Shipping inside *the Box*: Containerization and Trade

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Abstract

We quantify the effect of container technology on transport costs and trade by estimating the modal choice between containerization and breakbulk shipping from Turkish micro-data on export shipments. The model is motivated by novel facts that relate container usage to shipment, destination and firm characteristics. We find container transport to have a higher first-mile cost and a lower distance elasticity, making it cost effective in longer distances. *The box* explains a significant amount of the global trade increase since its inception: a quantitative exercise suggests that Turkish and U.S. maritime exports would have been about two-thirds of what they are today in the absence of containers.

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1 Introduction

The introduction of containers in the second half of 1950s marked a major innovation in transportation: *the box* improved efficiency by allowing automation in cargo handling, connecting sea transport with intermodal inland transport, and reducing spoilage/pilferage on and off the ship. All these benefits generated economies of scale and slashed transit times (Levinson, 2008; Hummels, 2007). Despite its ubiquity, the mechanisms through which containerization affected world trade are still unexplored. Understanding the drivers of container usage at the decision-making level is key to the measurement of transportation costs affecting the volume and composition of international trade. We provide the first such analysis using micro-data on the universe of Turkish export transactions at the firm, product and destination level for the year 2013.

We start by documenting novel facts from our data: despite the perception that international maritime trade is now *highly* containerized, there is still an important margin of modal choice for exporters. As of 2013, only 40 percent of Turkish maritime exports were containerized, with the non-containerized alternative—breakbulk—accounting for the rest.[1] The data shows large variation in container usage across firms, products and destinations. We find three patterns in this variation: first, it is by and large explained by exporting firms, rather than by products and destinations. Second, container usage increases with shipment size and distance to the destination, but decreases with unit prices. Third, container usage increases with firm size and labor productivity. These findings imply that, conditional on physical feasibility due to product characteristics and the necessary infrastructure being available in both the origin and the destination, exporting firms still face a choice on the mode of maritime transportation and only some of them find it optimal to ship in the box.

Informed by these facts, we propose and estimate a model of self-selection into containerized shipping by heterogenous firms. In the first stage, we estimate the variable cost of

[1] Breakbulk refers to shipping goods in the ship's hold, packed in cartons, bags, bales, or pallets, instead of in standardized containers. This shouldn't be confused with bulk cargo such as grains, coal and ores.

container shipping relative to breakbulk without making an assumption on firms' productivity distribution, using observed firm-product-destination level export revenues by mode. In the second stage, we use these estimates along with additional structure on firm productivities and parameter values from the literature to recover relative fixed trade costs by mode.

As our first contribution, we provide empirical evidence that supports the conjecture that container shipping is subject to a higher scale but has a lower distance elasticity, facilitating increased trade with more distant destinations. The *box* decreases variable shipping costs to the destination at the median distance between 10 to 20 percent. As our second contribution, we use the quantified model to undertake a counterfactual exercise, which suggests that the availability of container shipping increases trade substantially. In the absence of the *box*, Turkish and U.S. maritime exports would have been about two-thirds of their level in 2013. Finally, we show that the quantitative results are invariant to whether transport costs are additive or multiplicative as long as the former specification takes into account the endogenous quality choice for exports.

Our paper contributes to an empirical literature that investigates the effect of technological advancements in transportation on trade. Using data from 19th century India, Donaldson (Forthcoming) estimates that railroads reduced the cost of trading, narrowed inter-regional price gaps, and increased trade volumes. Pascali (2014) estimates the impact of steamships on the first wave of trade globalization. Focusing on airplanes, Harrigan (2010) investigates how geography and the choice of shipping mode interact in shaping comparative advantages and trade patterns. Hummels and Schaur (2013) use variation in transport modes across US imports at the origin-product level to identify the ad-valorem equivalent time costs of shipping. Micco and Serebrisky (2006) estimate that the liberalization of air cargo markets reduces air transport costs by about nine percent by enabling the efficiency gains from air transport.

As to the impact of containerization, Hummels (2007) estimates that doubling the share of containerized trade decreases shipping costs between 3 to 13 percent. In a study of port efficiency, Blonigen and Wilson (2008) find that a ten percentage increase in the share of containerized trade between US and foreign ports reduces import charges by around 0.6 percent. These seemingly low effects pose a puzzle: if container shipping is indeed a technological revolution, why don't we see more dramatic effects on trade? In contrast, Bernhofen, El-Sahli, and Kneller (2016) find a large effect. Using a panel data of industry-level bilateral trade for 157 countries, they identify the effect of containerization through countries' differential dates of adoption of container facilities. Their results suggest that containerization contributed more to the increase of world trade during the 1962-1990 period than trade policy changes such as GATT tariff cuts and regional trade agreements. Our contribution is the use of micro data to estimate the structural parameters of shipping technologies in a model of heterogeneous firms making modal decisions.

Our model is related to Rua (2014) who investigates the international diffusion of container technology.[2] She presents a Melitz (2003) type heterogeneous firm model of trade in which containerization lowers the variable cost of shipping goods but involves a fixed cost. As a result, only more productive firms prefer containerized shipping to break-bulk. Using country-level data, she finds that fixed costs and network effects are the main determinants of the adoption of containerization. We model firm selection in a similar way but our focus is in estimating these costs in order to quantify the role of containerization in trade volumes. The estimated model in turn allows us to do quantitative counterfactual analysis.

The next section introduces the data and documents the facts motivating our model and estimation.

[2]The high level of non-containerized maritime shipping in our data is consistent with Rua (2014) who documents that the global share of containerization in general cargo, i.e., containerizable goods, barely reached 70 percent by mid-2000s; see figure I in her paper.

2 Data and Three Empirical Facts

2.1 Basic Characteristics of the Data

The confidential micro-data accessed from the premises of the Turkish Statistical Institute (TSI) is based on customs forms and contains all Turkish export transactions that took place in 2013.[3] Each transaction records the identity of the exporting firm, 8-digit Harmonized System (HS) product code, value, weight (in kilograms) and quantity (in specified units, e.g. pair, number, liter, etc.) of the shipment, destination country, and the mode of transportation (truck, rail, vessel, air, pipeline). A separate binary variable informs us whether goods were shipped in a container or not. For reasons related to disclosure restrictions, our data excludes HS heading 27—mineral fuels, oils, waxes, and bituminous substances—and HS heading 93—arms and ammunition, parts and accessories. Following common practice, we also drop small transactions (firm-product-destination exports with an annual value of less than USD 5,000) from the dataset as they are likely to introduce noise into our estimates.

Unsurprisingly, containerization is associated with maritime shipments: 97.8% of all containerized exports by value are by sea. Only 0.3% and 1.2% of air and land exports are containerized, respectively. Therefore, we restrict the sample to vessel exports to coastal destinations. Excluded landlocked destinations constitute a small share of exports (8%), and an even smaller share of containerized exports (1.9%).

Table 1 presents further relevant summary statistics from our data. Our dataset covers 27,241 exporters, 5,557 8-digit HS products, and 139 destination countries. The top panel of the table shows the fraction of observations with no containerization or full containerization. The respective fractions are small at the destination or product level: share of containerized exports lies strictly between zero and one to almost all destinations in about 75% of 8-digit HS product codes. Nevertheless, the extensive margin contributes significantly to the variation

[3]The entire dataset spans 10 years from 2003 to 2013. We choose to work with the latest available year when the container usage in Turkey peaks. This also allows us to avoid the recession years.

in container use at the firm-level: about one-third of Turkish exporters never shipped in containers, and another one-third shipped only in containers in the year 2013. The value of containerized exports is either zero or one for about 90% of observations (firm-product-destination level).

While the mean value and weight (Kg) of containerized shipments are lower than those of break-bulk shipments, the opposite holds for the medians. It is worth noting that these descriptive statistics are contaminated by compositional effects. Therefore, we now proceed to a more nuanced analysis that controls for compositional effects in order to tease out salient patterns on container usage from our data.

2.2 Three Facts about Container Usage

We now present three micro facts on the use of containerization in monthly maritime export shipments at the product-destination-firm level. In each case, we first summarize the stylized evidence and then explain the underlying analysis. These facts subsequently guide our modeling choices in estimating the parameters of shipping technologies.

Fact 1: **A large share of the variation in containerization is explained by firms, rather than by products and destinations.**

As reported above, around half of all annual vessel exports are containerized, with varying fractions of full or no containerization across products, destinations and firms. We now explore the components of the overall variation in container usage. A priori, one may expect product characteristics to be the primary determinant of whether a shipment will be containerized or not. After all, bulk commodities such as ores or grains are hardly fit for the box, whereas anectodes of global trade convey the image that some goods, such as apparel and consumer electronics, are stackable and thus highly containerized. Similarly, one may expect that the characteristics of the destination country, such as the existence of the appropriate infrastructure or level of development, to be key determinants since the technology is presumably expensive and dependent on specialized ports and intermodal logistics.

For visual inspection, we plot the intensive-margin distribution of container share in vessel exports aggregated over months in Figure 1. Evidently, there is large variation across shipments (Panel A), with high heterogeneity across all dimensions (Panels B-D). For statistical analysis, we run a series of fixed-effect regressions and analyze their fit in Table 2. We denote firms by a, products by j, and destination countries by d.[4] The raw effects in the first column are the R_k^2's from regressing container shares on single fixed-effects $k \in \{a, j, d\}$ in the top panel and on pair fixed effects $k \in \{aj, ad, jd\}$ in the bottom panel. In order to purge out compositional effects, we report partial (adjusted) R^2's isolating the unique contribution of each component in the second column.[5]

Table 2 shows that, in terms of individual effects, product categories and destinations have little explanatory power. Firm-specific factors, both in terms of raw and isolated effects, account for a substantial fraction of the variation.[6] Looking at joint effects, the partial coefficient of firm-destination pairs equals 0.735, suggesting that containerization in international trade is predominantly determined by firms' modal choices that vary across countries.

Fact 2: Container usage is increasing in shipment size and distance to the destination, but is decreasing in unit value of the shipment.

