Price Discrimination and Competition in International Transportation *

Anna Ignatenko†

June 7, 2023

Abstract

This paper uses uniquely detailed freight price data to study the determinants of transportation costs and their implications as a trade friction. I document empirical regularities violating both the Law of One Price in the shipping industry and the "iceberg" trade cost assumption. I show that conditional on the shipment's value, freight prices fall with the shipment's and exporter's size within narrowly defined routes. I then develop a trade model that integrates both economies of scale and price discrimination as mechanisms generating these findings. Finally, I test the model and provide causal evidence of competition affecting price dispersion using an exogenous weather-related shock as an instrument to competition. This shows price discrimination affects transportation costs. The implication is that competition increases the extent of quantity discounts thus giving further advantage to larger firms in international trade.

Keywords: price discrimination; shipping; transport costs; quantity discounts; trade

JEL codes: F10, F12, F14, D22, D43

* *Acknowledgements:* This paper is a revised version of Chapter 1 of my doctoral dissertation. I am very thankful to my advisors, Rob Feenstra, Andre Boik, Deborah Swenson, and Alan Taylor for their invaluable guidance and support. I would also like to thank Sam Kortum, Ahmad Lashkaripour, Volodymyr Lugovskyy, Brendan Price, Kadee Russ, Ina Simonovska, Sanjay Singh, Sasha Skiba, the Midwest Trade Meeting, and Asia Pacific Trade Seminars for helpful comments and suggestions. All errors are my own.

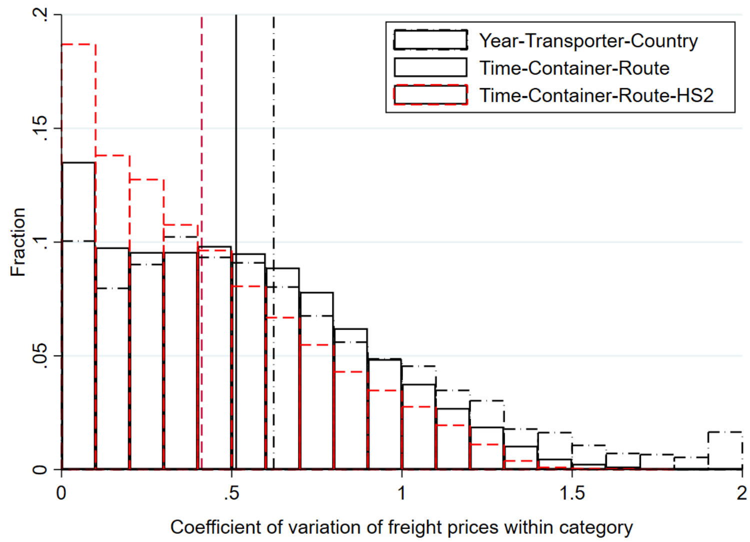
† Department of Economics, NHH Norwegian School of Economics, Helleveien 30, 5045, Bergen, Norway; e-mail: anna.ignatenko@nhh.no

1 Introduction

Transport costs are a major barrier to intra- and international trade that affects welfare, allocation of resources within and across countries, and economic development (Donaldson, 2018; Allen and Arkolakis, 2019; Fajgelbaum and Schaal, 2020; Brancaccio et al., 2020). They are not an exogenous friction, but endogenous prices for transportation services offered by transport companies with market power (Hummels et al., 2009; Brancaccio et al., 2020; Asturias et al., 2019). Besides raising prices above seller's marginal costs, market power has distributional implications: it encourages sellers to engage in price discrimination and vary prices across their buyers. Evidence of price discrimination has been found by industrial organization economists in markets for airline tickets, coffee, retail gasoline, advertising, medical devices, wholesale pharmaceuticals, etc. (Shepard, 1991; Borenstein and Rose, 1994; McManus, 2007; Gerardi and Shapiro, 2009; Ellison and Snyder, 2010; Grennan, 2013). Despite their central role in most domestic and international markets, surprisingly little is known about transport companies' pricing decisions and their distributional consequences.

In this paper, I provide evidence of price discrimination in international transportation and derive its implications for firms participating in international trade. I show that price discrimination by transport companies yields an additional cost advantage for more productive firms that are larger and transport larger shipments.

I leverage information on shipment-level freight prices charged for transportation of a universe of import shipments from Paraguayan customs data. This dataset is unique as it combines detailed data on trading firms and traded products with data on transport companies, detailed routes and freight prices. For each shipment, it records individual exporter and transport company used for its delivery to Paraguayan border. This allows me to investigate whether and how transport companies vary freight prices with exporters' and shipments' characteristics. Furthermore, the data identifies shipments transported at the same time on board of the same transportation vehicle from the same pick-up to the same drop-off locations. This allows me to distinguish freight price variation due to discriminatory pricing from variation in transport company's marginal costs. Finally, the data covers river segment of transportation, where the number of transport companies is frequently affected by weather conditions. This allows me to identify a causal effect of competition among transport companies on



the extent to which they engage in price discrimination.

I find substantial variation of per-ton freight prices across shipments within a transport company, even after accounting for detailed transportation route, time, conditions, and transported product type. Figure illustrates this by plotting the distribution of coefficients of variation of per-ton freight prices within transporters. Across shipments from a given country and year, the average coefficient of variation of per-ton freight prices within transporter is equal to 60%. To account for differences in travel distance, speed and transportation conditions in this variation, I compute coefficients of variation for shipments sharing a "container"[1] from pick-up to drop-off locations. They account for 20%, 12%, and 30% of all imported shipments by count, weight, and value, respectively. This reduces per-ton freight price variation and results in the average coefficient of variation of 50%. To account for differences in shipments' volumes, care and handling requirements, I compute coefficients of variation for shipments of goods in the same 2-digit Harmonized systems (HS2) category.[2] This further reduces the average coefficient of variation of freight prices to 40%, similar to that found in dry bulk ocean shipping in Brancaccio et al. (2020).

[1]The term "container" is used here loosely, to refer to shipments on board of the same transportation vehicle that travel together to Paraguayan customs from the same pick-up to the same drop-off locations. They include shipments transported within a truck that does not use a container.

[2]For example, HS2 product categories distinguish between products made of stone (HS2 68), glass (HS2 69) and ceramics (HS2 70).

Variation in per-ton freight prices of a given transport company that remains after controlling for the exact travel route, time, and transported product type seemingly violates the Law of One Price. To rationalize this, I embed a standard model of monopolistic price discrimination on the part of a transport company into a standard international trade environment. In this theoretical framework, transportation is an essential input producers differing in their productivity purchase from a monopoly transport company. The transport company can have economies of scale and designs an optimal pricing schedule knowing the distribution of producers' productivities. As in Mussa and Rosen (1978) and Maskin and Riley (1984), it offers combinations of freight payments and quantities that encourage producers to reveal their productivities and allows the transport company to extract their maximum willingness-to-pay. As more productive producers have higher willingness-to-pay, the transport company in equilibrium offers them quantity discounts to encourage them to reveal it.

Allowing for price discrimination in transportation sector in an international trade environment yields several novel insights. First, it implies that more productive producers with shipments of larger quantities pay lower per-unit freight prices because of either economies of scale or lower mark-ups charged by the transport company. Because transportation is an essential input for all producers, this results in an additional cost advantage of more productive producers. Second, the equilibrium freight payment in this framework is predicted to be a log-linear function of both shipment's weight and value. It embeds an "iceberg" transport costs assumption, commonly used in international trade, and other pricing schemes as special cases, and permits a comparison of their implications.

Exploiting variation *across* containers, I show that there is room for economies of scale in transportation, whereby shipments transported within larger containers are charged lower prices by the same carrier. When studying *within*-container variation of freight prices, I find that larger shipments of a given product type also receive substantial discounts from the carrier. Specifically, a one percent increase in shipment's weight increases the freight payment by only 0.5 percent. I show that this pattern is consistent with price discrimination behavior but not other explanations.

Interestingly, the shipment size effect remains intact even after accounting for the overall exporter size and long-term contracts between exporters and carriers. I find that, conditional on the shipment's size in a given manifest, larger exporters transporting with a given transport company and overall larger exporters pay lower per-ton freight prices. This is consistent with a different type of price discrimination by transport companies – based on the differences in the observed demand elasticities across exporters.

The main prediction of the model with respect to the role of competition in determining freight prices is that entry reduces freight prices on average and increasingly so for exporters with larger shipments. I test this prediction using water level in Paraguay's major river as an instrument for competition. I show that when water level unexpectedly drops, it prohibits navigation by standard-sized barges and thus limits the level of competition in the river segment. When faced with lower level of competition as a result of a high water level in the river, a transport company offers smaller quantity discounts. I obtain this after controlling for other time-varying confounding factors (such as fuel prices) and taking predictability of the shock into account.

