which implies $p^{tc}_{ij} < p^{tb}_{ij}$ as containerization is considered to be a force that improves the efficiency of transportation services and as a result reducing transport costs.

Firm's Export and Transport Decision All firms in each country produce and sell domestically and can be partitioned into three groups based on their export and transport status: firms that do not export, firms that export using break-bulk shipping technology, and firms that export using containerization. These three groups are partitioned by the two zero-profit cutoff productivities, ϕ^{*b}_{ij} and ϕ^{*c}_{ij}, as shown in Figure 3.1.

A firm from country j with productivity ϕ who produces for its domestic market will export to i using shipping technology $d \in \{b, c\}$ if and only if its profits from exporting using break-bulk shipping technology inclusive of fixed costs exceed zero

$$\pi^b_{ij}(\phi) \geq 0 \tag{3.17}$$

From equations (3.9) and (3.10) and with *endogenous trade costs*, equation (3.17) can be written as (see derivation in Appendix B.1)

$$\frac{1}{\sigma}\left[\frac{\sigma}{\sigma-1}\left(\frac{w_j}{\phi}+p_{ij}^{tb}\right)\right]^{1-\sigma}P_i^{\sigma-1}Y_i - w_j f_{ij}^b \geq 0$$
$$\phi \geq w_j\left\{\left[\frac{\sigma\left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1} w_j f_{ij}^b}{P_i^{\sigma-1}Y_i}\right]^{\frac{1}{1-\sigma}} - p_{ij}^{tb}\right\}^{-1} \equiv \phi_{ij}^{b*} \tag{3.18}$$

ϕ_{ij}^{b*} is the cutoff productivity level for exporting firms. If $\phi \geq \phi_{ij}^{b*}$, a firm will export using either break-bulk shipping technology or containerization.

A firm from country j with productivity ϕ will export to i using shipping technology c if and only if its profits from using containerization exceed its profits from using break-bulk shipping

$$\pi_{ij}^c(\phi) \geq \pi_{ij}^b(\phi) \tag{3.19}$$

From equations (3.9) and (3.10) and with *endogenous trade costs*, equation (3.19) can be written as

$$\frac{1}{\sigma}\left[\frac{\sigma}{\sigma-1}\left(\frac{w_j}{\phi}+p_{ij}^{tc}\right)\right]^{1-\sigma}P_i^{\sigma-1}Y_i - w_j f_{ij}^c \geq \frac{1}{\sigma}\left[\frac{\sigma}{\sigma-1}\left(\frac{w_j}{\phi}+p_{ij}^{tb}\right)\right]^{1-\sigma}P_i^{\sigma-1}Y_i - w_j f_{ij}^b$$
$$\left(\frac{w_j}{\phi}+p_{ij}^{tc}\right)^{1-\sigma} - \left(\frac{w_j}{\phi}+p_{ij}^{tb}\right)^{1-\sigma} \geq \left[\frac{\left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1}\sigma w_j(f_{ij}^c - f_{ij}^b)}{P_i^{\sigma-1}Y_i}\right] \tag{3.20}$$

Thus, with *endogenous trade costs*, there is no analytic expression for ϕ_{ij}^{c*}. ϕ_{ij}^{c*} will be the level of productivity that equalizes the profits from using containerization and profits from using break-bulk shipping

$$\pi_{ij}^c(\phi_{ij}^{c*}) = \pi_{ij}^b(\phi_{ij}^{c*})$$
$$\left(\frac{w_j}{\phi_{ij}^{c*}}+p_{ij}^{tc}\right)^{1-\sigma} - \left(\frac{w_j}{\phi_{ij}^{c*}}+p_{ij}^{tb}\right)^{1-\sigma} = \left[\frac{\left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1}\sigma w_j(f_{ij}^c - f_{ij}^b)}{P_i^{\sigma-1}Y_i}\right] \tag{3.21}$$

ϕ_{ij}^{c*} is the cutoff productivity level for exporting firms that use shipping technology c. If $\phi \geq \phi_{ij}^{c*}$, a firm will export using containerization and the equilibrium distribution of productivity for exporting firms is given by $\mu_{ij}^c(\phi) = \frac{g(\phi)}{1-G(\phi_{ij}^{c*})}$. This is the conditional distribution of $g(\phi)$ on $[\phi_{ij}^{c*}, \infty)$ where $1 - G(\phi_{ij}^{c*})$ is the probability of exporting using shipping technology c and $g(\phi)$ is the exogenous distribution of productivity levels. Thus, if $\phi_{ij}^{b*} \leq \phi < \phi_{ij}^{c*}$, a firm will export using shipping technology b and the equilibrium distribution of productivity for exporting firms is given by $\mu_{ij}^{b}(\phi) = \frac{g(\phi)}{\left(1-G(\phi_{ij}^{b*})-(1-G(\phi_{ij}^{c*}))\right)}$. This is the conditional distribution of $g(\phi)$ on $[\phi_{ij}^{b*}, \phi_{ij}^{c*})$ where $\left(1 - G(\phi_{ij}^{b*}) - (1 - G(\phi_{ij}^{c*}))\right) = G(\phi_{ij}^{c*}) - G(\phi_{ij}^{b*})$ is the probability of exporting using shipping technology b. Moreover, since all firms in i produce and sell domestically, the equilibrium distribution of productivity for all firms is equal to the exogenous distribution of productivity levels, $\mu_{ii}(\phi) = g(\phi)$.

The cutoff productivities ϕ_{ij}^{c*} and ϕ_{ij}^{b*} then can be used to determine the mass of firms exporting from j to i using shipping technology c, M_{ij}^{c}, and b, M_{ij}^{b}, which are given by

$$M_{ij}^{c} = [1 - G(\phi_{ij}^{c*})]M_j \tag{3.22}$$

$$M_{ij}^{b} = [G(\phi_{ij}^{c*}) - G(\phi_{ij}^{b*})]M_j \tag{3.23}$$

where M_j is the mass of all firms (non-exporting and exporting) in j which is normalized to 1. Additionally, cutoff productivities ϕ_{ij}^{c*} and ϕ_{ij}^{b*} can be used to determine average prices charged by exporting firms that use containerization, exporting firms that use break-bulk, and non-exporting firms

$$\begin{aligned}
\int_{k\in\Omega_j} p_{ij}^{c}(k)^{1-\sigma}dk &= \int_0^\infty \left[\frac{\sigma}{\sigma-1}\left(\frac{w_j}{\phi} + p_{ij}^{tc}\right)\right]^{1-\sigma} M_{ij}^{c}\mu_{ij}^{c}(\phi)d\phi \\
&= \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \int_{\phi_{ij}^{c*}}^{\infty} \left(\frac{w_j}{\phi} + p_{ij}^{tc}\right)^{1-\sigma} [1 - G(\phi_{ij}^{c*})]M_j \frac{g(\phi)}{1 - G(\phi_{ij}^{c*})}d\phi \\
&= \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} M_j \int_{\phi_{ij}^{c*}}^{\infty} \left(\frac{w_j}{\phi} + p_{ij}^{tc}\right)^{1-\sigma} dG(\phi)
\end{aligned} \tag{3.24}$$

$$\begin{aligned}
\int_{k\in\Omega_j} p_{ij}^{b}(k)^{1-\sigma}dk &= \int_0^\infty \left[\frac{\sigma}{\sigma-1}\left(\frac{w_j}{\phi} + p_{ij}^{tb}\right)\right]^{1-\sigma} M_{ij}^{b}\mu_{ij}^{b}(\phi)d\phi \\
&= \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \int_{\phi_{ij}^{b*}}^{\phi_{ij}^{c*}} \left(\frac{w_j}{\phi} + p_{ij}^{tb}\right)^{1-\sigma} [G(\phi_{ij}^{c*}) - G(\phi_{ij}^{b*})]M_j \frac{g(\phi)}{G(\phi_{ij}^{c*}) - G(\phi_{ij}^{b*})}d\phi \\
&= \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} M_j \int_{\phi_{ij}^{b*}}^{\phi_{ij}^{c*}} \left(\frac{w_j}{\phi} + p_{ij}^{tb}\right)^{1-\sigma} dG(\phi)
\end{aligned} \tag{3.25}$$

$$\int_{k\in\Omega_i} p_{ii}(k)^{1-\sigma}dk = \left(\frac{\sigma}{\sigma-1}w_i\right)^{1-\sigma} M_i \int_{\phi_{ii}}^{\infty} \phi^{\sigma-1} dG(\phi) \tag{3.26}$$

The derivations of the aggregate price index, average prices charged by each type of firm, and export flows, are given in Appendix B.2. These expressions can be simplified for the special case of the Pareto distribution. See Appendix B.3.

3.2 Equilibrium Conditions

In this section, I solve for the general equilibrium of the model presented in the previous section.

3.2.1 Price indices

The aggregate price index in each country i is given by

$$\begin{aligned} P_i &= \left[\sum_{j\in N} \int_{k\in\Omega_j} p_{ij}(k)^{1-\sigma}dk\right]^{\frac{1}{1-\sigma}} \\ &= \left[\sum_{j,j\neq i} \left(\int_{k\in\Omega_j} p_{ij}^{c}(k)^{1-\sigma}dk + \int_{k\in\Omega_j} p_{ij}^{b}(k)^{1-\sigma}dk\right) + \int_{k\in\Omega_i} p_{ii}(k)^{1-\sigma}dk\right]^{\frac{1}{1-\sigma}} \end{aligned} \tag{3.27}$$

With *endogenous trade costs* (3.27) becomes

$$\begin{aligned} P_i = &\Bigg[\sum_{j,j\neq i} \Bigg(\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} M_j \int_{\phi_{ij}^{c*}}^{\infty} \left(\frac{w_j}{\phi} + p_{ij}^{tc}\right)^{1-\sigma} dG(\phi) + \\ &\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} M_j \int_{\phi_{ij}^{b*}}^{\phi_{ij}^{c*}} \left(\frac{w_j}{\phi} + p_{ij}^{tb}\right)^{1-\sigma} dG(\phi)\Bigg) + \left(\frac{\sigma}{\sigma-1}w_i\right)^{1-\sigma} M_i \int_{\phi_{ii}}^{\infty} \phi^{\sigma-1} dG(\phi)\Bigg]^{\frac{1}{1-\sigma}} \end{aligned} \tag{3.28}$$

3.2.2 Labor market equilibrium

The labor market equilibrium condition ensures that labor market income in each country i equals spending, i.e. a country's labor market income equals the implicit demand for labor via spending on goods the country produces.

$$
\begin{aligned}
Y_i = w_i L_i &= \sum_{j \in N} \int_{k \in \Omega_{ij}} p_{ij}(k) c_{ij}(k) dk \\
&= \sum_{j, j \neq i} \Big(\int_{k \in \Omega_j} p^c_{ij}(k) c^c_{ij}(k) dk + \int_{k \in \Omega_j} p^b_{ij}(k) c^b_{ij}(k) dk \Big) + \int_{k \in \Omega_i} p_{ii}(k) c_{ii}(k) dk
\end{aligned} \tag{3.29}
$$

With *endogenous trade costs*, (3.29) becomes

$$
\begin{aligned}
Y_i = &w_i L_i = P_i^{\sigma-1} Y_i \sum_{j, j \neq i} \Bigg[\Big(\frac{\sigma}{\sigma - 1} \Big)^{1-\sigma} M_j \int_{\phi^{c*}_{ij}}^{\infty} \Big(\frac{w_j}{\phi} + p^{tc}_{ij} \Big)^{1-\sigma} dG(\phi) + \\
&\Big(\frac{\sigma}{\sigma - 1} \Big)^{1-\sigma} M_j \int_{\phi^{b*}_{ij}}^{\phi^{c*}_{ij}} \Big(\frac{w_j}{\phi} + p^{tb}_{ij} \Big)^{1-\sigma} dG(\phi) \Bigg] + P_i^{\sigma-1} Y_i \Big(\frac{\sigma}{\sigma - 1} w_i \Big)^{1-\sigma} M_i \int_{\phi_{ii}}^{\infty} \phi^{\sigma-1} dG(\phi)
\end{aligned} \tag{3.30}
$$

3.2.3 Trade balance condition

The trade balance condition ensures that total value of containerized and break-bulk exports from each country j to all trade partners $i \neq j$ equal to country j's value of containerized and break-bulk imports from all trade partners $i \neq j$. Country i's expenditure on varieties produced by firms in j, X_{ij}, is given by equation (3.5). Thus, the trade balance condition is

$$
\begin{aligned}
\sum_{j, j \neq i} \left(\sum_{i, i \neq j} X_{ij} \right) &= \sum_{j, j \neq i} \left(\sum_{i, i \neq j} X_{ji} \right) \\
\sum_{j, j \neq i} \left(\sum_{i, i \neq j} \left(X^c_{ij} + X^b_{ij} \right) \right) &= \sum_{j, j \neq i} \left(\sum_{i, i \neq j} \left(X^c_{ji} + X^b_{ji} \right) \right)
\end{aligned} \tag{3.31}
$$

where

$$
X^c_{ij} = P_i^{\sigma-1} Y_i \int_{k \in \Omega_j} p^c_{ij}(k)^{1-\sigma} dk = P_i^{\sigma-1} Y_i \Big(\frac{\sigma}{\sigma - 1} \Big)^{1-\sigma} M_j \int_{\phi^{c*}_{ij}}^{\infty} \Big(\frac{w_j}{\phi} + p^{tc}_{ij} \Big)^{1-\sigma} dG(\phi) \tag{3.32}
$$

$$X_{ij}^{b} = P_i^{\sigma-1} Y_i \int_{k\in\Omega_j} p_{ij}^{b}(k)^{1-\sigma} dk = P_i^{\sigma-1} Y_i \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} M_j \int_{\phi_{ij}^{b*}}^{\phi_{ij}^{c*}} \left(\frac{w_j}{\phi} + p_{ij}^{tb}\right)^{1-\sigma} dG(\phi) \quad (3.33)$$

3.3 Numerical Exercise

In this section, I conduct a numerical exercise that illustrates the impact of productivity gains due to containerization on firms' productivity, trade flows and welfare by solving a symmetric two-country version of the model and assuming that the distribution of productivities is Pareto (see the steps in Appendix C.1). Table 3.1 summarizes the parameters and exogenous variables of the model and their assigned values. The parameters are designed to capture two symmetric countries like the United States in the 2000s. The goal of this exercise is to show how the model-generated variables will be affected when container transport productivity triples. Improved efficiency, bigger ships and more effective organization of the shipping operation have brought about a steady reduction in transport costs and higher quality of service.

