Price Discrimination in International Transportation: Evidence and Implications *

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Abstract

Despite the recognized complexity of the international shipping industry, most trade models treat transport costs as a multiplicative exogenous friction, fixed at the bilateral country level. In this paper, I use a uniquely detailed freight price data from a new customs data set to study transport costs not only as a trade friction, but also as prices of business services traded between firms. I document empirical regularities inconsistent with both the Law of One Price in the shipping industry and the "iceberg" trade cost assumption: freight prices vary substantially across shipments within narrowly defined routes and conditional on the shipment's value. I show theoretically that these regularities are rationalized in a standard model of trade with transportation sector, in which carriers engage in standard price discrimination activities studied in industrial organization literature. In support of the model, I show empirically that freight carriers price discriminate across exporters, especially through sizable quantity discounts, and charge overall larger exporters lower prices irrespective of the shipment's size. Using the structure of the model, I show that this strategic pricing behavior of freight carriers generates a substantial deviation of transport costs from the "iceberg" assumption. Using an exogenous weather-related shock to the level of competition in the shipping industry, I find that competition increases the extent of quantity discounts thus giving further advantage to larger firms participating in international trade. These results have important policy and welfare implications, especially for developing countries that pay substantially higher transportation costs than developed nations.

Keywords: price discrimination; shipping; transport costs; quantity discounts; trade
JEL codes: F10, F12, F14, D22, D43

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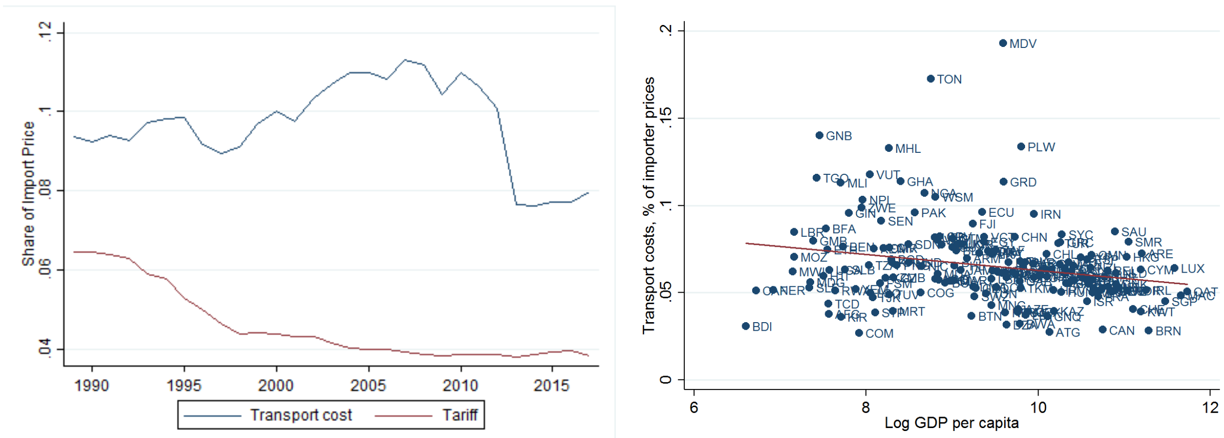
1 Introduction

Despite substantial technological progress in logistics over the past decades, transport costs remain one of the largest barriers to international trade. Figure 1a shows that transport costs place an increasingly large burden on US importers, especially relative to import tariffs, which have drastically declined due to several waves of trade liberalization. In 2017, on average, transport cost and import tariffs accounted for about 8% and 4% of prices US importers paid, respectively. Notice that relative to their levels thirty years ago in 1989, import tariffs have decreased by more than 70%, while transport costs have decreased by only 18%. These numbers do not reflect the costs of inland transportation incurred by importers to reach consumers, and thus underestimate the burden that transport costs place on final consumers. In addition, US data underestimates the magnitude of transport costs in developing countries, which are known to be larger and believed to impede the development (cf. Limao and Venables (2001), Hummels et al. (2009)). Figure 1b illustrates this fact by showing that even among US trade partners, richer countries face lower transport costs as a share of importer prices.



(a) Transport charges remain higher in the US (b) Transport charges are higher in poorer partners

Figure 1: Transport costs are a large barrier to trade, especially in developing countries

Data Source: U.S. Census Bureau available through Schott (2008)

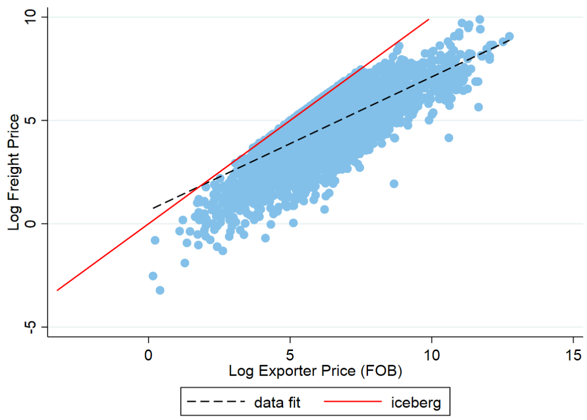
Based on their sheer size, transport costs cannot be invisible or inconsequential to manufacturers and consumers worldwide, yet the lack of systematic micro-level data on freight prices makes them largely invisible to the researchers studying their determinants and effects. As a result, to analyze the patterns and structure of trade flows and to quantify the welfare effects of investment in transport infrastructure, the literature adopts a simplified "iceberg" formulation for transport costs, under which a fixed share of the value shipped on a given route melts during its transportation. In this paper, I take a different approach: using information on freight prices at the shipment level from a new customs data set, I document price discrimination by freight carriers, and then evaluate both theoretically and empirically how competition in transportation sector affects the level and distribution of freight prices across shippers.

Unlike other trade barriers, transport costs are inherently prices of transportation services determined as an outcome of interaction of transport companies, exporters and importers. However, transport costs are rarely analyzed explicitly as input prices, because freight prices are hardly observed in datasets together with their sellers and buyers. This paper makes progress on this front and treats transportation as an input by leveraging several unique features of transaction-level customs data from Paraguay. First, this data records freight prices, separately from insurance, for each imported shipment of each exporter-importer pair with detailed description of products it contains (Harmonized systems 8-digit product code (HS8)). Second, for each shipment, it details a transport method and a name of the carrier that was used on the last leg of travel. Importantly, the data allows me to identify shipments that were transported at the same time by the same carrier on board of the same vehicle from the exact same pick-up to the exact same drop-off locations. This feature of the data is crucial for separating the markup- and the cost-based variation of freight prices across different shipments.

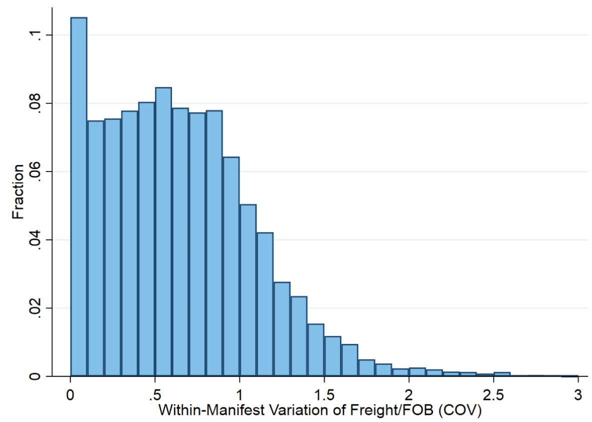
This new customs data allows me to document several stylized facts on freight price variation in international transactions. Figure 2 illustrates the main empirical regularities that motivate my subsequent investigation of transport costs: in contrast to the "iceberg" assumption, freight prices are not directly proportional to the value, and vary substantially across shipments transported on the same vehicle by the same carrier at the same time. Figure 2a shows that although a one percent increase in the vehicle's value should be translated into a one percent increase in its freight price if transport costs were indeed "iceberg", the data reflects a different pattern. Figure 2b suggests that, across all manifests, freight prices as a share of the shipment's value are not constant, but vary substantially with average coefficient of variation of 65%.

To understand the sources and consequences of this freight price variation, I develop a new model of international trade with endogenous transport costs, by adapting a standard model of nonlinear pricing from industrial organization (Mussa and Rosen (1978), Maskin and Riley (1984)) to the standard international trade environment with firm heterogeneity (Melitz (2003), Chaney (2008)). In its most general form, this model predicts three sources of freight price variation that I further investigate empirically: economies of scale, price discrimination, and the level of competition in transportation industry. Under the standard in the international trade literature assumptions of CES preferences and a Pareto distribution of firm productivities, the model suggests that, in equilibrium, transport costs are partly proportional to the producer price and partly proportional to the quantity shipped.

When the model is taken to the data, I find that 20 to 30% of the freight price is determined by the value of the shipment, while 30 to 40% of it is determined by the size (weight) of the shipment. Exploiting variation *across* manifests, I show that there is room for economies of scale in transportation, whereby shipments transported as a part of a larger group of shipments are



(a) Freight prices are not directly proportional to the product's value (vehicles from the US)



(b) Freight prices vary across shipments imported simultaneously by the same carrier on the same vehicle

Figure 2: Micro-level freight prices are not fully accounted for by an iceberg trade cost assumption.

Data Source: U.S. Census Bureau available through Schott (2008)

charged lower prices by the same carrier, conditional on the country of purchase and product type. When studying *within*-manifest 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 proxies are added for the overall exporter/importer size and long-term contracts between exporters/importers and carriers are accounted for. The data suggests that, conditional on the shipment's size on a given manifest, exporter-carrier and importer-carrier pairs with larger annual volume of trade pay lower per-ton freight prices. This is again consistent with the theory that shippers price discriminate across importers and exporters of different size, but not cost-based explanations. Similarly, overall larger exporter and importers that ship larger volumes with other carriers also receive a discount when transporting a shipment of a given size.

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. Besides its uniquely detailed customs data, Paraguay offers an environment particularly suitable for studying the effect of competition in transportation industry on transport costs faced by importers. Firstly, it is a developing landlocked country that heavily depends on inland transportation in both direct trade with its land-neighbors and transit of goods from its long-distance partners.[1] Therefore, apart from the policy implications for Paraguay itself, understanding the

[1]My back-of-the-envelop calculations suggest that transport costs during transit accounts for more than a half of ad-valorem equivalent of transport costs for goods imported from Paraguay's non-contiguous trade partners.

effects of competition in inland transportation is also important for trade between land-neighbors, which accounts for about 25% of world trade flows. Secondly, when importing bulky products and shipments from its long-distance partners, Paraguay relies on the Paraguay-Parana river system, the navigability of which acts as a plausibly exogenous shock to the number of transport companies in a given month. When the water level of this river is low, which occurs about 50% of the time in the year, shipments by river are drastically reduced, causing an exogenous decrease in competition among shippers along the river as well as using alternative transportation methods.

Using the water level and navigation restrictions in the upstream part of the Paraguay river as an instrument for competition, I find that, when faced with an increased competition as a result of a high water level in the river, a freight carrier increases the size of the discounts offered to the exporters with larger shipments in a given month. I obtain this same result in two separate subsamples of carriers - river carrier and road carriers, and after controlling for other time-varying confounding factors (such as fuel prices and capacity restrictions limiting economies of scale at times of low river level). These findings thus suggest that liberalization of inland transportation that, unlike maritime transportation, complements investment in transport infrastructure as way to low trade barriers, increased trade volumes, and development.

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.

The rest of the paper is organized as follows. In Section 2, I introduce a new customs data set and document several stylized facts on freight price determinants and their variation. In Section 3, I develop a new model of trade with endogenous transport sector that can rationalize these stylized facts. In Section 3, I provide an extensive empirical test of the model, confirming that the observed freight price variation reflects both the economies of scale and price discrimination of freight carriers. In Section 4, I empirically study the effect of competition in transportation industry on the level and dispersion of freight prices across exporters. In Section 5, I further discuss the implications of my findings and conclude.

2 Data and Stylized Facts

2.1 A new customs data from Paraguay

In this paper, I exploit a rich transaction-level customs dataset from Paraguay, a landlocked developing country in South America. Being a landlocked economy, Paraguay has developed particularly strong trade relations with its land neighbors - Argentina, Brazil, and Bolivia. In 2013, the three countries accounted for about 50% of Paraguayan imports, by value. However, long-distance trade also plays an important role in Paraguay's economy: its largest overseas partners - US and China are responsible for 13% and 17% of the country's imports in 2013, respectively. In absence of relatively inexpensive maritime transportation, Paraguay, like many other developing and landlocked economies, heavily relies on inland transportation in both direct trade with its neighbors and transit trade with its long-distance partners. Together with its uniquely detailed customs data, this fact makes Paraguay a particularly interesting case for examining the determinants of transport costs and their implications for international trade.