In general, by studying transport costs at the micro-level, this paper seeks to contribute to several strands of the literature. Firstly, it contributes to the literature studying transport cost variation across time and space at a more aggregate (country-product, country-product-mode) level (cf. Limao and Venables (2001), Hummels (2007), Hummels and Schaur (2013), Hummels and Skiba (2004), Hummels et al. (2009), etc.) by highlighting individual firms, whose strategic interaction can potentially explain the documented aggregate patterns. Mark-ups and insufficient competition in transportation industry can explain the low pass-through of cost shocks into freight prices and higher transport costs in developing countries. Secondly, by showing empirically that freight prices are largely inconsistent with the "iceberg" trade cost formulation, this paper complements the literature offering structural estimates non-iceberg trade costs (Sørensen (2014), Irarrazabal et al. (2015), etc.). It suggests that because transport cost are non-iceberg, the welfare gains from transport cost reductions through improved infrastructure are larger than those predicted under the "iceberg" assumption (Donaldson and Hornbeck (2016), Donaldson (2018), Allen and Arkolakis (2019), etc.). In addition, my results imply that competition in international transport industry complements the investment in transport infrastructure as means to reducing trade barriers. By explicitly treating transport cost as endogenously determined prices of transportation services, an essential input in any transaction of goods, this paper speaks to the new and growing literature on market power and buyer power in international trade (cf. De Loecker and Eeckhout (2017), Kikkawa et al. (2017), Morlacco (2018), Cajal-Grossi et al. (2019), Macedoni and Tyazhelnikov (2019), etc.). Extended to other traded inputs, my findings suggest that although larger buyers often purchase higher-quality products, they also pay lower prices, *conditional* on quality.

2 Data

I use Paraguayan customs data covering a universe of Paraguay's import transactions from 2013 to 2018 as a source of micro-level freight price data. As an agricultural economy, Paraguay imports mainly manufactured consumer and intermediate goods such as machinery, electronics, and transportation. Because Paraguay is a landlocked country, a large share (45% by value) of its imported goods is exported there from adjacent Argentina, Brazil, and Bolivia. Paraguay's major long-distance trade partners – the US and China – account for about 14% and 16% of its annual imports by value, respectively. In absence of direct access to maritime transportation, Paraguay relies heavily on inland transportation (roads, rivers, and air) in imports from its neighbors and long-distance partners.

Besides its geographic location, several unique features of its customs data make Paraguay particularly well-suited for studying freight prices and their implications for international trade. First, the data provides information on how goods in each import transaction were transported according to a bill of lading. It is a contract issued by a transport company to an exporter detailing firms' names, transported goods, their quantities and weight, destination, free-on-board (excluding freight and insurance) values and freight payments in US dollars (separately from insurance). I define a shipment as a collection of import transactions with the same bill of lading identifier and examine how its freight payment is determined by a transport company.

Second, the data records information that identifies shipment's detailed transportation route, speed, and conditions. It comes from cargo manifests submitted by transport companies used on the last leg of transportation of each shipment.[3] They list all goods that were transported simultaneously by a transport company on board of a given vehicle at a given point in time from a specific pick-up to a specific drop-off locations. For each vehicle's trip, a transport company submits as many cargo manifests as there are stops on the way to a customs post. I define a "container" as a collection of shipments with the same manifest identifier, and investigate the sources of variation in freight payments across shipments *within* a container unrelated to transport companies' marginal costs.

Third, the data provides information on shipments, firms, and the level of competition in transportation sector as distinct sources of freight payments' variation. It reports an 8-digit code in Harmonized Systems (HS) classification of each product in a shipment and their weight in kilograms, which I use to proxy for its volume. It tracks shipments exported by individual firms and transported by individual transport companies using their company names.[4] I rely on firm identifiers to measure their observed characteristics and the level of competition among transport companies.

Finally, the data offers an exogenous weather-related source of variation in the level of competition among transport companies over time. It is based on the frequently observed low water levels in Paraguay's major river – Parana. When the water level drops below three meters, it becomes unnavigable by standard vessels, which lessen competition in transportation industry. I collect data on water levels in this river from La Dirección de Meteorología e Hidrología and estimate the effect of competition in transportation sector on freight payments across shipments.

2.1 Summary statistics

Goods are transported to Paraguay by roads, rivers and air either directly from adjacent Argentina, Brazil and Bolivia, or from non-adjacent countries after a transshipment in Argentina, Brazil or Uruguay. Table 1 shows that exporters from adjacent countries predominantly use road transportation (trucks) on the last and very likely the only leg of travel. Exporters from non-adjacent countries predominantly use

[3]For shipments from adjacent to Paraguay Argentina, Brazil, and Bolivia, which account for about a half of Paraguay's import, the last leg of travel is highly likely to be its only leg of travel.

[4]I cleaned and standardized company names using methods of textual analysis, similar to those in Bernard et al. (2018). See Appendix for details.

	Shipments, %	Weight, %	Value, %	Freight/Value, %
	Panel A: From Adjacent Countries			
Road	90	62	76	10
River	2	37	22	9
Air	8	1	2	15
	Panel B: From Non-adjacent Countries			
Road	35	19	31	13
River	37	80	51	15
Air	28	1	27	20

Table 1. Modes of transportation of Paraguayan imports, 2013 - 2018

river transportation as a mode of transshipment. Depending on a transport mode, transshipment accounts for 60% to 80% of the total costs of transporting goods from non-adjacent countries. Expectedly, rivers transport the heaviest and least expensive goods, while air carries the lightest and most expensive ones. Relative to the value of goods (excluding freight and insurance), air transportation is expectedly the most expensive transportation mode.

Import shipments, exporters, and transport companies in Paraguayan customs data show a large degree of heterogeneity in their observed characteristics. Annually, there are around 108 500 import shipments shipped to Paraguay by roughly 25 800 exporters via transportation services of around 306 transport companies (transporters). Table 2 shows that an average import shipment weights 30 ton, contains products from two 2-digit HS categories (HS2) that are worth 53 000 US dollars and cost an exporter 3000 US dollars to transport. However, import shipments exhibit large variation in their sizes, content, and freight payments.

Exporters often share a container when transporting their goods to Paraguay. On average, a transport company simultaneously transports two shipments from two exporters on board of the same vehicle following the same route from given pick-up to drop-off locations. By definition, shipments sharing a container also share transport company's operating costs associated with a transport vehicle, traveled distance, speed, time, and transportation conditions (such as refrigeration). Therefore, variation in freight payments across shipments within a container cannot be driven by variation in these costs.

	Mean	Median	Std. Dev.
Freight per shipment, '000 $	3	2	12
Weight per shipment, ton	30	5	400
Value per shipment, '000 $	53	19	168
# HS2 per shipment	2	1	2
# Shipments per container	2	1	4
# Exporters per container	2	1	3
# HS2 per container	3	1	4
# Shipments per transporter-year	357	109	860
Weight per transporter-year, ton	11 206	2 212	32 461
# Exporters per transporter-year	125	19	358
# Shipments per exporter-year	5	1	28
Weight per exporter-year, ton	148	3	2767
# Transporters per exporter-year	11	2	32

Table 2. Import shipments, exporters and transporters in Paraguayan customs data

Exporters and transport companies too substantially differ in their sizes in terms of the number of annually transported shipments and weight. An average transport company transports 357 shipments or 11 206 ton per year, which comprises about 0.3% of annually imported shipments by count and weight. However, four largest transport companies altogether account for about 20% and 25% of annually imported shipments by count and weight, respectively. These larger transport companies are likely to have market power to charge freight prices above their marginal costs. Likewise, an average exporter exports only 5 shipments ans 148 ton per year, while the four largest ones export 5% and 17% of annual shipments by count and weight, respectively.

Although contracts' length is unobserved in the data, it is consistent with both long-term contracts between exporters and transporters and a spot market for transportation services. In a year, on average, a transporter contracts with 125 distinct exporters, while an exporter contracts with 11 distinct transport companies. An main transport company of an exporter, on average, transports around 80% and 90% of the exporter's annual shipments by count and weight, respectively. Similarly, a transport

Dependent variable:	*Adj.* R^2 *Freight/Ton* (1)	*Freight/Value* (2)
Distance, Border, Language, Colony, Year	0.17	0.05
Country×Year	0.27	0.07
Country×HS2×Year	0.60	0.27
Country×HS2×Mode×Year	0.78	0.33
Country×HS2×Transporter×Year	0.85	0.49
Country×HS2×Container	0.88	0.54

Table 3. Determinants of Freight/Ton and Freight/Value

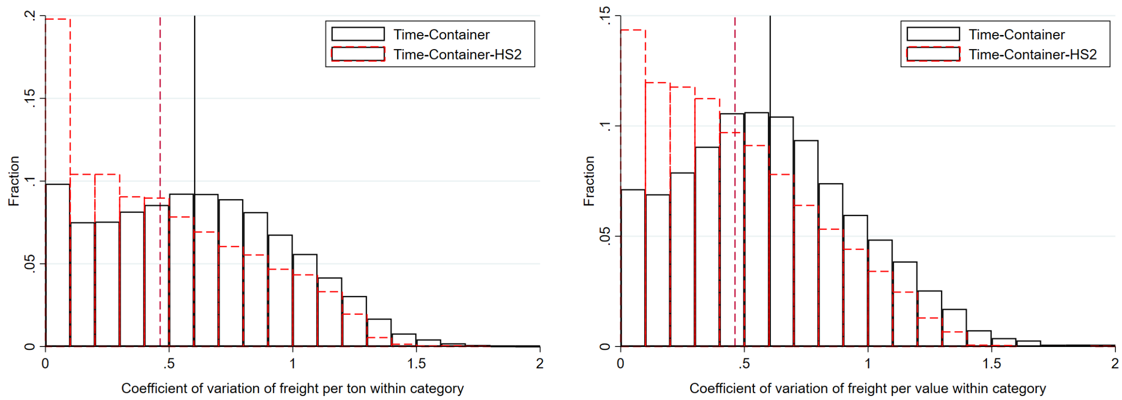
Notes: HS2 stands for a 2-digit Harmonized system's code of a product. Transporter denotes a transport company. Container identifies shipments transported by the same transport company, on board of the same vehicle, following the same route between specific pick-up and drop-off locations.

company's main exporter accounts for around 46% and 40% of the company's annual shipments by count and weight, respectively. Therefore, even if exporters have longer term contracts with their mainly used transport companies, they also likely to use spot contracts when shipping with alternative transporters.