Table 3.2 reports the model-generated country-level and firm-level variables. A reduction in variable container transport cost due to an improvement in container transport labor productivity will lead to an increase in profits of a container exporting firm whose productivity is greater than the threshold productivity necessary to export with containers (c-cutoff). The more productive this firm is, the greater the increase in its profits. This results in a shift of the c-cutoff to the left, as shown in Figure 3.2, which means that the most productive break-bulk exporters will switch to containerization. Thus, the mass of container exporters increases.

As container transport costs decline due to an increase in the efficiency of containerization two things happen. First, exporting firms who are already containerizing their exports will containerize more. This happens because when container transport costs decline, the price that these exporting firms charge for their products decreases as the price includes container transport costs. Thus, this decline in the price leads to an increase in the demand for containerized exports by importers and in turn increase in supply by exporters who will containerize more. This result is known as the intensive margin. Second, the most productive break-bulk exporters, who were not containerizing their exports previously, will switch to containerization. This result is known as the extensive margin. Both effects will increase containerized exports and welfare.

To produce this higher containerized exports, new and existing container exporting firms will increase their demand for labor, which in turn drives up wages. However, higher wages will decrease profits of break-bulk exporters. As a result, the break-bulk cutoff, which is the minimum productivity required to export, will shift to the right. Thus, the least productive break-bulk exporters are forced to exit the export market and the mass of break-bulk exporters will shrink.

Additionally, the model implies that an increase in container transport productivity has two opposing effects on container transport costs. It decreases the container transport cost but not proportionally because wages also rise due to the increased demand for labor by exporting firms. Which of the two opposing effects will dominate depends on the existing level of container transport productivity. In addition, the model implies that an improvement in container transport labor productivity will increase the average productivity of exporting firms because, first, the least productive break-bulk exporters are forced to exit the export market, and second, the mass of high productivity exporters, who containerize their exports, increases. Moreover, labor will be allocated from the least productive break-bulk exporters, who exit the export market, toward the more productive break-bulk exporters, who adopt containers.

Chapter 4

Conclusion

This dissertation investigates empirically and quantitatively the determinants of containerization in the United States. Even though containers are now over 50 years old, as of 2010 only 61 percent of containerizable U.S. exports used containers, suggesting that the container revolution is still taking place. But the share did increase by almost 10 percentage points in the last decade. My dissertation investigates whether this growth is driven by demand forces, such as a shift in preferences towards highly containerized products, or supply forces, such as continued improvements in container transport technology that make the use of containers cheaper.

I perform within-between type decomposition, which includes entry and exit, to study the sources of the recent growth in the containerized share of U.S. containerizable exports at the product level. The majority of this growth is driven by a broad increase in the share of each product that is containerized, rather than a shift from exports of products that are less containerized towards exports of products that are highly containerized. This finding is consistent with technology induced improvements in container shipping, that make containerization more efficient and thus cheaper, as the possible driver of growth in containerization.

To test this hypothesis, I empirically estimate a panel regression of the containerized share of U.S. containerizable exports on container freight rates after controlling for various fixed effects. My empirical methodology recognizes that demand factors can also affect container freight rates and to control for that I use an instrumental variable approach. The instrumental variable that I use is a Bartik-type instrument and is based on the idea that a decline in average container freight rates due to technological improvements have greater effects on long distance transportation than on short distance transportation. To construct the instrument and run the instrumental variable regressions, I use an unbalanced panel data set of bilateral port-level exports by product, and bilateral port-level container freight rates from 2010 to 2018. The regression results show that declines in container freight rates are associated with statistically significant and economically large increases of bilateral containerized export shares. Thus, there is empirical evidence supporting the responsiveness of containerization to changes in container freight rates caused by technological improvement in the container transport industry. In addition, the effects are heterogeneous across products. I find that products that are less containerized are affected more by declines in container freight rates than products that are highly containerized.

Finally, to assess the welfare gains from the technology induced increase in containerization, I develop a firm-level general equilibrium trade model with endogenous transport costs in which heterogeneous firms make both export and transport decisions. The model builds on the monopolistic competition framework with heterogeneous firms in terms of productivity. In contrast to the international trade literature that relies on exogenous transport costs, this dissertation emphasizes the role of transport in international trade by allowing for endogenous transport costs. My model's innovation is that changes in transport costs reflect both changes in transportation sector productivity and wages. The model implies that technology induced decline in container transport costs makes some exporting firms to switch their transport mode to containerization and increases trade, welfare and the average productivity of exporting firms.

My plan for future work is to perform an in-depth calibration and parameterization of my theoretical model and use it to conduct quantitative exercises. I aim to assess quantitatively the effects of containers on bilateral trade to explore how much of the increase in trade can be attributed to improvements in container transport technology.

Tables and Figures

Table 2.1: Decomposition Results of Containerized Export Share Growth by HS6 Products, 2010-2018

$t-1$	t	$\Delta \frac{X_t^c}{X_t^{c+b}}$	Within Share	Between Share	Cross Share	Entry Share	-Exit Share	Net Entry Share
All HS6 Products								
2010	2018	0.077	1.789	0.144	-0.418	-0.497	-0.018	-0.515
Adjusted HS6 Products								
2010	2018	0.092	1.503	0.166	-0.219	-0.444	-0.006	-0.449

Notes: The table shows results from the decomposition of the aggregate change of U.S. containerized exports to the the rest of the world (X^c) as a share of U.S. containerizable exports (X^{c+b}) into within-, between-, cross-, entry- and exit-product effects between 2010 and 2018. I conduct the decomposition using the sample of all containerizable HS6 products (1st row) and a restricted sample after adjusting HS6 products to account for the changes in the classification of products that occurred in 2007 and 2017 (2nd row).

Table 2.2: Within Effects of Top 10 HS6 Products, 2010-2018

	HS6 Code	"Within" Effect
All HS6 Products		
Passenger Vehicles (cylinder capacity >3000cc)	870324	0.0043
Medicaments	300490	0.0034
Parts For Boring or Sinking Machinery	843143	0.0026
Parts And Attachments For Derricks	843149	0.0022
Chicken Cuts And Edible Offal	020714	0.0020
Electric generating sets (other than wind powered)	850239	0.0020
Tobacco, Partly Or Wholly Stemmed/stripped	240120	0.0019
Gas Turbine Parts	841199	0.0019
Passenger Vehicles (1500cc<cylinder capacity<3000cc)	870323	0.0018
Gas Turbines of a Power Exceeding 5,000 Kw	841182	0.0013
		0.0235
Adjusted HS6 Products		
Medicaments	300490	0.0044
Chicken Cuts And Edible Offal	020714	0.0025
Electric generating sets (other than wind powered)	850239	0.0025
Tobacco, Partly Or Wholly Stemmed/stripped	240120	0.0025
Gas Turbine Parts	841199	0.0024
Organo-inorganic Compounds	293100	0.0022
Gas Turbines of a Power Exceeding 5,000 Kw	841182	0.0017
Waste and Scrap of Paper or paperboard	470710	0.0016
Cotton (Not Carded Or Combed)	520100	0.0016
Aluminum Oxide (Except Artificial Corundum)	281820	0.0013
		0.0226

Notes: The within-product effect is based on product-level changes in containerized shares, weighted by initial product shares of containerizable exports.

Table 2.3: Decomposition Results of Containerized Export Share Growth by HS2 Products, 2010-2018

$t-1$	t	$\Delta \frac{X_t^c}{X_t^{c+b}}$	"Within" Share	"Between" Share
2010	2018	0.077	1.464	-0.464

Notes: The table shows results from the decomposition of the aggregate change of U.S. containerized exports to the the rest of the world (X^c) as a share of U.S. containerizable exports (X^{c+b}) into within- and between-product effects between 2010 and 2018.

Table 2.4: Within Effects of Top 10 HS2 Products, 2010-2018

	HS2 Code	"Within" Effect
Nuclear Reactors, Boilers, Machinery; Parts	84	0.0335
Electric Machinery; Equipment and Parts	85	0.0108
Vehicles, Except Railway Or Tramway, And Parts	87	0.0095
Plastics And Articles Thereof	39	0.0075
Pharmaceutical Products	30	0.0063
Wood And Articles Of Wood; Wood Charcoal	44	0.0049
Meat And Edible Meat Offal	02	0.0048
Optical, Photographic, Medical or Surgical Instruments	90	0.0046
Miscellaneous Chemical Products	38	0.0044
Wood Pulp; Recovered (waste & scrap) paper or paperboard	47	0.0039
		0.0902

Notes: The within-product effect is based on product-level changes in containerized shares, weighted by initial product shares of containerizable exports.

Table 2.5: Summary Statistics

	Mean/SD	Median	Min	Max
Real Container Freight Rate (US dollars)	1,592	1,411	467	4,532
	(800.57)			
Containerized share of containerizable exports	0.86	0.92	0	1
	(0.18)			
Observations	10,085			
Δ Real Container Freight Rate (US dollars)	-127	-117	-1,278	773
	(213.66)			
ΔContainerized share of containerizable exports	0.01	0	-0.30	0.30
	(0.09)			
Observations	8,407			

Notes: Each annual observation is at a U.S. port-foreign country and HS2 product-level. Data set includes 3 U.S. origin ports (Houston, Los Angeles, and New York) and 12 foreign destinations (10 OECD and 2 non-OECD countries) from 2010 to 2018. Container freight rate is the bilateral transport cost per 20-foot container and is converted into real terms using the seasonally adjusted Consumer Price Index for all urban consumers. Containerizable exports are exports of non-bulk products for which the share of containerized exports in total seaborne exports is greater than or equal to 10 percent.
Source: Drewry Maritime Research and U.S. Census Bureau.

Table 2.6: Ordinary Least Squares (OLS) and Two Stage Least Squares (2SLS) Estimates

	Dependent variable: Change in Containerized Share of Containerizable Exports (1) OLS	 (2) 2SLS
Change in Container Freight Rate	-0.008 (0.005)	-0.092*** (0.034)
Product FE	Yes	Yes
Origin-destination FE	Yes	Yes
Time FE	Yes	Yes
R-squared	0.05	-
Observations	8,407	8,407

Notes: The table reports the results of the panel OLS and 2SLS regressions $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}} = \beta \Delta CFR_{ijt} + \mu_g + \mu_{ij} + \mu_t + \Delta e_{ijgt}$ where $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}}$ is the first differenced containerized share of containerizable exports from U.S. port i to foreign country j in product g and ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. The instrument for ΔCFR_{ijt} is the annual growth rate in the average container freight rate across origin-destination pairs weighted by the initial bilateral container freight rate. Standard errors are reported in parentheses. * $p < 0.1$ ** $p < 0.05$ ***$p < 0.01$

Table 2.7: First Stage Regression

	Dependent variable: Change in Container Freight Rate
IV	2.477***
	(0.168)
Product FE	Yes
Origin-destination FE	Yes
Time FE	Yes
R-squared	0.45
F-statistic	216
Observations	8,407

Notes: The table reports the results of the first stage regression $\Delta CFR_{ijt} = \gamma Z_{ijt} + \alpha_g + \alpha_{ij} + \alpha_t + u_{ijgt}$ where ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. Z_{ijt} is the instrument for ΔCFR_{ijt} and is the annual growth rate in the average container freight rate across all origin-destination pairs weighted by the initial bilateral container freight rate. Standard errors are reported in parentheses. * $p < 0.1$ ** $p < 0.05$ ***$p < 0.01$

Table 2.8: Aggregated HS2 Product-Specific Effect of Container Freight Rate on Conatinerized Share of U.S. Containerizable Exports

Aggregated HS2 Code	Product Description	
1	Animal & Animal Products	-0.096** (0.049)
2	Vegetable Products	-0.073* (0.042)
3	Foodstuffs	-0.061 (0.041)
4	Mineral Products	-0.108** (0.048)
5	Chemicals & Allied Industries	-0.095** (0.040)
6	Plastics/Rubbers	-0.090* (0.047)
7	Raw Hides, Skins, Leather, & Furs	-0.062 (0.075)
8	Wood & Wood Products	-0.097** (0.045)
9	Textiles	-0.091** (0.041)
10	Footwear/Headgear	-0.048 (0.058)
11	Stone/Glass	-0.118* (0.063)
12	Metals	-0.131*** (0.044)
13	Machinery/Electrical	-0.122*** (0.046)
14	Transportation	-0.075 (0.050)
15	Miscellaneous	-0.089* (0.046)
	Origin-destination FE	Yes
	Time FE	Yes
	Observations	8407

Notes: The table reports the results of the estimated β_g coefficients of the IV regression $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}} = \sum_{g=1}^{G} \beta_g [\Delta CFR_{ijt} * \mu_g] + \mu_{ij} + \mu_t + e_{ijgt}$ where $g = 1, ..., 15$ are aggregated containerizable HS2 products. $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}}$ is the first differenced containerized share of containerizable exports from U.S. port i to foreign country j in product g and ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. β_g coefficients capture product-specific effects of container freight rate on the containerized export share of each HS2 product. The instrument for ΔCFR_{ijt} is the annual growth rate in the average container freight rate across origin-destination pairs weighted by the initial bilateral container freight rate. Standard errors are reported in parentheses. * $p < 0.1$ ** $p < 0.05$ ***$p < 0.01$