Paraguay custom's data reports the entire universe of import transactions on a daily basis for the period 2013 - 2018. Each transaction is described with relatively standard, for this type of trade data, characteristics: importing firm's identification number, exporting firm's company name, free-on-board (FOB) value in $US, cost-insurance-freight (CIF) value in $US, quantity, net and gross weight in kilograms, 8-digit HS classification code, and a country of purchase of the good. A unique feature of this data is that, apart from these characteristics, it also contains detailed information on how and at what cost each good was transported. Specifically, for each transaction, the data records the mode of transportation; freight costs separately from insurance costs; carrier and transport owner, used on the last leg of its travel. Notice that for Paraguay's land neighbors (Argentina, Brazil, and Bolivia), the last leg of travel is effectively the only leg of travel. Hence, in the data, the carrier and transport owner used to carry goods directly between Paraguay and its land neighbors are observed. Therefore, by recording data on individual exporters (buyers), carriers (sellers), prices and services sold, Paraguayan customs data is uniquely suitable for studying transport costs as freight prices.

There are three major modes of transportation that can be used on the last leg of a shipment's travel: trucks, river vessels, and airplanes. Trucks dominate in trade between Paraguay and its land neighbors, where they carry about 75% and 65% of shipments by value and weight, respectively. Shipments from non-contiguous countries mostly enter Paraguay via three ways: by sea with connecting inland waterway shipment after transshipment in Argentina or Uruguay; by sea with connecting road transport after transshipment in Brazil, Argentina or Uruguay; or by air with transshipment in Colombia, Chile, Brazil or Argentina. The data suggests that inland waterways is a dominant mode used on the last leg of travel, by both value (49%) and weight (81%) with road and air freight accounting for about 36% and 15% by value, respectively. The reason is that two large rivers in South America - Paraguay and Parana - flow through Paraguay and connects it to the ocean in Uruguay and Argentina. Interestingly, these rivers occasionally become unnavigable at least for standard vessels used in Paraguay (Mississippi-type barges with vessel draft of 9 feet). I exploit this feature of Paraguay's geography to identify an exogenous change in the number of carriers in a given month in my empirical analysis of the effect of competition on freight prices.

Although the focus of the literature studying transport costs in trade is on maritime transportation, my data suggests that inland transit of shipments through third-countries accounts for about a half of total transport costs faced by exporters from overseas. Table 1 presents the average and median values of a freight payment as a share of the shipment's (customs-insurance-freight, CIF) value. As expected, air and road transport modes are, respectively, the most and the least expensive methods of transportation. By comparing the ad-valorem equivalent of transport costs within transport modes and across the two subsamples of countries, we can see that transit transportation accounts for 57%, 78%, and 68% for road, river and air segments, respectively.

	Land-neighbors		Non-neighbors	
	Mean	Median	Mean	Median
Road	4.7%	3%	8.2%	6.6%
River	7.3%	6.4%	9.4%	7%
Air	7.9%	5%	11.7%	8.9%

Table 1: Ad valorem equivalent of transportation costs, by mode, 2013.

Importantly, the ad-valorem freight costs substantially vary across shipments containing a given product on a given route. Figure 3 shows that freight payment as a share of the exporter price (Freight/FOB ratio) is not constant at the country-HS8 level, as implied by the "iceberg" formulation of trade costs. In fact, the coefficient of variation of the freight payments is substantial and is only mildly reduced to about 60% when taking into account the differences in freight prices across transport modes.

The goal of the subsequent empirical and theoretical analysis is to understand the sources of this large variation of freight prices at the disaggregated level. In particular, in what follows I explore the role of several factors that could explain the freight price variation: carrier heterogeneity, within-carrier economies of scale in transportation, and variable mark-ups charged by the same carrier for different shipments.

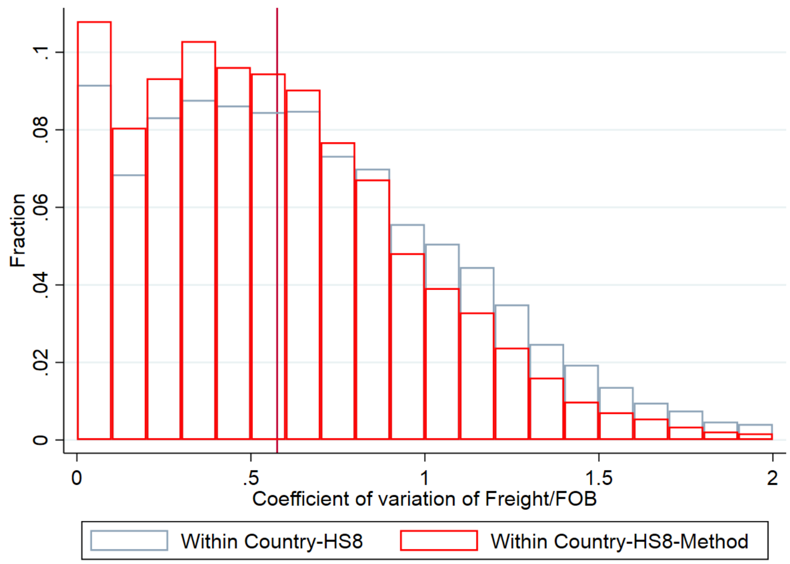


Figure 3: Variation of freight payments across shipments within country-product, 2017.

Separating the role of variable mark-ups from cost differences in explaining price variation has proved to be empirically challenging. The standard approach in the literature is to impose some theoretical structure on the data, calibrate the model, and compute mark-ups that match the model's predictions (cf. De Loecker and Goldberg (2014), De Loecker et al. (2016), De Loecker and Eeckhout (2018)). In this paper, I take a different approach and make use of the detailed proxies for the carriers' costs uniquely available in Paraguay's customs data to isolate the freight price variation due to the mark-ups variation. Specifically, for each shipment, my data attaches a number of the cargo manifest, under which it was imported to Paraguay. This cargo manifest lists all goods that a given freight carrier transported on board of a given vehicle at a given point in time following the same same route.[2] Importantly, it means that if the carrier stopped several times to pick-up cargo from different shippers, he/she will submit as many manifests as there were stops. Therefore, when studying the freight price variation across shipments listed on the same manifest, I can effectively absorb any differences in freight prices that could arise because, for example, of the expedited shipment, more efficient travel routes, special conditions for the vehicle, as well as all the time-varying shock to the carrier's cost.

Table 2 shows that, on average, at the end of a trip, carriers submit about 7 different manifests, with this number being higher for trucks (8 manifests per trip, on average), and lower for river vessels and airplanes (4 and 6 manifests per trip, respectively). The difference across transport modes is consistent with the fact that trucks operate on a more flexible schedule and can make more stops compared to river vessels, that often have fixed routes and fixed schedules. Trucks stop more often in different locations of their customers (exporters), which results in them having fewer

[2] A carrier submits as many manifests as there are routes on its vehicle's way to a specific customs post.

exporters listed within one manifest (4 exporters per manifest, on average, compared to 9 exporters per manifest, across all transport modes). The opposite is true for river vessels and airplanes: since they stop in just a few locations to pick up their cargo, many exporters have to deliver their goods to those locations, leading to many more exporters listed on one manifest. Similar patterns hold for the number of importers listed on one manifest. Because exporters often load cargo destined for more than two importers, the number of importers per manifest is for all transport modes smaller than the number of exporters per manifest. Since exporters generally specialize in what they export, fewer exporters listed on one manifest implies that, for trucks, there will be fewer different product types within a manifest.

	Mean	Median	Std. Dev.
	All Transport Modes		
# Manifests/Carrier a year	979.8	668	795.7
# Manifests/Carrier a day	6.9	6	4.7
# Exporters/Manifest	8.8	2	17.4
# Importers/Manifest	8.1	2	15.3
# Product types/Manifest	44.4	25	50.4
	Road		
# Manifests/Carrier a year	1229.4	1163	812.9
# Manifests/Carrier a day	7.6	7	5.0
# Exporters/Manifest	3.6	1	5.4
# Importers/Manifest	3.3	1	5.0
# Product types/Manifest	34.5	18	40.1
	River		
# Manifests/Carrier a year	260.7	116	341.8
# Manifests/Carrier a day	3.7	3	2.5
# Exporters/Manifest	13.4	8	14.5
# Importers/Manifest	12.5	8	13.3
# Product types/Manifest	62.4	49	58.3
	Air		
# Manifests/Carrier a year	478.9	426	347.7
# Manifests/Carrier a day	5.8	5	4.0
# Exporters/Manifest	22.2	7	31.8
# Importers/Manifest	20.1	7	27.3
# Product types/Manifest	61.0	40	62.9

Table 2: Manifests summary statistics, 2013.

Therefore, when combining information on what shipments were imported to Paraguay as a group with the information on what products they contain, I can control for the most sources of the carriers' cost variation. Yet, in the next subsection, I show that I even at that level of granularity, I am still finding a non-negligible variation of freight prices across shipments.

2.2 Stylized Facts

Here, I use the richness of the Paraguay's customs dataset to document several stylized facts on freight price variation and the potential forces driving this variation.

Fact 1. Freight prices vary substantially across shipments imported by the same carrier at the same time following the exact same route.

The data exhibits a large degree of variation of freight prices as a share of exporter prices (exclusive of freight payments) across shipments from a given country. Panel A of Table 3 shows that both the standard proxies for transport costs, distance and a common border dummy, and country fixed effects explain a surprisingly small fraction of this variation - 3% and 4%, respectively. This could be due to large variations in travel routes within- and across- transport methods from a given country to Paraguay. However, freight price variation does not disappear even after I account for the carrier, transport vehicle and the exact same pick-up and drop-off locations, using a unique feature of the data, which record a manifest number listing all shipments shipped together at the same time.

Figure 4 illustrates the variation of freight prices (as a share of exporter prices) across shipments transported by the same carrier, on board of the same vehicle from the exact same pick-up to the exact same drop-off location. It plots the distribution of the coefficient of variation of freight prices. Only in about 10% of all manifests this coefficient of variation is less than 10%, whiles it average value across all manifests and years is equal to 60%.

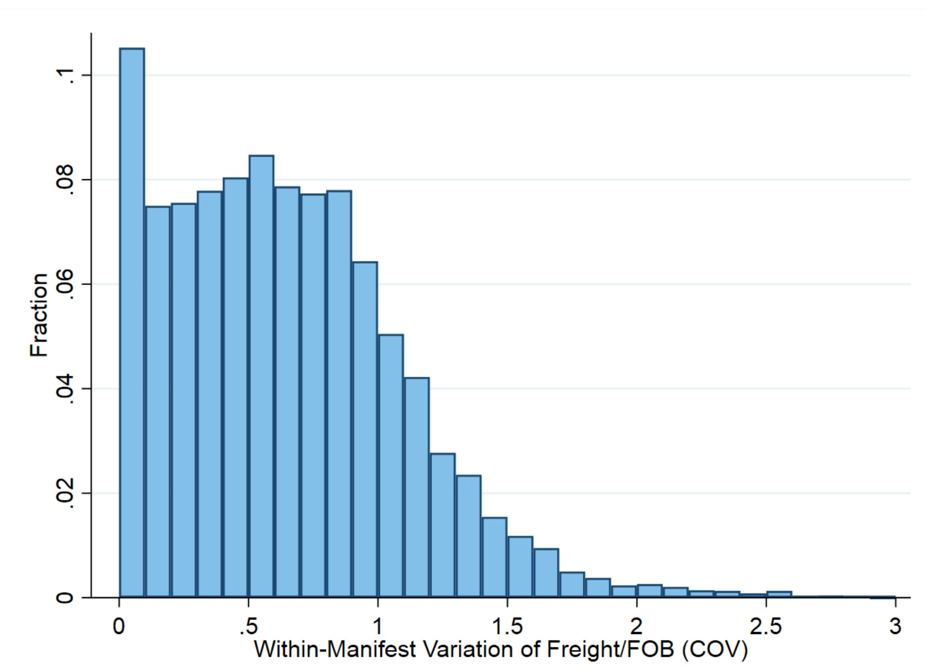


Figure 4: Variation of freight prices (as a share of exporter prices) across shipments listed on the same manifest, 2017

It means that the "iceberg" formulation of transport costs can approximate the actually incurred transport costs relatively closely only in a very small subsample of shipments in the data. For the majority of the shipments, however, this assumption is far from reality, which calls for additional explorations of the determinants of transport costs. The next two stylized fact hint that exporter heterogeneity and shipment's weight can be potential sources of this freight price variation.

Fact 2. Exporter heterogeneity is at least as important as country and product characteristics in explaining the observed freight price variation.

Panel A of Table 3 shows that exporting country, transport method and product type (defined at the HS4-digit level) fixed effects explain one third of the freight price variation. Additionally accounting for exporting firm fixed effects almost doubles the explained variation in freight prices. Exporter fixed effects alone explain 45% of the observed freight price variation, conditional on the country, transport method, and product type. Panel B of the same table explores what is driving such a large role of exporters in explaining the variation of freight prices using a subsample of consolidated (across at least two exporters) shipments.

	R^2	N obs
	Panel A: Country and Firm factors	
Distance, Common Border	0.03	395 773
Country	0.04	395 833
Country, Method, HS4	0.33	395 785
Country, Method, HS4, Exporter	0.60	390 795
	Panel B: Cost and Mark-up factors	
Country-Manifest	0.81	93 073
Country-Manifest, HS4	0.85	93 073
HS4, Exporter	0.69	90 257
Country-Manifest, HS4, Exporter	0.89	88 806

Table 3: The determinants of within-year Freight/FOB Value variation

Notes: HS4 stands for a 4-digit Harmonized system's code of a product, Manifest identifies a carrier, pick-up and drop-off locations, time of transportation, and the vehicle. Only shipments containing products of only one HS4-code were included in the estimation. Estimates in Panel B were obtained in a subsample of consolidated shipments (shared between at least two different exporters).