2.2 Freight payments' variation across shipments

Using Paraguayan customs data, I document several novel facts on freight payments' variation across shipments. Firstly, I show that commonly used proxies for transportation costs explain only a small share of the observed variation in prices for transportation services. I define a transportation service with transported goods' weight, and calculate their prices as freight per ton ratios. Column (1) of Table 3 shows that distance between countries, common border, common language and colonial ties explain only 17% of freight price variation across shipments. Accounting for unobserved country-level determinants of transportation costs with country fixed effects explains only 27% of this variation. Additionally controlling for the type of transported products with their HS2 code explains 60% of the observed freight-per-ton variation. Taking into account differences in transportation modes on the last leg of travel increases the explained share of freight-per-ton variation to 78%.

Secondly, I show that variation in freight prices across shipments cannot be fully



(a) Freight price variation violating the Law of One Price

(b) Freight-to-value variation violating the "iceberg" assumption

Figure 1. Large within-container variation in freight prices and freight-to-value ratios

explained by variation in shipment values, as implied by the "iceberg" formulation of trade costs. Under the commonly used "iceberg" trade cost assumption, freight price charged for a shipment is proportional to the shipment's value with a coefficient of proportionality constant at a route-level. In contrast, in column (2), Table 3 shows that freight-to-value ratios substantially vary across shipments even within narrowly defined routes. Standard proxies for "iceberg" trade costs such as distance, common border, common language and colonial ties explain only 5% of the observed variation in freight-to-value ratios. Unobserved country-, product- and transport mode-level determinants of transportation costs can only explain up to 33% of this variation.

Thirdly, I find that a significant share of freight-per-ton variation and its deviations from the iceberg trade cost assumption is explained by transport companies' pricing decisions. Table 3 reports that within-transporter freight-per-ton variation across shipments from a given country containing products of a given type accounts for 15% of its total variation. It explains an even larger share – 51% – of the observed variation in freight-to-value ratios violating the iceberg trade cost assumption.

Finally, I demonstrate that this freight price variation by transport companies is not fully explained by variation in their marginal costs. Table 3 shows that 80% (= 12%/15%) of within-transporter freight price variation is driven by freight price variation across shipments sharing a container at a given point in time and space.

For a transport company, such shipments have identical costs associated with exact traveled distance, speed, time, and transportation conditions. Yet, transport companies vary freight prices across these shipments in an economically significant way. Figure 1a illustrates this by plotting the distribution of the coefficients of variation of freight prices across shipments within a container transported by a given transport company. The average coefficient of variation of freight prices within a container is equal to 60%. Accounting for shipment's volume and handling costs with product fixed effects only slightly reduces this variation bringing the average coefficient of variation to just under 50%. Freight-to-value ratios exhibit a similar degree of variation within a container, as shown in Figure 1b. It means that shipment's value also cannot explain variation in freight charges across shipments.

3 Theoretical Framework

In this section, I develop a theoretical framework, to understand the sources and consequence of freight price variation across shipments within narrow trade routes. I treat transportation as an essential input purchased by manufacturers differing in productivity from transport companies with economies of scale and market power. I derive patterns of freight price variation under the assumption that without observing manufacturers' willingness to pay for transportation a transport company can engage in second-degree price discrimination. It is consistent with high market concentration, buyer heterogeneity, and at least partial reliance on spot contracts in transportation sector documented above. The proposed framework yields testable implications of a standard nonlinear pricing from industrial organization for exporting manufacturers in a standard international trade environment. However, qualitatively, its predictions hold more generally and do not rely on any specific functional form assumptions.

3.1 Technologies and market structures

Consider a standard international trade environment as in Melitz (2003). An industry is populated by a continuum of manufacturers each of which produce a single differentiated product variety. The only input in production is labor, inelastically supplied at its aggregate country level at a common wage rate w. Manufacturers' production technology consists of constant marginal costs and fixed overhead costs $F > 0$. While the fixed costs are common across all manufacturers, marginal costs vary with firm productivity φ. It is drawn by manufacturers from a known distribution with cumulative distribution function $G(\varphi)$ and remains their private information. When exporting, manufacturers incur exogenous multiplicative trade costs $\tau \geq 1$ (*ie.* tariffs) and pay for transportation services.

Unlike in a standard international trade framework, prices of transportation services are not exogenous and not necessarily proportional to the transported variety's value. Instead, they are determined endogenously by a transport company that can enjoy both market power and non-constant returns to scale. It incurs total costs $K(Q)$ when transporting Q units of goods, which implies constant marginal costs, economies or diseconomies of scale if $K'(Q) = 0$, $K'(Q) < 0$ or $K'(Q) > 0$, respectively. In the empirical analysis in Section X, I allow for a fixed cost component in transport companies' costs and estimate its effect on freight price variation.

To highlight the role of a transport company's market power, I assume a monopoly in transportation sector. I focus on spot-market transactions in transportation sector and assume that a transport company does not observe manufacturers' productivities but knows their distribution $G(\varphi)$. The empirical analysis in Section X relaxes both of these assumptions and documents the effects of competition among transport companies and long-term contracts on freight price variation.

In this environment, a transport company achieves maximum profits by offering a menu of freight payment - quantity combinations (*freight payment schedule*), as shown in Mussa and Rosen (1978), Maskin and Riley (1984). The equilibrium freight price schedule comprises the sub-game perfect Nash equilibrium in the following game. First, the transport company announces its freight price schedule. Then manufacturers hire labor, purchase transportation services, and decide how much to sell to a foreign market. At the end, consumers purchase and consume manufactured goods.

3.2 Firms' problems

Let $\bar{q}(\varphi) \equiv \underset{q \geq 0}{\text{argmax}}\{[p(q) - w\tau/\varphi]\, q\}$ denote the optimal production quantity of a manufacturer with productivity φ for a market with inverse demand function $p(q)$. It is naturally strictly increasing in manufacturer's productivity φ. Under free disposal, the maximum profit of manufacturer φ offered a freight payment - quantity contract (q, T) is $\pi(q, \varphi) - T$, where

$$\pi(q, \varphi) = [p(\min\{q, \bar{q}(\varphi)\}) - w\tau/\varphi] \min\{q, \bar{q}(\varphi)\} - F \tag{1}$$

This profit function has two properties important for the transport company's choice of the freight price schedule. Firstly, it is strictly increasing and strictly concave in q for $q \in [0, \bar{q}(\varphi))$. Secondly, manufacturers with higher productivity benefit more from an increase in quantity of transportation services. These properties can be summarized in the following way:

$$\frac{\partial \pi(q, \varphi)}{\partial q} \geq 0, \quad \frac{\partial^2 \pi(q, \varphi)}{\partial q^2} < 0, \quad \frac{\partial^2 \pi(q, \varphi)}{\partial q \partial \varphi} \geq 0 \tag{2}$$

Because the transport company only knows the distribution of manufacturers' productivity, it chooses a menu of contracts (q, T), to maximize its *expected* profits:

$$\max_{\varphi,^*(q(\varphi), T(\varphi))} \int_{\varphi^*}^{+\infty} T(q(\varphi)) g(\varphi) d\varphi - K(Q), \quad Q \equiv \int_{\varphi^*}^{+\infty} q(\varphi) g(\varphi) d\varphi$$