Table 3.1: Summary of Parameters and Exogenous Variables

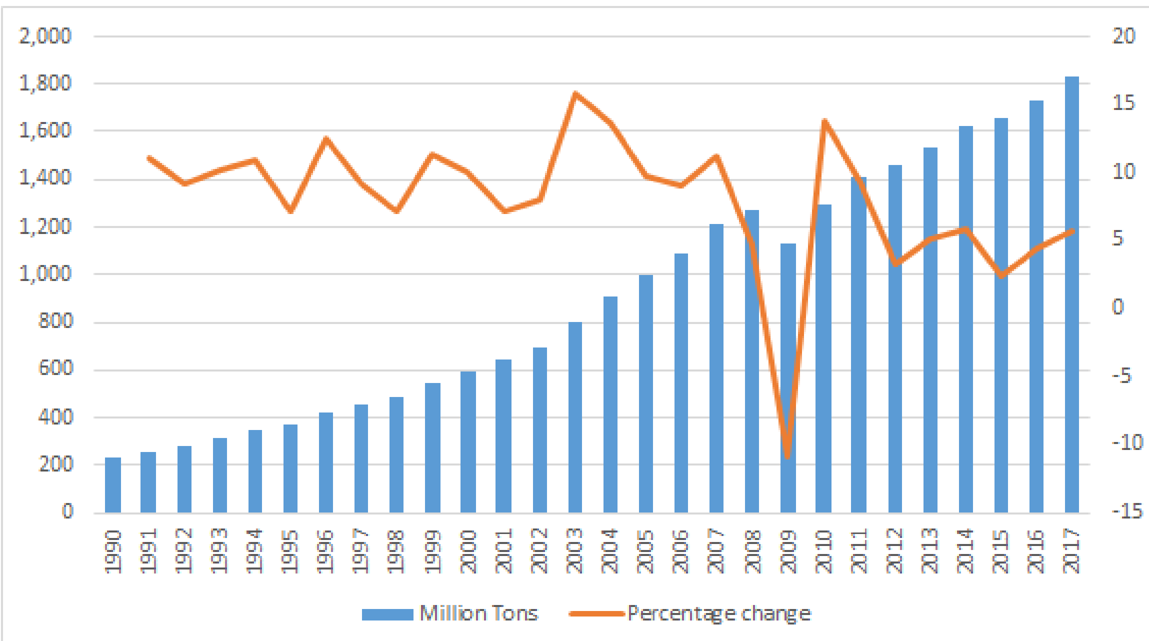
Parameter	Definition	Value $\forall i, j = \{1, 2\}$
θ	Shape Parameter of Pareto Distribution	4.25
σ	Elasticity of Substitution	4
L_j	Labor	10
A_{ij}^b	Labor Productivity of Transportation Sector with b	7
A_{ij}^c	Labor Productivity of Transportation Sector with c	10 and 30
f_{ij}^b	Fixed Export Cost with b	1
f_{ij}^c	Fixed Export Cost with c	2

Table 3.2: Results of an Increase in Container Transport Productivity

Variable	$A^c_{ij} = 10$	$A^c_{ij} = 30$	Percentage Change
Country-level			
Wage	1.22	1.26	3.45%
Price	1	1	0.00%
Transport B-Price	0.17	0.18	3.45%
Transport C-Price	0.12	0.04	-65.54%
Value of B-Exports	1.51	0.56	-62.81%
Value of C-Exports	0.96	2.96	208.88%
Total Value of Exports	2.46	3.52	42.80%
Real GDP	12.16	12.58	3.44%
Export Share of GDP	0.20	0.28	40.00%
C-Export Share	0.39	0.84	116.31%
Firm-level			
Export B-Cutoff	1.44	1.50	4.18%
Export C-Cutoff	2.48	1.78	-28.20%
Mass of B-Exporters	0.19	0.09	-51.86%
Mass of C-Exporters	0.02	0.09	308.53%
Total Fixed Cost	0.23	0.26	13.39%

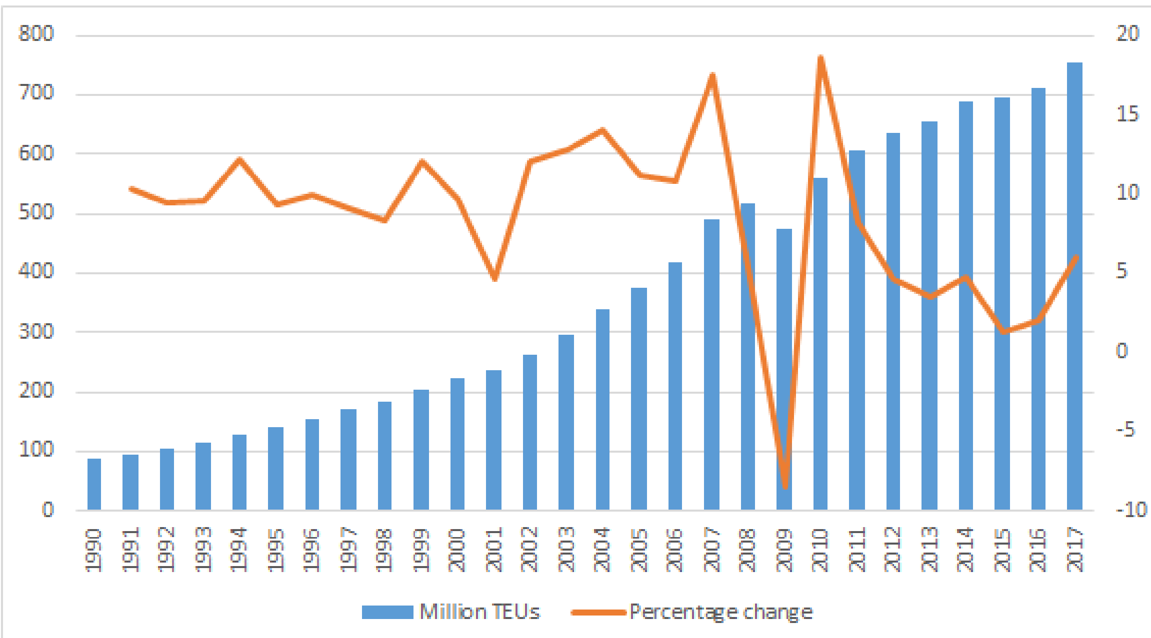
Notes: The table reports the effects of lower container transport costs due to an improvement in container transport productivity on the model-generated country-level and firm-level variables. *C* denotes container transport, while *B* denotes break-bulk transport.

Figure 1.1: World Containerized Seaborne Trade, 1990-2017 (Million tons and percentage annual change)



Source: Review of Maritime Transport (2017), United Nations Conference on Trade and Development (UNCTAD)

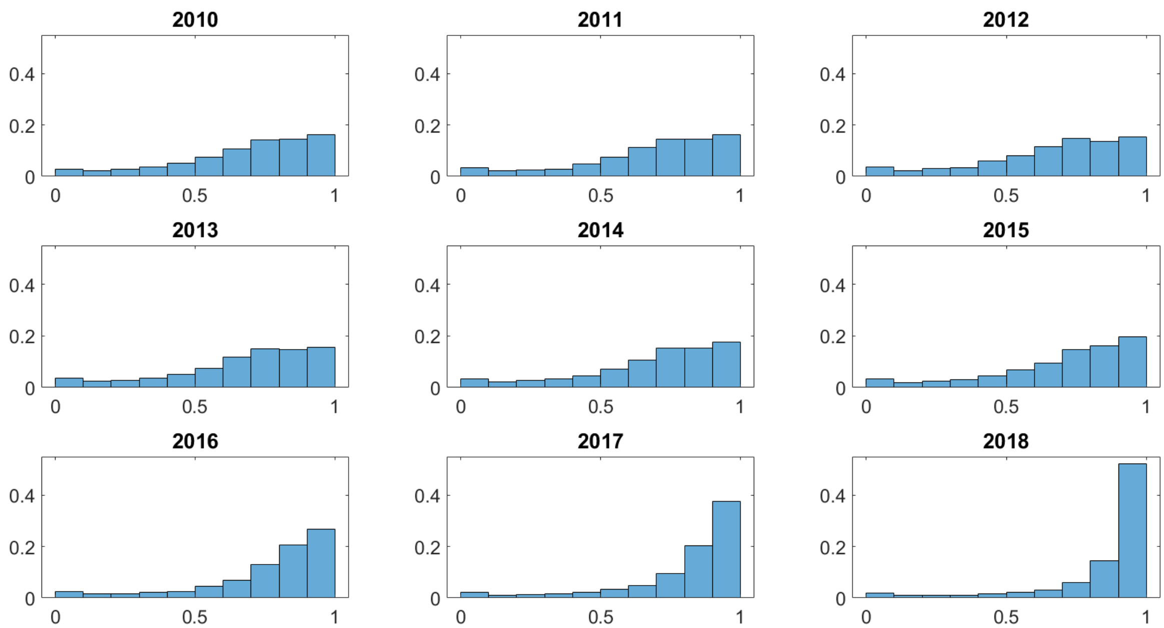
Figure 1.2: World Container Port Traffic, 1990-2017 (Million 20-foot equivalent units and percentage annual change)



Source: United Nations Conference on Trade and Development (UNCTAD)

Notes: Port container traffic measures the flow of containers from land to sea transport modes and vice versa, in twenty-foot equivalent units (TEUs), a standard-size container.

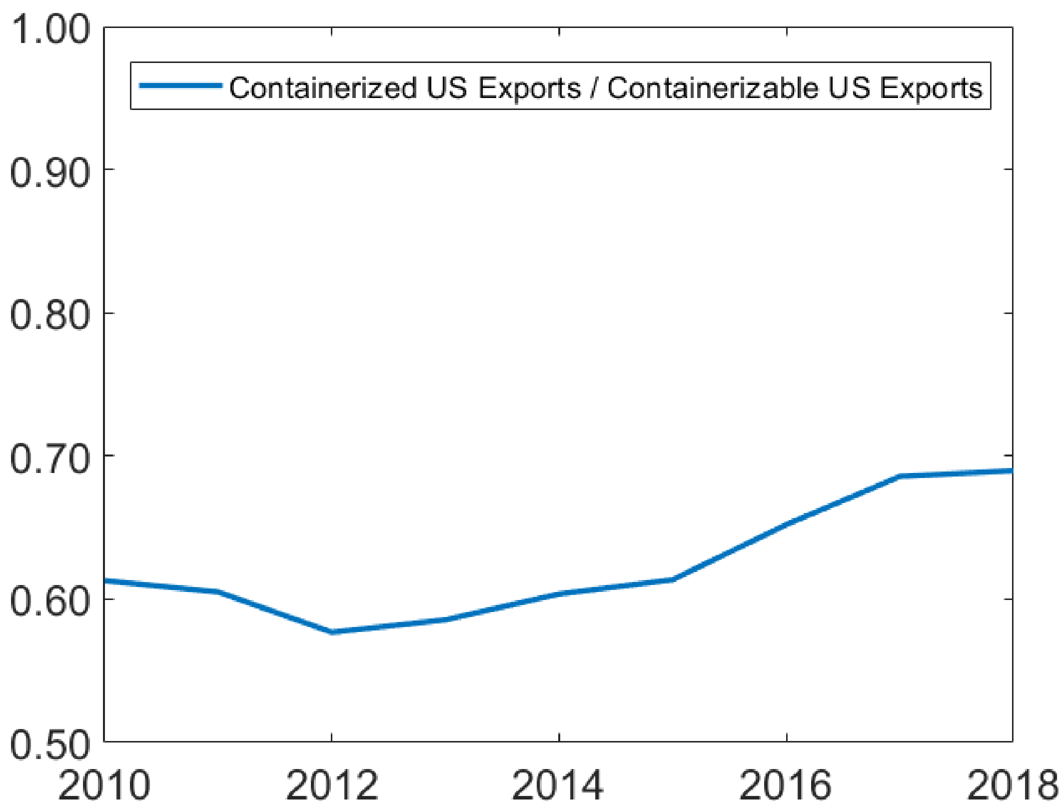
Figure 2.1: HS6 Product Distribution of Share of U.S. Containerized Seaborne Exports in Total Containerizable Seaborne Exports, 2010-2018



Source: U.S. Census Bureau

Notes: X axis shows the share of containerized seaborne exports in total seaborne exports and Y axis shows the fraction of HS6 products.