On the one hand, exporters can differ in the quality of transportation services they demand, they can have different locations within a given country, and they can contract with very different transport companies. In this case, exporter fixed effects are picking up the cost-based variation in freight prices across shipments. On the other hand, a given transport company can choose to charge different prices to different exporters, conditional on the costs of providing the services. In this case, exporter fixed effects are reflecting the markup-based variation in freight prices across shipments. To asses which of the two factors (cost-based or markup-based factors) are captured by the exporter fixed effects, in Panel B, I include controls for the carrier, transport vehicle, pick-up and drop-off locations, in addition to exporter- and product type-fixed effects. Comparing the results reported in the second and fourth rows of Panel B, I find that exporter heterogeneity unrelated to the cost-based variation in freight prices accounts for at least 5% of the explained variation. Notice that this contribution is even bigger than that of the country characteristics, reported in Panel A. On the other hand, cost-based explanations unrelated to the exporter effects account for at most 22.5% of the explained variation, while the selection of exporters into certain travel routes and transport companies accounts for the remaining 72.5% of the variation.

Fact 3. Freight prices vary with the shipment's weight at least as much as with the shipments value.

Table 4 establishes this fact by estimating the relationship between the freight payment, on the one hand, and the shipment's weight and/or its value, on the other hand, using within country-manifest variation. Although column (1) shows that the shipment's value explains a large share of variation of freight payments, the estimated coefficient is significantly less than 1, which is its value implied by the "iceberg" assumption. Columns (2) and (4) I study how much more variation can the shipment's weight alone explain relative to the shipment's value. Both net and gross (inclusive of the packaging) weight have a somewhat larger explanatory power relative to the value, based on the R^2 in either case. Interestingly, in column (5) the effect of the shipment's gross weight does not disappear after additionally controlling for its value. In fact, it demonstrates that freight carriers offer discounts to larger shipments. Specifically, conditional on its value, when shipment's weight increase by one percent, the estimates imply only a 0.3 percent increase in the associated freight payment. However, comparing the coefficients on value in columns (1) and (5) reveals that an increase in the shipment's value has a smaller effect on the freight payment when its weight does not change. It means that about half of the effect of shipment's value is actually due to its size that is correlated with its value.

Although the results reported in Table 4 are obtained conditional on all costs common to all shipments on board of the same vehicle at the same time, shipment-specific cost factors and mark-up variation are equally plausible reasons for the negative relationship between per-ton freight prices and shipment's size. The next stylized fact suggests that freight prices are likely to include at least some mark-up due to the market structure in transportation industry and can vary with varying levels of competition in the industry.

Fact 4. The market structure in transportation industry features a few large firms and a competitive fringe.

When viewing transport costs as prices of freight services, it appears important to understand the market environment, in which carriers make their pricing decisions. Table 5 summarizes the number of carriers (on the last leg of travel from all directions), separately by transport mode, as well as the shares of the largest four firms (based on annual weight transported and revenue received) as one of the measures of market concentration in the industry. There are a lot more road carriers than there are river and air freight carriers in the market, and all segments appear fairly

Dependent Variable:	log *Freight*				
	(1)	(2)	(3)	(4)	(5)
log *Value*	0.578***		0.322***		0.298***
	(0.030)		(0.024)		(0.019)
log *NetWeight*		0.455***	0.282***		
		(0.022)	(0.011)		
log *GrossWeight*				0.477***	0.310***
				(0.025)	(0.015)
Constant	1.498***	3.416***	1.800***	3.198***	1.769***
	(0.154)	(0.092)	(0.144)	(0.103)	(0.139)
Country-Manifest	Y	Y	Y	Y	Y
N obs	359717	359717	359717	359717	359717
N clusters	40156	40156	40156	40156	40156
R2	**0.832**	**0.857**	**0.875**	**0.863**	**0.878**

Robust standard errors clustered at exporter level in parentheses.
Data at the Bill of Lading (shipment) level.
* p<0.10, ** p<0.05, *** p<0.01

Table 4: Shipment's weight and shipment's value is the two determinants from freight prices

concentrate.

	# Carriers/year	CR4[3] (Weight)	CR4 (Revenue)
Road	228	25.5%	16.7%
River	23	56.3%	47.4%
Air	19	72.2%	70.6%

Table 5: Number of carriers across transport mode, and measures of market concentration

Figure 5 shows that even in the road transport, where there are hundreds of carriers offering transportation services to Paraguay annually, a few large firms dominate the sub-market. In air and river segments of the market several large firms each account for at least 15% of the volume of trade imported to Paraguay a year. Despite their small market share, the myriad of small carriers can discipline the behavior of the large carriers by representing an extra competition.

Overall, the three stylized facts described above hint in the direction of three potential determines of freight prices and their variation across shipments: cost economies, price discrimination by freight carriers with market power, and the extent of competition in transportation industry. In the next section, I develop a new model of trade with endogenous transport costs motivated by these stylized facts that will guide my empirical investigation of the determinants of freight prices.

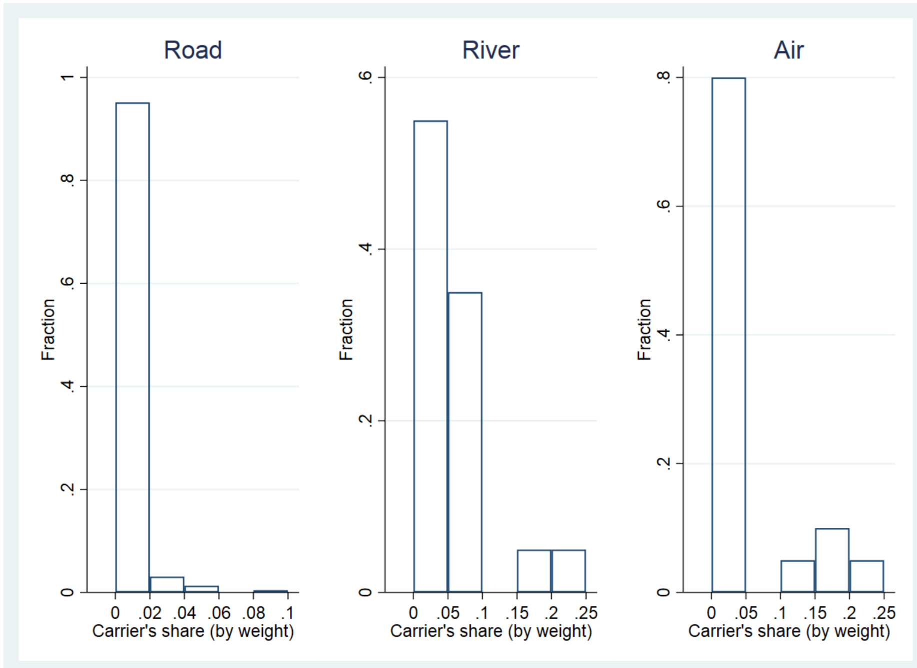


Figure 5: The distribution of carriers' market shares, by transport mode

3 Theoretical Model

I now describe a new model of trade that embeds a standard model of nonlinear pricing from industrial organization literature into a standard model of trade and generates the freight price variation consistent with the documented stylized facts.

This model views transportation services as an input in production of domestically or internationally traded goods. As producers of this "input", freight carriers play a central role in determining the size and distribution of transport costs across manufacturers of goods. The buyers of their transportation services are manufacturers, which, as in standard models of international trade, are heterogeneous in their productivity and, hence, size. In this section, I show that this environment naturally leads to the freight price variation across shipments in equilibrium. Specifically, the model predicts that the carrier charges lower prices for larger shipments either to pass along the economies of scale onto manufacturers transporting larger shipments (*cost channel*), or to screen the manufacturers and effectively exercise her market power (*mark-up channel*). The carrier resorts to the screening of her buyers because of the informational asymmetry: instead of observing each manufacturer's productivity, which determines the buyer's willingness to pay for transportation services, the carrier only knows the *distribution* of productivities in population. Therefore, to maximize her profits, the carrier uses her knowledge of productivity distribution to design a price-quantity schedule that, in equilibrium, induces the manufacturers to truthfully reveal their productivity and, hence, their willingness to pay for transportation services. Adapting the argument of the classic nonlinear pricing models of Mussa and Rosen (1978) and Maskin and

Riley (1984) to the international trade environment, I show how, in equilibrium, this price-quantity schedule implies that the freight carrier engages in price discrimination by charging manufacturers with larger shipment lower per-unit mark-ups.

I start by illustrating carriers pricing decisions in a simple case with only two different buyers and one monopoly carrier, then extend the model to have a continuum of heterogeneous buyers and several competing carriers.

3.1 Two types of exporters

To begin with, consider a simple case, when there is only one industry[4] in each country and there are only two types of manufacturers: high-productivity (H) and low-productivity (L) types. The only input in manufacturing is labor, which is supplied inelastically at its aggregate level L_i and which firms in country i can hire at a common wage rate w_i. Firm production technology consist of constant marginal costs and fixed overhead costs $F > 0$. The fixed costs are common across all firms, while marginal costs depend on firm productivity $\varphi_j,\ \ j = \{H, L\},\ \ \varphi_H > \varphi_L$. When selling goods to country n, the producers face identical and *independent* demands, $q_{ni} = q(p_{ni})$, and pay (exogenous) multiplicative trade costs τ_{ni} (i.e. tariffs, insurance costs, etc.).

Selling manufactured goods to any market n requires that firms from country i purchase transportation services from their local carrier. This carrier is a monopolist[5] that alone serves all destinations $n = 1, \dots N$ at a marginal cost of k_{ni} per unit of goods transported. When deciding what price to charge to each manufacturer, the carrier does not directly observe the manufacturers' types, but she knows their distribution in population. Specifically, the carrier knows that with probability α a given manufacturer is of H-type (high-productivity), and with probability $1 - \alpha$ the manufacturer is of L-type (low-productivity).

In this environment of asymmetric information, the carrier cannot engage in third-degree price discrimination, but she can utilize her knowledge of the types' distribution to design an optimal price-quantity schedule that results in higher profits than the uniform pricing. Under such price-quantity schedule, the carrier will sell q^L_{ni} units of transportation services to type-L manufacturer and q^H_{ni} units to type-H manufacturer in exchange for the total payments of T^L_{ni} and T^H_{ni} from each type, respectively. Having purchased quantity $q^j_{ni},\ \ j \in \{H, L\}$ of transportation services, country i's manufacturer j, in principle, can sell any quantity $q' \in [0, q^j_{ni}]$ to destination n (free disposal assumption). In equilibrium, however, it is never optimal for the manufacturers to under-utilize the purchased transportation services.

The sequence of events is as follows. First, country i's carrier announces a price-quantity schedule for transportation services. In stage two, all active manufacturers hire labor and purchase transportation services from the carrier and decide how much to sell to each destination they are

[4] Extending the analysis to multiple sector is straightforward and results in qualitatively analogous results.

[5] The set-up can be easily extended to feature a competitive fringe of carriers as well (cf. (Herweg and Müller (2013))).

active in. In this simple case, I focus on the carrier's pricing decisions and abstract from any effects carrier's decisions can have on firm's entry/exit. In other words, here I restrict attention to situations, when fixed costs of production are low enough for both firms to be active in all markets. However, in a fully-fledged model with a continuum of buyer types, I discuss the endogenous determination of firms' entry and exit decisions.

In what follows, I solve for the optimal price-quantity schedule in transportation sector as a sub-game perfect Nash equilibrium using backward induction.

The Manufacturer's problem. In the second stage, a manufacturer with productivity φ_j located in country i and selling to country n chooses how much to sell to destination n. The optimal quantity, q^*_{ni}, is defined as

$$q^*_{ni}(\varphi) \equiv \underset{q \geq 0}{\text{argmax}}\{[p_{ni}(q) - w_i \tau_{ni}/\varphi]\, q\}, \tag{1}$$

where $p_{ni}(q)$ is the inverse demand function in country n for goods from country i. Naturally, q^*_{ni} is increasing in firm productivity φ_i such that $q^*_{ni}(\varphi_H) > q^*_{ni}(\varphi_L)$. The possibility of free disposal implies that under shipping contract (q, T), a manufacturer j from country i selling to destination j receives maximum profits of $\pi(q, \varphi_j) - T$, where

$$\pi(q, \varphi_j) = [p(\min\{q, q^*_{ni}(\varphi_j)\}) - w_i \tau_{ni}/\varphi_j] \min\{q, q^*_{ni}(\varphi_j)\} - F \tag{2}$$

This profit function has two important properties. First, firm j's profits $\pi(q, \varphi_j)$ are strictly increasing and strictly concave in q when $0 \leq q < q^*_{ni}(\varphi_j)$ and constant when $q \geq q^*_{ni}(\varphi_j)$. Second, the high productivity firm benefits more from an increase in quantity of transportation services than the low productivity one, or, formally

$$\text{for all } \; 0 \leq q' < q'' \leq q^*_{ni}(\varphi_H), \;\; \pi(q'', \varphi_H) - \pi(q', \varphi_H) > \pi(q'', \varphi_L) - \pi(q', \varphi_L) \tag{3}$$

These two properties are important in the analysis of the carrier's choice of an optimal price-quantity schedule, which I proceed to next.