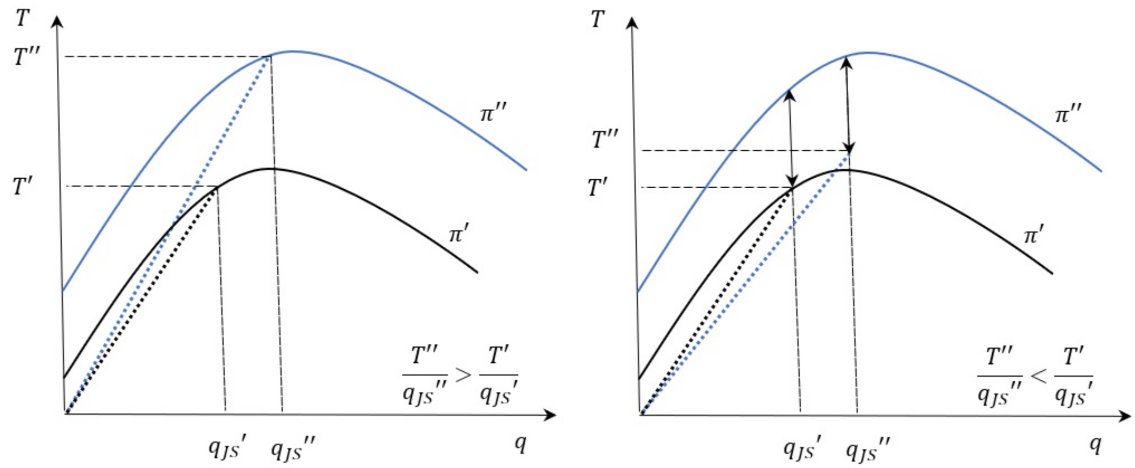
subject to incentive compatibility (IC) and individual rationality (IR) constraints:

$$\forall \varphi, \varphi' : \quad \pi(q(\varphi), \varphi) - T(q(\varphi)) \geq \pi(q(\varphi'), \varphi) - T(q(\varphi')) \tag{IC}$$

$$\forall \varphi : \quad \pi(q(\varphi), \varphi) - T(q(\varphi)) \geq 0 \tag{IR}$$

These constraints are an outcome of asymetric information and transport company's inability to observe individual manufacturers' productivities. The incentive compatibility constraints ensure that each manufacturer prefers a transportation contract intended to her rather than that intended to another manufacturer. The individual rationality contraints ensure that all manufacturers receive non-negative profits after paying for transportation services.

Figure 2 illustrates the role of asymetric information in the transport company's



(a) Freight prices: full information (b) Freight prices: asymmetric information

Figure 2. Mechanisms of freight price variation under full and asymmetric information

choice of freight prices, keeping its *marginal costs constant* ($K'(Q) = 0$). It shows profit functions of two manufacturers with productivities $\phi'' > \phi'$, as well as freight payments and quantities/ offered to them by the transporter. If the transport company knew and could distinguish manufacturers by their productivity, it would offer each of them contracts with quantities maximizing their joint surplus and payments fully extracting their profits. Figure 2a shows that, expectedly, this environment with full information implies that a more productive manufacter is offered larger quantities $q''_{JS} > q''_{JS}$ for larger total freight payment, $T'' > T'$. Moreover, in equilibrium, under full information, a more productive manufacturer is offered a higher per-unit freight price, $T''/q''_{JS} > T'/q'_{JS}$, represented by the slope of the dotted line from the origin.

In contrast, in the environment with asymmetric information, the transport company does not observe the manufacturer's productivities and cannot distinguish between them. This incentivizes the more productive manufacturer to "pretend" to be a less productive one (for example, by splitting the shipment) and take advantage of the lower per-unit freight price. Figure 2b illustrates that this strategy increases the more productive manufacturer's profits from zero to a positive value depicted by the interval with the arrows. To prevent this, under asymetric information, the transport company lowers the freight payment charged to the higher productivity manufacturers under full information by this value. Figure 2b illustrates that this implies that, under asymmetric information, a more productive manufacturer is offered larger quantities for larger total freight payment but lower per-unit freight prices, $T''/q''_{JS} < T'/q'_{JS}$. I next formally show that such quantity discounts are an outcome of equilibrium mark-up variation by a transport company in the environment with asymetric information.

3.3 Equilibrium freight price variation

Under asymmetric information, the incentive compatibility and individual rationality constraints can be incorporated in the transport company's profit maximization problem in the following way (see Appendix A for details):

$$\max_{q,\varphi^*} \int_{\varphi^*}^{+\infty} \pi(q(\varphi),\varphi)g(\varphi)d\varphi - K(Q) - \int_{\varphi^*}^{+\infty} \frac{\partial \pi(q,\varphi)}{\partial \varphi}(1-G(\varphi))d\varphi, \tag{3}$$

where the last term represents the transfer of the transport company's profits to more productive manufacturers compatible with their incentives. The transport company first chooses quantities and then sets freight payments that extract manufacturers' profits without violating their IR and IC constraints. The next proposition establishes the necessary conditions for the solution $\{\varphi^*, q(\varphi), T(\varphi)\}$.

Proposition 1. *If manufacturers' profit functions satisfy conditions in (2), there exists a threshold productivity φ^* below which the manufacturers are not served by the transport company. For $\varphi \in [\varphi^*, +\infty]$, the functions $q(\varphi)$ and $T(\varphi)$ that solve the transport company's maximization problem in (3) satisfy the following conditions:*

$$\frac{\partial \pi(q,\varphi)}{\partial q} = K'(Q) + \frac{\partial^2 \pi(q,\varphi)}{\partial \varphi \partial q}\frac{1-G(\varphi)}{g(\varphi)} \tag{4}$$

$$\frac{\partial T(q)}{\partial q} = \frac{\partial \pi(q,\varphi)}{\partial q} \tag{5}$$

If $\varphi^* \in (0,+\infty)$, it solves the following exclusion condition:

$$\pi(q(\varphi^*),\varphi^*)g(\varphi^*) - K'(Q(\varphi^*))q(\varphi^*) - \frac{(1-G(\varphi^*))}{g(\varphi^*)}\frac{\partial \pi(q(\varphi^*),\varphi^*)}{\partial \varphi} = 0 \tag{6}$$

Moreover, the least productive manufacturer φ^* served by the transport company obtains zero net profits, ie. the boundary condition $\pi(q(\varphi^*), \varphi^*) = T(q(\varphi^*))$ is satisfied.

Proof. *See Appendix Y.*

These conditions imply that, in equilibrium, more productive manufacturers are offered transportation contracts with larger quantities and lower freight prices. Condition (4) shows that the quantity offered to a manufacturer equalizes its marginal profit with the transport company's marginal cost plus a nonnegative distortion term. This term is an outcome of informational asymmetries. It disappears as $\varphi \to +\infty$, which means that the highest productivity manufacturer is offered the joint-profit maximizing quantity. All other manufacturers are offered less than the joint-profit maximizing quantity that increases in manufacturer's productivity if $(1-G(\varphi))/g(\varphi)$, decreases in φ.[5] Intuitively, $(1-G(\varphi))/g(\varphi)$ captures the probability of contracting with a manufacturer more productive than φ. When it becomes larger (as φ falls), the transport company lowers the quantity offered to lower productivity manufacturer φ, to make it less lucrative to the higher productivity ones. By offering larger quantities to more productive manufacturers, the transport company isolates highly productive manufacturers and extracts more surplus from their higher willingness to pay.

Condition (5) shows that freight payment for a chosen quantity is set to equalize the transport company's marginal cost with the manufacturer's marginal benefit and the boundary condition. Using condition (4) and manufacturer's profits (1) in condition (5) reveals two sources of marginal freight price variation in equilibrium – transport company's marginal costs and mark-ups:

$$\frac{\partial T(q)}{\partial q} = \underbrace{K'(Q)}_{\text{variable MC}} + \underbrace{\frac{w\tau}{\varphi^2}\frac{1-G(\varphi)}{g(\varphi)}}_{\text{variable mark-up}} \tag{7}$$

Keeping transport company's marginal costs constant, its mark-ups decrease in manufacturer's productivity given that $(1-G(\varphi))/g(\varphi)$ decreases in φ. Since, at the same time, more productive manufacturers are offered larger quantities, this means that the mark-ups decrease in the offered quantities.

The extent of pricing discrimination in a form of discounts in equilibrium is gov-

[5]This function is decreasing in φ for a large class of distribution functions, including uniform, normal, Pareto, exponential, logistic and any other distribution with nondecreasing density.

erned by the extent of productivity heterogeneity across manufacturers. Holding manufacturers' productivities constant, if the share of high productivity manufacturers is high, $(1 - G(\varphi))/g(\varphi)$ is large, and the mark-up reduction high productivity firms get relative to low productivity ones is large. If it is close to zero, screening out highly productive manufacturers is not worth the profit loss from quantity discounts.

Corollary. *In equilibrium, a transport company offers more productive manufacturers transportation contracts with larger quantities, larger total freight payments, but lower mark-ups. This mark-up variation implies quantity discounts in transportation.*

Proof. *See above.*

The necessity to offer quantity discounts to larger manufacturers makes the transport company restrict the number of manufacturers it serves in equilibrium. When serving less productive manufacturers, it trades off extra profits it can extract from them, on the one hand, and accumulated discounts ensuring incentive compatibility of more productive manufacturers, on the other. The minimum manufacturer's productivity that solves this trade-off is determined from exclusion condition in (6). Therefore, in this environment, the manufacturers' cut-off productivity is a transport company's decision rather than an outcome of fixed costs, as in standard models of international trade.

Although quantity discounts in transportation do not rely on any specific functional form assumptions, the exact shape of the freight payment schedule does depend on consumer preferences and distribution of firm productivities. To derive its implications for firms in international trade, I specify consumer preferences and distribution of firm productivities matching a standard international trade environment.