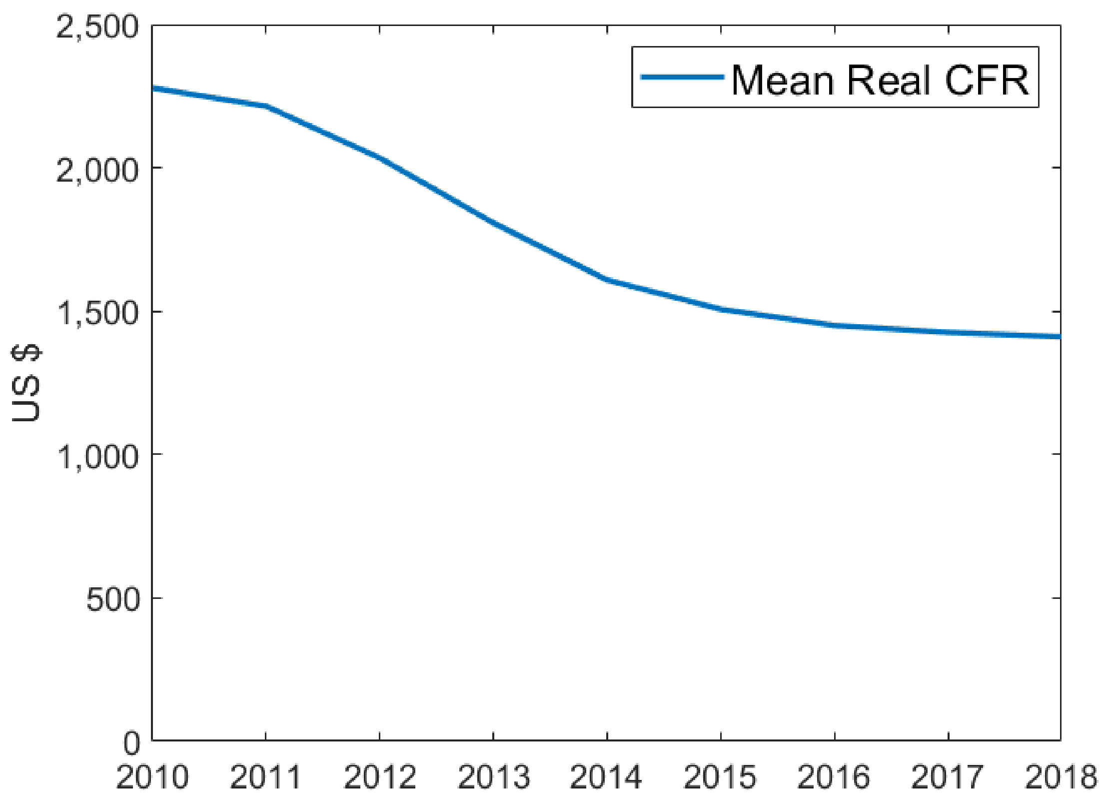
Figure 2.2: Containerized Share of U.S. Containerizable Exports to the Rest of the World, 2010-2018



Source: U.S. Census Bureau

Notes: Containerizable exports are exports of non-bulk products for which the share of containerized exports in total seaborne exports is greater than or equal to 10 percent.

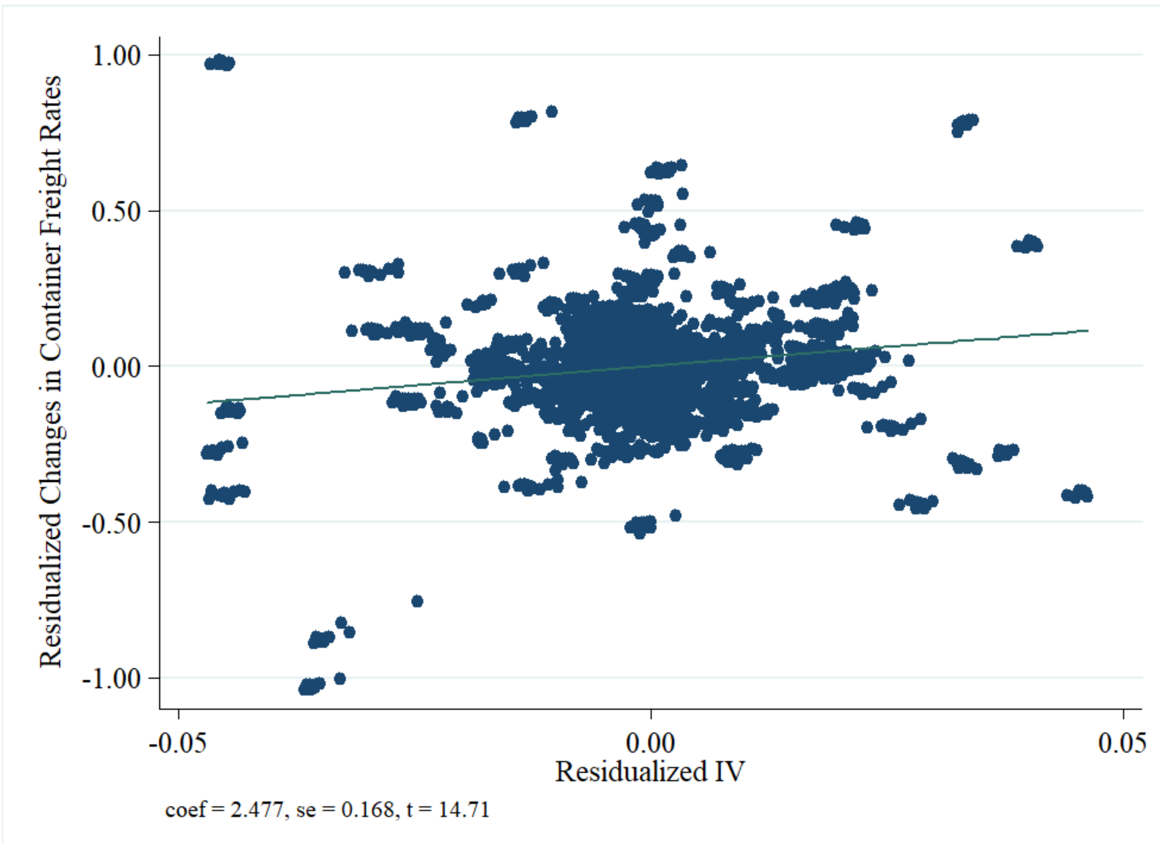
Figure 2.3: Real Mean Container Freight Rate of U.S. Containerized Exports, 2010-2018



Source: Drewry Maritime Research

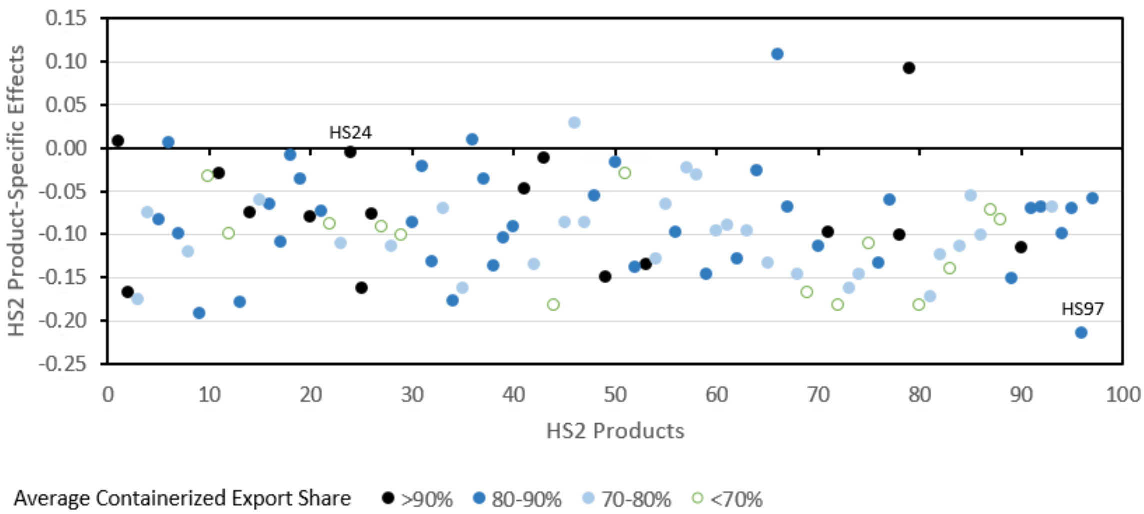
Notes: Container freight rate is the bilateral transport cost per 20-foot container and is converted into real terms using the seasonally adjusted Consumer Price Index for all urban consumers. The figure shows the average container freight rate across port-pairs in my data set. My data set includes 3 U.S. origin ports (Houston, Los Angeles, and New York) and 12 foreign destinations (10 OECD and 2 non-OECD countries) from 2010 to 2018.

Figure 2.4: First Stage Regression



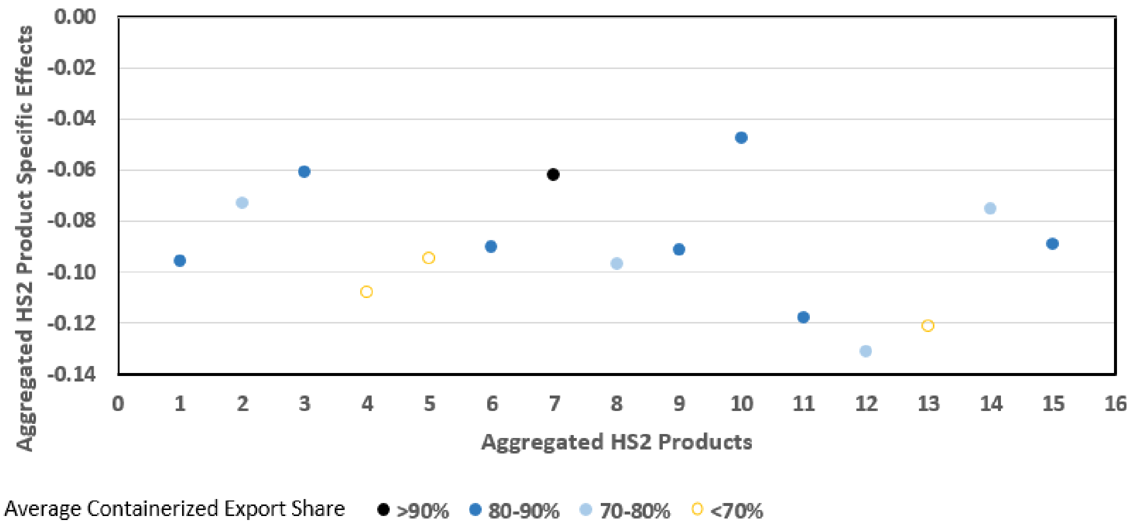
Notes: IV is the annual growth rate in average container freight rate across origin-destination pairs weighted by the initial origin-destination specific container freight rate.

Figure 2.5: HS2 Product-Specific Effect of Raising Container Freight Rate on Containerized Share of U.S. Containerizable Exports



Notes: The figure plots the results of the estimated β_g coefficients of the IV regression $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}} = \sum_{g=1}^{G} \beta_g [\Delta CFR_{ijt} * \mu_g] + \mu_{ij} + \mu_t + e_{ijgt}$ where $g = 1, ..., 98$ are containerizable HS2 products, along with their average containerized share of U.S. containerizable exports. $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}}$ is the first differenced containerized share of containerizable exports from U.S. port i to foreign country j in product g and ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. μ_g are product fixed effects, μ_{ij} are origin-destination fixed effects and μ_t are time fixed effects. These coefficients capture product-specific effects of container freight rate on the containerized export share of each HS2 product. The instrument for ΔCFR_{ijt} is the annual growth rate in the average container freight rate across origin-destination pairs weighted by the initial bilateral container freight rate.

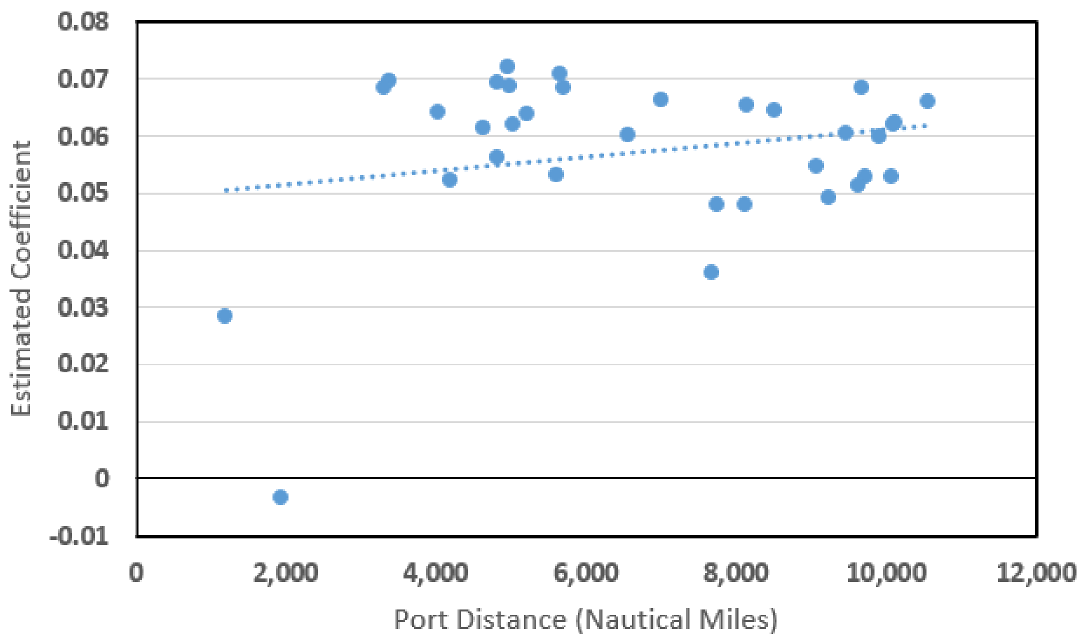
Figure 2.6: Aggregated HS2 Product-Specific Effect of Raising Container Freight Rate on Containerized Share of U.S. Containerizable Exports



1	Animal & Animal Products	9	Textiles
2	Vegetable Products	10	Footwear/Headgear
3	Foodstuffs	11	Stone/Glass
4	Mineral Products	12	Metals
5	Chemicals & Allied Industries	13	Machinery/Electrical
6	Plastics/Rubbers	14	Transportation
7	Raw Hides, Skins, Leather, & Furs	15	Miscellaneous
8	Wood & Wood Products		