The Carrier's problem. Recall that there is only one carrier in country i that serves all firms $j = H, L$ and all destinations $n = 1, \ldots, N$. Suppose this carrier is not restricted to offering the same price to all destinations and all shippers within one route. Since destinations can be viewed as independent markets, the carrier's problem can be split into N independent profit maximization problems - one for each destination.

If the carrier could separate a firm with low productivity from that with high productivity, she would offer two different prices to two firms after solving two separate profit maximization problems. However, the carrier only knows the probabilities of dealing with each type of firms. Therefore, in the first stage, the carrier chooses two contracts $\left(q^L_{ni}, T^L_{ni}\right)$ and $\left(q^H_{ni}, T^H_{ni}\right)$ to maximize the *expected* profits:

$$\pi_{ni}^C = \alpha\left[T_{ni}^H - k_{ni}q_{ni}^H\right] + (1-\alpha)[T_{ni}^L - k_{ni}q_{ni}^L] \tag{4}$$

There are several demand constraints that the monopolist faces when solving this profit maximization problem. First, each exporter should receive non-negative profits after paying for transportation services (individual rationality (*IR*) constraints):

$$\pi(q_{ni}^H, \varphi_H) - T_{ni}^H \geq 0$$

$$\pi(q_{ni}^L, \varphi_L) - T_{ni}^L \geq 0$$

Second, each exporter should prefer to purchase a contract intended to him rather than that intended to another exporter (incentive compatibility (*IC*) constraints):

$$\pi(q_{ni}^H, \varphi_H) - T_H \geq \pi(q_{ni}^L, \varphi_{ni}^H) - T_{ni}^L$$

$$\pi(q_{ni}^L, \varphi_L) - T_L \geq \pi(q_{ni}^H, \varphi_L) - T_{ni}^H$$

From these two constraint it immediately follows that, in equilibrium, $q_{ni}^H > q_{ni}^L$ and $T_{ni}^H > T_{ni}^L$ (for proof, see Appendix A). In other words, by offering high quantity and high price to the high-productivity firm, and low quantity and low price to the low-productivity firm, the carrier achieves a complete sorting of the manufacturers by type.

Third, free disposal implies that in equilibrium it is never optimal for the carrier to offer any quantity $q_{ni}^j > q_{ni}^*(\varphi_j)$ to any of the firms j. To see this, suppose, by contradiction, in equilibrium, the carrier chooses $q_{ni}^H > q_{ni}^*(\varphi_H)$. Then, keeping q_{ni}^L, T_{ni}^L and T_{ni}^H the same, the carrier could reduce the quantity offered to the high-productivity firm to $q_{ni}^*(\varphi_H)$. This would not affect the IR constraint for the low-productivity firm. Due to free disposal, $\pi(q_{ni}^H, \varphi_H) = \pi(q_{ni}^*(\varphi_H), \varphi_H)$, and, hence, the IR and IC constraints for the high-productivity firm will also remain unaffected. Finally, the decrease in quantity offered to high-productivity firm will strictly relax the IC constraint for the low-productivity firm. Therefore, all constraints remain satisfied, but the monopolist's costs of shipping are strictly lower and profits are strictly higher than under the original contract. This contradicts the optimality of the initial contract, and means that, in equilibrium, $q_{ni}^H \leq q_{ni}^*(\varphi_H)$. The same logic applies to the low-productivity firm; hence, in equilibrium, $q_{ni}^L \leq q_{ni}^*(\varphi_L)$.

Returning to the carrier's problem, it can be shown (see Appendix A) that, given the concavity of the manufacturers' profit functions and the fact that the carrier wants prices to be as high as possible, the two out of four demand constraints stated above will be binding in equilibrium. Specifically, the low-productivity manufacturer will be charged his maximum willingness to pay, and the high-productivity manufacturer will be charged the price that makes him indifferent between purchasing his own contract and that of the low-productivity manufacturer. In other words, it is

IR_L and IC_H constraints that bind in equilibrium:

$$\pi(q_{ni}^L, \varphi_L) - T_{ni}^L = 0 \qquad (IR_L)$$
$$\pi(q_{ni}^H, \varphi_H) - T_{ni}^H = \pi(q_{ni}(\varphi_L), \varphi_H) - T_{ni}^L \qquad (IC_H)$$

Using these conditions in the carrier's profit function, we can re-write the carrier's problem on route ni as

$$\max_{q_{ni}^H, q_{ni}^L} \pi_{ni}^C = \alpha \left[\pi(q_{ni}^H, \varphi_H) - \pi(q_{ni}^L, \varphi_H) + \pi(q_{ni}^L, \varphi_L) - k_{ni} q_{ni}^H\right] + (1-\alpha)[\pi(q_{ni}^L, \varphi_L) - k_{ni} q_{ni}^L]$$

Next, I describe and analyze the optimal price-quantity schedule that arises from this profit maximization problem.

The Optimal price-quantity schedule for transportation services. The quantity of transportation services sold to the high-productivity exporter is determined from the following first-order condition:

$$\frac{\partial \pi(q_{ni}^H, \varphi_H)}{\partial q_{ni}^H} = k_{ni} \tag{5}$$

It means that, under the optimal price-quantity schedule, the high-productivity firm's marginal willingness to pay for transportation services is equal to the marginal costs of providing such services. In other words, in equilibrium, the high-productivity firm is offered an efficient quantity - the result known in industrial organization literature as *"no distortion at the top"*.

The quantity of transportation services sold to the low-productivity manufacturer, on the other hand, is distorted downwards relative to the efficient level. To see this, consider now the first-order condition with respect to q_{ni}^L:

$$\alpha \left[-\frac{\partial \pi(q_{ni}^L, \varphi_H)}{\partial q_{ni}^L} + \frac{\partial \pi(q_{ni}^L, \varphi_L)}{\partial q_{ni}^L}\right] + (1-\alpha)\left[\frac{\partial \pi(q_{ni}^L, \varphi_L)}{\partial q_{ni}^L} - k_{ni}\right] = 0$$

Rearranging the terms obtains

$$\frac{\partial \pi(q_{ni}^L, \varphi_L)}{\partial q_{ni}^L} = \alpha \frac{\partial \pi(q_{ni}^L, \varphi_H)}{\partial q_{ni}^L} + (1-\alpha) k_{ni} > k_{ni}, \tag{6}$$

where the last inequality follows from the monotonicity and single-crossing properties of the profit functions derived above. This inequality, in turn, suggests that quantity of services offered to the low-productivity firm is less than efficient. The extent of distortion depends on the probability of contracting with the high-productivity firm, α: the higher this probability, the larger is this distortion.

Intuitively, since high-productivity firms have higher willingness to pay for transportation services, the carrier would want to maximize his return from these high-demanders. The only problem is that high-productivity firms can "pretend" to be low-productivity firms and keep some surplus to themselves. To prevent them from doing so, the carrier has to distort the quantity offered to the low-productivity firms such that this option becomes unattractive to the high-productivity firms. Of course, it results in losing some profits from the low-productivity firms, but this loss is outweighed by gains from the high-productivity firms, more so, when there is relatively more high-productivity firms in the population. In the extreme case, when α is sufficiently large, the carrier might find it optimal not to serve the low-productivity manufacturer by offering $q^L_{ni} = 0$. [6]

What the analysis has revealed so far is that, in equilibrium, *(i)* quantity and total payment for transportation services increase in shipper's productivity, and *(ii)* the high-productivity firm is offered the efficient quantity, while the quantity offered to the low-productivity firm is distorted downwards. Notice that these two results are general and do not depend on any demand-side parameters. What remains to establish is how exactly the total freight payment depends on the quantity of transportation services purchased.

The answer to this question does depend on the shape of manufacturers' profit functions, which, in turn, depends on the specific form of consumer preferences. However, as Maskin and Riley (1984) show, the described contracts often lead to quantity discounts under fairly mild demand-side restrictions. Quantity discounts in transportation would imply that high-productivity firms pay lower *per unit* price for transportation: $T^H_{ni}/q^H_{ni} < T^L_{ni}/q^L_{ni}$. In the two-buyer-types case, quantity discounts arise in equilibrium as long as the following condition is satisfied:

$$\frac{\pi(q^{H^*}_{ni}, \varphi_H) - \pi(q^{L^*}_{ni}, \varphi_H)}{q^{H^*}_{ni} - q^{L^*}_{ni}} < \frac{\pi(q^{L^*}_{ni}, \varphi_L)}{q^{L^*}_{ni}},$$

where stars (*) denote the optimal quantity of transportation chosen by the carrier. In the limiting case when $\varphi_L \to \varphi_H = \varphi$ and, by monotonicity, $q^{L^*}_{ni} \to q^{H^*}_{ni} = q^*_{ni}$ this condition can be rewritten as

$$\frac{\partial \pi(q^*_{ni}, \varphi)}{\partial q^*_{ni}} q^*_{ni} < \pi(q^*_{ni}, \varphi) \quad \Leftrightarrow \quad k_{ni} q^*_{ni} < \pi(q^*_{ni}, \varphi)$$

In other words, the carrier offers quantity discounts in equilibrium if the *joint* profits of the vertically integrated firm is positive. If this condition is satisfied, then we have established that (*iii*) the high-productivity firm is offered quantity discounts in equilibrium, and thus is charged a lower per-unit mark-up. To understand the implications of results (*i*) - (*iii*) for consumer prices, we need to go back to the manufacturer's problem.

Consumer goods' prices. In equilibrium, the quantities of transportation services, $q^{H^*}_{ni}$ and $q^{L^*}_{ni}$, determine the supply of goods in country n produced by manufacturers in country i. The

[6] Formally, the threshold probability for α can be shown to be equal to

$$\hat{\alpha} \equiv \frac{p_{ni}(0) - w_i \tau_{ni}/\varphi_L - k_{ni}}{p_{ni}(0) - w_i \tau_{ni}/\varphi_H - k_{ni}},$$

which is strictly less than unity for all demand functions with $p_{ni}(0) < \infty$. Note that for the commonly used in international trade literature CES demand function, $p_{ni}(0) = \infty$, implying that the carrier will always serve both types of manufacturers (because $\hat{\alpha} = 1$).

consumer prices in n are then determined from the inverse demand function and the first order conditions in (5) and (6) as

$$\frac{\partial p(q_{ni}^H)}{\partial q_{ni}^H} q_{ni}^H + p(q_{ni}^H) - w_i \tau_{ni}/\varphi_H = k_{ni} \tag{7}$$

$$\frac{\partial p(q_{ni}^L)}{\partial q_{ni}^L} q_{ni}^L + p(q_{ni}^L) - w_i \tau_{ni}/\varphi_L = k_{ni} + \frac{\alpha}{1-\alpha} \left[w_i \tau_{ni}/\varphi_L - w_i \tau_{ni}/\varphi_H \right] \tag{8}$$

Notice that in a standard model of trade with exogenous "iceberg" (multiplicative) transport costs, the right-hand sides of both equations are equal to zero. In contrast, when transportation services are viewed as an input purchased by the manufacturers, the marginal prices for transportation services appear on the right-hand sides of (7) and (8). As a result, consumers are charged a multiplicative mark-up over the manufacturer's total marginal costs (inclusive of the marginal transport costs):

$$p_{ni}(\varphi_H) = \frac{\varepsilon_{ni}(\varphi_H)}{\varepsilon_{ni}(\varphi_H)+1} \left[\underbrace{\frac{w_i \tau_{ni}}{\varphi_H}}_{\text{production}} + \underbrace{k_{ni}}_{\text{transportation}} \right]$$

$$p_{ni}(\varphi_L) = \frac{\varepsilon_{ni}(\varphi_L)}{\varepsilon_{ni}(\varphi_L)+1} \left[\underbrace{\frac{w_i \tau_{ni}}{\varphi_L}}_{\text{manufacturing}} + \underbrace{k_{ni} + \frac{\alpha}{1-\alpha} \left(\frac{w_i \tau_{ni}}{\varphi_L} - \frac{w_i \tau_{ni}}{\varphi_H} \right)}_{\text{transportation}} \right],$$

where $\varepsilon_{ni}(\varphi_j) \equiv \frac{p_{ni}(q)}{p'_{ni}(q)q}|_{q=q^*_{ni}(\varphi_j)}$ denotes demand elasticity, which, in general case, can vary across and within the manufacturers depending on quantity demanded. However, even under constant demand elasticity (CES utility), producer (FOB) mark-ups will still vary across manufacturers in this model due to the additive transport costs. Apart from being additive, transport costs are also *heterogeneous* across manufacturers: since the carrier offers quantity discounts to larger shippers, larger manufacturers face lower marginal transport costs, which amplifies their initial (exogenous) cost advantage relative to the smaller manufacturers.