3.4 Implications for a standard model of international trade

Suppose consumers have a CES utility with elasticity of substitution $\sigma > 1$, and manufacturers draw productivity from Pareto distribution with shape parameter $\theta > \sigma - 1$. In this environment, consumer demand on manufacturer φ's variety is $q(\varphi) = Ap(\varphi)^{-\sigma}$, while hazard rate for the distribution of manufacturers' productivities is $g(\varphi)/(1 - G(\varphi)) = \theta/\varphi$. Then, equilibrium freight payment – quantity schedule offered by a transport company is determined by the conditions in Proposition 1:

$$\frac{\partial \pi(q,\varphi)}{\partial q} = K'(Q) + \frac{w\tau}{\varphi\theta} \tag{8}$$

$$\frac{\partial T(q)}{\partial q} = \frac{\partial \pi(q,\varphi)}{\partial q} \tag{9}$$

$$\left[A^{1/\sigma} q(\varphi^*)^{-1/\sigma} - \frac{w\tau}{\varphi^*} - K'(Q) - \frac{w\tau}{\varphi^*\theta}\right] q(\varphi^*) = F \tag{10}$$

$$\pi(q(\varphi^*)) = T(q(\varphi^*)). \tag{11}$$

Combining these conditions yields the following relationship between total freight payment and quantity of transportation services in equilibrium (see Appendix Y):

$$T(q) = \frac{1}{\theta+1} p(q)q + \frac{\theta}{\theta+1} K'(Q)q - \frac{1}{\theta+1} F \;\text{ for }\; q \geq \left(\frac{F\sigma}{A^{1/\sigma}}\right)^{\sigma/(\sigma-1)} \tag{12}$$

This freight payment schedule has three properties that I use in Section 4 to test for quantity discounts as a form of price discrimination by a transport company. First, it implies that per-unit freight prices decline with transported quantity, as illustrated in Figure 2. From (12), per-unit freight prices can be expressed as follows:

$$\frac{T(q)}{q} = \frac{1}{\theta+1} A^{1/\sigma} q^{-1/\sigma} + \frac{\theta}{\theta+1} K'(Q) - \frac{1}{\theta+1} \frac{F}{q}$$

All else equal, they decrease in transported quantity q and increase in per-unit value of transported goods, $p = A^{1/\sigma} q^{-1/\sigma}$. Another way to establish quantity discounting is by showing that a one percent increase in transported quantity results in less than one percent increase in total freight payment. In other words, total freight payment elasticity with respect to quantity in (12) is less than one:

$$\frac{\partial T(q)}{\partial q} \frac{q}{T} = \frac{\frac{\sigma}{\sigma-1} A^{1/\sigma} q^{-1/\sigma} + \theta K'(Q) + \theta K''(Q) q}{A^{1/\sigma} q^{-1/\sigma} + \theta K'(Q) - F/q} < 1$$

Second, although quantity discounts are larger under economies of scale in transportation, they arise in (12) due to mark-up variation even if transport company's marginal costs are constant. This is because the transport company charges lower mark-ups for transportation of larger quantities. Under constant marginal costs of transportation, transport company's mark-up implied by (12) is

$$\frac{\frac{\partial T(q)}{\partial q} - K'(Q)}{K'(Q)} = \frac{1}{\theta+1} \frac{\frac{\sigma-1}{\sigma} A^{1/\sigma} q^{-1/\sigma} - K'(Q)}{K'(Q)}$$

It decreases with quantity at a rate increasing in the degree of manufacturer heterogeneity in productivity. When θ gets smaller, manufacturers become more heterogeneous in their productivities with more productive ones accounting for a larger share of output. Faced with a higher share of highly productive manufacturers with larger willingness to pay, the transport company screens them out more intensively through larger quantity discounts. It charges higher mark-ups to less productive manufacturers thus generating larger variation in freight prices across manufacturers.

Third, the elasticity of total freight payment in (12) with respect to quantity is less than one, even conditional on the value of transported goods. In other words, a one percent increase in transported quantity implies less than a one percent increase in charged freight payment, conditional on the value of transported goods. This follows from (12) written in log-deviations from freight payment for the smallest quantity q^*:

$$\log \frac{T(q)}{T(q^*)} = \frac{1}{\theta+1} \frac{p(q^*)q^*}{T(q^*)} \log \frac{p(q)q}{p(q^*)q^*} + \frac{\theta}{\theta+1} \frac{K'(Q)q^*}{T(q^*)} \log \frac{q}{q^*} \tag{13}$$

Here, $\frac{1}{\theta+1}\frac{p(q^*)q^*}{T(q^*)}$ and $\frac{\theta}{\theta+1}\frac{K'(Q)q^*}{T(q^*)}$ are total freight payment elasticities with respect to transported value, conditional on quantity, and with respect to transported quantities, conditional on value, respectively. The latter is less than one and increasing in transport company's marginal costs $K'(Q)$ and heterogeneity in manufacturers' productivity captured by θ.

Freight payment schedule in (12) distinguishes price discrimination in a form of quantity discounts from other pricing schemes in transportation it nests as special cases. A standard in international trade "iceberg" formulation of trade costs implies that freight payment is proportional to transported goods' value, $p(q)q$, with proportionality coefficient $(\tilde{\tau}-1)/\tilde{\tau}$. It arises as a special case in (12) when $K'(Q) = 0$ and $\theta = 1/(\tilde{\tau}-1)$. As in case of price discrimination by a transport company, it implies per-unit freight prices decreasing in quantity and total freight payment elasticity with respect to quantity less than unity. However, under the "iceberg" formulation, the variation in per-unit freight prices is entirely explained by variation in per-unit values of transported goods. As a result, conditional on the value of transported goods, total freight payment elasticity with respect to quantity in this case is equal to zero.

Identifying a pricing scheme in transportation sector is important because of its implications for importer price variation and pass-through of transportation costs into importer prices. According to condition (9), in equilibrium, manufacturer φ incorporates marginal freight payment into price charged to an importer as follows:

$$p(\varphi) = \frac{\sigma}{\sigma-1}\left[\underbrace{\frac{w\tau}{\varphi}}_{\text{production}} + \underbrace{K'(Q) + \frac{w\tau}{\varphi\theta}}_{\text{transportation}}\right] \tag{14}$$

It consists of three components: i) constant mark-up paid by importers under CES demand; ii) manufacturer's marginal production costs, and iii) manufacturer's marginal freight payment as a sum of the transport company's marginal cost and price-cost margin. Note that when transportation costs are not of an iceberg type ($K'(Q) > 0$), manufacturer's mark-up over production cost is not constant despite the CES demand function. In contrast, it increases in firm's productivity because more productive manufacturers have lower perceived demand elasticity as larger share of importer price is independent of the manufacturer's price.

Under iceberg formulation of transportation costs ($K'(Q) = 0$ and $\theta = \tilde{\tau} - 1$), changes in transportation costs $\tilde{\tau}$ are fully passed through into importer prices: $\frac{d\log p(\varphi)}{d\log\tilde{\tau}} = 1$.[6] In contrast, when a transport company engages in price discrimination, changes in its marginal costs are not fully passed through into importer prices:

$$\frac{d\log p(\varphi)}{d\log K'(Q)} = \frac{K'(Q)}{\frac{\sigma}{\sigma-1}\left(\frac{w\tau}{\varphi}(1+1/\theta) + K'(Q)\right)} \leq 1$$

All else equal, the pass-through rate of transport company's marginal costs into importer prices increases in the manufacturer's productivity, φ. This is because more productive manufacturers are charged lower mark-ups in the transportation sector. At the same, holding manufacturer's productivity constant, pass-through of transport marginal costs into importer prices decreases when manufacturer heterogeneity increases causing larger quantity discounts. Hence, accounting for heterogeneity in

[6] When importer's demand is not CES and more productive manufacturers face lower demand elasticity, they pass through a smaller share of transportation costs shocks into importer prices.

manufacturer's productivities and the extent of quantity discounts in transportation sector is important when estimating welfare gains from transport costs reductions through improvements in transport infrastructure.

4 Evidence of price discrimination in international transportation

In this section, I provide evidence of price discrimination by transport companies in a form of quantity discounts. I do so by testing its distinct implications discussed above relative to other pricing schemes and forms of price discrimination. I quantify the relevance of the iceberg formulation for transportation costs, economies/diseconomies of scale, and price discrimination based on observable and unobservable firm characteristics for freight price variation documented above.

4.1 Identification strategy

To diagnose the sources of freight price variation, I first test properties of the freight payment schedule that arise under general demand and distributional assumptions when a transport company engages in price discrimination. Proposition 1 and its corollary suggest that equilibrium total freight payments increase in the shipment size and feature quantity discounts. To test this prediction, I estimate the following log-linear relationship between total freight payments and shipment sizes:

$$\log T_{icd}(\varphi) = \beta \log q_{icd}(\varphi) + \log \psi_{icd} + \varepsilon_{icd}(\varphi), \tag{15}$$

where $T_{icd}(\varphi)$ is a total freight payment charged by transport company i for transportation of manufacturer φ's shipment of size $q_{icd}(\varphi)$ from country c at time d. The first term captures equilibrium mark-up variation with shipment's size, while the second term, $\log \varphi_{icd}$, captures transport company's total costs of its transportation.