Container shipping displays economies of scale due to high infrastructure costs and the large vessel sizes required to utilize these investments (see Stopford, 2009, chap. 13). Also called the "first-mile cost," the decline in unit costs with scale and distance is a key characteristic

[4]To account for potential seasonal effects in container ship schedules, we pair destinations with months but suppress the time subscript, i.e., d refers to a destination-month pair.

[5]That is, for each k, we first regress container shares on fixed effects (μ_k, μ_{-k}) and find the fit. For instance, for $k = a$ (firm), that would be the $R^2_{a,jd}$ of the regression $ContShr_{ajd} = \mu_a + \mu_{jd} + \epsilon_{ajd}$, where μ_{jd} represents sector-destination pair fixed effects. We then drop the factor of interest $k = a$ to find R^2_{jd} from the regression $ContShr_{ajd} = \mu_{jd} + \epsilon_{ajd}$. The difference $R^2_{a,jd} - R^2_{jd}$ is the coefficient of partial determination, capturing the unique contribution of $k = a$ to the overall variation.

[6]These factors do not include firm location and access to ports as all international ports in Turkey also have container terminals. In other words, firm location does not matter for the relative access to container shipping.

of how transportation and shipping technologies affect trade. This cost structure is plausibly passed on from shipping companies to trading firms—as corroborated by minimum shipment requirements and differential pricing practices for full-container load and less-than-container load shipments. We can thus expect container usage and its geographic determinants to correlate with parcel size. Table 3 confirms this conjecture: controlling for additional destination characteristics such as contiguity to Turkey and potential seasonal effects through destination-month fixed effects, container usage is increasing in transaction size and distance to destination and decreasing in their interaction (columns 1-2). Direct effects of destination characteristics drop out in column 3 due to fixed effects, but the coefficients of the shipment size and the interaction effect remain significant and robust. The effect of distance is economically important: increasing the destination distance by 10 percent increases container usage by about 6.38 percentage points at the median shipment weight.

Table 4 shows that container usage is also correlated with unit value of shipments, defined as shipment value per quantity measured in physical units.[7] In particular, controlling for shipment weight, lower unit values within a firm-product pair are associated with higher container usage. The second and third columns restrict the sample respectively to differentiated and non-differentiated goods, defined according to the classification developed by Rauch (1999). Results show that the negative association of container usage with unit values holds for differentiated goods only. The finding may be indicative of quality differentiation with respect to choice of transport mode. In particular, if transport costs are additive and unit shipping costs are higher in breakbulk, for a given firm-product pair, Alchian-Allen effect implies a negative relationship between container usage and quality. To account for this mechanism, we will incorporate endogenous quality differentiation to the model presented in the next section.

[7] Unit of measurement does not vary within a given 8-digit HS product code.

Fact 3: Container usage is increasing in total sales, employment and productivity of the exporter, with no economies of scope.

Per Fact 1, the most significant factor in explaining modal choice is the identity of exporting firms. Theoretically, heterogeneity in productivity or quality, together with fixed costs of container shipping, could induce firms to sort into using the technology (Rua, 2014). To investigate this, Table 5 reports the results from regressing container usage on various firm-level characteristics. Across all specifications, it is important to control for shipment size to ensure that the effect is not going through the shipment-specific scale economies documented in Fact 2, and for compositional effects through product-destination fixed effects. Total firm exports, employment, sales, and labor productivity (value of sales per worker) are all positively and significantly correlated with container usage (columns 1-4). When total exports and labor productivity are jointly controlled for in column 5, only the former is significant, suggesting that the mechanism goes through exports. In column 6, we include the number of 8-digit HS products exported by the firm to a given destination and find no evidence of economies of scope for container usage.

In concluding this section, we reiterate that the micro-level export data show substantial variation in container usage within narrow product categories and destination countries, with an overall variation largely accounted for by firms and systematically varying with firm and destination characteristics. Next section presents a transport mode choice model for heterogeneous firms that is consistent with these stylized facts and is amenable to estimation.

3 Model

To explain the choice between containerization and breakbulk at the firm-level, we now present a simple partial-equilibrium trade model with heterogeneous firms. Taking as given the demand in export destinations, monopolistically competitive firms make optimal pricing, quality and mode of transport choices. In line with mounting evidence (Hummels and Skiba, 2004; Irarrazabal, Moxnes, and Opromolla, 2015), we assume per-unit transport costs as our baseline specification. To take into account the potential Alchian-Allen effect—increased relative demand for high-quality products in the presence of additive transport costs—we incorporate quality differentiation to the model. This framework helps us characterize the conditions under which there is positive selection into container usage, and yields estimable equations that pin down the structural parameters of the two transport technologies. We later present an alternative version of the model with iceberg trade costs and without quality differentiation. As will be demonstrated and explained below, the choice between the two versions of the model does not affect our empirical strategy, and the predictions obtained from a counterfactual exercise about the effect of containerization on trade remain invariant to the specification of transport costs.

Demand There is one source country exporting to multiple destinations indexed by d. It is populated by a large number of firms, which are heterogenous in productivity a and produce a continuum of horizontally and vertically differentiated varieties. As now standard in the literature, we use the productivity index to represent varieties produced by these monopolistically competitive firms.

Consumer preferences in destination d are represented by a quality-augmented CES aggregate as in Baldwin and Harrigan (2011) and Kugler and Verhoogen (2012):

$$Q_d = \left[\int \left[z_d(a) q_d(a) \right]^{\frac{\sigma-1}{\sigma}} dG(a) \right]^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

where $z_d(a)$ denotes the quality, σ the elasticity of substitution, $q_d(a)$ quantity consumed and $G(a)$ the distribution of firm productivity. Utility maximization yields the following demand for each differentiated variety:

$$q_d(a) = X_d P_d^{\sigma-1} z_d(a)^{\sigma-1} \tilde{p}_d(a)^{-\sigma}, \tag{2}$$

where X_d is the spending allocated to the sector in destination d, $\tilde{p}_d(a)$ is the consumer price, and P_d is a quality-augmented CES price index defined as:

$$P_d^{1-\sigma} = \int \left(\frac{\tilde{p}_d(a)}{z_d(a)} \right)^{1-\sigma} dG(a).$$

Supply Consumer prices (c.i.f.) differ from the producer prices (f.o.b.) because of trade costs, which have a specific component t_d^m that varies by destination and endogenously chosen transport mode $m = \{b, c\}$ (for break-bulk or container), and an exogenous ad-valorem component $\tau_d > 1$ that depends only on the destination:[8]

$$\tilde{p}_d^m(a) = \tau_d \big[p_d(a) + t_d^m \big]. \tag{3}$$

In modeling quality production, we follow Feenstra and Romalis (2014) and assume that a firm with productivity a uses l units of labor (expressed in efficient labor units) to produce one unit of product with quality $z_d(a)$:

$$z_d(a) = (a \cdot l)^{\theta}, \tag{4}$$

where $\theta \in (0, 1)$ represents diminishing returns in the production of quality. The quality production function implies marginal cost of production given by

$$C_d(a, z) = \frac{z_d(a)^{1/\theta}}{a} w, \tag{5}$$

where w is the unit cost of labor input and the numéraire. We now describe firms' optimal pricing, quality and transport mode decisions.

[8] A vast majority of countries apply tariffs on transport inclusive prices—see footnote 10 in Feenstra and Romalis (2014).

Optimal Price and Quality Given mode m, firms maximize operating profits by solving

$$\pi_d^m(a) \;=\; \max_{p,z} \left\{ q_d^m(a) \cdot \left[p_d^m(a) - C_d(a,z) \right] \right\},$$

where $q_d^m(\cdot)$ captures the dependence of demand (equation 2) on m through the consumer price (3). First-order condition with respect to price yields

$$p_d^m(a) = \frac{\sigma C_d(a,z) + t_d^m}{\sigma - 1}. \tag{6}$$

Similarly, first-order condition with respect to quality yields:

$$z_d^m(a)^{1/\theta} = \frac{\theta}{1-\theta} \cdot a \cdot t_d^m. \tag{7}$$

Substituting (7) into (5) and using (6) gives the following optimal price as a function of unit transport costs:

$$p_d^m(a) = \chi \cdot t_d^m, \tag{8}$$

where $\chi = \frac{1}{\sigma-1}\left(\frac{\sigma\theta}{1-\theta} + 1\right)$. Equation (8) describes a simple linear relationship between f.o.b. prices and specific transport costs. Given the profit-maximizing price and quality, the revenue of a firm with productivity a exporting to destination d using transport technology m is given by:

$$r_d^m(a) \;=\; \Theta_d \cdot a^{\theta(\sigma-1)} \cdot (t_d^m)^{-(\sigma-1)(1-\theta)}, \tag{9}$$

where $\Theta_d = \chi(\chi+1)^{-\sigma} \left(\frac{\theta}{1-\theta}\right)^{\theta(\sigma-1)} X_d P_d^{\sigma-1} \tau_d^{-\sigma}$. Subtracting variable costs at the optimal quality choice and rearranging terms, operating profits are given by

$$\pi_d^m(a) \;=\; \frac{\chi+1}{\chi\sigma} \cdot r_d^m(a). \tag{10}$$

Choice of Transport Mode A firm exporting to destination country d pays a mode-specific fixed cost $f_d^m > 0$. Net export profit for using each transport mode is simply:

$$\Pi_d^m(a) \; = \; \pi_d^m(a) - f_d^m. \tag{11}$$

A firm exports to a destination in a container if $\Pi_d^c(a) \geq \Pi_d^b(a)$. The following condition is necessary and sufficient to induce productivity-based selection into containerization and thus make the model consistent with Fact 3:

$$\frac{f_d^c}{f_d^b} > \left(\frac{t_d^c}{t_d^b}\right)^{-(\sigma-1)(1-\theta)}. \tag{12}$$

This restriction on relative fixed and variable trade costs is a modified version of the condition for selection into exporting in Melitz (2003): only sufficiently productive exporters choose container to breakbulk shipping. Therefore, the marginal exporter uses break-bulk and can be characterized by $\tilde{a}_d^b$ satisfying $\Pi_d^b(\tilde{a}_d^b) = 0$. The marginal *containerized* exporter $\tilde{a}_d^c$ is defined by $\Pi_d^c(\tilde{a}_d^c) = \Pi_d^b(\tilde{a}_d^c)$, and satisfies $\tilde{a}_d^c > \tilde{a}_d^b$.