To make the model more comparable to the standard international trade models, I know extend it to feature a continuum of manufacturers purchasing transportation services from a single monopoly carrier to serve any destination.

3.2 A continuum of buyer types

Consider the same economy as above, except this time suppose there is a continuum of heterogeneous manufacturers with productivity $\varphi \in (0, +\infty)$, each choosing to produce a differentiated variety. The carrier still does not observe each firm's productivity, but knows the distribution of productivities, $G(\varphi)$. Since productivity unambiguously identifies a firm, in what follows I use

φ to denote firm productivity as well as to index its type. Using this notation, for each manufacturer φ, the monopoly carrier offers a contract that consists of the quantity of transportation services $q(\varphi)$ and total freight payment $T(q(\varphi))$. To account for the role of the economies of scale in transportation, this time I assume a more general cost function $K(Q)$, $Q = \int q(\varphi)g(\varphi)d\varphi$ for the carrier. Again, the goal is to find the optimal price-quantity schedule chosen by the carrier and to understand how it affects consumer prices of goods in any destination. When solving for the optimal price-quantity schedule in this seemingly more complicated environment, I follow the same steps as in a more simple two-buyers case, but leave the details for the Appendix.

The manufacturer's problem. Allowing for a continuum of firm types does not change firm's problem stated in (2), which now has the following important properties:

$$\frac{\partial \pi_{ni}(q_{ni}, \varphi)}{\partial q_{ni}} \geq 0, \quad \frac{\partial^2 \pi_{ni}(q_{ni}, \varphi)}{\partial q_{ni}^2} < 0, \quad \frac{\partial^2 \pi_{ni}(q_{ni}, \varphi)}{\partial q_{ni} \partial \varphi} \geq 0 \tag{9}$$

In words, firms' profits are increasing and concave in quantities, and the marginal profits are increasing in the firm type - its productivity.

Carrier's problem. Faced with a continuum of heterogeneous buyers, the monopolist carrier in country i operating on trade routes $n = 1, \ldots, N$ solves a version of the profit maximization problem in (4):

$$\max_{\varphi^*_{ni}, T_{ni}(\varphi), q_{ni}(\varphi)} \pi_i^C = \max_{\varphi^*_{ni}, T_{ni}(\varphi), q_{ni}(\varphi)} \sum_{n=1}^{N} \int_{\varphi^*_{ni}}^{+\infty} T(q_{ni}(\varphi)) g_{ni}(\varphi) d\varphi - K(Q_{ni})$$

As in the two-buyers case, the carrier faces a set of individual rationality (IR) and incentive compatibility (IC) constraints, which in this case can be expressed as follows:

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

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

Because consumer demands and firm costs are independent across destination, the carrier maximizes her profits subject to these constraints separately for each destination market. With this in mind, and for simplicity of the notation, in what follows I omit the trade route subscripts from the notation.

Using the fact that both (IC) constraints and (IR) constraint for the smallest buyers bind in equilibrium, I show in Appendix A that the carrier's problem on a given trade route can be expressed as

$$\max_{q, \varphi^*} \int_{\varphi^*}^{+\infty} \pi(q(\varphi), \varphi) g(\varphi) d\varphi - K(Q) - \int_{\varphi^*}^{+\infty} \frac{\partial \pi(q, \varphi)}{\partial \varphi} (1 - G(\varphi)) d\varphi, \tag{10}$$

where $Q = \int_{\varphi^*}^{+\infty} q(\varphi)g(\varphi)d\varphi$. The next proposition establishes the necessary conditions for the solution $\{\varphi^*, q(\varphi), T(\varphi)\}$.

Proposition 1. *If the manufacturer's profit function satisfies the conditions in (9), there exist a threshold productivity φ^* below which the manufacturers are not served by the carrier. For $\varphi \in [\varphi^*, +\infty]$, the functions $q(\varphi)$ and $T(\varphi)$ that solve the carrier's maximization problem in (10) satisfy the following conditions:*

$$\frac{\partial \pi(q, \varphi)}{\partial q} = K'(Q) + \frac{\partial^2 \pi(q, \varphi)}{\partial \varphi \partial q} \frac{1 - G(\varphi)}{g(\varphi)} \tag{11}$$

$$\frac{\partial T(q)}{\partial q} = \frac{\partial \pi(q, \varphi)}{\partial q} \tag{12}$$

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

$$\pi(q(\varphi^*), \varphi^*)g(\varphi^*) - K(Q(\varphi^*)) - (1 - G(\varphi^*)) \frac{\partial \pi(q(\varphi^*), \varphi^*)}{\partial \varphi} = 0 \tag{13}$$

Moreover, the smallest manufacturer φ^* served by the carrier on a route obtains zero net profits, ie. the boundary condition $\pi(q(\varphi^*), \varphi^*) = T(q(\varphi^*))$ is satisfied.

Condition (11) is simply the derivative of (10) with respect to quantity q, which determines the optimal quantity of services offered to the manufacture of type φ. This condition states that the marginal profit of each manufacturer is set equal to the carrier's marginal cost and a nonnegative distortion term that arises due to informational asymmetries in the market. Given this quantity, the total freight payment can be found from condition (12) and the boundary condition. Notice that conditions (11) and (12) together imply that marginal freight prices can vary across the manufacturers for two reasons: economies of scale in transportation, and variable mark-ups across shipments of different sizes. And finally, the exclusion restriction in (13) reflects the trade-off faced by the carrier between expanding the customer base and lowering the tariff, which leaves zero net profits to the smallest buyer, φ^*. Intuitively, when including less productive manufacturers with smaller willingness to pay, the carrier needs to add contracts with smaller payments and give out larger discounts to keep the large manufacturers' contracts incentive compatible. For a small enough manufacturer, φ^*, the accumulated discounts are too big to justify serving smaller shippers. Therefore, in this model, the selection of firms into exporting to any destination is driven by the profit maximizing decisions of the carrier instead of the exogenous fixed costs of exporting.

To see how, under some fairly mild condition, Proposition 1 implies quantity discounts in transportation as in a more simple two-buyers case, first use the definition of $\pi(q, \varphi)$ from (2) to re-write the condition in (11), again dropping the subscripts, as

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

If the inverse of the hazard rate function $1 - G(\varphi)/g(\varphi)$ is decreasing in φ[7], then larger, more productive manufacturers are offered shipping contracts with larger q. To see that the optimal contracts also imply a price-cost margin decreasing in the manufacturer type, φ, and hence q, use conditions (11) and (12) to write this margin as

$$\frac{\frac{\partial T(q)}{\partial q} - K'(Q)}{\frac{\partial T(q)}{\partial q}} = \frac{\frac{w\tau}{\varphi^2}\frac{1-G(\varphi)}{g(\varphi)}}{K'(Q) + \frac{w\tau}{\varphi^2}\frac{1-G(\varphi)}{g(\varphi)}}$$

This condition shows that as long as the carrier's marginal costs are constant or decreasing in total quantity shipped, then the carrier's mark-ups are decreasing in firm productivity.

Notice that the optimality of quantity discounts in transportation depends solely on the distribution of the firm productivities, and is independent of consumer preferences. However, obtaining the equilibrium relationship between total freight payment T and quantity shipped q functional form of the optimal price-quantity schedule, requires imposing more structure on both the demand and supply sides. In the next subsection, I assume CES consumer preferences and Pareto distribution of firm productivities to develop a test of the model against several alternative hypothesis of freight price determination.

Before doing that, I solve for the equilibrium consumer prices in a general case and discuss how they are affected by quantity discounts in transportation sector.

Consumer goods' prices. Since the carrier makes a take-it-or-leave-it offer to each firm, the offered quantity of transportation determines how many units a firm can sell in each destination. Consumer goods' prices are then determined from the demand in each destination as

$$p_{ni}(\varphi) = \frac{\varepsilon_{ni}(\varphi)}{\varepsilon_{ni}(\varphi)+1}\left(\underbrace{\frac{w_i\tau_{ni}}{\varphi}}_{\text{production cost}} + \underbrace{K'(Q_{ni}) + \frac{w_i\tau_{ni}}{\varphi^2}\frac{1-G_{ni}(\varphi)}{g_{ni}(\varphi)}}_{\text{transport cost}}\right), \tag{14}$$

where $\varepsilon_{ni}(\varphi) \equiv \frac{p'_{ni}q_{ni}(\varphi)}{p_{ni}(\varphi)}$ denotes the inverse demand elasticity. As in the two-buyers case, consumers are charged a price that is a mark-up over firm's total marginal costs, which consist of the marginal production and marginal transport costs. Being an additive cost component, transportation costs create a wedge between producer (free-on-board, FOB) and consumer (customs-insurance-freight, CIF) prices. This wedge differs across firms with different productivities due to the quantity discounts offered by freight carriers. The size of the quantity discounts, in turn, depends on how different the manufacturers are in terms of their productivity (or size), as reflected by the hazard rate. Therefore, the model suggests that the observed variation in consumer prices partly reflects heterogeneity in endogenous transport costs across exporters.

Overall, the proposed theoretical framework rationalizes the freight price variation across ship-

[7] The hazard rate function is increasing for a large class of distribution functions, including the uniform, the normal, the Pareto, the exponential, the logistic and any other distribution with nondecreasing density.

ments on a given trade route through the lens of nonlinear pricing by freight carriers. Its main testable prediction derived under very general demand- and supply- side assumptions is that transport costs are per-unit trade costs that are decreasing in the manufacturer's productivity and the shipment size. To gain further insights on the determinants of freight prices, in the next subsection I impose more structure on the model, in line with the standard Melitz-Chaney framework.

3.3 Freight Carrier Discounts in the Melitz-Chaney framework

Suppose that in the environment described above, a representative consumer in each country n has a CES utility over a continuum of differentiated goods with demand elasticity $\sigma > 1$, and firm productivities are drawn from the Pareto distribution with shape parameter, θ. In addition, for simplicity, assume that the carrier's cost function exhibits constant marginal cost k_{ni} on trade route between n and i.

Under these assumptions, Proposition 1 implies that $q_{ni}(\varphi)$, $T(q_{ni}(\varphi))$, and φ^*_{ni} are the solution to the carrier's profit maximization problem if the following conditions are satisfied:

$$\frac{\partial \pi(q_{ni}, \varphi)}{\partial q_{ni}} = k_{ni} + \frac{w_i \tau_{ni}}{\varphi \theta} \tag{15}$$

$$\frac{\partial T(q_{ni})}{\partial q_{ni}} = \frac{\partial \pi(q_{ni}, \varphi)}{\partial q_{ni}} \tag{16}$$

$$\left[A_n^{1/\sigma} q_{ni}(\varphi^*_{ni})^{-1/\sigma} - \frac{w_i \tau_{ni}}{\varphi^*_{ni}} - k_{ni} - \frac{w_i \tau_{ni}}{\varphi^*_{ni} \theta} \right] q_{ni}(\varphi^*_{ni}) = F \tag{17}$$

$$\pi(q_{ni}(\varphi^*_{ni})) = T(q_{ni}(\varphi^*_{ni})), \tag{18}$$

where $A_n \equiv Y_n P_n^{\sigma-1}$, and $Y_n \equiv w_n L_n$, $P_n \equiv \left(\sum_{i=1}^{N} \int_{\varphi^*_{ni}}^{\infty} p_{ni}^{1-\sigma}(\varphi) g_{ni}(\varphi) d\varphi \right)^{\frac{1}{1-\sigma}}$ are country n's income and the ideal consumer price index, respectively.

Conditions (15) and (16) lead to quantity discounts in transportation sector, whereby the biggest manufacturer ($\varphi \to +\infty$) is charged no mark-up by the carrier and all other manufacturers are charged a positive and decreasing in firm-productivity mark-up. The speed at which marginal freight prices decrease in firm size depends on the Pareto shape parameter θ that drives the dispersion of firm productivities in population. Higher θ implies that firms are more homogeneous (more output is concentrated among the smallest and least productive firms), which reduces the size of the discount that larger firms get relative to the smaller ones.

Condition (17) shows that the selection of firms into exporting in this model is not driven by the exogenous fixed costs of exporting, but rather is the result of the carrier's strategic behavior. This condition predicts that larger markets and markets with lower marginal shipping costs will have more entrants from a given country. Moreover, this condition demonstrates a trade-off between the size of the discount the carrier offers to the larger firms and the number of exporters on the route.

When the manufacturers are more homogeneous (θ is larger), the discounts are smaller, but there are more firms served by the carrier (φ^*_{ni} is smaller).

Now we can use the advantage of assuming the specific functional forms for the demand and distribution functions and explicitly solve for the equilibrium price-quantity schedule. Putting together the conditions in (15) - (18), it can be shown that it takes the following form

$$T(q_{ni}) = \frac{\theta}{\theta+1}F + \frac{1}{\theta+1}p(q_{ni})q_{ni} + \frac{\theta}{\theta+1}k_{ni}q_{ni} \tag{19}$$

In other words, incorporating a price discriminating monopolist carrier into a standard model of trade with CES utility and Pareto distribution of firm productivities results in total freight payments depending on both the (CIF) value of the shipment as well as its weight. In contrast, the commonly used iceberg trade cost assumption implies that total freight payment is exogenously proportional to the value of the shipment and is independent of the size of the shipment, conditional on its value.