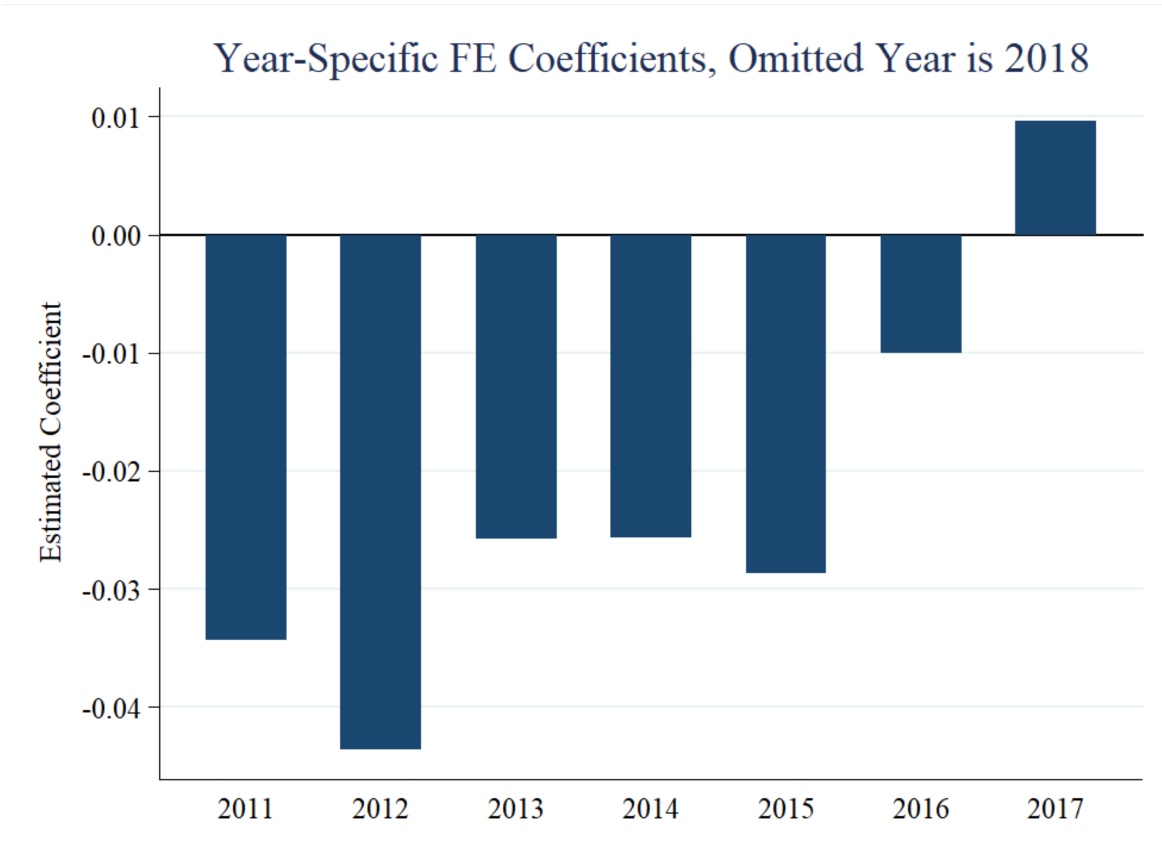
Notes: The figure plots the results of the estimated β_g coefficients of the IV regression $\Delta\frac{X^c_{ijgt}}{X^{c+b}_{ijgt}} = \sum_{g=1}^{G}\beta_g[\Delta CFR_{ijt} * \mu_g] + \mu_{ij} + \mu_t + e_{ijgt}$ where $g = 1, ..., 15$ are aggregated containerizable HS2 products, along with their average containerized share of U.S. containerizable exports. $\Delta\frac{X^c_{ijgt}}{X^{c+b}_{ijgt}}$ is the first differenced containerized share of containerizable exports from U.S. port i to foreign country j in product g and ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. μ_g are product fixed effects, μ_{ij} are origin-destination fixed effects and μ_t are time fixed effects. These coefficients capture product-specific effects of container freight rate on the containerized export share of each HS2 product. The instrument for ΔCFR_{ijt} is the annual growth rate in the average container freight rate across origin-destination pairs weighted by the initial bilateral container freight rate.

Figure 2.7: Relationship between the Estimated Coefficients on Origin-Destination Fixed Effects (Omitted Port Pair is Houston (USA)-Veracruz (MEX)) and Port Distance



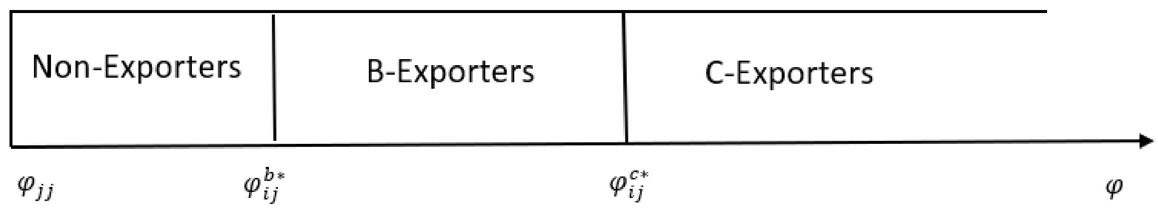
Notes: The figure plots the relationship between port distance and the estimated coefficients on origin-destination fixed effects, μ_{ij}, in the IV regression $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}} = \sum_{g=1}^{G} \beta_g [\Delta CFR_{ijt} * \mu_g] + \mu_{ij} + \mu_t + e_{ijgt}$ where $g = 1, ..., 15$ are aggregated containerizable HS2 products. $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}}$ is the first differenced containerized share of containerizable exports from U.S. port i to foreign country j in product g and ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. The instrument for ΔCFR_{ijt} is the annual growth rate in the average container freight rate across origin-destination pairs weighted by the initial bilateral container freight rate.

Figure 2.8: Estimated Coefficients on Year Fixed Effects



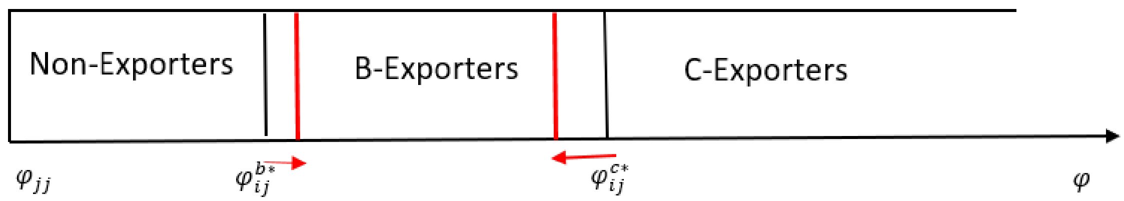
Notes: The figure plots the estimated coefficients on year fixed effects, μ_t, in the IV regression $\Delta\frac{X^c_{ijgt}}{X^{c+b}_{ijgt}} = \sum_{g=1}^{G}\beta_g[\Delta CFR_{ijt} * \mu_g] + \mu_{ij} + \mu_t + e_{ijgt}$ where $g = 1, ..., 15$ are aggregated containerizable HS2 products. $\Delta\frac{X^c_{ijgt}}{X^{c+b}_{ijgt}}$ is the first differenced containerized share of containerizable exports from U.S. port i to foreign country j in product g and ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. The instrument for ΔCFR_{ijt} is the annual growth rate in the average container freight rate across origin-destination pairs weighted by the initial bilateral container freight rate.

Figure 3.1: Exporters' Choice of Shipping Technology



Notes: C-exporters are exporters who containerize their exports, while B-exporters transport their exports break-bulk.

Figure 3.2: Exporters' Choice of Shipping Technology after an Increase in Container Transport Labor Productivity



Notes: C-exporters are exporters who containerize their exports, while B-exporters transport their exports break-bulk.

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Appendices

A Data Appendix

A.1 Containerized and Seaborne Trade Data

Cargo is containerized when it is placed in standard shipping containers that can be handled interchangeably on vessels, in terminals, and via inland transport modes. Standard containers used in international maritime trade come in three lengths: 20 feet, 40 feet, and 45 feet.

Containerized and seaborne trade data is obtained from the U.S. Census Bureau's USA Trade Online. USA Trade Online data reports annual value and weight of trade in goods (imports and exports) between US ports and foreign countries with commodities disaggregated to the six-digit Harmonized System (HS) level and by transport mode (seaborne and containerized seaborne). The Harmonized Commodity Description and Coding System generally referred to as "Harmonized System" or simply "HS" is a multipurpose international product nomenclature developed by the World Customs Organization (WCO). It comprises about 5000 commodity groups; each identified by a six digit code, arranged in a legal and logical structure and is supported by well-defined rules to achieve uniform classification.

Export data is available for years 2002-2017. Exports are valued on a free alongside ship (FAS) basis, which reflects transaction price including inland freight, insurance and other charges incurred in placing the merchandise alongside the ship at the port of export. The value excludes the cost of loading the merchandise aboard the exporting carrier and also excludes freight, insurance, and any charges or transportation costs beyond the port of export.

A.2 Container Freight Rate Data

Container freight rates at the port level are obtained from Drewry Maritime Research (Drewry). They are based on averages of representative rates paid by 28 freight forwarders located in Europe, Middle East, North America, South America and Asia to ocean carriers for a particular month. These rates represent spot market rates in dollars for Full Container Loads (FCL). Standard containers used in international maritime trade come in three lengths: 20 feet, 40 feet, and 45 feet. Drewry provides container freight rate data for 20-foot and 40-foot containers. In this dissertation, I use container freight rates for standard 20-foot containers. Rates are also affected by seasonal and short-term supply-demand factors, notably by the peak season in the trades from Asia.

The monthly/bimonthly rate benchmarks include the base ocean rate, the Terminal Handling Charge (THC) both at origin and destination, the fuel surcharge (Bunker Adjustment Factor (BAF)) and all other surcharges levied by ocean carriers.[1] However, they do not include inland transport costs at origin and destination. Container freight rates are converted into real terms using the seasonally adjusted Consumer Price Index for all urban consumers.

The port pairs in my data set are between 3 US ports (Houston, Los Angeles, and New York) and the following foreign countries (ports): Australia (Melbourne), Chile (San Antonio), China (Shanghai), India (Nhava Sheva), Japan (Yokohama), Korea (Busan), Mexico (Manzanillo and Veracruz), New Zealand (Auckland), North Continent Europe base port (Rotterdam (Netherlands)), Turkey (Istanbul), UK (Felixstowe), and Mediterranean base port (Genoa (Italy)). [2, 3] These port pairs cover transpacific trade (US to the industrial centers of Japan, the Far East and the Middle East and vice versa), transatlantic trade (US

[1] Other surcharges include: Currency Adjustment Factor, Peak Season Surcharge, Equipment management surcharge, Port additional/port dues, Emergency risk surcharge, Port security charge / International Ship and Port facility security (ISPS) charge, Carrier security charge, Suez Canal transit fee/surcharge, Panama Canal surcharge, Gulf of Aden surcharge, Port congestion surcharge.

[2] Drewry provides container freight data between US East, West and Gulf Coast ports and Central China (Shanghai), North China (Tianjin) and South China (Yantian). In this case, I select the port of Shanghai, which is the largest container port in China.

[3] Drewry provides container freight data between US East and Gulf Coast ports and Mexico (Veracruz) and between US West Coast port and Mexico (Manzanillo).

East and Gulf Coast to North Continent Europe and the Mediterranean and vice versa), and North-South trade (US to Latin America, Australia and New Zealand and vice versa).

B Theory Appendix

B.1 Zero-profit cutoff productivity

A firm from country j with productivity ϕ will export to i using shipping technology $d \in \{b, c\}$ if and only if its profits from exporting using break-bulk shipping technology inclusive of fixed costs exceed zero

$$\begin{aligned}
\pi_{ij}^{b}(\phi) &\geq 0 \\
\frac{1}{\sigma}\left[\frac{\sigma}{\sigma-1}\left(\frac{w_j}{\phi}+p_{ij}^{tb}\right)\right]^{1-\sigma} P_i^{\sigma-1}Y_i - w_j f_{ij}^{b} &\geq 0 \\
\left(\frac{w_j}{\phi}+p_{ij}^{tb}\right) &\leq \left[\frac{\sigma\left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1} w_j f_{ij}^{b}}{P_i^{\sigma-1}Y_i}\right]^{\frac{1}{1-\sigma}} \\
\frac{w_j}{\phi} &\leq \left[\frac{\sigma\left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1} w_j f_{ij}^{b}}{P_i^{\sigma-1}Y_i}\right]^{\frac{1}{1-\sigma}} - p_{ij}^{tb} \\
\phi &\geq w_j\left\{\left[\frac{\sigma\left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1} w_j f_{ij}^{b}}{P_i^{\sigma-1}Y_i}\right]^{\frac{1}{1-\sigma}} - p_{ij}^{tb}\right\}^{-1} \equiv \phi_{ij}^{b*}
\end{aligned} \tag{B.1}$$

B.2 Aggregation

The aggregate price index in country i is given by

$$P_i = \left[\sum_{j\in N}\int_{k\in\Omega_j} p_{ij}(k)^{1-\sigma}dk\right]^{\frac{1}{1-\sigma}} \tag{B.2}$$

Let $\mu_{ij}^{d}(\phi)$ be the equilibrium probability density function of the productivities over a subset of $(0,\infty)$ of firms from country j that export to country i using shipping technology $d \in \{b, c\}$ and let $\mu_{ii}(\phi)$ be the equilibrium probability density function of the productivities over a subset of $(0,\infty)$ of firms from country i that sell to the domestic market of country

i. Moreover, let M_{ij}^{d} be the equilibrium mass of firms in j exporting to i using shipping technology d and let M_{ii} be the mass of firms in i that sell to the domestic market. Since all firms, exporting and non-exporting, sell domestically, the mass of firms in i that sell to the domestic market equals the mass of all firms in i, $M_{ii} = M_i = 1$, which is normalized to 1. Then, the average prices charged by all firms in j exporting to i can be written as

$$\int_{k\in\Omega_j} p_{ij}^{d}(k)^{1-\sigma}dk = \int_0^{\infty} p_{ij}^{d}(\phi)^{1-\sigma} M_{ij}^{d}\mu_{ij}^{d}(\phi)d\phi \tag{B.3}$$

Average prices charged by non-exporting firms in i can be written as

$$\begin{aligned}\int_{k\in\Omega_i} p_{ii}(k)^{1-\sigma}dk &= \int_0^{\infty}\Big(\frac{\sigma}{\sigma-1}\frac{w_i}{\phi}\Big)^{1-\sigma} M_{ii}\mu_{ii}(\phi)d\phi \\ &= \Big(\frac{\sigma}{\sigma-1}w_i\Big)^{1-\sigma} M_i\int_0^{\infty}\phi^{\sigma-1}\mu_{ii}(\phi)d\phi\end{aligned} \tag{B.4}$$

while average prices charged by exporting firms are given by

$$\int_{k\in\Omega_j} p_{ij}^{d}(k)^{1-\sigma}dk = \Big(\frac{\sigma}{\sigma-1}\Big)^{1-\sigma}\int_0^{\infty}\Big(\frac{w_j}{\phi}+p_{ij}^{t}\Big)^{1-\sigma} M_{ij}^{d}\mu_{ij}^{d}(\phi)d\phi \tag{B.5}$$

and trade flows are given by

$$\begin{aligned}X_{ij}^{d} &= P_i^{\sigma-1}Y_i\int_{k\in\Omega_j} p_{ij}^{d}(k)^{1-\sigma}dk \\ &= P_i^{\sigma-1}Y_i\Big(\frac{\sigma}{\sigma-1}\Big)^{1-\sigma}\int_0^{\infty}\Big(\frac{w_j}{\phi}+p_{ij}^{t}\Big)^{1-\sigma} M_{ij}^{d}\mu_{ij}^{d}(\phi)d\phi\end{aligned} \tag{B.6}$$

Equation (B.6) looks like a gravity equation. The mass of firms that export to i using shipping technology $d \in \{b, c\}$, M_{ij}^{d}, are given by equations (3.22) and (3.23) .