4 Estimation

The model of firm selection into exporting and containerization is based on two novel sets of parameters that we wish to estimate: mode-dependent variable and fixed export costs (t_d^m, f_d^m). Progressing in two stages, we first parameterize and estimate relative variable transport costs using observed firm-product-destination level export revenues by mode of shipping, controlling for selection through appropriate fixed effects. This flexible approach allows us to estimate variable costs without making a distributional assumption for firm productivity. In the second stage, we use these estimates along with additional structure on firm productivities to recover relative fixed trade costs by mode.

4.1 Estimation Strategy

To derive estimating equations from model-based firm revenue and mode-choice rules, we specify variable transport costs by:

$$t_d^m \; = \; \bar{t}_m \cdot dist_d^{\delta_m}, \tag{13}$$

where $dist_d$ is the distance to destination country d. The parameters $\bar{t}_m$ and δ_m capture the mode-specific first-mile costs and distance elasticities, respectively. Based on Fact 2 documented above, we anticipate containerization to have a higher first-mile cost ($\bar{t}_c > \bar{t}_b$) and a lower distance elasticity ($\delta_c < \delta_b$).

Under this parameterization, log revenues can be written as (see Appendix A1 for details)

$$\begin{aligned} \ln r_d(a) \; = \; \ln\left(\frac{r_d^b(\tilde{a}_d^b)}{(\tilde{a}_d^b)^{\theta(\sigma-1)}}\right) \; & + \; (\sigma-1)\theta \ln a \\ & + \; (1-\sigma)(1-\theta)\big[\ln(\bar{t}_c) - \ln(\bar{t}_b)\big] \cdot CONT \\ & + \; (1-\sigma)(1-\theta)(\delta_c - \delta_b) \cdot CONT \cdot \ln dist_d, \end{aligned} \tag{14}$$

where the indicator function $CONT$ denotes container usage, i.e., $CONT = 1$ for $a \geq \tilde{a}_d^c$ and zero otherwise.

Equation (14) forms the basis of our estimation. To implement an empirical specification, we have to consider two issues. First, each firm produces a single variety j in the model, whereas many firms operate in multiple sectors and export multiple products belonging to a given sector, $s(j)$, in the data.[9] Empirically, we group 8-digit HS products under 4-digit HS sectors, and use appropriate firm and sector fixed effects to distinguish multi-product exporters' sales in different sectors.[10] This approach also allows us to take into account

[9] As discussed above, Fact 3 motivates our abstraction from economies of scope in container usage: multi-product firms make independent shipping mode decisions for each product. There may be, however, economies of scope in other activities leading to the emerge of multi-product firms.

[10] For instance, HS heading 8703 refers to "Motor vehicles for the transport of persons," which we consider as a sector. Finer 8-digit levels distinguish varieties according to body type, ignition type and engine capacity.

demand variations across sectors in a given destination, i.e., denote spending allocated to a sector s as X_{sd}. Second, we observe monthly firm-product-destination-mode level export sales in our data, capturing multiple transactions realized within the year. Firms may face transaction-specific *i.i.d.* revenue shocks ϵ_{ajdm}, realized after pricing and shipping decisions have been made, which is the error term in estimating equation (14).

The first term in (14) is common to all firms in sector s exporting to destination d, and thus can be captured by sector-destination fixed effect (α_{sd}). The second term contains firm productivity, and thus can be captured by a firm fixed effect (α_a). So, our estimating equation can be written as:

$$\begin{aligned} \ln r_{ajdm} &= \underbrace{(1-\sigma)(1-\theta)\big[\ln(\bar{t}_c) - \ln(\bar{t}_b)\big]}_{\eta_1} \cdot CONT_{ajdm} \\ &+ \underbrace{(1-\sigma)(1-\theta)(\delta_c - \delta_b)}_{\eta_2} \cdot CONT_{ajdm} \cdot \ln dist_d \\ &+ \alpha_{sd} + \alpha_a + \epsilon_{ajdm}, \end{aligned} \tag{15}$$

where the indicator function $CONT$ is a dummy taking the value one if there is a containerized shipment in the observed firm-product-destination level flow.

4.2 Estimation Results

Table 6 presents the results from estimating equation (15). Our dependent variable is measured in terms of deviations from the respective 8-digit HS product means: $\ln(r_{ajdm}/\overline{r}_j)$, where $\overline{r}_j$ denotes the mean value of exports at the product-level. This is equivalent to adding 8-digit HS product fixed effects in estimation, which would control for, among other things, product-specific prices.

In the first column, we start with the direct effect of containerization without interaction terms to gauge whether containerization is associated with larger trade flows. Controlling for demand-related factors with sector-destination fixed effects and supply-related factors (e.g.

firm productivity) with firm-sector fixed effects, containerized exports are indeed 27 percent ($e^{0.240} - 1$) larger than break-bulk exports.

The second column of table 6 presents results from estimation of equation (15). Contrasted with the first column, adding the interaction between the container dummy and distance to destination reverses the sign of the coefficient η_1 on $CONT_{ajdm}$ to negative. This is consistent with our hypothesis that containerization has a higher first-mile cost than breakbulk shipping: since $\sigma > 1$ and $\theta < 1$, a negative η_1 estimate implies $\bar{t}_c > \bar{t}_b$. The coefficient η_2 on the interaction between $CONT_{ajdm}$ and $\ln dist_d$ is estimated to be positive and statistically significant, which implies a smaller elasticity of container shipping with respect to distance, $\delta_c < \delta_b$. In column 3, we replace firm fixed effects with firm-sector level fixed effects to account for potential sectoral heterogeneity in productivity distributions or the elasticity of substitution. The estimates of both η_1 and η_2 remain stable compared to the second column.

The specifications presented so far control for demand and supply factors related to sector-destination and firm-productivity pairs but ignore selection into containerization. In particular, a positive revenue shock at the firm-sector-destination level would increase the probability of containerization, creating an upward bias in the estimate of η_1 and driving it towards zero. To address this, remember that a firm operating in sector s would prefer containerized exports if $\Pi^c_{sd}(a) \geq \Pi^b_{sd}(a)$, where net profits depend on revenues as derived in equation (11). Using the expressions for revenues in Appendix A1, profit gains from shipping in a container can be derived as follows:

$$\Pi^c_{sd}(a) - \Pi^b_{sd}(a) \;=\; \frac{\chi + 1}{\chi\sigma} \cdot \left[\left(\frac{t^c_d}{t^b_d} \right)^{-(\sigma-1)(1-\theta)} - 1 \right] \cdot (f^c_d - f^b_d) \cdot r^b_{sd}(a).$$

Since the expression above varies at the firm-sector-destination level, selection into containerization can be accounted for by replacing sector-destination and firm-sector fixed effects in the estimating equation (15) with firm-sector-destination fixed effects α_{asd}. In this specification, the parameters of interest, η_1 and η_2, are identified from variation in container usage within a firm-sector-destination triplet across transactions. We can consistently estimate the parameters as long as firms face transaction-specific revenue shocks that do not systematically vary with the mode of transport.

The fourth column of table 6 presents the results. Compared to the estimates in column 3, estimates of both η_1 and η_2 are larger in absolute value. In particular, the estimate of η_1 more than doubles (in absolute value) when selection into containerization is accounted for. This result is consistent with our prior that selection into containerization should drive the estimate of η_1 towards zero.

In the next section, we will use our preferred estimates from the last column of table 6, parameter values from the literature, and further moments from the data to recover the unobserved relative variable and fixed costs of containerization. Recovering these costs will allow us to undertake model-consistent counterfactuals, yielding predictions for the contribution of containerization to the growth of global trade in the past several decades.

5 Recovering Trade Costs

To recover transport technology parameters $(\bar{t}_m, \delta_m)$ from the estimates of (η_1, η_2) in equation (15), we need to quantify σ and θ. As typical in the literature (Anderson and Van Wincoop, 2004; Coşar and Demir, 2016), the elasticity of substitution σ cannot be separately identified from the distance elasticity of trade costs. In our case, an additional parameter θ, capturing the supply of quality, enters the picture.

To proceed, we exploit further moments of the data related to the intensity of container usage in the aggregate and in the extensive margin. Under the assumption that the unconditional firm productivity a is drawn from a Pareto distribution with domain $a \in [1, \infty]$ and shape parameter k satisfying $k > \theta(\sigma - 1)$ similar to Chaney (2008), we can derive analytic expressions for destination-level share of containerized exports, μ_d, and the fraction of firms using container shipping, μ_d^{ext} (see Appendix A2 for the details):

$$\mu_d = \frac{\int_{\tilde{a}_d^c}^{\infty} r_d(a)dG(a)}{\int_{\tilde{a}_d^b}^{\infty} r_d(a)dG(a)} = \frac{(\Delta t_d)^{-(\sigma-1)(1-\theta)}\left(\frac{\Delta f_d - 1}{(\Delta t_d)^{-(\sigma-1)(1-\theta)}-1}\right)^{\frac{\theta(\sigma-1)-k}{\theta(\sigma-1)}}}{1+\left(\frac{\Delta f_d - 1}{(\Delta t_d)^{-(\sigma-1)(1-\theta)}-1}\right)^{\frac{\theta(\sigma-1)-k}{\theta(\sigma-1)}}\cdot\left[(\Delta t_d)^{-(\sigma-1)(1-\theta)}-1\right]}, \tag{16}$$

and

$$\mu_d^{ext} = \frac{\int_{\tilde{a}_d^c}^{\infty} dG(a)}{\int_{\tilde{a}_d^b}^{\infty} dG(a)} = \left(\frac{\Delta f_d - 1}{(\Delta t_d)^{-(\sigma-1)(1-\theta)}-1}\right)^{\frac{-k}{\theta(\sigma-1)}}, \tag{17}$$

where $\Delta f_d = f_d^c/f_d^b$ denotes relative fixed costs, and $\Delta t_d = t_d^c/t_d^b$ denotes relative variable trade costs. Using the functional form (13) for transport costs,

$$\Delta t_d = \frac{t_d^c}{t_d^b} = \left(\frac{\bar{t}_c}{\bar{t}_b}\right)\cdot dist_d^{(\delta_c-\delta_b)}. \tag{18}$$

The set of parameters to be calibrated is (σ, θ, k) as well as relative fixed costs Δf_d. The elasticity of substitution σ and Pareto parameter k are widely estimated in the literature. We take $\sigma = 4$ and $k = 4.25$ from Melitz and Redding (2015).