Using the fact that CIF and FOB values are related through $p(q_{ni})q_{ni} = \tau_{ni}p^{fob}(q_{ni})q_{ni} + T(q_{ni})$, we can re-write equation (19) as

$$T(q_{ni}) = F + \frac{\tau_{ni}}{\theta}p^{fob}(q_{ni})q_{ni} + k_{ni}q_{ni} \tag{20}$$

Hence, re-writing freight payment for a given quantity in percentage changes relative to its value at the cut-off, $q_{ni}(\varphi^*) \equiv q^*_{ni}$, gives[8]:

$$\frac{T(q_{ni}) - T(q^*_{ni})}{T(q^*_{ni})} = \frac{\tau_{ni}}{\theta}\frac{p^{fob}(q^*_{ni})q^*_{ni}}{T(q^*_{ni})}\left[\frac{p^{fob}(q_{ni})q_{ni} - p^{fob}(q^*_{ni})q^*_{ni}}{p^{fob}(q^*_{ni})q^*_{ni}}\right] + \frac{kq^*_{ni}}{T(q^*_{ni})}\left[\frac{k_{ni}q_{ni} - k_{ni}q^*_{ni}}{k_{ni}q^*_{ni}}\right] \tag{21}$$

Approximating the percentage changes in square brackets with logarithms results in the following log-linear relationship:

$$\log T(q_{ni}) = \alpha_p \log p^{fob}(q_{ni})q_{ni} + \alpha_q \log q_{ni} \tag{22}$$

where $\alpha_p \equiv \frac{\tau_{ni}}{\theta}\frac{p^{fob*}q^*_{ni}}{T(q^*_{ni})}$ and $\alpha_q \equiv \frac{kq^*_{ni}}{T(q^*_{ni})}$ are the shares of value- and weight-related components of freight payments charged to the smallest exporter, respectively. The equilibrium relationship shows that these shares are simultaneously the conditional elasticities of freight payments with respect to value and weight, respectively, both positive but less than unity.

The equilibrium relationship in (22), derived within a trade model with endogenous transport costs and price discrimination, embeds in itself several alternative pricing schemes that could arise in transportation sector. Firstly, if carriers charge freight prices in direct proportion to the (FOB) price of a product shipped, then $\alpha_p = 1$ and $\alpha_q = 0$, as under "iceberg" trade cost assumption. On the other extreme, if freight prices are constant per-unit costs to the exporter, then $\alpha_p = 0$

[8] I thank Rob Feenstra for bringing this decomposition to my attention.

and $\alpha_q = 1$. If there are economies of scale in transportation, then these per-unit costs would vary across shipments, and $\alpha_q < 1$, while $\alpha_p = 1$. And finally, it is also possible that the carrier's costs, in general, depend on both shipments' value and its weight, reflecting, for example, that more expensive and heavier products require extra packaging or extra care during handling. In that case, it could be that $\alpha_p < 1$ and $\alpha_q < 1$, even in the most competitive market where carriers have absolutely no market power.

In the next section, I use these differential predictions of the two models to test the model of quantity discounting in transportation against these various alternative hypothesis. Besides showing empirically that freight payments depend on both value and weight of the shipments, I demonstrate that this dependence is not an artifact of the cost structure in transportation, but is an outcome of freight carriers exercising their market power. In Section 5 I study the effect of competition on freight prices to both understand the policy implications and to provide additional evidence of the fact that freight prices and their variation is an outcome of the carriers' market power. In order to do that, we first need to introduce competition among carriers in the model discussed above.

3.4 Oligopolistic Competition and Price discrimination

Here I extend the model described above by allowing for multiple freight carriers to compete on each trade route and show that, under certain conditions, quantity discounts are optimal in equilibrium with multiple carriers. Then, by comparing the predictions of this extended model with those obtained in a model featuring a monopolist carriers, I derive the theoretical predictions on the effect of competition on the level and distribution of freight prices. In the empirical part of the paper, I test these predictions using a plausibly exogenous variation in competition among carriers.

First, I illustrate the theoretical predictions on the effect of competition on freight prices in a simple two-buyers model described in Section 3.1. I incorporate competition in the model by allowing both manufacturers to have an outside option of purchasing transportation services elsewhere or producing them themselves.[9] Specifically, suppose that when rejecting the carrier's offer, manufacturer $j = \{L, H\}$ acquires transportation services from the alternative supply, which leaves manufacturer j with net profits of $\tilde{\pi}(\varphi_j)$. The existence of these alternative transportation services leaves the incentive compatibility constraints of either manufacturer unchanged, and only changes their individual rationality constraints that now reflect their outside options:

$$\pi(q_H, \varphi_H) - T_H \geq \tilde{\pi}(\varphi_H) \qquad (IR_H)$$

$$\pi(q_L, \varphi_L) - T_L \geq \tilde{\pi}(\varphi_L) \qquad (IR_L)$$

[9] See Boik and Takahashi (2018) for a more general treatment of competition in a model of nonlinear pricing, which yields similar predictions.

Hence, now the carrier maximizes (dropping the subscripts)

$$\max_{\{T_j,q_j\}_{H,L}} \quad \pi^C = \alpha\,(T_H - kq_H) + (1-\alpha)(T_L - kq_L)$$

subject to

$$\pi(q^H, \varphi_H) - T_H \geq \pi(q^L, \varphi_H) - T_L \qquad (IC_H)$$

$$\pi(q^L, \varphi_L) - T_L \geq \pi(q^H, \varphi_L) - T_H \qquad (IC_L)$$

$$\pi(q_H, \varphi_H) - T_H \geq \tilde{\pi}(\varphi_H) \qquad (IR_H)$$

$$\pi(q_L, \varphi_L) - T_L \geq \tilde{\pi}(\varphi_L) \qquad (IR_L)$$

Since the (IC) constraints remain unchanged, it is still true that it is sufficient that the (IC_H) constraint binds in equilibrium. Notice that if $\tilde{\pi}(\varphi_H) = \tilde{\pi}(\varphi_L) = \tilde{\pi}$, then, given the properties of the profit functions discussed above, it is also true that it is sufficient that only the (IR_L) constraint binds in equilibrium. In this case, using these two binding conditions in the carrier's profit maximization, we can re-write it as

$$\max_{q_H,q_L} \ \pi^C = \alpha\,(\pi(q_H,\varphi_H) - \pi(q_L,\varphi_H) + \pi(q_L,\varphi_L) - kq_H) + (1-\alpha)(\pi(q_L,\varphi_L) + \bar{\pi} - kq_L),$$

which only differs by an additive constant $(1-\alpha)\bar{\pi}$ from the simple model without outside options. Hence, this profit maximization problem yields the same optimal quantities, q_H^*, q_L^* as the simple model and freight payments shifted downward by the amount $\bar{\pi}$. It follows that if competition in transportation sector benefits all manufacturers equally through offering them equal reservation profits, then there will be a parallel shift of the price-quantity scheduling without it changing its slope.

Now suppose that $\tilde{\pi}(\varphi_H) \neq \tilde{\pi}(\varphi_L)$. In this case, $\pi(q_j, \varphi_j) - T_j - \bar{\pi}(\varphi_j)$ might not be increasing anymore, because $\pi'_\varphi(q_j, \varphi_j) - \bar{\pi}'(\varphi_j)$ can be negative. In fact, when $\bar{\pi}'(\varphi_j) < 0$ and smaller firms have better outside options in transportation, then it is again sufficient that only (IC_H) and (IR_L) constraints bind in equilibrium. This, in turn, means that even with heterogeneous outside options offered by the competitors, an incumbent carrier can find it optimal (when $\bar{\pi}'(\varphi_j) < 0$) to offer the monopoly quantities, $q_H^M = q_H^{JS}$ and $q_L^M < q_L^{JS}$[10], in exchange for the freight payments shifted downward by the amount of $\bar{\pi}(\varphi_L)$. In contrast, when $\bar{\pi}'(\varphi_j) > 0$, there are three cases to consider: (*i*) neither IC_L nor IC_H bind in equilibrium, (*ii*) only IC_H binds in equilibrium, and (*iii*) only IC_L binds in equilibrium. Which of these cases emerges in equilibrium depends on how different the outside options are across the manufacturers relative to the difference in their productivity, i.e. on the size of $\frac{\bar{\pi}(\varphi_H)-\bar{\pi}(\varphi_L)}{w\tau/\varphi_L - w\tau/\varphi_H}$.

Intuitively, the carrier's goal is to extract as much profits as possible from the largest manufacturers with high willingness to pay by creating the incentives for them to truthfully reveal

[10] Recall that JS denotes efficient allocations when the joint surplus of the buyer and the seller are maximized.

their type. When the outside options of the large manufacturers are no better or slightly better than those of the small manufacturers, the carrier needs to ensure that the large manufacturers have no incentives to choose the small manufacturers' contracts and that the small manufacturers are participating (only IC_H and IR_L bind). When the large manufacturers' outside options are improving relative to the small manufacturers', the carrier starts to worry about their participation too (both IR_L and IR_H are now binding on top of IC_H). By offering a reduction in the freight payment to the larger manufacturers, the carrier also has lower incentives to degrade the small manufacturers' quantity relative to the first best. At some point, the total freight payment charged to the large manufacturers is low enough that there is no reason to worry about them switching to the small firms' contracts at all (neither IC_H nor IC_L bind). It can be shown that in this case, the carrier offers efficient quantities to both manufacturer types. In the limit, the large manufacturers' outside options drive their prices down so much that their contracts become attractive to the small manufacturers, in which case the carrier needs to ensure that the IC_L constraint binds. When doing this, the carrier is forced to increase the quantity offered to the large manufacturers beyond the efficient level, and to keep the quantity offered to the small manufacturers precisely at the efficient level.

Notice that the above analysis suggests that if competition implies better outside options for the larger manufacturers, then it incentives the incumbent carrier to (weakly) increase the quantities of services offered to either manufacturer type, relative to the monopoly. The large manufacturers are only offered an increase in their quantity relative to the monopoly when competition offers them much higher outside options relative to the small firms. To understand how it affects the extent of quantity discounting in the market, it remains to investigate the effect of competition on the freight payments.

First, suppose that the carrier does not have incentives to offer more than the efficient quantity to the large manufacturers so that only the quantity offered to the small manufacturers are improved under competition relative to the monopoly. Figure 6 (left panel) shows graphically that competition cannot make the price-quantity schedule steeper. Intuitively, when there are relatively beneficial outside options available for the large manufacturers, the carrier has to reduce their per-ton prices, but recoups the loss in profits by increasing the per-ton prices charged to the smaller manufacturers. Now consider the case, when the carrier strictly increases both quantities when faced with competition: large manufacturers are offered quantity exceeding the efficient one, while small manufacturers are offered their efficient quantity. This case is illustrated in the right panel of Figure 6, which shows that competition flattens the price-quantity schedule in this case too. Hence, we have established that by flattening the price-quantity schedule competition increase the extent of quantity discounting in transportation sector.

In what follows, I extend the logic of this simple case to the more general scenario with a continuum of buyers, and show that the same result holds: in response to competition, the incumbent sellers are expected to reduce the prices charged to the larger buyers relatively more than those

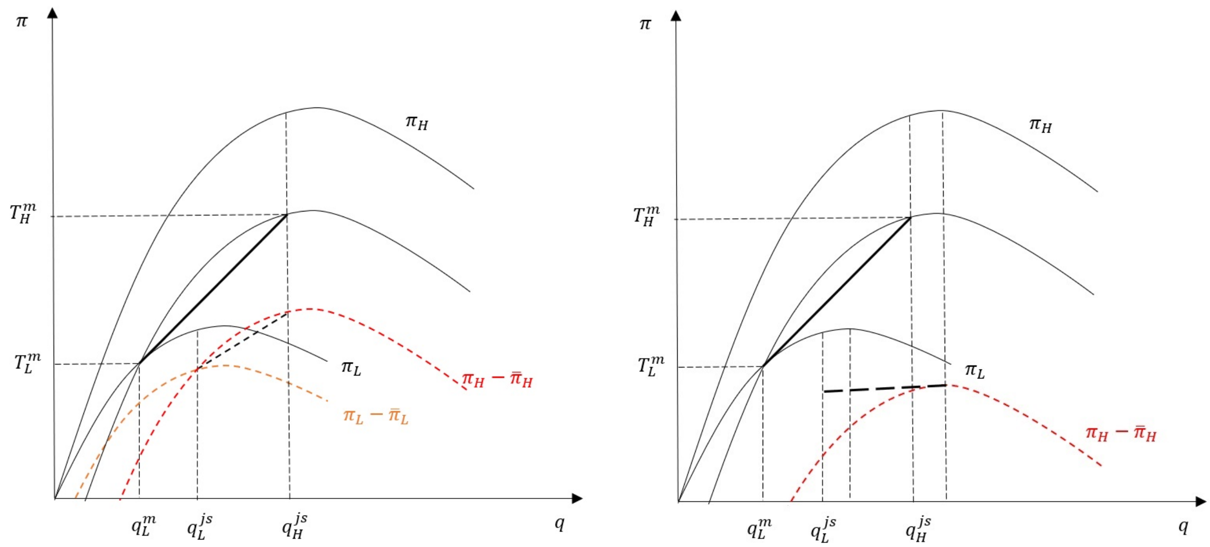


Figure 6: The effect of competition on the extent of quantity discounts

charged to the smaller ones, thus increasing the extent of quantity discounts.