B.3 Special case of Pareto distribution of productivities

An analytical expression for equations (3.24), (3.25) and (3.26) can be derived when the distribution of productivity across firms is Pareto. The assumption that firm productivities are Pareto distributed, first, provides a good approximation of the distribution of firm sizes in the United States, and second, is analytically tractable.[4] With scale parameter of 1 and shape parameter of θ, the CDF of the Pareto distribution is

$$G(\phi) = 1 - \phi^{-\theta} \tag{B.7}$$

for $\phi \geq 1$. Let $g(\phi) = \theta\phi^{-\theta-1}$ be the PDF of the Pareto distribution and assume that $\theta > \sigma - 1$. The integral in equation (3.26) becomes

$$\begin{aligned}
\int_{\phi_{ii}}^{\infty} \phi^{\sigma-1} dG(\phi) &= \int_{\phi_{ii}}^{\infty} \phi^{\sigma-1} g(\phi) d\phi \\
&= \int_{\phi_{ii}}^{\infty} \phi^{\sigma-1} (\theta\phi^{-\theta-1}) d\phi \\
&= \theta \int_{\phi_{ii}}^{\infty} \phi^{\sigma-\theta-2} d\phi \\
&= \frac{\theta}{\theta+1-\sigma} (\phi_{ii})^{\sigma-\theta-1}
\end{aligned} \tag{B.8}$$

while the integrals in equations (3.24) and (3.25) become

$$\begin{aligned}
\int_{\phi_{ij}^{c*}}^{\infty} \left(\frac{w_j}{\phi} + p_{ij}^{tc}\right)^{1-\sigma} dG(\phi) &= \int_{\phi_{ij}^{c*}}^{\infty} \left(\frac{w_j}{\phi} + p_{ij}^{tc}\right)^{1-\sigma} \theta\phi^{-\theta-1} d\phi \\
&= \theta \int_{\phi_{ij}^{c*}}^{\infty} \left(\frac{w_j}{\phi} + p_{ij}^{tc}\right)^{1-\sigma} \phi^{-\theta-1} d\phi
\end{aligned} \tag{B.9}$$

$$\begin{aligned}
\int_{\phi_{ij}^{b*}}^{\phi_{ij}^{b*}} \left(\frac{w_j}{\phi} + p_{ij}^{tb}\right)^{1-\sigma} dG(\phi) &= \int_{\phi_{ij}^{b*}}^{\phi_{ij}^{b*}} \left(\frac{w_j}{\phi} + p_{ij}^{tb}\right)^{1-\sigma} \theta\phi^{-\theta-1} d\phi \\
&= \theta \int_{\phi_{ij}^{b*}}^{\phi_{ij}^{b*}} \left(\frac{w_j}{\phi} + p_{ij}^{tb}\right)^{1-\sigma} \phi^{-\theta-1} d\phi
\end{aligned} \tag{B.10}$$

[4] According to Chaney (2008), Pareto distribution is a good candidate for a theoretical model of firm selection into export market as exporters are large firms, and are therefore in the upper tail of the size distribution, and the Pareto distribution is a good approximation of the upper tail of the distribution of firm sizes.

Next, I show that the integral in equation (B.9) is finite

$$\begin{aligned}
\int_{\phi_{ij}^{c*}}^{\infty}\left(\frac{w_j}{\phi}+p_{ij}^{tc}\right)^{1-\sigma}dG(\phi) &= \int_{\phi_{ij}^{c*}}^{\infty}\left(\frac{w_j}{\phi}+p_{ij}^{tc}\right)^{1-\sigma}\theta\phi^{-\theta-1}d\phi \\
&= \theta\int_{\phi_{ij}^{c*}}^{\infty}\left(\frac{w_j}{\phi}+p_{ij}^{tc}\right)^{1-\sigma}\phi^{-\theta-1}d\phi \\
&= \theta\int_{\phi_{ij}^{c*}}^{\infty}\left(\frac{w_j}{\phi}+p_{ij}^{tc}\right)^{1-\sigma}\frac{\phi^{1-\sigma}}{\phi^{1-\sigma}}\phi^{-\theta-1}d\phi \\
&= \theta\int_{\phi_{ij}^{c*}}^{\infty}\left(w_j+p_{ij}^{tc}\phi\right)^{1-\sigma}\phi^{\sigma-\theta-2}d\phi \\
&= \theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{(w_j+p_{ij}^{tc}\phi)^{\sigma-1}}\frac{1}{\phi^{\theta+2-\sigma}}d\phi \\
&= \theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{(w_j+p_{ij}^{tc}\phi)^{k_1}}\frac{1}{\phi^{k_2}}d\phi
\end{aligned} \tag{B.11}$$

where $k_1=\sigma-1>1$ and $k_2=\theta+2-\sigma>1$. Let $k_3=min\{k_1,k_2\}$, then

$$\theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{(w_j+p_{ij}^{tc}\phi)^{k_1}}\frac{1}{\phi^{k_2}}d\phi \le \theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{(w_j+p_{ij}^{tc}\phi)^{k_3}}\frac{1}{\phi^{k_3}}d\phi = \theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{(w_j\phi+p_{ij}^{tc}\phi^2)^{k_3}}d\phi \tag{B.12}$$

but since $k_3>1$

$$\theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{(w_j\phi+p_{ij}^{tc}\phi^2)^{k_3}}d\phi \le \theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{w_j\phi+p_{ij}^{tc}\phi^2}d\phi \tag{B.13}$$

and since $w_j\phi>0$

$$\theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{w_j\phi+p_{ij}^{tc}\phi^2}d\phi \le \theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{p_{ij}^{tc}\phi^2}d\phi = -\frac{\theta}{p_{ij}^{tc}}\frac{1}{\phi}\bigg|_{\phi_{ij}^{c*}}^{\infty} = \frac{\theta}{p_{ij}^{tc}\phi_{ij}^{c*}} < \infty \tag{B.14}$$

Combining (B.11), (B.12), (B.13) and (B.14) yields

$$\int_{\phi_{ij}^{c*}}^{\infty}\left(\frac{w_j}{\phi}+p_{ij}^{tc}\right)^{1-\sigma}dG(\phi) = \theta\int_{\phi_{ij}^{c*}}^{\infty}\frac{1}{(w_j+p_{ij}^{tc}\phi)^{k_1}}\frac{1}{\phi^{k_2}}d\phi < \infty \tag{B.15}$$

C Model Solution Appendix

C.1 Numerical Exercises

The two-country version of the model has 16 unknowns. In each country, there is the mass of exporting firms who containerize, M^c_{ij}, the mass of exporting firms who use break-bulk shipping, M^b_{ij}, the two productivity cutoffs, ϕ^{*b}_{ij} and ϕ^{*c}_{ij}, the two transport prices, p^{tb}_{ij} and p^{tc}_{ij}, the wage rate, w_j, and the aggregate price level, P_j. The steps to solve the two-country version of the model with *endogenous trade costs* are the following:

1. Using equation (3.18) the two productivity cutoffs for exporting firms who use break-bulk shipping, ϕ^{b*}_{12} and ϕ^{b*}_{21} can be written as functions of w_1, w_2, P_1, and P_2. However, there is no analytic expression for the two productivity cutoffs for exporting firms who use containerization ϕ^{c*}_{12} and ϕ^{c*}_{21} as indicated by condition (3.21).

2. Assuming the Pareto distribution, the price index (3.28) can be written as function of w_1, w_2, P_1, P_2, M_1, M_2, ϕ^{*b}_{12}, ϕ^{*b}_{21}, ϕ^{*c}_{12} and ϕ^{*c}_{21}. However, ϕ^{b*}_{12} and ϕ^{b*}_{21} can be written as functions of w_1, w_2, P_1, and P_2. Moreover, the mass of all firms in country 1 and 2 is assumed to equal 1. That is $M_1 = 1$, and $M_2 = 1$.

3. Set the trade balance condition (3.31), which is a function of w_1, w_2, P_1, P_2, ϕ^{*b}_{12}, ϕ^{*b}_{21}, ϕ^{*c}_{12} and ϕ^{*c}_{21}.

4. Set $P_1 = 1$ (numeraire).

5. Solve numerically the non-linear system of five equations (two price indices, two productivity cutoff conditions for exporting firms who use containerization and one trade balance condition) in five unknowns w_1, w_2, P_2, ϕ^{*c}_{12} and ϕ^{*c}_{21}.

6. Given wages, use equation (3.16) to back out for each country the two transport prices, p^{tb}_{ij} and p^{tc}_{ij}.

7. Given wages and prices, use equation (3.18) to back out the two productivity cutoffs for exporting firms who use break-bulk shipping, ϕ^{b*}_{12} and ϕ^{b*}_{21}.

8. Given the productivity cutoffs, use equation (3.22) to find the mass of exporting firms who containerize, M_{ij}^c: $M_{12}^c = [1 - G(\phi_{12}^{c*})]M_2 = (\phi_{12}^{c*})^{-\theta}$ and $M_{21}^c = [1 - G(\phi_{21}^{c*})]M_1 = (\phi_{21}^{c*})^{-\theta}$.

9. Given the productivity cutoffs, use equation (3.23) to find the mass of exporting firms who use break-bulk shipping, M_{ij}^b: $M_{12}^b = [G(\phi_{12}^{c*}) - G(\phi_{12}^{b*})]M_2 = (\phi_{12}^{b*})^{-\theta} - (\phi_{12}^{c*})^{-\theta}$ and $M_{21}^b = (\phi_{21}^{b*})^{-\theta} - (\phi_{21}^{c*})^{-\theta}$.

To check the solution of the model, I verified that the following conditions are satisfied:

1. Labor market equilibrium (not used in solving the model)

   For each country, I calculate total spending on goods produced domestically and imported using both transport modes (i.e. the RHS of the labor market equilibrium condition 3.29) and verify that it equals the labor market income (i.e. the LHS of the labor market equilibrium condition 3.29).

2. Indirect utility function

   The first order condition with respect to $c_{ij}(k)$ that results from the utility maximization problem of the representative household in country i is the following:

$$c_{ij}(k) = \frac{U_i}{(\lambda p_{ij}(k))^{\sigma}} \tag{C.1}$$

   where λ is the Lagrange multiplier. From further manipulation of equation (C.1) it can be shown that

$$U_i = \lambda Y_i \tag{C.2}$$

   and

$$\lambda = \frac{1}{P_i} \tag{C.3}$$

   where P_i is the aggregate price index in country i. Substituting (C.2) and (C.3) into (C.1) gives

$$c_{ij}(k) = p_{ij}(k)^{-\sigma} P_i^{\sigma-1} Y_i \tag{C.4}$$

which is optimal consumption and import demand in terms of the prices. Combining equations (C.2) and (C.3) yields that the indirect utility function in each country i equals $\frac{Y_i}{P_i}$. To verify that this holds, for each country I calculate indirect utility by plugging optimal consumption given by equation (C.4) in the utility function given by equation (3.1)

$$\begin{aligned}
U_i =& \left[\sum_{j \in N} \int_{k \in \Omega_{ij}} c_{ij}(k)^{\frac{\sigma-1}{\sigma}} dk \right]^{\frac{\sigma}{\sigma-1}} \\
=& \left[\sum_{j, j \neq i} \Big(\int_{k \in \Omega_j} c_{ij}^c(k)^{\frac{\sigma-1}{\sigma}} dk + \int_{k \in \Omega_j} c_{ij}^b(k)^{\frac{\sigma-1}{\sigma}} dk \Big) + \int_{k \in \Omega_i} c_{ii}(k)^{\frac{\sigma-1}{\sigma}} dk \right]^{\frac{\sigma}{\sigma-1}} \\
=& \left[\sum_{j, j \neq i} \Big(\int_0^\infty c_{ij}^c(\phi)^{\frac{\sigma-1}{\sigma}} M_{ij}^c \mu_{ij}^c(\phi) d\phi + \int_0^\infty c_{ij}^b(\phi)^{\frac{\sigma-1}{\sigma}} M_{ij}^b \mu_{ij}^b(\phi) d\phi \Big) + \right. \\
& \left. \int_0^\infty c_{ii}(\phi)^{\frac{\sigma-1}{\sigma}} M_{ii} \mu_{ii}(\phi) d\phi \right]^{\frac{\sigma}{\sigma-1}}
\end{aligned} \tag{C.5}$$

with *endogenous trade costs*, (C.5) becomes

$$\begin{aligned}
U_i =& P_i^{\sigma-1} Y_i \Bigg\{ \sum_{j, j \neq i} \Bigg[\Big(\frac{\sigma}{\sigma-1} \Big)^{1-\sigma} M_j \int_{\phi_{ij}^{c*}}^\infty \Big(\frac{w_j}{\phi} + p_{ij}^{tc} \Big)^{1-\sigma} dG(\phi) + \\
& \Big(\frac{\sigma}{\sigma-1} \Big)^{1-\sigma} M_j \int_{\phi_{ij}^{b*}}^{\phi_{ij}^{c*}} \Big(\frac{w_j}{\phi} + p_{ij}^{tb} \Big)^{1-\sigma} dG(\phi) \Bigg] + \Big(\frac{\sigma}{\sigma-1} w_i \Big)^{1-\sigma} M_i \int_{\phi_{ii}}^\infty \phi^{\sigma-1} dG(\phi) \Bigg\}^{\frac{\sigma}{\sigma-1}}
\end{aligned} \tag{C.6}$$

and then I verify that U_i equals $\frac{Y_i}{P_i} = \frac{w_i L_i}{P_i}$.