The following procedure pins down the quality production parameter θ along with relative fixed costs: from the data, we take the empirical moments (μ_d, μ_d^{ext}) as the median across sectors for each destination. For all values of $\theta \in [0, 1]$, we back out $(\bar{t}_c/\bar{t}_b)$ and $(\delta_c - \delta_b)$ from (η_1, η_2) estimates of equation (15). Given distances, we use equation (18) to construct destination-specific relative variable transport costs, Δt_d. To back out Δf_d, we plug Δt_d and the parameter values (σ, k, θ) into equation (16) and use the empirical moment μ_d on the left hand side. We then use $(\Delta t_d, \Delta f_d)$ along with parameter values (σ, k, θ) in equation (17) to calculate the model-implied extensive margin moment. The value of θ is picked such that the median of this moment across destinations matches its empirical value of $\text{median}_d\,\{\mu_d^{ext}\} = 0.74$, yielding $\theta = 0.304$.[11]

Variable Trade Costs Given $\sigma = 4$, the calibrated value $\theta = 0.304$ and estimates of (η_1, η_2) from the last column of table 6 imply $(\bar{t}_c/\bar{t}_b) = 1.2$, i.e., the first-mile cost of container shipping is

[11] The resulting correlation between the observed and model-implied extensive margin across destinations is about 0.78.

about 20% larger than that of breakbulk shipping. While it has a higher first-mile cost, container shipping has a smaller distance elasticity: $\delta_c - \delta_b = -0.04$.

Top panel of figure 2 plots $\widehat{\Delta t_d}$ against distance. The solid line is drawn using baseline parameter values, while the dashed line sets $\sigma = 6$ (and re-calibrates θ) to check robustness to an empirically relevant higher value of σ. The negative gradient of relative variable container costs with respect to distance is consistent with the observed pattern in the data that container usage is increasing in distance to the destination (Fact 2). Using the benchmark estimates, variable cost savings from containerization reach 23 percent when the distance variable reaches 20,000 km. Cost savings are large for major trading pairs, amounting to 19 percent for Germany-USA and 21 percent for China-USA. For the latter pair, the lower bound for cost savings implied at the higher level of $\sigma = 6$ is around 11 percent.

Note that the combination of a higher first-mile cost and a lower distance elasticity implies that container shipping becomes cheaper beyond a breakeven distance. The horizontal line in the top panel of figure 2 marks the breakeven distance implied by our estimates, which is 58 km. Since it only depends on our estimates of η_1 and η_2, the breakeven distance remains unchanged across panels.[12] This rather short breakeven distance is consistent with the raw data in that all destination countries, however close they are in proximity to Turkey, receive some containerized maritime exports (see the first row of table 1). Concurrently, it is consistent with the importance of firms, rather than destinations, in explaining container usage (Fact 1): if all destinations are situated beyond the breakeven distance, which is the case in our data, the large variation in container usage should come from firm-destination level heterogeneity. In the model, firm selection into container shipping is driven by relative destination-dependent fixed cost of exporting $\Delta f_d = f_d^c / f_d^b$, which we present next.

Fixed Trade Costs Bottom panel of figure 2 plots the histogram of calibrated relative fixed costs of containerized exports. Fixed cost of containerization is 40 to 100 percent higher than that of breakbulk, with a median of 70 percent across destinations.

[12] This follows from $t_d^b(\widetilde{dist}) = t_d^c(\widetilde{dist})$, which yields $\widetilde{dist} = \exp\left(\frac{\ln(\bar{t}_c) - \ln(\bar{t}_b)}{\delta_b - \delta_c}\right) = \exp\big(-\hat{\eta}_1/\hat{\eta}_2\big)$.

Several channels could justify higher fixed costs associated with containerization. For instance, container links between ports are less frequent than break-bulk links. This implies, for any given shipment, the exporter has to spend additional effort to better manage the production and inventory scheduling. Another source is the importance of transaction-specific scale in container shipping: if the shipment size is large enough to fill a container (full-container-load), firms can schedule door-to-door shipping services. Otherwise, if the shipment is less-than-container load, exporters have to purchase additional services from freight-forwarders who consolidate and store shipments at ports. Due to the cargo handling involved, such services typically involve additional costs.

Iceberg Specification of Trade Costs The baseline model assumes that trade costs are composed of an ad-valorem part τ_d and an additive part t_d^m. We now investigate the implications of assuming that trade costs take the multiplicative "iceberg" form. Since multiplicative trade costs do not affect firm's choice of product quality, we set $z(a) = 1$ for all firms. We assume that trade costs can be written as the product of two terms: destination tariffs that do not vary between shipping modes τ_d, and distance-mode dependent costs $t_d^m \geq 1$, such that $T_d^m = \tau_d \cdot t_d^m$ units of a good must be shipped to destination d in order for one unit to arrive.

With this specification, consumer prices in destination d are given by:

$$\tilde{p}_d^m(a) = T_d^m \cdot p(a). \tag{19}$$

Since we abstract from quality differentiation, firms maximize profits with respect to price only, yielding

$$p_d^m(a) = \frac{\sigma}{\sigma - 1} \cdot \frac{1}{a} \cdot T_d^m. \tag{20}$$

Given demand in destination d for the variety exported by firm a, we can write firm revenues as:

$$r_d^m(a) \;=\; \Theta_d \cdot a^{\sigma-1} \cdot (t_d^m)^{1-\sigma}, \tag{21}$$

where $\Theta_d = \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} X_d P_d^{\sigma-1} \tau_d^{1-\sigma}$. Condition (12) that induces productivity-based selection into containerization becomes:

$$\frac{f_d^c}{f_d^b} > \left(\frac{t_d^c}{t_d^b}\right)^{1-\sigma}.$$

As in Appendix A1, we can write revenues of firm a from its export sales to a destination country d in terms of the revenues of the marginal firm exporting to the same destination:

$$r_d(a) = \begin{cases} r_d^b(\tilde{a}_d^b)\left(\frac{a}{\tilde{a}_d^b}\right)^{\sigma-1}\left(\frac{t_d^c}{t_d^b}\right)^{1-\sigma} & \text{if } a \geq \tilde{a}_d^c, \\ r_d^b(\tilde{a}_d^b)\left(\frac{a}{\tilde{a}_d^b}\right)^{\sigma-1} & \text{if } a < \tilde{a}_d^c. \end{cases} \tag{22}$$

Finally, container share for the model with iceberg-type trade costs becomes

$$\mu_d = \frac{(\Delta t_d)^{1-\sigma}\left(\frac{\Delta f_d - 1}{(\Delta t_d)^{1-\sigma}-1}\right)^{\frac{\sigma-k-1}{\sigma-1}}}{1+\left(\frac{\Delta f_d - 1}{(\Delta t_d)^{1-\sigma}-1}\right)^{\frac{\sigma-k-1}{\sigma-1}}\cdot\left[(\Delta t_d)^{1-\sigma}-1\right]}. \tag{23}$$

Note that letting transport costs to be multiplicative does not modify our estimating equation. Using the same specification for $t_d^m = \bar{t}_m \cdot dist_d^{\delta_m}$, revenue expressions (21)-(22) still imply the estimating equation (15) without the term containing θ. In other words, the model with additive trade costs and quality differentiation delivers a reduced form equation that is isomorphic to the one derived from a model with multiplicative trade costs and no quality differentiation. This interesting result can be traced to the optimal pricing expression (8) derived under additive trade costs, which is multiplicative due to the presence of the quality margin.

Using the baseline estimates of (η_1, η_2) from the fourth column of table 6, along with $\sigma = 4$, we back out $(\bar{t}_c/\bar{t}_b) = \exp(\eta_1)/(1-\sigma) = 1.135$ and $(\delta_c - \delta_b) = \eta_2/(1-\sigma) = -0.03$. Using the implied Δt_d, we then back out relative fixed costs Δf_d from the empirical aggregate container shares μ_d using the expression above. Top and bottom panels of figure 3 plot relative variable trade costs Δt_d and histogram of relative fixed trade costs Δf_d. While relative variable costs look qualitatively and quantitatively similar to its counterpart at the top panel of figure 2, iceberg specification implies smaller variable cost savings from containerization. This is evident from the flatter cost gradient with respect to distance at top panels. The implied variable cost saving for a shipping between China and USA is 15 percent when transport costs are deemed to be multiplicative, compared to

21 percent when they are assumed to be additive. When the elasticity of substitution is set higher to $\sigma = 6$, the implied cost savings are much more similar between multiplicative and additive specifications (dashed lines at the top panels of both figures).