Consider the environment described in Section 3.2, but now suppose that there are two or more identical carriers with the same cost functions operating between any two countries. These carriers compete in nonlinear price-quantity menus to exclusively serve any given manufacturer. The strategy of each carrier $j = 1, \ldots, J$ is to offer an incentive compatible menu $(q_j(\varphi), T_j(\varphi)$ for all manufacturers φ. The manufacturer φ's surplus from choosing to contract with carrier j is $\tilde{\pi}(q_j(\varphi), \varphi) = \pi(q_j(\varphi), \varphi) - T_j(\varphi)$. The manufacturer then decides which carrier to contract with. Formally, manufacturer φ chooses a vector $x(\varphi) = (x_1(\varphi), x_2(\varphi), \ldots, x_J(\varphi))$ of probabilities of contracting with, where $\sum_{j=1}^{J} x(\varphi)_j = 1$ and $x_j(\varphi) \geq 0$. Given a vector of manufacturer's surpluses associated with purchasing from any of the carriers, $\tilde{\pi}(\varphi) = (\tilde{\pi}_1(\varphi), \tilde{\pi}_2(\varphi), \ldots, \pi_J(\varphi)))$, the manufacturer's contracting decision satisfies:

$$x_j(\varphi, \tilde{\pi}(\varphi)) = \begin{cases} 0 & \text{if } \tilde{\pi}_j(\varphi) < \bar{\pi}_j(\varphi) = \max_{i \neq j} \pi_i(\varphi) \\ \geq 0 & \text{otherwise,} \end{cases}$$

where $\bar{\pi}_j(\varphi)$ is the highest surplus manufacturer φ could get an an outside option, when not purchasing from any other carrier on the market but carrier j.

Given the decisions of all manufacturing firms, $x = \{x_j(\varphi, \tilde{\pi}(\varphi)))\}_{j,\varphi}$, and the strategies of other carriers, $\tilde{\pi}_{-j} = \{\tilde{\pi}_i(\varphi)\}_{i \neq j, \varphi}$, carrier j chooses an incentive compatible menu $(q_j(\varphi), T_j(\varphi))$ for each manufacturer φ to maximize her profits expressed as:

$$\max_{\{q_j(\varphi), T_j(\varphi)\}_{\varphi}} \int_{\varphi^*}^{\infty} x_j(\varphi, \tilde{\pi}(\varphi)) T_j(\varphi) g(\varphi) d\varphi - K(Q_j) \tag{23}$$

subject to the following constraints:

$$\pi(q_j(\varphi),\varphi) - T_j(\varphi) \geq \pi(q_j(\varphi'),\varphi) - T_j(\varphi') \quad \forall\ \varphi,\varphi' \tag{IC}$$

$$x_j(\varphi,\tilde{\pi}(\varphi)) > 0 \quad \forall\ \varphi,\varphi', \tag{IR}$$

where $Q_j \equiv \int\limits_{\varphi^*}^{\infty} x_j(\varphi,\tilde{\pi}(\varphi))q_j(\varphi)g(\varphi)d\varphi$. Notice that the manufacturer's contracting decision implies that the (IR) constraints can be written as $\pi(q_j(\varphi),\varphi) - T_j(\varphi) \geq \bar{\pi}_j(\varphi)$, where $\bar{\pi}_j(\varphi)$ is exogenous for carrier j.

Attanasio and Pastorino (2015) show that in a symmetric case this problem can be reduced to a monopoly problem with type-dependent outside options extensively discussed in Jullien (2000). To see this, notice first that if all carriers are identical, then in equilibrium $\bar{\pi}_j(\varphi)$ is independent of j and can be written as $\bar{\pi}(\varphi)$. And secondly, if the competing carriers are identical, then the manufacturers contract with each of them with equal probability and, hence, $x_j(\varphi,\tilde{\pi}(\varphi)) = 1/J$. Using these two results in the oligopoly problem (23), it can be reduced to the following problem

$$\max_{\{q(\varphi),T(\varphi)\}_\varphi} \int_{\varphi^*}^{\infty} \frac{1}{J} T(\varphi)g(\varphi)d\varphi - K\left(Q\right) \tag{24}$$

subject to

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

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

where $Q \equiv \int\limits_{\varphi^*}^{\infty} q(\varphi)g(\varphi)/Jd\varphi$. The main difference between this problem and that discussed in Section 3.2 is that when negotiating a contract with a carriers, manufacturers now have a non-zero outside options in the form of the surplus offered to them by the alternative carriers on the route. The availability of these outside options is reflected in the (IR) constraints that state that the manufacturer's surplus from contracting with a given carrier should be no less than the surplus offered to that manufacturers by other carriers on the route. Notice that since other carriers are allowed to price discriminate across their buyers, the outside option $\bar{\pi}(\varphi)$ can vary across the manufacturers.

Using the local version of the (IC) constraints and denoting the multiplier on the (IR) constraint for manufacturer φ with $d\gamma(\varphi)$, we can express the problem in (24) is a Lagrangian form as

$$\max_{\{q(\varphi)\}} \int_{\varphi^*}^{\infty} \frac{1}{J}\pi(q(\varphi),\varphi)g(\varphi)d\varphi + \int_{\varphi^*}^{\infty} \frac{\partial\pi(q(\varphi),\varphi)}{\partial\varphi}\left(1 - \frac{1}{J} + \frac{G(\varphi)}{J} - \gamma(\varphi)\right)d\varphi - K(Q) \tag{25}$$

subject to the slackness condition

$$\int_{\varphi^*}^{\infty} (\pi(q(\varphi),\varphi) - T(\varphi) - \bar{\pi}(\varphi))\, d\gamma(\varphi) = 0,$$

where $q(\varphi)$ is a weakly increasing function, and $\gamma(\varphi) \equiv \int_{\varphi^*}^{\varphi} d\gamma(x)$ is the cumulative multiplier on the (*IR*) constraint for manufacturer φ. Attanasio and Pastorino (2015) show that this multiplier can be treated as a cumulative distribution function: it is nonnegative, nondecreasing, and equals to 1 at $\varphi \to \infty$. Notice that in a case of monopoly, reservation next profits are the same for all manufacturers and are equal to zero. In other words, the current problem collapses to the monopoly one discussed in Section 3.2 when $J = 1$ and $\bar{\pi}(\varphi) = 0\ \forall\varphi$, which means that the (*IR*) constraint binds only for the smallest manufacturer φ^* and $\gamma(\varphi) = 1\ \forall\varphi$.

The carrier's first order conditions associated with problem (25) characterize the optimal choice of $T(\varphi)$ and $q(\varphi)$:

$$\frac{\partial\pi(q(\varphi),\varphi)}{\partial q} = K'(Q) + \frac{1 - G(\varphi) - J(1-\gamma(\varphi))}{g(\varphi)} \frac{\partial^2\pi(q(\varphi),\varphi)}{\partial\varphi\partial q} \tag{26}$$

$$\int_{\varphi^*}^{\infty} (\pi(q(\varphi),\varphi) - T(\varphi) - \bar{\pi}(\varphi))\, d\gamma(\varphi) = 0$$

Adapting the argument of Jullien (2000), I show in the Appendix that these conditions represent a unique optimal solution to the carrier's problem in which all manufacturers are served if the following assumptions are satisfied:

(*i*) *Potential separation:* Quantity $q^*(\varphi,\gamma)$ that solves 26 is a weakly increasing function of φ for all $\gamma \in [0,1]$, the sufficient conditions for which are: $\frac{\partial}{\partial\varphi}\left(\frac{G(\varphi)}{g(\varphi)}\right) \geq 0 \geq \frac{\partial}{\partial\varphi}\left(\frac{1-G(\varphi)}{g(\varphi)}\right)$.

(*ii*) *Homogeneity:* All carriers offer locally compatible menus, i.e. $\frac{\partial\bar{\pi}(\varphi)}{\partial\varphi} = \frac{\partial\pi(\bar{q}(\varphi),\varphi)}{\partial\varphi}$ and $\bar{q}(\varphi)$ is weakly increasing in φ.

(*iii*) *Full participation:* Each carrier can make nonnegative profits by supplying the reservation quantity $\bar{q}(\varphi)$ in exchange for the payment $\bar{T}(\varphi)\ \forall\varphi$, which leaves manufacturer φ t with reservation net profits $\bar{\pi}(\varphi)$.

Proposition 2. *Under the assumptions of potential separation, homogeneity, and full participation, there exist a unique optimal price-quantity schedule that ensures full participation. A price-quantity schedule* $\{T(\varphi), q(\varphi)\}_{\varphi}$ *is optimal if and only if it satisfies the following conditions:*

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

$$\int_{\varphi^*}^{\infty} \left(\pi(q(\varphi),\varphi) - T(\varphi) - \bar{\pi}(\varphi)\right) d\gamma(\varphi) = 0$$

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

$$\pi(q(\varphi^*),\varphi^*) = T(q(\varphi^*))$$

Moreover, the optimal total freight payment schedule exhibits quantity discounts, i.e. $T''(q) = T''(\varphi(q)) < 0$*.*

This proposition thus implies that, when faced with a number of competitors, under certain mild conditions carriers' offer larger quantities of transportation services to larger manufacturers at a lower per-unit price. To understand how competition affects the size of the discounts, compare the first-order conditions of the carrier in case of monopoly (Section 3.2) and that in case of oligopoly (26). First, notice that for the largest manufacturer ($\varphi \to +\infty$), $\gamma(\varphi) = 1$, which leads to the same (efficient) quantity offered to the largest manufacturer in either case. For all other firms, however, $\varphi < +\infty$ and $\gamma(\varphi) < 1$, which means that under oligopoly, the right-hand side of (26) for these manufacturers is smaller than under monopoly, and more so when the number of carriers, J in transportation industry goes up. It means that competition reduces the marginal prices and increases the quantity of transportation services offered to all by the largest manufacturer. Next proposition states that larger manufacturers experience a larger marginal price reduction as a result of competition, meaning that competition increases the degree of quantity discounting in the market.

This proposition implies that the optimal quantity $q(\varphi)$ is increasing in the manufacturer productivity φ, the optimal freight payment can be expressed as a function of quantity: $T(\varphi) = \tilde{T}(\varphi(q)))$. Then to establish the optimality of quantity discounts in equilibrium, it remains to show that the freight payment schedule is concave in q, i.e. $T''(q) < 0$. The next proposition states the conditions under which this is true.

Proposition 3. *Under the assumptions of potential separation, homogeneity, and full participation, if* $\frac{\partial}{\partial \varphi} \frac{G(\varphi)}{g(\varphi)} \frac{g(\varphi))}{G(\varphi)} \geq 1$*, and the reservation net profit functions are convex enough, then* $T''(q) \leq 0 \;\forall q$ *and, hence, there are quantity discounts in oligopolistic transportation sector.*

The proposed theoretical framework of price discrimination in international transportation industry thus generates several predictions with respect to the determinants of freight prices. Firstly, it suggests that per-ton freight prices descrease in the shipment size for two reasons: economies of scale realized by the carrier and passed onto the exporters, and price discrimination in the form of lower mark-ups charged for transportation of larger quantities. Secondly, the extended version of the model predicts that in response to an increase in competition, freight carriers reduce their average mark-ups by offering even larger discounts to larger shippers. Now I proceed by taking these prediction to the firm-level data on freight prices uniquely available in Paraguay customs dataset.

4 Empirical Evidence of Price Discrimination in International Transportation

4.1 Identification

In this section, I develop a strategy to empirically test the predictions of the model derived in the previous section, and contrast them with other potential pricing schemes in transportation industry.[11] Recall that, in its most general form, under very general consumer preferences and distributions of firm productivities, the model predicts that the freight payment schedule, $T(q)$, is an increasing and concave function of the shipment's size, q. The exact functional form of this schedule, however, depends on the specific type of consumer preferences and a distribution of firm productivities. In this section, I choose to work with the CES consumer preferences and a Pareto distribution of productivities, for two reasons: (*i*) they are most commonly used in international trade literature, and (*ii*) conveniently, they result in the explicit log-linear specification of the freight payment function, as shown in equation (22).