D Additional Tables

Table D.1: Share of "Total" Effects of Top 10 HS6 Products, 2010-2018

	HS6	C/N/X	Share of "Total" Effect
All HS6 Products			
Passenger Vehicles (cylinder capacity $>$3000cc)	870324	C	0.079
Parts For Boring or Sinking Machinery	843143	C	0.051
Medicaments	300490	C	0.048
Antisera And Other Blood Fractions	300212	N	0.039
Ferrous Waste & Scrap	720449	C	0.034
Gas Turbines of a Power Exceeding 5,000 Kw	841182	C	0.032
Passenger Vehicles (1500cc$<$cylinder capacity$<$3000cc)	870323	C	0.031
Ethylene polymers (in primary forms)	390140	N	0.028
Electric generating sets (other than wind powered)	850239	C	0.025
Tobacco, Partly Or Wholly Stemmed/stripped	240120	C	0.023
			0.389
Adjusted HS6 Products			
Medicaments	300490	C	0.051
Ferrous Waste & Scrap	720449	C	0.039
Gas Turbines of a Power Exceeding 5,000 Kw	841182	C	0.037
Electric generating sets (other than wind powered)	850239	C	0.030
Tobacco, Partly Or Wholly Stemmed/stripped	240120	C	0.025
Organo-inorganic Compounds	293100	C	0.024
Gas Turbine Parts	841199	C	0.022
Chicken Cuts And Edible Offal	020714	C	0.022
Waste and Scrap of Paper or paperboard	470710	C	0.022
Meat of Bovine Animals	020230	C	0.022
			0.293

Notes: *C* denotes continuing products, *N* denotes entering products, and *X* denotes exiting products. For continuing products the share of total effect is the share of the sum of within, between and cross effects in the overall change in the containerized share across all products. For entering and exiting products the share of total effect is the share of entry and exit effects in the overall change in the containerized share across all products, respectively.

Table D.2: Share of "Total" Effects of Top 10 HS2 Products, 2010-2018

	HS2	Share of Total Effect
Vehicles, Except Railway Or Tramway, And Parts Etc	87	0.182
Pharmaceutical Products	30	0.168
Meat And Edible Meat Offal	02	0.140
Oil Seeds; Miscellaneous Grains, Seeds, Fruit, Plants	12	0.093
Miscellaneous Chemical Products	38	0.083
Wood And Articles Of Wood; Wood Charcoal	44	0.079
Edible Fruit & Nuts; Citrus Fruit Or Melon Peel	08	0.065
Miscellaneous Edible Preparations	21	0.043
Electric Machinery; Equipment and Parts	85	0.042
Essential Oils; Perfumery, Cosmetic Preparations	33	0.041
		0.936

Notes: The share of total effect is the share of the sum of within and between effects in the overall change in the containerized export share across all products.

Table D.3: HS2 Product-Specific Effect of Raising Container Freight Rate on Containerized Share of U.S. Containerizable Exports

HS2	Product Description		HS2	Product Description	
1	Live Animals	0.007 (0.086)	31	Fertilizers	-0.021 (0.077)
2	Meat And Edible Meat Offal	-0.168* (0.098)	32	Tanning & Dye Ext Etc; Dye, Paint, Putty Etc; Inks	-0.131** (0.063)
3	Fish, Crustaceans & Aquatic Invertebrates	-0.175* (0.103)	33	Essential Oils Etc; Perfumery, Cosmetic Etc Preps	-0.070 (0.062)
4	Dairy Prods; Birds Eggs; Honey; Ed Animal Pr Nesoi	-0.076 (0.070)	34	Soap Etc; Waxes, Polish Etc; Candles; Dental Preps	-0.177*** (0.066)
5	Products Of Animal Origin, Nesoi	-0.084 (0.107)	35	Albuminoidal Subst; Modified Starch; Glue; Enzymes	-0.162* (0.091)
6	Live Trees, Plants, Bulbs Etc.; Cut Flowers Etc.	0.006 (0.172)	36	Explosives; Pyrotechnics; Matches; Pyro Alloys Etc	0.010 (0.096)
7	Edible Vegetables & Certain Roots & Tubers	-0.100 (0.067)	37	Photographic Or Cinematographic Goods	-0.036 (0.082)
8	Edible Fruit & Nuts; Citrus Fruit Or Melon Peel	-0.120 (0.096)	38	Miscellaneous Chemical Products	-0.136** (0.067)
9	Coffee, Tea, Mate & Spices	-0.192 (0.160)	39	Plastics And Articles Thereof	-0.104* (0.059)
10	Cereals	-0.034 (0.081)	40	Rubber And Articles Thereof	-0.092 (0.071)
11	Milling Products; Malt; Starch; Inulin; Wht Gluten	-0.030 (0.069)	41	Raw Hides And Skins (no Furskins) And Leather	-0.047 (0.094)
12	Oil Seeds Etc.; Misc Grain, Seed, Fruit, Plant Etc	-0.100 (0.078)	42	Leather Art; Saddlery Etc; Handbags Etc; Gut Art	-0.135 (0.129)
13	Lac; Gums, Resins & Other Vegetable Sap & Extract	-0.179 (0.209)	43	Furskins And Artificial Fur; Manufactures Thereof	-0.011 (0.161)
14	Vegetable Plaiting Materials & Products Nesoi	-0.074 (0.173)	44	Wood And Articles Of Wood; Wood Charcoal	-0.182** (0.085)
15	Animal Or Vegetable Fats, Oils Etc. & Waxes	-0.061 (0.089)	45	Cork And Articles Of Cork	-0.086 (0.180)
16	Edible Preparations Of Meat, Fish, Crustaceans Etc	-0.065 (0.073)	46	Mfr Of Straw, Esparto Etc.; Basketware & Wickerwrk	0.028 (0.149)
17	Sugars And Sugar Confectionary	-0.110 (0.076)	47	Wood Pulp Etc; Recovd (waste & Scrap) ppr & pprbd	-0.086 (0.095)
18	Cocoa And Cocoa Preparations	-0.008 (0.092)	48	Paper & Paperboard & Articles (inc Papr Pulp Artl)	-0.055 (0.066)
19	Prep Cereal, Flour, Starch Or Milk; Bakers Wares	-0.036 (0.091)	49	Printed Books, Newspapers Etc; Manuscripts Etc	-0.150** (0.069)
20	Prep Vegetables, Fruit, Nuts Or Other Plant Parts	-0.080 (0.076)	50	Silk, Including Yarns And Woven Fabric Thereof	-0.017 (0.081)
21	Miscellaneous Edible Preparations	-0.074 (0.073)	51	Wool & Animal Hair, Including Yarn & Woven Fabric	-0.031 (0.148)
22	Beverages, Spirits And Vinegar	-0.088 (0.068)	52	Cotton, Including Yarn And Woven Fabric Thereof	-0.137 (0.087)
23	Food Industry Residues & Waste; Prep Animal Feed	-0.111 (0.103)	53	Veg Text Fib Nesoi; Veg Fib & Paper Yns & Wov Fab	-0.135 (0.292)
24	Tobacco And Manufactured Tobacco Substitutes	-0.005 (0.119)	54	Manmade Filaments, Including Yarns & Woven Fabrics	-0.128 (0.113)
25	Salt; Sulfur; Earth & Stone; Lime & Cement Plaster	-0.163** (0.073)	55	Manmade Staple Fibers, Incl Yarns & Woven Fabrics	-0.066 (0.120)
26	Ores, Slag And Ash	-0.077 (0.087)	56	Wadding, Felt Etc; Sp Yarn; Twine, Ropes Etc.	-0.097 (0.071)
27	Mineral Fuel, Oil Etc.; Bitumin Subst; Mineral Wax	-0.091 (0.063)	57	Carpets And Other Textile Floor Coverings	-0.023 (0.142)
28	Inorg Chem; Prec & Rare-earth Met & Radioact Compd	-0.113* (0.065)	58	Spec Wov Fabrics; Tufted Fab; Lace; Tapestries Etc	-0.031 (0.171)
29	Organic Chemicals	-0.102 (0.063)	59	Impregnated Etc Text Fabrics; Tex Art For Industry	-0.147 (0.098)
30	Pharmaceutical Products	-0.086 (0.126)	60	Knitted Or Crocheted Fabrics	-0.095 (0.122)

Table D.3: HS2 Product-Specific Effect of Raising Container Freight Rate on Containerized Share of U.S. Containerizable Exports (continued)

HS2	Product Description		HS2	Product Description	
61	Apparel Articles And Accessories, Knit Or Crochet	-0.089	81	Base Metals Nesoi; Cermets; Articles Thereof	-0.183*
		(0.076)			(0.107)
62	Apparel Articles And Accessories, Not Knit Etc.	-0.128*	82	Tools, Cutlery Etc. Of Base Metal & Parts Thereof	-0.172**
		(0.073)			(0.073)
63	Textile Art Nesoi; Needlecraft Sets; Worn Text Art	-0.096	83	Miscellaneous Articles Of Base Metal	-0.124
		(0.081)			(0.090)
64	Footwear, Gaiters Etc. And Parts Thereof	-0.027	84	Nuclear Reactors, Boilers, Machinery Etc.; Parts	-0.141**
		(0.074)			(0.060)
65	Headgear And Parts Thereof	-0.133	85	Electric Machinery Etc; Sound Equip; Tv Equip; Pts	-0.113*
		(0.096)			(0.066)
66	Umbrellas, Walking-sticks, Riding-crops Etc, Parts	0.108	86	Railway Or Tramway Stock Etc; Traffic Signal Equip	-0.055
		(0.178)			(0.077)
67	Prep Feathers, Down Etc; Artif Flowers; H Hair Art	-0.069	87	Vehicles, Except Railway Or Tramway, And Parts Etc	-0.101
		(0.167)			(0.066)
68	Art Of Stone, Plaster, Cement, Asbestos, Mica Etc.	-0.146	88	Aircraft, Spacecraft, And Parts Thereof	-0.072
		(0.112)			(0.143)
69	Ceramic Products	-0.168	89	Ships, Boats And Floating Structures	-0.084
		(0.104)			(0.133)
70	Glass And Glassware	-0.113	90	Optic, Photo Etc, Medic Or Surgical Instrments Etc	-0.150*
		(0.089)			(0.091)
71	Nat Etc Pearls, Prec Etc Stones, Pr Met Etc; Coin	-0.097	91	Clocks And Watches And Parts Thereof	-0.115
		(0.125)			(0.146)
72	Iron And Steel	-0.183	92	Musical Instruments; Parts And Accessories Thereof	-0.070
		(0.119)			(0.088)
73	Articles Of Iron Or Steel	-0.162**	93	Arms And Ammunition; Parts And Accessories Thereof	-0.069
		(0.064)			(0.097)
74	Copper And Articles Thereof	-0.146**	94	Furniture; Bedding Etc; Lamps Nesoi Etc; Prefab Bd	-0.069
		(0.073)			(0.081)
75	Nickel And Articles Thereof	-0.111	95	Toys, Games & Sport Equipment; Parts & Accessories	-0.099
		(0.112)			(0.068)
76	Aluminum And Articles Thereof	-0.133*	96	Miscellaneous Manufactured Articles	-0.070
		(0.072)			(0.085)
78	Lead And Articles Thereof	-0.061	97	Works Of Art, Collectors' Pieces And Antiques	-0.214*
		(0.112)			(0.128)
79	Zinc And Articles Thereof	-0.101	98	Special Classification Provisions, Nesoi	-0.058
		(0.120)			(0.149)
80	Tin And Articles Thereof	0.092			
	(0.215)				
	Origin-destination FE	Yes			
	Time FE	Yes			
	R-squared	-			
	Observations	8407			

Notes: The table reports the results of the estimated β_g coefficients of the IV regression $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}} = \sum_{g=1}^{G} \beta_g[\Delta CFR_{ijt} * \mu_g] + \mu_{ij} + \mu_t + e_{ijgt}$ where $g = 1, ..., 98$ are containerizable HS2 products. $\Delta \frac{X^c_{ijgt}}{X^{c+b}_{ijgt}}$ is the first differenced containerized share of containerizable exports from U.S. port i to foreign country j in product g and ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. μ_g are product fixed effects, μ_{ij} are origin-destination fixed effects and μ_t are time fixed effects. These coefficients capture product-specific effects of container freight rate on the containerized export share of each HS2 product. The instrument for ΔCFR_{ijt} is the annual growth rate in the average container freight rate across origin-destination pairs weighted by the initial bilateral container freight rate. Standard errors are reported in parentheses. * $p < 0.1$ ** $p < 0.05$ ***$p < 0.01$