Price discrimination by a transport company under asymmetric information (second-degree) in a form of quantity discounts implies that mark-ups decrease in shipment size and $0 < \beta < 1$. I estimate β using shipment's weight as a measure of its size, and container fixed effects as a proxy for transport company's marginal costs.

I address several standard endogeneity concerns that can hinder the interpretation of the estimated coefficient as evidence of quantity discounts. First, I alleviate simultaneity bias in the estimate of β common in price elasticity estimation. It can arise if manufacturers with larger shipments demand transportation services of higher quality. Not accounting for differences in transportation quality then introduces an upward bias in the estimate of β. Container fixed effects absorb much of the variation in transportation quality related to speed of delivery and general transportation conditions (such as refrigeration). To additionally account for differences in handling quality, I include product type fixed effects.

Second, I account for several sources of omitted variable bias in the estimates. It can arise if a transport company price discriminates based on observed differences in elasticities of demand for transportation across manufacturers with different productivities. Then, since more productive manufacturers transport larger quantities, this alternative type (third-degree) of price discrimination would bias the estimates of β downwards. To correct for this bias, I add quantities transported annually by a manufacturer as a proxy for its overall size and demand elasticity.

Another source of the omitted variable bias is variation in transport company's marginal costs across shipments. It can arise if transport companies have economies of scale at the shipment rather than container level, as assumed in the theoretical framework. A transport company can have economies of scale if its technology features fixed costs, for example, associated with filling out paperwork and undergoing customs procedures. Then it can offer lower freight prices to larger shipments thus introducing a downward bias in the estimate of β. To measures the extent of this bias, I estimate β in subsamples of shipments from countries with varying level of required paperwork and those that qualify for simplified customs procedures.

Alternatively, transport company's marginal costs can decrease in shipment's size. In this case, larger shipments are offered smaller freight payments, which further encourages manufacturers to transport in larger quantities and biases β estimate downwards. Although container fixed effects account for the economies of scale at the container level, they cannot correct bias introduced by economies of scale at the shipment level.

To separate variation in transport company's mark-ups and marginal costs across shipments of various sizes, I estimate the effect of competition on freight price variation. Specifically, I estimate the following specification:

$$\log T_{icd}(\varphi) = \beta \log q_{icd}(\varphi) + \beta_{nq} \log N_{cd} \times \log q_{icd}(\varphi) + \beta_n \log N_{cd} + \log \psi_{icd} + \varepsilon_{icd}(\varphi) \quad (16)$$

where N_{cd} denotes the number of transport companies on route c at time d. If freight price variation across shipments is entirely driven by shipment-level economies of scale, then the level of competition among transport companies on a route should not affect the extent of per-unit freight price variation. In other words, economies of scale at the shipment level in combination with constant mark-ups implies $\beta_{nq} = 0$. In contrast, if shipment size has any effect on mark-ups, then the level of competition is expected to affect the extend of freight price variation and $\beta_{nq} \neq 0$.

In the Appendix, I allow for competition in transportation sector in a form of outside options as in Attanasio and Pastorino (2015) and show that competition among transport companies increases quantities discounts offered to larger shipments. This implies that $\beta_{nq} < 0$. This effect of seller competition on the extent of (second-degree) price discrimination was derived by Herweg and Müller (2013) and Boik and Takahashi (2018). This is the opposite of the predicted effect of competition among transport companies on the extend of price discrimination based on observed manufacturer's demand elasticities (third-degree). I show in the Appendix that in this case an increase in the level of competition among transport companies reduces price differentials across more and less productive manufacturers and $\beta_{nq} > 0$.

When estimating β_{nq}, I address concerns associated with endogeneity of entry.[7] I exploit unexpected variation in the water level in Paraguay river as an instrument for the number of transport companies in river segment in a given month. When it drops below three meters in a way unpredictable by the month, the river becomes not navigable for standard-size barges. This limits competition among transport companies in the river segment that month and causally identifies the effect of competition on the extent of price discrimination.

The final source of the omitted variable bias that I consider is variation in shipment's value. If freight payments are determined from shipment's value rather than

[7] Although firms are expected to endogenously enter markets with higher price levels, it is not clear whether more firms enter markets with higher price variation.

weight, and the two are positively correlated, this would bias β estimate upwards. To rule this out, I estimate the following specification

$$\log T_{icd}(\varphi) = \beta_q \log q_{icd}(\varphi) + \beta_{pq} \log \tilde{p}_{icd}(\varphi) q_{icd}(\varphi) + \log \psi_{icd} + \varepsilon_{icd}(\varphi), \tag{17}$$

where $\tilde{p}_{icd}(\varphi)q_{icd}(\varphi)$ is the free-on-board value of manufacturer φ's shipment transported with transport company i on route c. As derived in the theoretical framework above, price discrimination in a form of quantity discounts implies that $0 < \beta_q < 1$. In contrast, iceberg formulation of transportation costs implies $\beta_q = 0$ and $\beta_{pq} = 1$.

Table 4 summarizes how I use estimated coefficients in equations (15) - (17) to distinguish price discrimination in a form of quantity discounts from a range of alternative pricing schemes in transportation sector.

Table 4. Freight price variation under various pricing schemes

	β	β_{nq}	β_q	β_{pq}
Market-power-based freight price variation:				
Price discrimination based on quantity	< 1	< 0	< 1	> 0
Price discrimination based on demand elasticity	< 1	> 0	< 1	> 0
Cost-based freight price variation:				
Perfect competition, economies of scale	< 1	0	< 1	0
Iceberg transportation costs	< 1	0	0	1

4.2 Estimation results

Table 5 presents the results of estimating equation (15) that describes the relationship between total freight payment and shipment's size within a container using simple OLS. I estimate β coefficients separately in two subsamples of shipments: transported from adjacent (Brazil, Argentina, Bolivia) and not adjacent countries.This is because container fixed effects capture transport company's costs only on the last leg of travel, which is the only leg of travel only for shipments from adjacent countries. I use gross weight (inclusive of packaging) as a measure of shipment size and product codes at various levels of disaggregation to account for transportation quality.

Table 5. The relationship between freight and weight accounting for transportation quality

Dependent Variable:	$\log TotalFreightPayment$			
	(1)	(2)	(3)	(4)
$\log GrossWeight$	0.423***	0.436***	0.430***	0.441***
	(0.010)	(0.011)	(0.014)	(0.008)
$\log GrossWeight \times Nonadjacent$	0.102***	0.091***	0.091***	0.147***
	(0.012)	(0.012)	(0.015)	(0.010)
Constant	3.526***	3.490***	3.549***	3.316***
	(0.040)	(0.044)	(0.048)	(0.035)
Container	✓	✓	✓	✓
HS2 code	✓			
HS4 code		✓		
HS6 code			✓	
Main HS8 code				✓
N obs	119677	97837	80695	231549
N clusters	25482	21874	19043	34011
Adj. R^2	0.851	0.868	0.882	0.886

Robust standard errors clustered at exporter level in parentheses.

* p<0.10, ** p<0.05, *** p<0.01

I find that, consistently with price discrimination by a transport company, total freight payment increase in shipment size and feature quantity discounts. Columns (1) - (4) estimate β coefficient to be less than one in statistically and economically significant extent. In a subsample of adjacent countries, all else equal, within a container, a one percent increase in the size of a shipment of a given product type is associated with 0.4 perfect increase in the total freight payment. This association remains robust to accounting for product types at a more disaggregated level. It means that within-container differences in quality of transportation services have a small impact on variation in freight prices.

I show that these quantity discounts are not an outcome of price discrimination by a transport company based on observed differences in demand elasticities across manufacturers differing in productivity. To account for such differences, I additionally include gross weight transported annually by a manufacturer with a given transport

Table 6. Quantity discounts vs. manufacturer size effect in transportation

Dependent Variable:	$\log Freight$		
	(1)	(2)	(3)
$\log GrossWeight$	0.346***	0.407***	0.598***
	(0.017)	(0.024)	(0.044)
$\log GrossWeight \times Nonadjacent$	0.150***	0.084**	-0.001
	(0.022)	(0.034)	(0.045)
$\log Exporter\text{-}TransporterWeight$	-0.105***		
	(0.014)		
$\log GrossWeight \times \log Exporter\text{-}TransporterWeight$	0.014***		
	(0.001)		
$\log ExporterWeight$		-0.068***	
		(0.014)	
$\log GrossWeight \times \log ExporterWeight$		0.010***	
		(0.002)	
Constant	3.844***	3.662***	2.592***
	(0.057)	(0.102)	(0.185)
Container	✓	✓	✓
Exporter			✓
N obs	361647	268072	333254
N clusters	40991	17210	21054
Adj. R^2	0.864	0.876	0.916

Robust standard errors clustered at exporter level in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

company and overall, as well as exporter fixed effects. Table 6 presents the results. Columns (1) and (2) show that, indeed, manufacturers transporting more annually with a specific transport company and with all transport companies receive additional discounts. However, such discounts do not substantially change the extent of quantity discounting. Column (3) includes exporter fixed effects and shows that transport companies vary freight prices across shipments of the same exporter. This is consistent with price discrimination in a form of non-linear pricing and inconsistent with price discrimination based on observed demand elasticities.