6 Counterfactuals: Effect of Containerization on Trade

Having quantified relative transport costs, we now explore the extent to which the availability of container shipping increases trade. To address this question, we calculate two statistics: we first compare the current level of exports to a destination to the counterfactual level that would obtain if container shipping was not available:

$$\Delta EXP_1^d = \frac{\underbrace{\int_{\tilde{a}_d^b}^{\tilde{a}_d^c} r_d(a)dG(a) + \int_{\tilde{a}_d^c}^{\infty} r_d(a)dG(a)}_{\text{Current exports}}}{\underbrace{\int_{\tilde{a}_d^b}^{\infty} r_d(a)dG(a)}_{\text{Breakbulk only counterfactual exports}}} = 1 + \left(\Delta t_d^{-(\sigma-1)(1-\theta)} - 1\right)\left(\frac{\Delta f_d - 1}{\Delta t_d^{-(\sigma-1)(1-\theta)} - 1}\right)^{\frac{\theta(\sigma-1)-k}{\theta(\sigma-1)}}.$$

The second method assumes that the selection equation in (12) holds with equality, i.e., $\Delta f_d = \Delta t_d^{-(\sigma-1)(1-\theta)}$ for all d, due to a counterfactual decrease in the fixed cost of container shipping. In this case, all exporters to all destinations prefer containerization to breakbulk shipping. This statistic is given by

$$\Delta EXP_2^d = \frac{\underbrace{\int_{\widehat{a}_d^c}^{\infty} r_d(a)dG(a)}_{\text{Container only counterfactual exports}}}{\underbrace{\int_{\tilde{a}_d^b}^{\tilde{a}_d^c} r_d(a)dG(a) + \int_{\tilde{a}_d^c}^{\infty} r_d(a)dG(a)}_{\text{Current exports}}} = \frac{\Delta t_d^{-(\sigma-1)(1-\theta)}}{1 + \left(\Delta t_d^{-(\sigma-1)(1-\theta)} - 1\right)\left(\frac{\Delta f_d - 1}{\Delta t_d^{-(\sigma-1)(1-\theta)} - 1}\right)^{\frac{\theta(\sigma-1)-k)}{\theta(\sigma-1)}}}.$$

where $\widehat{a}_d^c$ denotes the ability of the marginal exporter to destination d when $\Delta f_d = \Delta t_d^{-(\sigma-1)(1-\theta)}$. While ΔEXP_1^d is informative about how much international trade has increased from the pre-container era to the present due to the availability of the technology, ΔEXP_2^d is informative about potential future increases due to further improvements in the technology to the point of full adaption.

We conduct these counterfactual exercises not just for Turkey but also for the U.S, using 2013 U.S. maritime exports disaggregated by product (6-digit HS classification), destination, and shipping mode from the publicly available U.S. Census Exports of Merchandise database. For each export destination of the U.S., we calculate Δt_d using our estimates and the appropriate sea distances, and then back out Δf_d using the methodology described in the previous section.

Figure 4 plots destination specific ΔEXP_1^d against sea distances. For both countries, containerization implies a significant increase in exports: median increase is 45 percent for Turkey, and 48 percent for the US. Stated in reverse, current trade levels would decrease by about a third if container technology did not exist ($\approx 0.45/1.45$). The gains reach 69 percent for the most remote trade partners.[13] Potential increases in trade if container shipping was fully adopted—to the point where it is preferred by all exporters—are also sizable: the median ΔEXP_2^d is 8.5 percent and 7 percent for Turkey and the U.S., respectively.

These results are invariant to transport costs being additive or multiplicative since ΔEXP_1^d and ΔEXP_2^d are functions of the observables $(\mu_d, dist_d)$ and the estimates of (η_1, η_2)—see Appendix A3 for details. To see the intuition, first note that the term $\Delta t_d^{-(\sigma-1)(1-\theta)}$ in ΔEXP_1^d and ΔEXP_2^d depends only on $dist_d$ and the estimates of (η_1, η_2). This is a direct result of both specifications yielding the same estimating equation. Second, we back out Δf_d from the same empirical container share moment μ_d—depending on the cost specification, this is equation (16) or (23). As a result, the model with additive costs and endogenous quality choice yields the same trade increase due to containerization as the model with multiplicative trade costs and no quality margin, when both models are quantified using the same salient moments of the data. For the very same reason, the values chosen for (σ, k) parameters do not matter for the magnitudes of ΔEXP_1^d and ΔEXP_2^d.

The two specifications, however, differ in the implied elasticity of trade to shipping costs. In the baseline (specific transport costs), containerization decreases variable trade costs to a destination located at the median distance from Turkey by about 20 percent. This implies a trade elasticity

[13] By construction, the exercise implies an increase of exports to all destinations. Such drastic changes in distance-related shipping costs, however, could potentially divert trade from nearby trade partners in a general equilibrium framework.

around 2.25 ($= 0.45/|-0.2|$). For the U.S., trade elasticity at the median distance is around 2.5. Since the estimated variable cost decrease is smaller under iceberg specification—see top panels of figures 2-3 and the discussion in the previous section—implied trade elasticities are larger, around 3.2 for Turkey and 3.5 for the U.S.

7 Conclusion

Using detailed Turkish export data, we quantify the effect of containerization on transport costs and trade by providing the first systematic estimation of firms' modal choice between containerized and breakbulk shipping. The results confirm the role of the box in the global economy: it implies variable cost savings around 20 percent at distances that are relevant for major trading economies, with a fixed cost around 50 to 100 percent higher than its breakbulk alternative. A counterfactual exercise suggests that in the absence of containerization, Turkish maritime exports would decrease by around a third. Container shipping is indeed a major driver of increased international trade in the past several decades.

Governments and international agencies have recently placed trade facilitation and investment in transport infrastructure as top policy priorities. Important for these initiatives is a better understanding and quantification of transport costs. This paper takes an important step in that direction. The next step should be to further unpack how market structure of the logistics sector interacts with infrastructure and technological improvements in determining these costs. Because of its intermodality and the large scale of investments, the box is central to this question.

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APPENDIX

A1 Derivation of the Revenue Function (equation 14)

Using the expression for revenues in equation (25), we can write revenue of a firm exporting in a given sector s to destination d using transport technology m as a function of the marginal firm exporting in the same sector to the same destination using transport technology m:

$$\frac{r_d^m(a)}{r_d^m(\tilde{a}_d^m)} = \left(\frac{a}{\tilde{a}_d^m}\right)^{\theta(\sigma-1)}, \tag{24}$$

where $\tilde{a}_d^m$ denotes the productivity of the marginal firm using transport technology m. The revenues of the marginal exporter can be written as:

$$r_d^m(\tilde{a}_d^m) \; = \; \Theta_d \cdot (\tilde{a}_d^m)^{\theta(\sigma-1)} \cdot (t_d^m)^{-(\sigma-1)(1-\theta)}, \tag{25}$$

where Θ_d is a function of spending allocated to sector s in destination country d, X_d. For the marginal firm choosing containerization to breakbulk, we have the following relationship between its revenues from containerization and its revenues from breakbulk shipping:

$$\frac{r_d^c(\tilde{a}_d^c)}{r_d^b(\tilde{a}_d^c)} = \left(\frac{t_d^c}{t_d^b}\right)^{-(\sigma-1)(1-\theta)}. \tag{26}$$

Putting the two expressions together, we can write firm revenues as follows:

$$r_d(a) = \begin{cases} r_d^b(\tilde{a}_d^b)\left(\frac{a}{\tilde{a}_d^b}\right)^{\theta(\sigma-1)}\left(\frac{t_d^c}{t_d^b}\right)^{-(\sigma-1)(1-\theta)} & \text{if } a \geq \tilde{a}_d^c, \\ r_d^b(\tilde{a}_d^b)\left(\frac{a}{\tilde{a}_d^b}\right)^{\theta(\sigma-1)} & \text{if } a < \tilde{a}_d^c. \end{cases}$$

Using the specific trade cost function (13) and the indicator function $CONT$ denoting container usage, i.e., $CONT = 1$ for $a \geq \tilde{a}_d^c$, and taking logarithms yields the expression (14) in the text.

A2 Derivation of the Container Share (equation 16)

Firm productivity is distributed Pareto with the CDF, k is shape parameter:

$$G(a) = 1 - a^{-k}, \tag{27}$$

Share of containerized exports for a given sector-destination pair is given by:

$$\mu_d \; = \; \frac{\int_{\tilde{a}_d^c}^{\infty} r_d(a)dG(a)}{\int_{\tilde{a}_d^b}^{\infty} r_d(a)dG(a)}.$$

We can write revenues in terms of revenues of the marginal exporter using equations (24) and (26) to obtain:

$$\begin{aligned}
\mu_d &= \frac{\int_{\tilde{a}_d^c}^{\infty} r_d(\tilde{a}_d^b)(\Delta t_d)^{-(\sigma-1)(1-\theta)}(a/\tilde{a}_d^b)^{\theta(\sigma-1)}dG(a)}{\int_{\tilde{a}_d^b}^{\tilde{a}_d^c} r_d(\tilde{a}_d^b)(a/\tilde{a}_d^b)^{\theta(\sigma-1)}dG(a) + \int_{\tilde{a}_d^c}^{\infty} r_d(\tilde{a}_d^b)(\Delta t_d)^{-(\sigma-1)(1-\theta)}(a/\tilde{a}_d^b)^{\theta(\sigma-1)}dG(a)} \\
&= \frac{(\Delta t_d)^{-(\sigma-1)(1-\theta)}(\tilde{a}_d^c)^{\theta(\sigma-1)-k}}{(\tilde{a}_d^b)^{\theta(\sigma-1)-k} + [(\Delta t_d)^{-(\sigma-1)(1-\theta)} - 1](\tilde{a}_d^c)^{\theta(\sigma-1)-k}},
\end{aligned}$$

where $\Delta t_d = t_d^c/t_d^b$.

Next, we use the profit functions in (10) and (11) to express marginal productivities in terms of trade costs:

$$\begin{aligned}
(\tilde{a}_d^b)^{\theta(\sigma-1)} &= \frac{\chi\sigma}{(\chi+1)\Theta_d} \cdot (t_d^b)^{(\sigma-1)(1-\theta)} \cdot f_d^b \\
(\tilde{a}_d^c)^{\theta(\sigma-1)} &= \frac{\chi\sigma}{(\chi+1)\Theta_d} \cdot \frac{1}{(t_d^c)^{-(\sigma-1)(1-\theta)} - (t_d^b)^{-(\sigma-1)(1-\theta)}} \cdot (f_d^c - f_d^b).
\end{aligned}$$

Substituting these in the expression for μ_d above and simplifying yield the following:

$$\mu_d = \frac{(\Delta t_d)^{-(\sigma-1)(1-\theta)}\left(\frac{\Delta f_d - 1}{(\Delta t_d)^{-(\sigma-1)(1-\theta)}-1}\right)^{\frac{\theta(\sigma-1)-k}{\theta(\sigma-1)}}}{1 + \left(\frac{\Delta f_d - 1}{(\Delta t_d)^{-(\sigma-1)(1-\theta)}-1}\right)^{\frac{\theta(\sigma-1)-k}{\theta(\sigma-1)}} \cdot \left[(\Delta t_d)^{-(\sigma-1)(1-\theta)} - 1\right]},$$

where $\Delta f_d = f_d^c/f_d^b$. Derivation of μ_d^{ext} follows similar steps.