Table D.4: HS2 Product-Specific First Stage Regressions

	Dependent variable: $\Delta CFR_{ijt} * \mu_g$																			
	$g=1$	$g=2$	$g=3$	$g=4$	$g=5$	$g=6$	$g=7$	$g=8$	$g=9$	$g=10$	$g=11$	$g=12$	$g=13$	$g=14$	$g=15$	$g=16$	$g=17$	$g=18$	$g=19$	$g=20$
$IV * \mu_1$	6.782***																			
	(0.013)																			
$IV * \mu_2$		3.257***																		
		(0.043)																		
$IV * \mu_3$			2.787***																	
			(0.034)																	
$IV * \mu_4$				2.817***																
				(0.044)																
$IV * \mu_5$					1.922***															
					(0.035)															
$IV * \mu_6$						3.681***														
						(0.042)														
$IV * \mu_7$							3.187***													
							(0.047)													
$IV * \mu_8$								2.771***												
								(0.034)												
$IV * \mu_9$									1.726***											
									(0.054)											
$IV * \mu_{10}$										2.809***										
										(0.050)										
$IV * \mu_{11}$											3.319***									
											(0.047)									
$IV * \mu_{12}$												2.775***								
												(0.052)								
$IV * \mu_{13}$													1.311***							
													(0.044)							
$IV * \mu_{14}$														1.888***						
														(0.038)						
$IV * \mu_{15}$															2.836***					
															(0.050)					
$IV * \mu_{16}$																2.772***				
																(0.044)				
$IV * \mu_{17}$																	3.168***			
																	(0.053)			
$IV * \mu_{18}$																		2.392***		
																		(0.035)		
$IV * \mu_{19}$																			2.755***	
																			(0.033)	
$IV * \mu_{20}$																				2.445***
																				(0.035)
R-squared	0.97	0.42	0.45	0.33	0.27	0.48	0.36	0.45	0.12	0.28	0.38	0.26	0.10	0.23	0.28	0.33	0.31	0.36	0.46	0.38
F-statistic	2714	59	67	41	31	78	47	66	10	32	51	30	9	25	33	41	37	47	70	50
Observations	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407

Table D.4: HS2 Product-Specific First Stage Regressions (continued)

	Dependent variable: $\Delta CFR_{ijt} * \mu_g$																			
	$g=21$	$g=22$	$g=23$	$g=24$	$g=25$	$g=26$	$g=27$	$g=28$	$g=29$	$g=30$	$g=31$	$g=32$	$g=33$	$g=34$	$g=35$	$g=36$	$g=37$	$g=38$	$g=39$	$g=40$
$IV * \mu_{21}$	2.357*** (0.041)																			
$IV * \mu_{22}$		2.997*** (0.048)																		
$IV * \mu_{23}$			2.920*** (0.035)																	
$IV * \mu_{24}$				3.114*** (0.037)																
$IV * \mu_{25}$					2.457*** (0.046)															
$IV * \mu_{26}$						3.305*** (0.045)														
$IV * \mu_{27}$							2.632*** (0.045)													
$IV * \mu_{28}$								2.903*** (0.046)												
$IV * \mu_{29}$									2.541*** (0.044)											
$IV * \mu_{30}$										1.703*** (0.040)										
$IV * \mu_{31}$											2.313*** (0.039)									
$IV * \mu_{32}$												2.701*** (0.045)								
$IV * \mu_{33}$													2.846*** (0.042)							
$IV * \mu_{34}$														2.349*** (0.042)						
$IV * \mu_{35}$															2.203*** (0.038)					
$IV * \mu_{36}$																2.626*** (0.030)				
$IV * \mu_{37}$																	2.699*** (0.030)			
$IV * \mu_{38}$																		2.609*** (0.035)		
$IV * \mu_{39}$																			2.649*** (0.042)	
$IV * \mu_{40}$																				2.286*** (0.045)
R-squared	0.29	0.33	0.46	0.46	0.26	0.40	0.30	0.33	0.30	0.18	0.30	0.31	0.36	0.28	0.30	0.48	0.51	0.41	0.33	0.24
F-statistic	34	40	69	72	29	56	35	40	34	18	35	37	46	32	35	76	85	57	41	26
Observations	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407

Table D.4: HS2 Product-Specific First Stage Regressions (continued)

	Dependent variable: $\Delta CFR_{ijt} * \mu_g$									
	$g = 41$	$g = 42$	$g = 43$	$g = 44$	$g = 45$	$g = 46$	$g = 47$	$g = 48$	$g = 49$	$g = 50$
$IV * \mu_{41}$	2.973***									
	(0.039)									
$IV * \mu_{42}$		2.048***								
		(0.051)								
$IV * \mu_{43}$			2.191***							
			(0.024)							
$IV * \mu_{44}$				3.201***						
				(0.042)						
$IV * \mu_{45}$					2.925***					
					(0.028)					
$IV * \mu_{46}$						3.959***				
						(0.034)				
$IV * \mu_{47}$							3.358***			
							(0.044)			
$IV * \mu_{48}$								2.535***		
								(0.044)		
$IV * \mu_{49}$									2.784***	
									(0.041)	
$IV * \mu_{50}$										5.851***
										(0.036)
R-squared	0.42	0.17	0.49	0.42	0.57	0.62	0.42	0.29	0.36	0.76
F-statistic	61	17	82	59	113	139	59	33	47	265
Observations	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407

	$g = 51$	$g = 52$	$g = 53$	$g = 54$	$g = 55$	$g = 56$	$g = 57$	$g = 58$	$g = 59$	$g = 60$
$IV * \mu_{51}$	3.481***									
	(0.026)									
$IV * \mu_{52}$		2.860***								
		(0.044)								
$IV * \mu_{53}$			1.859***							
			(0.019)							
$IV * \mu_{54}$				2.787***						
				(0.029)						
$IV * \mu_{55}$					3.165***					
					(0.031)					
$IV * \mu_{56}$						2.821***				
						(0.048)				
$IV * \mu_{57}$							2.557***			
							(0.018)			
$IV * \mu_{58}$								1.977***		
								(0.035)		
$IV * \mu_{59}$									2.263***	
									(0.036)	
$IV * \mu_{60}$										2.823***
										(0.046)
R-squared	0.69	0.34	0.52	0.53	0.56	0.30	0.71	0.28	0.32	0.32
F-statistic	190	42	93	95	105	36	205	32	39	38
Observations	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407

Table D.4: HS2 Product-Specific First Stage Regressions (continued)

	Dependent variable: $\Delta CFR_{ijt} * \mu_g$																		
	$g = 61$	$g = 62$	$g = 63$	$g = 64$	$g = 65$	$g = 66$	$g = 67$	$g = 68$	$g = 69$	$g = 70$	$g = 71$	$g = 72$	$g = 73$	$g = 74$	$g = 75$	$g = 76$	$g = 78$	$g = 79$	$g = 80$
$IV * \mu_{61}$	2.675***																		
	(0.048)																		
$IV * \mu_{62}$		2.875***																	
		(0.046)																	
$IV * \mu_{63}$			2.921***																
			(0.039)																
$IV * \mu_{64}$				2.545***															
				(0.043)															
$IV * \mu_{65}$					2.597***														
					(0.027)														
$IV * \mu_{66}$						3.811***													
						(0.049)													
$IV * \mu_{67}$							2.128***												
							(0.062)												
$IV * \mu_{68}$								1.786***											
								(0.041)											
$IV * \mu_{69}$									1.978***										
									(0.038)										
$IV * \mu_{70}$										2.112***									
										(0.039)									
$IV * \mu_{71}$											2.127***								
											(0.035)								
$IV * \mu_{72}$												1.880***							
												(0.045)							
$IV * \mu_{73}$													2.957***						
													(0.045)						
$IV * \mu_{74}$														3.125***					
														(0.050)					
$IV * \mu_{75}$															2.151***				
															(0.034)				
$IV * \mu_{76}$																2.747***			
																(0.049)			
$IV * \mu_{78}$																	3.610***		
																	(0.033)		
$IV * \mu_{79}$																		1.854***	
																		(0.036)	
$IV * \mu_{80}$																			3.318***
																			(0.038)
R-squared	0.28	0.33	0.41	0.30	0.53	0.42	0.13	0.19	0.25	0.27	0.31	0.18	0.35	0.32	0.33	0.28	0.60	0.25	0.48
F-statistic	32	40	56	35	93	61	12	19	27	30	37	18	45	40	41	33	125	27	77
Observations	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407

Table D.4: HS2 Product-Specific First Stage Regressions (continued)

	Dependent variable: $\Delta CFR_{ijt} * \mu_g$																	
	$g = 81$	$g = 82$	$g = 83$	$g = 84$	$g = 85$	$g = 86$	$g = 87$	$g = 88$	$g = 89$	$g = 90$	$g = 91$	$g = 92$	$g = 93$	$g = 94$	$g = 95$	$g = 96$	$g = 97$	$g = 98$
$IV * \mu_{81}$	2.925***																	
	(0.047)																	
$IV * \mu_{82}$		3.385***																
		(0.057)																
$IV * \mu_{83}$			2.767***															
			(0.041)															
$IV * \mu_{84}$				2.693***														
				(0.042)														
$IV * \mu_{85}$					2.689***													
					(0.043)													
$IV * \mu_{86}$						2.598***												
						(0.043)												
$IV * \mu_{87}$							2.688***											
							(0.039)											
$IV * \mu_{88}$								2.451***										
								(0.041)										
$IV * \mu_{89}$									2.556***									
									(0.040)									
$IV * \mu_{90}$										2.177***								
										(0.037)								
$IV * \mu_{91}$											2.303***							
											(0.029)							
$IV * \mu_{92}$												2.494***						
												(0.033)						
$IV * \mu_{93}$													2.730***					
													(0.032)					
$IV * \mu_{94}$														2.386***				
														(0.035)				
$IV * \mu_{95}$															2.960***			
															(0.046)			
$IV * \mu_{96}$																2.612***		
																(0.033)		
$IV * \mu_{97}$																	2.424***	
																	(0.029)	
$IV * \mu_{98}$																		3.352***
																		(0.040)
R-squared	0.32	0.30	0.37	0.33	0.33	0.31	0.38	0.31	0.33	0.31	0.44	0.41	0.48	0.37	0.34	0.43	0.47	0.46
F-statistic	39	35	47	41	40	37	49	36	41	37	66	57	76	47	42	64	73	71
Observations	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407

Notes: The tables report the results of the first stage regressions $\Delta CFR_{ijt} * \mu_g = \gamma_g[Z_{ijt} * \mu_g] + \mu_{ij} + \mu_t + u_{ijgt}$ where ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. Z_{ijt} is the instrument for ΔCFR_{ijt} and is the annual growth rate in the average container freight rate across all origin-destination pairs weighted by the initial bilateral container freight rate. μ_g are product fixed effects. All regressions include time fixed effects, μ_t, and origin-destination fixed effects, μ_{ij}. Standard errors are reported in parentheses. * $p < 0.1$ ** $p < 0.05$ ***$p < 0.01$

Table D.5: Aggregation of HS2 Products

Aggregated HS2 Codes	HS2 Codes	Product Description
1	1-5	Animal & Animal Products
2	6-15	Vegetable Products
3	16-24	Foodstuffs
4	25-27	Mineral Products
5	28-38	Chemicals & Allied Industries
6	39-40	Plastics/Rubbers
7	41-43	Raw Hides, Skins, Leather, & Furs
8	44-49	Wood & Wood Products
9	50-63	Textiles
10	64-67	Footwear/Headgear
11	68-71	Stone/Glass
12	72-83	Metals
13	84-85	Machinery/Electrical
14	86-89	Transportation
15	90-98	Miscellaneous

Notes: The aggregation of HS2 products comes from Foreign Trade Online.

Table D.6: Aggregated HS2 Product-Specific First Stage Regressions

	Dependent variable: $\Delta CFR_{ijt} * \mu_g$														
	$g=1$	$g=2$	$g=3$	$g=4$	$g=5$	$g=6$	$g=7$	$g=8$	$g=9$	$g=10$	$g=11$	$g=12$	$g=13$	$g=14$	$g=15$
$IV * \mu_1$	2.731***														
	(0.040)														
$IV * \mu_2$		2.670***													
		(0.049)													
$IV * \mu_3$			2.667***												
			(0.042)												
$IV * \mu_4$				2.641***											
				(0.046)											
$IV * \mu_5$					2.530***										
					(0.044)										
$IV * \mu_6$						2.505***									
						(0.044)									
$IV * \mu_7$							2.408***								
							(0.043)								
$IV * \mu_8$								2.823***							
								(0.043)							
$IV * \mu_9$									2.785***						
									(0.043)						
$IV * \mu_{10}$										2.552***					
										(0.043)					
$IV * \mu_{11}$											1.994***				
											(0.040)				
$IV * \mu_{12}$												2.648***			
												(0.047)			
$IV * \mu_{13}$													2.704***		
													(0.043)		
$IV * \mu_{14}$														2.636***	
														(0.041)	
$IV * \mu_{15}$															2.527***
															(0.038)
R-squared	0.36	0.28	0.35	0.30	0.34	0.30	0.28	0.36	0.36	0.30	0.25	0.32	0.33	0.35	0.38
F-statistic	303	198	260	222	220	219	210	285	275	232	167	214	263	278	298
Observations	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407	8407

Notes: The table reports the results of the first stage regressions $\Delta CFR_{ijt} * \mu_g = \gamma_g[Z_{ijt} * \mu_g] + \mu_{ij} + \mu_t + u_{ijgt}$ where ΔCFR_{ijt} is the first differenced Container Freight Rate (transport cost per 20-foot container) from U.S. port i to foreign country j. Z_{ijt} is the instrument for ΔCFR_{ijt} and is the annual growth rate in the average container freight rate across all origin-destination pairs weighted by the initial bilateral container freight rate. μ_g are product fixed effects. All regressions include time fixed effects, μ_t, and origin-destination fixed effects, μ_{ij}. Standard errors are reported in parentheses. * $p < 0.1$ ** $p < 0.05$ ***$p < 0.01$