Next, I rule out economies of scale at the shipment level as an mechanism behind the observed quantity discounts. I estimate the effect of competition among transport companies on freight price variation across shipments of a given transport company in a given month. Specifically, I estimate coefficient β_{nq} in equation (16) in a subsample of shipments transported by the river segment of transportation. Table 7 reports the results. Column (1) reports the effect of an increase in the number of river carriers (transporters) on average per-unit freight prices of shipments within transporter-exporter-year. Expectedly, in months with more carriers on the river, average per-unit prices are lower. Moreover, column (2) shows that when faced with more competition in a given month, a transport company gives out larger quantity discounts ($\beta_{nq} < 0$). This result is consistent with the predicted effect of competition on mark-up variation implied by price discrimination. However, it is not consistent with the effect of competition on per-unit freight prices implied by the shipment-level economies of scale predicted to be zero.

I demonstrate that this effect of competition on freight price variation across shipments is not driven by endogenous entry of transport companies. I instrument for the number of transporters in the river segment with a dummy variable equal to one when water level in Paraguay river drops below three meters. Figure shows that although there is predictable seasonality in the water level in this river, episodes of water level below three meters remain to be largely unpredictable. To further account for expectations, I control for the probability of a water level in a given month, when constructing the instrument.

Columns (3) reports the results of estimating a causal effect of competition among transport companies of freight price variation. It shows that an increase in the level of competition in transportation sectors leads to larger discounts offered to manufacturers transporting in larger quantities. Column (4) shows that an indicator for a low water level in Paraguay river has a direct effect on freight price variation. Column (5) reports that it is strongly positively correlated with the level of competition in the river segment of transportation.

Finally, I demonstrate that the negative relationship between per-unit freight prices and shipment size implied by the estimated elasticities is not driven by pricing based on shipment's value. I estimate equation (17) and report the results in Table 8. It shows that the total freight payment elasticity with respect to shipment's quantity,

Table 7. The effect of competition of transport companies on freight price variation

Dependent Variable:	log $Freight\ payment_{my}$				
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	IV	OLS	I stage
log $Weight_{my}$	0.782***	0.675***	0.674***	0.675***	-0.003
	(0.006)	(0.003)	(0.003)	(0.003)	(0.008)
log $\#Carriers_{my}$	-0.376***				
	(0.102)				
$\Delta \log Weight_{my} \times \Delta \log \#Carriers_{my}$		-0.023*	-0.119**		
		(0.013)	(0.060)		
$\Delta \log Weight_{my} \times \Delta \mathbb{1}_{my}\,[Water\ level \geq 3]$				-0.013**	0.110***
				(0.006)	(0.020)
log $Gas\ Price_{my}$	1.340***				
	(0.268)				
log $Producer\ Currency/\$_{my}$	0.360**				
	(0.173)				
log $Guarani/\$_{my}$	-0.428*				
	(0.254)				
Constant	4.217*	1.850***		1.850***	0.025
	(2.195)	(0.028)		(0.028)	(0.077)
Transporter-Exporter-Year	✓				
Transporter-Country-Year-Month		✓	✓	✓	✓
HS2-Month	✓	✓	✓	✓	✓
N obs	41134	98184	98184	98184	98184
N clusters	1477	1292	1292	1292	1292
Adj. R^2	0.929	0.792	0.667	0.792	0.418

Robust standard errors clustered at the time-carrier level in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

conditional on its value, is less than unity across all specifications. As predicted by the theoretical framework, this is consistent with price discrimination in a form of quantity discounts and inconsistent with the iceberg formulation of transportation costs.

In Table 9, I confirm that this result is not an outcome of measurement errors in

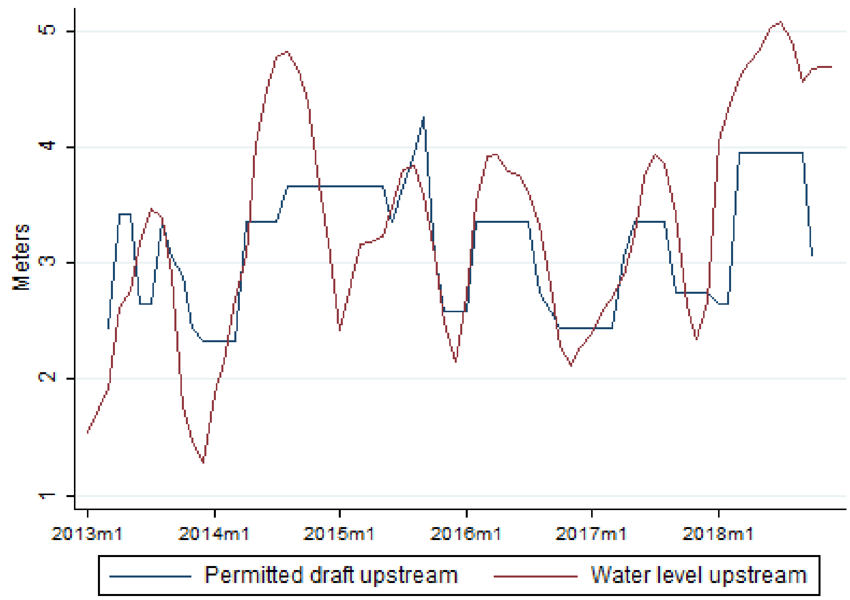


Figure 3. Variation in water levels and permitted draft upstream of Paraguay river
Data Source: La Dirección de Meteorología e Hidrología

shipment's weight. I use gross weight of products imported by a shipment's importer from its other suppliers in a given quarter as an instrument for the shipment size. Column (4) shows that the two variables are positively correlated, possibly through common importer-level demand shocks. In column (2), conditional freight payment elasticity with respect to quantity estimated using the instrumental variable approach is larger but still statistically significantly different from one. Although this results in smaller quantity discounts, they remain to be significant. Conditional on the shipment's value, a one percent increase in the shipment's weight increases freight payment by only 0.5 percent. This implies significant deviations of freight prices from the commonly used iceberg formulation.

Table 8. Freight price variation within container, conditional on shipment's value

Dependent Variable:	log *Freight payment*			
	(1)	(2)	(3)	(4)
log *Weight*	0.356***	0.370***	0.277***	0.302***
	(0.005)	(0.009)	(0.009)	(0.017)
log *Value*	0.264***	0.268***	0.213***	0.268***
	(0.006)	(0.010)	(0.009)	(0.015)
Nonadjacent	0.233***	0.169***		
	(0.030)	(0.046)		
log *Weight* × log *Nonadjacent*			0.112***	0.077***
			(0.013)	(0.022)
log *Value* × log *Nonadjacent*			0.035***	-0.011
			(0.012)	(0.021)
Constant	1.709***	1.669***	2.209***	1.861***
	(0.063)	(0.131)	(0.061)	(0.146)
Container	✓			
Container-HS2		✓		
Container-Country			✓	
Container-Country-HS2				✓
N obs	329425	133354	270240	96050
N clusters	59023	29565	45532	18284
Adj. R^2	0.859	0.916	0.888	0.936

* p<0.10, ** p<0.05, *** p<0.01

Robust standard errors clustered at the exporter level in parentheses.

5 Conclusions

This paper explores the micro-level determinants of transport costs - one of the largest barriers to international trade and development. It is one the first studies that by viewing transportation as an essential input to any cross-border transaction puts transportation on equal footing with other internationally traded inputs. In doing so, the paper overcomes the major empirical challenges faced by previous researchers by bringing in a new customs data set with detailed information on buyers and sellers of transportation services, freight prices, and shipment characteristics. This unique dataset allows me to document freight price variation not entirely consistent with a

Table 9. Freight price variation within container, conditional on shipment's value

Dependent Variable:	log *Freight payment*			log *Weight*
	OLS	IV	OLS	I stage
	(1)	(2)	(3)	(4)
log *Weight*	0.277***	0.469***		
	(0.009)	(0.064)		
log *Value*	0.213***	0.044	0.463***	0.892***
	(0.009)	(0.058)	(0.011)	(0.012)
log *Quarterly Weight, Other Suppliers*			0.019***	0.041***
			(0.003)	(0.006)
Constant	2.433***		1.874***	-1.620***
	(0.079)		(0.104)	(0.116)
Container-Country	✓	✓	✓	✓
N obs	115268	102204	102204	102204
N clusters	14387	13181	13181	13181
Adj. R^2	0.808	0.416	0.771	0.856
Kleibergen-Paap rk Wald F		50.296		

* $p<0.10$, ** $p<0.05$, *** $p<0.01$

Robust standard errors clustered at the exporter level in parentheses.

common "iceberg" trade cost formulation, but consistent with freight carriers engaging in various forms of price discrimination.