A3 Derivations for the Counterfactual Exercise

The first measure, ΔEXP_1, compares the current level of exports to a destination to the counterfactual level that would obtain if container shipping was not available:

$$\Delta EXP_1 = \frac{\int_{\tilde{a}_d^b}^{\tilde{a}_d^c} r_d(\tilde{a}_d^b)(a/\tilde{a}_d^b)^{\theta(\sigma-1)}dG(a) + \int_{\tilde{a}_d^c}^{\infty} r_d(\tilde{a}_d^b)(\Delta t_d)^{-(\sigma-1)(1-\theta)}(a/\tilde{a}_d^b)^{\theta(\sigma-1)}dG(a)}{\int_{\tilde{a}_d^b}^{\infty} r_d(\tilde{a}_d^b)(a/\tilde{a}_d^b)^{\theta(\sigma-1)}dG(a)}.$$

The numerator was derived in Appendix A2, and the denominator is:

$$r_d(\tilde{a}_d^b)(\tilde{a}_d^b)^{-\theta(\sigma-1)}(\tilde{a}_d^b)^{\theta(\sigma-1)-k}.$$

So, using the expressions for $\tilde{a}_d^b$ and $\tilde{a}_d^c$ in Appendix A2, we obtain:

$$\Delta EXP_1 \;=\; 1 + \left(\Delta t_d^{-(\sigma-1)(1-\theta)} - 1\right)\left(\frac{\Delta f_d - 1}{\Delta t_d^{-(\sigma-1)(1-\theta)} - 1}\right)^{\frac{\theta(\sigma-1)-k}{\theta(\sigma-1)}}. \tag{28}$$

The other measure, ΔEXP_2, compares the counterfactual level that would obtain if the relative fixed cost container shipping would fall such that $\Delta f_d = \Delta t_d^{-(\sigma-1)(1-\theta)}$ to the current level of exports to a destination. Let $\widehat{a}_d^c$ denote the ability of the marginal exporter to destination d when $\Delta f_d = \Delta t_d^{-(\sigma-1)(1-\theta)}$. Then, ΔEXP_2 is equal to:

$$\Delta EXP_2 \;=\; \frac{\int_{\widehat{a}_d^c}^{\infty} r_d(\widehat{a}_d^c)(a/\widehat{a}_d^c)^{\theta(\sigma-1)}dG(a)}{\int_{\tilde{a}_d^b}^{\tilde{a}_d^c} r_d(\tilde{a}_d^b)(a/\tilde{a}_d^b)^{\theta(\sigma-1)}dG(a) + \int_{\tilde{a}_d^c}^{\infty} r_d(\tilde{a}_d^b)(\Delta t_d)^{-(\sigma-1)(1-\theta)}(a/\tilde{a}_d^b)^{\theta(\sigma-1)}dG(a)}.$$

The denominator was derived in Appendix A2. The numerator is equal to $r_d(\widehat{a}_d^c)(\widehat{a}_d^c)^{-k}$, where $r_d(\widehat{a}_d^c) = \frac{\chi\sigma}{\chi+1}\Delta t_d^{-(\sigma-1)(1-\theta)} f_d^b$. Rearranging terms, we obtain:

$$\Delta EXP_2^d \;=\; \frac{\Delta t_d^{-(\sigma-1)(1-\theta)}}{1 + \left(\Delta t_d^{-(\sigma-1)(1-\theta)} - 1\right)\left(\frac{\Delta f_d - 1}{\Delta t_d^{-(\sigma-1)(1-\theta)} - 1}\right)^{\frac{\theta(\sigma-1)-k)}{\theta(\sigma-1)}}}. \tag{29}$$

To see that these expressions do not depend on the assumed values of (σ, θ, k) or relative fixed costs, Δf_d, define $W_d = \left(\frac{\Delta f_d - 1}{(\Delta t_d)^{-(\sigma-1)(1-\theta)} - 1}\right)^{\frac{\theta(\sigma-1)-k}{\theta(\sigma-1)}}$ to re-write the share of containerized exports to a given destination as:

$$\mu_d \;=\; \frac{(\Delta t_d)^{-(\sigma-1)(1-\theta)} W_d}{1 + W_d \cdot \left[(\Delta t_d)^{-(\sigma-1)(1-\theta)} - 1\right]},$$

where $(\Delta t_d)^{-(\sigma-1)(1-\theta)} = \exp(\eta_1) dist_d^{\eta_2}$. We can express W_d as a function of observables $(\mu_d, dist_d)$ and estimates of (η_1, η_2):

$$W_d = \frac{\mu_d}{\exp(\eta_1)dist_d^{\eta_2} - \mu_d\left(\exp(\eta_1)dist_d^{\eta_2} - 1\right)}.$$

Next, re-write ΔEXP_1 and ΔEXP_2 as functions of W_d:

$$\begin{aligned} \Delta EXP_1 &= 1 + \left(\exp(\eta_1)dist_d^{\eta_2} - 1\right) W_d, \\ \Delta EXP_2 &= \frac{\exp(\eta_1)dist_d^{\eta_2}}{1 + \left(\exp(\eta_1)dist_d^{\eta_2} - 1\right) W_d}. \end{aligned} \tag{30}$$

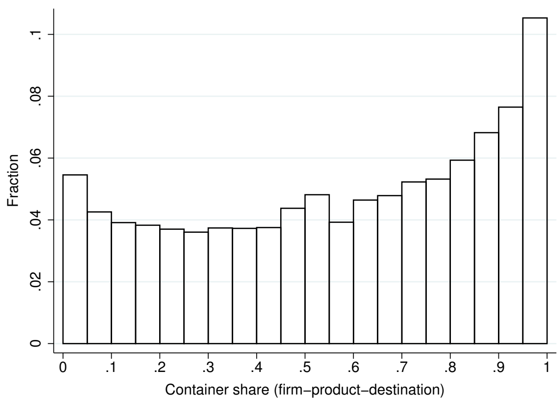
The expressions in (28) and (29) for the model with iceberg trade costs become:

$$\begin{aligned}\Delta EXP_1 &= 1+\left(\Delta t_d^{-(\sigma-1)}-1\right)\left(\frac{\Delta f_d-1}{\Delta t_d^{-(\sigma-1)}-1}\right)^{\frac{\sigma-1-k}{\sigma-1}}, \\ \Delta EXP_2 &= \frac{\Delta t_d^{-(\sigma-1)}}{1+\left(\Delta t_d^{-(\sigma-1)}-1\right)\left(\frac{\Delta f_d-1}{\Delta t_d^{-(\sigma-1)}-1}\right)^{\frac{\sigma-1-k}{\sigma-1}}}.\end{aligned}$$

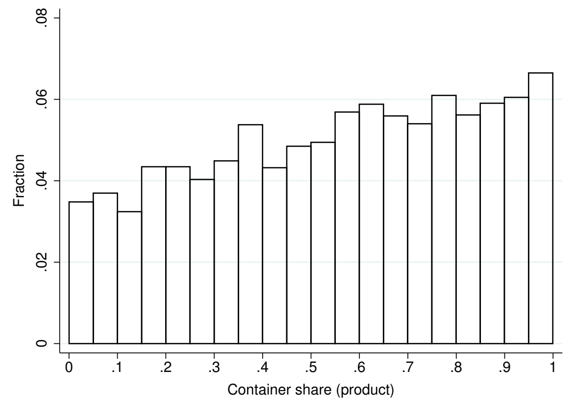
It is easy to see that the expressions above can be re-written as in (30) using the equation for the share of containerized exports in (23).

Figures and Tables

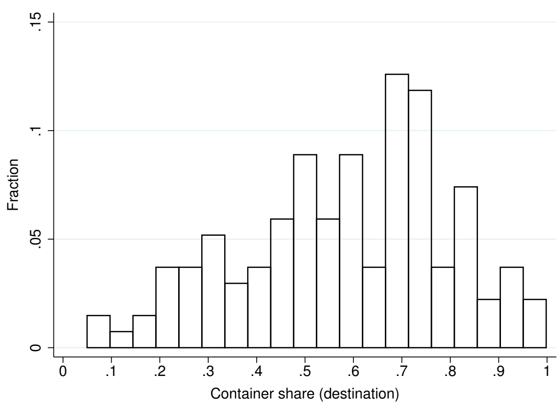
Figure 1: **Distribution of Container Shares**



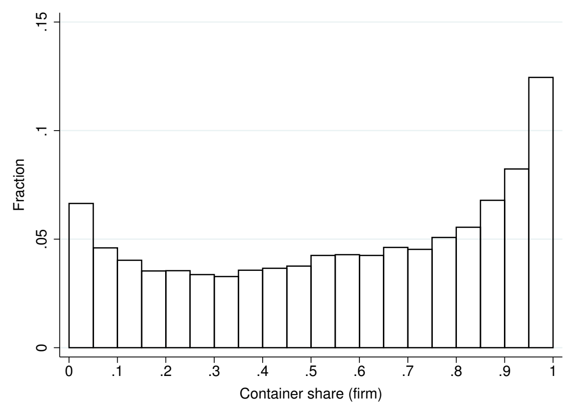
Panel A: Firm-Product-Destination



Panel B: Products



Panel C: Destinations



Panel D: Firms

Notes: Histogram of container shares, excluding mass points at 0 (no containerization at all) and 1 (full containerization). Panel A: 23,720 observations, Panel B: 4,166 8-digit HS products, Panel C: 135 destinations, Panel D: 8,941 firms.

Table 1: **Summary Statistics**

	Level of observation			
	Firm	Product	Destination	Firm-product-destination
Fraction of zeros (no containerization)	0.335	0.107	0.000	0.360
Fraction of ones (full containerization)	0.337	0.143	0.029	0.533
Share of containerized exports	0.524	0.556	0.598	0.527
Share of containerized exports (excl. zeros & ones)	0.571	0.551	0.586	0.568
	Number of			
	Firms	Products	Destinations	Observations
Vessel exports	27,241	5,557	139	220,993
Break-bulk	18,070	4,762	135	103,259
Containerized	18,112	4,961	139	141,454
	Mean		Median	
	Value (USD)	Quantity (Kg)	Value (USD)	Quantity (Kg)
Vessel exports	331,284.6	294,166	31,000	5,883
	(3,850,482)	(4,823,064)		
Break-bulk	378,407.7	378,274.7	28,673	4,201
	(5,046,657)	(5,945,869)		
Containerized	241,333.4	183,440.4	29,253	6,789
	(1,943,938)	(2,997,263)		

Notes: This table presents the summary statistics for the annualized data. Standard errors are in parentheses.

Table 2: **Explaining the Variation in Containerization (Fact 1)**

k	Raw effect (R^2_k)	Isolated effect ($R^2_{k,-k} - R^2_{-k}$)
Firm (a)	0.557	0.284
Product (j)	0.180	0.006
Destination (d)	0.240	0.078
Firm-product (aj)	0.620	0.458
Firm-destination (ad)	0.909	0.735
Product-destination (jd)	0.442	0.169

Notes: First column adjusted R^2_k's from regressing container shares $ContShr_{ajd}$ on individual (top panel) or paired (bottom panel) fixed effects. Second column reports the difference between the adjusted R^2 of the regression $ContShr_{ajd}$ on fixed effects including both the element of interest k as well as the remaining factors $-k$, and the adjusted R^2 of the regression $ContShr_{ajd}$ on the remaining factors $-k$ alone. For $k = i$, that would be the $R^2_{a,jd}$ of the regression $ContShr_{ajd} = \mu_a + \mu_{jd} + \epsilon_{ajd}$, where μ_{jd} represents product-destination pair fixed effects. Dropping the factor of interest, the regression $ContShr_{ajd} = \mu_{jd} + \epsilon_{ajd}$ yields R^2_{jd}. The difference $R^2_{a,jd} - R^2_{jd}$ is the coefficient of partial determination in the second column. Destination refers to a destination-month pair.

Table 3: **Economies of Scale and Distance in Containerization (Fact 2)**

	(1)	(2)	(3)
	$CONT_{ajdm}$	$CONT_{ajdm}$	$CONT_{ajdm}$
$\ln weight_{ajdm}$	0.00468***	0.0811***	0.0568***
	(0.00165)	(0.0160)	(0.0156)
$\ln dist_d$	0.0783***	0.158***	
	(0.00959)	(0.0242)	
$I\{contiguity_d = 1\}$	0.0704***	0.0611***	
	(0.0211)	(0.0197)	
$\ln weight_{ajdm} \cdot \ln dist_d$		-0.00917***	-0.00527***
		(0.00184)	(0.00186)
Observations	711743	711743	711743
R^2	0.746	0.746	0.789
Firm-product-month FE	+	+	+
Destination-month FE			+

Notes: The dependent variable $CONT_{ajdm}$ is a binary variable that takes the value one if there is a positive containerized flow at the firm-product-destination level in a given month. $\ln weight_{ajdm}$ denotes the logarithm of the weight (kg) of the export flows. Robust standard errors clustered at the destination-month-level in parentheses. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Table 4: **Unit Values and Containerization (Fact 2)**

	All	Differentiated	Non-differentiated
	(1)	(2)	(3)
	$CONT_{ajdm}$	$CONT_{ajdm}$	$CONT_{ajdm}$
$\ln weight_{ajdm}$	0.00986***	0.0116***	0.00570***
	(0.000848)	(0.000892)	(0.00126)
$\ln UV_{ajdm}$	-0.00701***	-0.00772***	-0.00298
	(0.00138)	(0.00157)	(0.00278)
Observations	711742	532277	179465
R^2	0.690	0.697	0.682
Firm-product-month FE	+	+	+
Destination-month FE	+	+	+

Notes: The dependent variable $CONT_{ajdm}$ is a binary variable that takes the value one if there is a positive containerized flow at the firm-product-destination level in a given month. Column headings refer to the sample used to produce them. Product differentiation is based on the classification developed by Rauch (1999). $\ln weight_{ajdm}$ denotes the logarithm of the weight (kg) of the export flows. $\ln UV_{ajdm}$ denotes the logarithm of the unit value, defined as value per quantity. Robust standard errors clustered at the destination-month-level in parentheses. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Table 5: **Firm Characteristics and Containerization (Fact 3)**

	(1) $CONT_{ajdm}$	(2) $CONT_{ajdm}$	(3) $CONT_{ajdm}$	(4) $CONT_{ajdm}$	(5) $CONT_{ajdm}$	(6) $CONT_{ajdm}$
$\ln weight_{ajdm}$	0.0144***	0.0172***	0.0162***	0.0171***	0.0149***	0.0145***
	(0.00189)	(0.00287)	(0.00284)	(0.00293)	(0.00284)	(0.00280)
$\ln exports_a$	0.0169***				0.0169***	0.0179***
	(0.00197)				(0.00329)	(0.00355)
$\ln employment_a$		0.0104**				
		(0.00473)				
$\ln sales_a$			0.0191***			
			(0.00371)			
$\ln laborproductivity_a$				0.0136***	0.00158	0.00288
				(0.00461)	(0.00536)	(0.00605)
$NumProducts_{ad}$						-0.000133
						(0.000237)
Observations	711743	437208	437208	437208	437208	437208
R^2	0.673	0.725	0.726	0.725	0.726	0.726
Product-destination-month FE	+	+	+	+	+	+

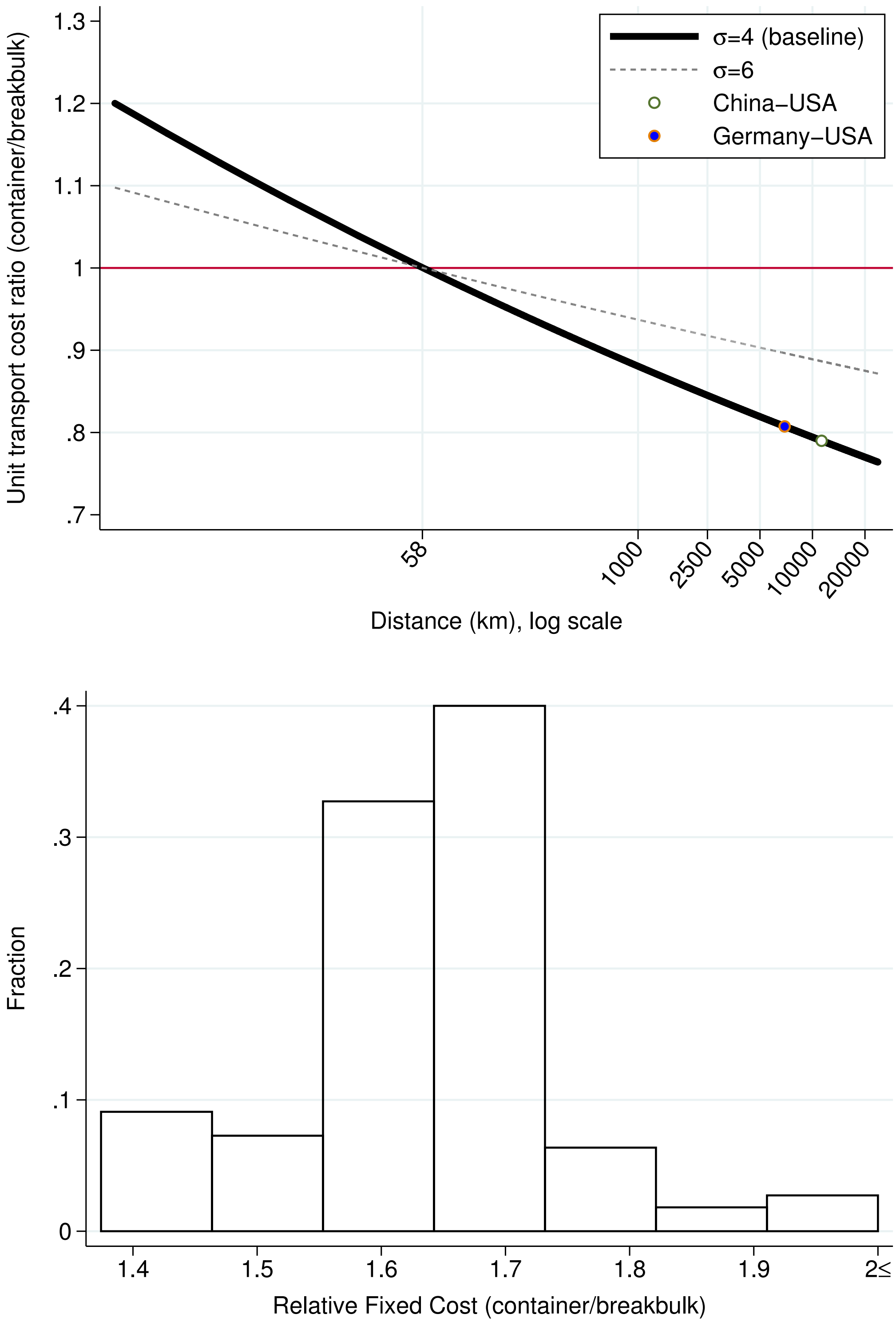
Notes: The dependent variable $CONT_{ajdm}$ is a binary variable that takes the value one if there is a positive containerized flow at the firm-product-destination level in a given month. $\ln weight_{ajdm}$ denotes the logarithm of the weight (kg) of the export flows. $\ln exports_a$ is the logarithm of the total value of exports of firm i, $\ln employment_a$ the logarithm of the average number of paid employees, $\ln sales_a$ the logarithm of total sales, and $\ln laborproductivity_a$ the logarithm of labor productivity defined as total revenues per employee. Robust standard errors in parentheses are clustered at the firm-level. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Table 6: **Unit Transport Cost Estimation Results**