By documenting sizable discounts for larger exporters and exporters with larger shipments, this paper confirms that transport costs are not an exogenous friction, but rather are an endogenous outcome of firms' strategic interactions. These results are important for our understanding of transport costs as an impediment to trade and for designing an efficient policy to address the high level of transport cost, especially in developing countries. To that end, the paper shows that competition in transportation industry reduces the freight prices, especially for larger exporters, and thus complements investments in transport infrastructure as a means to reducing transport costs that impede trade and development. Moreover, because freight prices are shown to be applied per unit rather than per value, the investment in transport infrastructure are expected to have much larger welfare effects compared to those obtained under the "iceberg" formulation of transport costs (cf. Donaldson and Hornbeck (2016), Donaldson (2018), Allen and Arkolakis (2019)).

Obtained for a specific input - transportation services, my results can yet shed light of how prices of other internationally traded goods are negotiated. An important advantage of focusing on the transportation services is that it is a relatively homogeneous input in the sense that detailed information on the carrier, travel route, vehicle used, and product shipped almost entirely describes its quality. Therefore, my uniquely detailed customs data, allows me to establish empirically that larger buyers and buyers purchasing larger quantities get better prices from a given seller, *conditional* on quality. This result complements previous findings that larger firms purchase higher quality goods (cf. Kugler and Verhoogen (2011), Feenstra and Romalis (2014), Blaum et al. (2013)). In addition, this finding demonstrates that it is not necessary for larger buyers to have monopsony/oligopsony power to get better prices (as in Morlacco (2018), Macedoni and Tyazhelnikov (2019)), as this effect can result simply from the suppliers exercising their market power through price discrimination. Yet, none of the workhorse models of trade today allows for the prices to vary across buyers as a result of price discrimination. Understanding the consequences of this fact for allocative efficiency and welfare gains from trade thus seems to be a fruitful avenue for future research.

From theoretical perspective, this paper also makes an important contribution by showing how firm heterogeneity in international trade combined with informational asymmetries and market power gives raise to nonlinear contracts. This paper show that when sellers do not observe their buyer's demand elasticity, they can still price discriminate by designing a pricing scheme that makes buyers truthfully reveal their willingness to pay. Although nonlinear pricing is a well-documented phenomenon in the industrial organization literature (cf. McManus (2007), Cohen (2008), Busse and Rysman (2005), Boik and Takahashi (2018)), this paper is one the first to document it in cross-border transactions. Under nonlinear pricing, mark-ups vary based on the quantity or quality purchase even within the same buyer-seller pair. Hence, they can generate trade lumpiness over time, and result into larger pass-through of cost shocks for larger buyers. Although, mark-up variation across sellers has been shown to have important implications for exchange rate pass-through (cf. Berman et al. (2012), Amiti et al. (2014)), the implications of the nonlinear pricing for shock propagation remains unexplored in the literature.

Overall, this paper adds new insights on the role of strategic interaction of firms in international trade. By focusing on the international transportation, it documents what determines transport costs an how they can be addressed as a major trade barriers. Yet, its main results are equally important for our understanding of price variation and market power in cross-border transactions.

References

Allen, T. and Arkolakis, C. (2019). The welfare effects of transportation infrastructure improvements. Technical report, National Bureau of Economic Research.

Amiti, M., Itskhoki, O., and Konings, J. (2014). Importers, exporters, and exchange rate disconnect. *American Economic Review*, 104(7):1942–78.

Asturias, J., García-Santana, M., and Ramos, R. (2019). Competition and the welfare gains from transportation infrastructure: Evidence from the golden quadrilateral of india. *Journal of the European Economic Association*, 17(6):1881–1940.

Attanasio, O. and Pastorino, E. (2015). Nonlinear pricing in village economies. Technical report, National Bureau of Economic Research.

Berman, N., Martin, P., and Mayer, T. (2012). How do different exporters react to exchange rate changes? *The Quarterly Journal of Economics*, 127(1):437–492.

Bernard, A., Bøler, E., and Dhingra, S. (2018). 10 firm-to-fi rm connections in colombian imports. *World Trade Evolution*, page 333.

Blaum, J., Lelarge, C., and Peters, M. (2013). Non-homothetic import demand: Firm productivity and quality bias.

Boik, A. and Takahashi, H. (2018). Fighting bundles: The effects of competition on second degree price discrimination. *Available at SSRN 3249290*.

Borenstein, S. and Rose, N. L. (1994). Competition and price dispersion in the us airline industry. *Journal of Political Economy*, 102(4):653–683.

Brancaccio, G., Kalouptsidi, M., and Papageorgiou, T. (2020). Geography, transportation, and endogenous trade costs. *Econometrica*, 88(2):657–691.

Busse, M. and Rysman, M. (2005). Competition and price discrimination in yellow pages advertising. *RAND Journal of Economics*, pages 378–390.

Cajal-Grossi, J., Macchiavello, R., and Noguera, G. (2019). International buyers' sourcing and suppliers' markups in bangladeshi garments.

Chaney, T. (2008). Distorted gravity: the intensive and extensive margins of international trade. *American Economic Review*, 98(4):1707–21.

Cohen, A. (2008). Package size and price discrimination in the paper towel market. *International Journal of Industrial Organization*, 26(2):502–516.

De Loecker, J. and Eeckhout, J. (2017). The rise of market power and the macroeconomic implications. Technical report, National Bureau of Economic Research.

Donaldson, D. (2018). Railroads of the raj: Estimating the impact of transportation infrastructure. *American Economic Review*, 108(4-5):899–934.

Donaldson, D. and Hornbeck, R. (2016). Railroads and american economic growth: A "market access" approach. *The Quarterly Journal of Economics*, 131(2):799–858.

Ellison, S. F. and Snyder, C. M. (2010). Countervailing power in wholesale pharmaceuticals. *The Journal of Industrial Economics*, 58(1):32–53.

Fajgelbaum, P. D. and Schaal, E. (2020). Optimal transport networks in spatial equilibrium. *Econometrica*, 88(4):1411–1452.

Feenstra, R. C. and Romalis, J. (2014). International prices and endogenous quality. *The Quarterly Journal of Economics*, 129(2):477–527.

Gerardi, K. S. and Shapiro, A. H. (2009). Does competition reduce price dispersion? new evidence from the airline industry. *Journal of Political Economy*, 117(1):1–37.

Grennan, M. (2013). Price discrimination and bargaining: Empirical evidence from medical devices. *American Economic Review*, 103(1):145–177.

Herweg, F. and Müller, D. (2013). Price discrimination in input markets: Quantity discounts and private information. *The Economic Journal*, 124(577):776–804.

Hummels, D. (2007). Transportation costs and international trade in the second era of globalization. *Journal of Economic Perspectives*, 21(3):131–154.

Hummels, D., Lugovskyy, V., and Skiba, A. (2009). The trade reducing effects of market power in international shipping. *Journal of Development Economics*, 89(1):84–97.

Hummels, D. and Skiba, A. (2004). Shipping the good apples out? an empirical confirmation of the alchian-allen conjecture. *Journal of political Economy*, 112(6):1384–1402.

Hummels, D. L. and Schaur, G. (2013). Time as a trade barrier. *American Economic Review*, 103(7):2935–59.

Irarrazabal, A., Moxnes, A., and Opromolla, L. D. (2015). The tip of the iceberg: a quantitative framework for estimating trade costs. *Review of Economics and Statistics*, 97(4):777–792.

Jullien, B. (2000). Participation constraints in adverse selection models. *Journal of Economic Theory*, 93(1):1–47.

Kikkawa, A. K., Magerman, G., and Dhyne, E. (2017). Imperfect competition and the transmission of shocks: The network matters. Technical report, Working Paper.

Kugler, M. and Verhoogen, E. (2011). Prices, plant size, and product quality. *The Review of Economic Studies*, 79(1):307–339.

Limao, N. and Venables, A. J. (2001). Infrastructure, geographical disadvantage, transport costs, and trade. *The World Bank Economic Review*, 15(3):451–479.

Luo, Y., Perrigne, I., and Vuong, Q. (2018). Structural analysis of nonlinear pricing. *Journal of Political Economy*, 126(6):2523–2568.

Macedoni, L. and Tyazhelnikov, V. (2019). Oligopoly and oligopsony in international trade.

Maskin, E. and Riley, J. (1984). Monopoly with incomplete information. *The RAND Journal of Economics*, 15(2):171–196.

McManus, B. (2007). Nonlinear pricing in an oligopoly market: The case of specialty coffee. *The RAND Journal of Economics*, 38(2):512–532.

Melitz, M. (2003). The impact of trade on aggregate industry productivity and intra-industry reallocations. *Econometrica*, 71(6):1695–1725.

Morlacco, M. (2018). Market power in input markets: Theory and evidence from french manufacturing. Technical report, Working Paper.

Mussa, M. and Rosen, S. (1978). Monopoly and product quality. *Journal of Economic theory*, 18(2):301–317.

Schott, P. K. (2008). The relative sophistication of chinese exports. *Economic policy*, 23(53):6–49.

Shepard, A. (1991). Price discrimination and retail configuration. *Journal of Political Economy*, 99(1):30–53.

Sørensen, A. (2014). Additive versus multiplicative trade costs and the gains from trade liberalizations. *Canadian Journal of Economics/Revue canadienne d'économique*, 47(3):1032–1046.