	Coefficient	(1) $\ln(r_{ajdm}/\overline{r}_j)$	(2) $\ln(r_{ajdm}/\overline{r}_j)$	(3) $\ln(r_{ajdm}/\overline{r}_j)$	(4) $\ln(r_{ajdm}/\overline{r}_j)$
$CONT_{ajdm}$	η_1	0.240***	-0.129**	-0.165***	-0.381*
		(0.00745)	(0.0601)	(0.0629)	(0.223)
$CONT_{ajdm} \cdot \ln dist_d$	η_2		0.0456***	0.0515***	0.0936***
			(0.00736)	(0.00771)	(0.0271)
Observations		711743	711743	711743	711743
R^2		0.462	0.462	0.571	0.827
Sector-destination-month FE		+	+	+	
Firm FE		+	+		
Firm-sector FE				+	
Firm-sector-destination-month FE					+

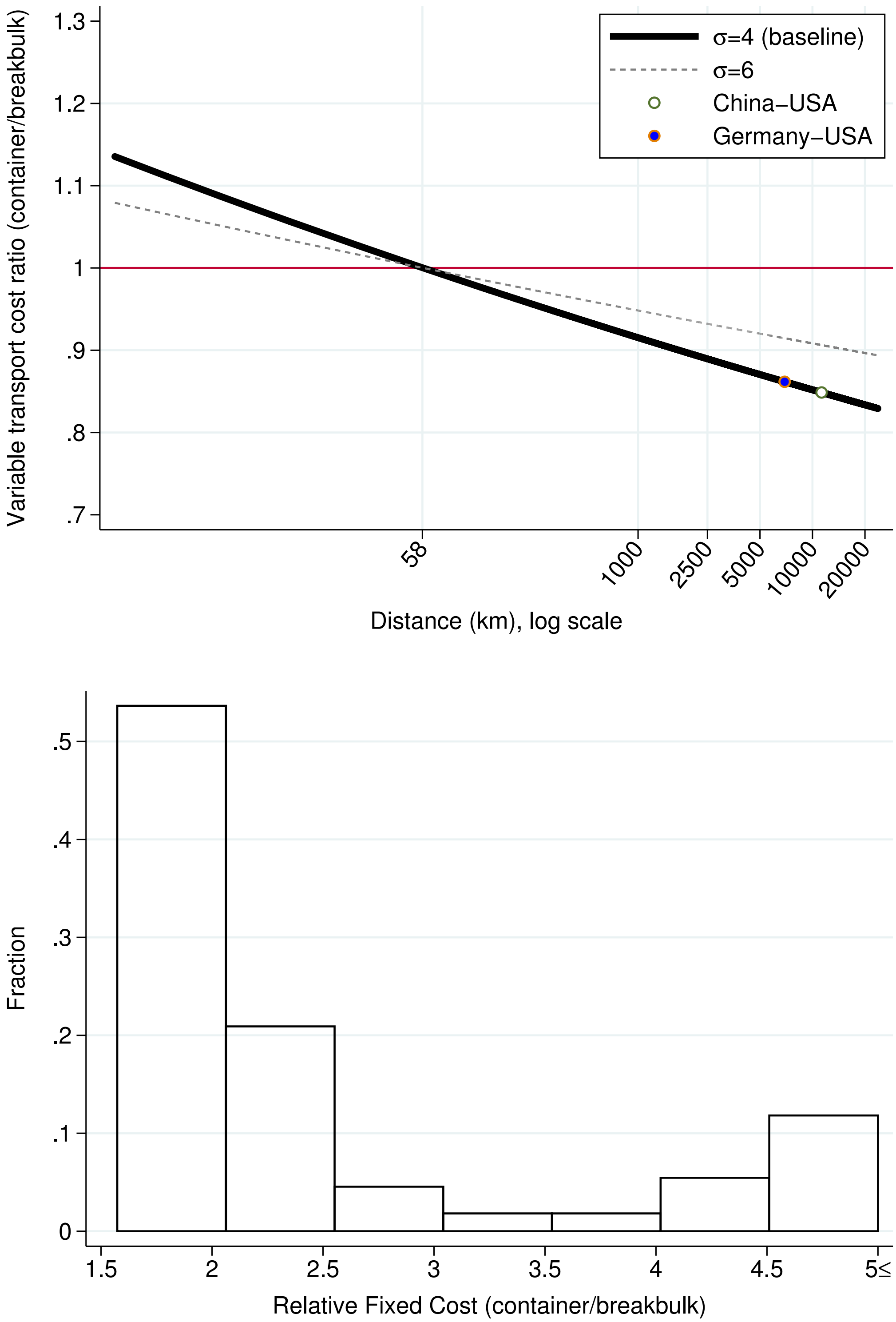
Notes: The dependent variable is the logarithm of the value of export revenue at the firm-product-destination-month-mode level, measured in terms of deviations from the respective product-level means. $CONT_{ajdm}$ is a binary variable that takes the value one if there is a positive containerized flow at the firm-product-destination-month level. Robust standard errors clustered at the product-destination-month level in parentheses. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Figure 2: **Relative Variable and Fixed Trade Costs (Additive Specification)**



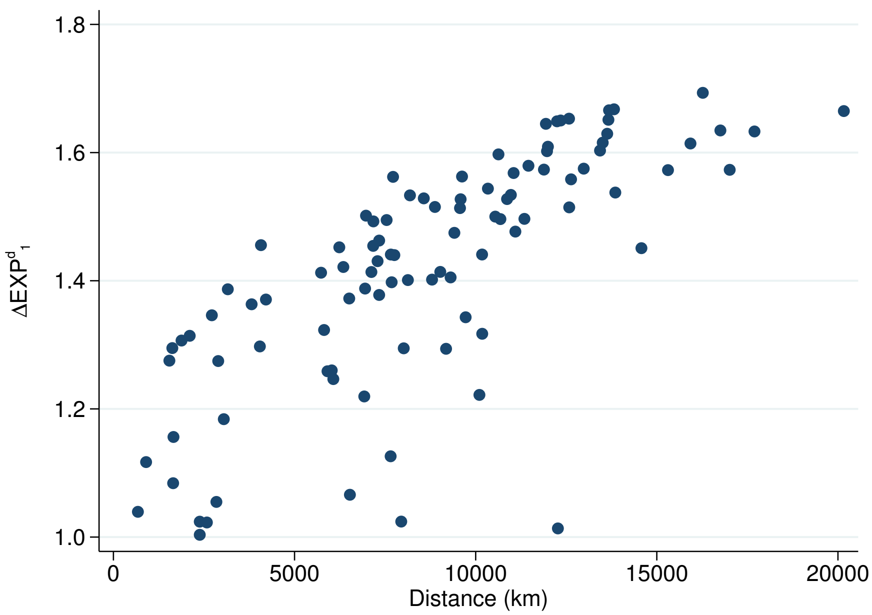
Notes: The upper panel shows the variable cost $\widehat{\Delta t_d} = t_d^c/t_d^b$ against distance. Red (blue) point marks USA-China (USA-Germany), and the horizontal line at 1 marks the breakeven distance. The bottom panel is the histogram of relative fixed cost values ($\widehat{\Delta f_d}$) calibrated to destination countries in the data using the baseline value of $\sigma = 4$.

Figure 3: **Relative Variable and Fixed Trade Costs (Multiplicative Specification)**

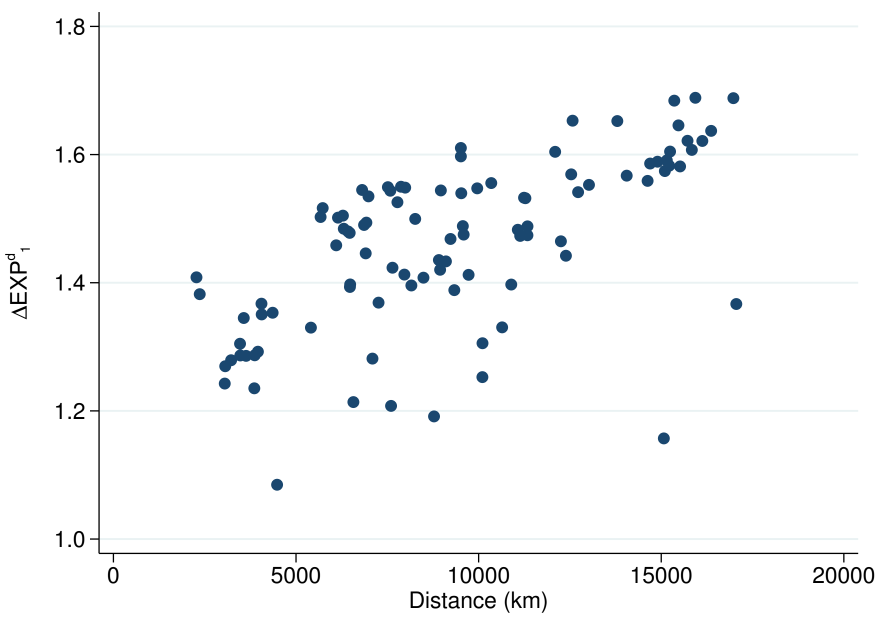


Notes: The upper panel shows the variable cost $\widehat{\Delta t_d} = t_d^c/t_d^b$ against distance. Red (blue) point marks USA-China (USA-Germany), and the horizontal line at 1 marks the breakeven distance. The bottom panel is the histogram of relative fixed cost values ($\widehat{\Delta f_d}$) calibrated to destination countries in the data using the baseline value of $\sigma = 4$.

Figure 4: **Increase in Trade due to Containerization**



Panel A: Turkey



Panel B: USA

Notes: This figure plots ΔEXP_1^d, the ratio of current level of exports to a destination d to the counterfactual level that would obtain if container shipping was not available. Each dot is an export destination from Turkey (top panel) and the US (bottom panel) as the source country.