In this section, I discuss the identification of the shape of the freight payment schedule, when the pairs of payments and quantities $(T(\varphi), q(\varphi)), \varphi \in [\varphi^*, +\infty)$ are observed, and the payment schedue $T(q)$ itself is unknown. Under CES consumer preferences and a Pareto distribution of buyer productivities, the nonlinear pricing model developed in the previous section implies that the observed payments and quantities of transportation services lie on the curve $t = T(q)$ defined as (dropping the country subscripts):

$$\log T(q) = \alpha_p \log p^{fob}(q)q + \alpha_q \log q$$

Notice that this relationship between T and q is due to the fact that both the payments and the quantities depend on the buyer productivity ("type"), which is the ony unobserved random term in the model of Section 3. In reality, however, the observed prices and quantities may not lie on a curve for several reasons: for instance, we may not observe perfectly the payment or quantities purchased (measurement error), or the transportation services can be horizontally and/or vertically differentiated in more than one dimension. This reasoning calls for an additional source of randomness in equation (22), which I will denote with ϵ. Then the model-based empirical specification to estimate becomes:

$$\log T_{eicd} = \alpha_p \log pq_{eicd} + \alpha_q \log q_{eicd} + \epsilon_{eicd}, \tag{27}$$

[11] See Luo et al. (2018) for the discussion of structural estimation of the model's parameters.

where e, i, c, d denote exporter, importer, carrier, and time, respectively, T_{eicd} is freight payment at the shipment (identified with Bill of lading in the data) level, pq_{eicd} and q_{eicd} are its FOB value and quantity, respectively. If $E[\epsilon \| q, pq] = 0$, then the coefficients α_p and α_q are unbiased and consistent estimators of the conditional elasticities of the freight payment schedule with respect to shipment's value and weight, respectively. The model of price discrimination in transportation suggests that $0 < \alpha_q < 1$, irrespective of any specific demand or supply-side assumptions, while its Melitz-Chaney version additional implies that $0 < \alpha_p < 1$ too. However, the violation of the assumption that $E[\epsilon \| q, pq] = 0$ would result in biased estimated of these coefficients. Below I outline all potential threats to identification associated with $E[\epsilon \| q, pq] \neq 0$, and discuss how I address them using the richness of my data set.

Firstly, ϵ_{eicd} can contain carrier-time-specific cost shocks to the carrier's productivity. Positive shocks to the carrier's marginal costs increase the price charged by the carrier and reduce the demand for the carrier's services, leading to a downward bias in the OLS estimate of α_q. Analogously, if there are economies of scale at the carrier-time level, it will also bias the estimate of α_q downwards. To account for these sources of bias in the estimates, I include a set of manifest-country fixed effects as control variables in my baseline specification in (27). As I discussed earlier, a manifest identifies the carrier, exact distance traveled, time of the travel, as well as transport vehicle used by the carrier on the last leg of travel. Since the last leg of travel is likely to be the only leg of travel only for shipments coming from land-neighboring countries, I interact manifest with country of purchase to absorb the average costs of transportation from long-distant trade partners.

Secondly, ϵ_{eicd} can reflect unobserved heterogeneity of transportation services offered by the same carrier to different shippers. The manifest-country fixed effects absorb most variation in quality of services, related to the timeliness/speed of delievery, and the general regime of transportation (ie. refrigeration), because all shipments listed on the same cargo manifest were transported on the same vehicle at the same time following the exact same route. However, shipments on the same vehicle can require different handling or different packaging, which would result in different freight payments for reasons unrelated to price discrimination. To account for the differences in packaging across shipments, I use the gross weight that includes the weight of the packaging itself rather than the net weight as a measure of shipment size. Since demand for special packaging and handling mainly depends on the characteristics of products being shipped, I include product fixed effects in my baseline specification to absorb any potential variation in the costs of packaging and handling across shipments. I experiment with three different definitions of the product: 2-digit, 4-digit, 6-digit HS codes. Defining product at a more disaggregated level allows to better control for quality of transportation services, but substantially reduces the sample size. This is because I carry the analysis at the shipment level (identified by the Bill of Lading), and most shipments include multiple different products at most levels of product definition.

Thirdly, ϵ_{eicd} can be capturing unobserved shipper (importer or exporter) heterogeneity correlated with the shipment's size. For example, bigger exporters or importers can use their size to negotiate better prices of transportation for themselves or firms that have established long-term relationship with the carrier can obtain discounts. If bigger exporters/importers and long-term partners also tend to ship larger shipments, omitting firm characteristics from (22) will introduce a downward bias in the estimate of α_q. I use several strategies in attempt to correct for this bias: first, I add the total weight shipped by an exporter/importer with a given carrier or other carriers within a year in specification (22); and second, I include a set of exporter or importer fixed effects in the baseline specification. Controlling for the overall exporter/importer size eliminates the bias caused mainly by differential pricing across small/large shippers (third-degree price discrimination), while exporter/importer fixed effects additionally absorb any differences in other firm characteristics that could cause prices to vary across exporters/importers.

Finally, ϵ_{eicd} can include a non-classical measurement error, which, when correlated with the shipment size or value, will result in biased estimators of α_p and/or α_q. To show that my results are not driven by the measurement error, I use a monthly average exchange rate faced by the exporters from a given country with their suppliers as an instrument for the shipment's size. Besides identifying the country of purchase for each shipment, the data also records the country of origin of each product in the shipment, which in about 25% of case differs from the country of purchase. An appreciation of currency of the country of origin relative to the country of purchase implies a plausibly exogenous negative shock to an exporter in a given country of purchase. Thus, exporters facing an appreciation of the currency of their suppliers receive a negative cost shock to their productivity and are expected to ship smaller shipments to Paraguay and pay higher per-unit prices fo transportation services. I show that this instrumental variables identification strategy yields the results similar to those obtained when controlling for the product types within manifests.

To summarize this discussion of my empirical strategy, in the next section I will estimate the following specification:

$$\log T_{eicd} = \alpha_p \log pq_{eicd} + \alpha_q \log q_{eicd} + \Gamma X_{eicd} + \epsilon_{eicd}, \tag{28}$$

where, to ensure unbiased estimates of α_p and α_q, vector X_{eicd} introduces the following control variables:

(a) f_{cdn}: manifest-country fixed effects.

(b) *HS2 code, HS4 code, Manifest-Country-HS2 code, Manifets-Country-HS4 code*: product-type fixed effects (defined as a 2- and 4- digit code in HS classification), and their interactions with the Manifest-Country fixed effects.

(c) $\log TripWeight$: total gross weight of all shipments transported by the carrier at the same time on board of the same vehicle following the same route.

(d) $\log ExporterCarrierWeight$, $\log ImporterCarrierWeight$: annual gross weight transported by a given exporter/importer with a given carrier.

(e) $\log ExporterWeight$, $\log ImporterWeight$: annual gross weight exported/imported by a given exporter/importer with all other carriers.

In the next section, I present the results of estimating equation (28) and argue that they are evidence of *(i)* economies of scale in transportation, *(ii)* buyer size effect, and *(iii)* second-degree price discrimination in the form of quantity discounts.

4.2 Price discrimination of Freight Carriers

In this subsection, I show that per-ton freight prices decrease with the shipment size and the overall exporter and importer size, due to both economies of scale and price discrimination by freight carriers.

In Table 6 I measure shipment size with its gross weight (inclusive of the packaging) and estimate equation (22) using the within manifest-country variation in payments for transportation and shipment sizes. When estimating the relationship between shipment size and payment for transportation, I allow for this relationship to be different in two different subsamples: Paraguay's land neighbors (Argentina, Brazil, and Bolivia) and trade partners that do not share a border with Paraguay. The estimates could vary across these sub-samples because manifests identify shipments that traveled together only on the last leg of travel, while shipments from non-contiguous countries are likely to have more than one leg of travel and, hence, more than one carrier following potentially very different travel routes. In contrast, shipments from contiguous countries are likely to have only one leg of travel, which means that for these subsample, shipments listed on the same manifest share the carrier, transport vehicle, as well as pick-up and drop-off locations.

In columns (1) - (4), I experiment with different definitions of product types included in the shipment as controls for the quality of transportation services. In columns (1) and (2) the relationship between total freight payment and shipment's size is estimated in the subsamples of shipments with only one HS 2-digit and HS 4-digit products, respectively. The estimates suggest that, within a given country-manifest, a one percent increase in shipments gross weight, increases the payment for its transportation by only 0.42-0.43 percent. This less than proportional increase in payment implies that the per-ton freight prices decrease in the shipment size. In columns (3) and (4), I interact manifest-country fixed effects with the HS 2- and HS 4-digit fixed effects to capture any variation in handling and packaging costs across shipments within country-manifest. The same qualitative pattern holds even at this, very granular, level: a one percent increase in the shipment size is associated with a 0.49 - 0.56 percent increase in the total freight payment, which, again, means that per-ton freight prices are lower for larger shipments.

To account for any other sources of simultaneity bias that cannot be controlled for with product types, in column (5) I implement the instrumental variable approach to estimate equation (22). The instrumental variable - the average monthly exchange rate between the currency of the exporter's country and that of his suppliers in countries of origin of his products - is a strong predictor of the shipment size, and is likely to affect the freight prices only through the shipment size. This identification strategy results in a similar estimates of the coefficient on weight as those obtained using OLS and controls for product types. It means that for the causal interpretation of the

Table 6: The relationship between freight and weight with controls for quality of services

Dependent Variable:	$\log Freight$				
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	OLS	OLS	IV
$\log GrossWeight$	0.423***	0.436***	0.487***	0.562***	0.520***
	(0.010)	(0.011)	(0.027)	(0.050)	(0.090)
$\log GrossWeight \times Nonborder$	0.102***	0.091***	0.009	0.052	
	(0.012)	(0.012)	(0.029)	(0.053)	
Constant	3.526***	3.490***	3.501***	2.713***	
	(0.040)	(0.044)	(0.077)	(0.173)	
Manifest-Country	Y	Y	N	N	Y
HS2 code	Y	N	N	N	N
HS4 code	N	Y	N	N	N
Manifest-Country-HS2 code	N	Y	N	N	N
Manifest-Country-HS4 code	N	N	N	Y	N
N obs	119677	97837	32673	12828	47672
N of clusters	25482	21874	10596	5086	12856
R2	0.851	0.868	0.899	0.925	0.507
Cragg-Donald Wald F					90.87
Kleibergen-Paap rk Wald F					16.38

Robust standard errors clustered at exporter level in parentheses.

Data at the Bill of Lading (shipment) level.

Nonborder equals 1 for shipments from countryies other than Argentina, Brazil and Bolivia, and 0 otherwise.

IV: average monthly exchange rate faced by exporter from a given country with its suppliers in other countries.

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

relationship between shipment's size and freight payments, it is enough to control for the product type. Therefore, to avoid the substantial reduction in the sample size and, in what follows, I will use HS 2- or HS 4-digit codes as controls for quality of transportation services.

Notice that the negative relationship between total freight payment and shipment size in Table 6 is estimated using variation across shipments listed on the same manifest and coming from the same country (within manifest-country). Hence, this relationship cannot be driven by the economies of scale at the trip (manifest) level. Yet, the same relationship would arise if there were cost economies at the shipment level, and the carrier had lower marginal costs when transporting a heavier shipment. In that case, however, the carrier's pricing would solely depend on the shipment's absolute size (weight) and not on its size relative to the overall capacity of a given trip. This is in contrast to the second-degree price discrimination mechanisms that suggests that the carrier prices her services based on the shipments' relative size. To explore the role of the economies of scale at the shipment level, in Table 7, I estimate a version of equation (28) with controls for the weight transported on a given manifest and its interaction with the shipment's weight. In column (1), the negative sign of the coefficient on $\log TripWeight$ suggests that conditional on the shipment's size, shipments transported as a part of a larger vessel or truck get an additional discount. This result is the evidence of the economies of scale at the trip level. In column (2), however, the positive sign on the interaction of the total weight of a given trip and the shipment size means that carriers do not price shipments based on their absolute weight. In fact, the estimates imply that when a shipment of a given size is a part of the larger manifest, its relative size becomes smaller, and the price for transportation services increases. Columns (3) - (6) show that this result holds in all segments of transportation and after including product type fixed effects to account for the differences in the quality of transportation services. The economies of scale cannot explain the importance of the shipment's *relative* size for the price charged for its transportation, even if carriers' costs decrease in its *absolute* size, but it can be explained by second-degree price discrimination by freight carriers. Therefore, I argue that the negative relationship between per-ton freight prices and shipment's size within manifests is not entirely driven by cost economies, but, at least partially, is due to the freight carriers charging smaller mark-ups when transporting larger shipments. Now the question is what causes this variation in mark-ups across shipments: is it an outcome of larger exporters getting better prices or larger shipments obtaining better prices, conditional on the exporter size?

To answer this question, in Table 8, I study the relationship between the per-ton freight prices and various measures of shipper sizes. Columns (1) and (2) show that, conditional on the shipment size, exporters and importers that ship more with a given carrier in a given year get better prices. This result is expected if, for example, either an exporter or an importer has a long-term contract with a given carrier, and because of this are charged a lower per-ton freight prices. Notice, however, that exporters and importers with larger annual shipping volume with a given carrier, receive smaller discounts when shipping larger shipments, as suggested by the positive coefficient on the interaction term between shipment size and the total relationship-specific weight. In columns (3) and (4), I measure the exporter and importer size with the total annual weight shipped by a firm with other carriers, and find that it is also negatively associated with the per-ton freight prices charged for the shipment of a given size. Viewing this measure as a proxy for the overall firm-size, this result suggests that larger buyers of transportation services get better per-ton prices, conditional on the quality of the services. Yet, accounting for the overall firm-size effect on prices does not eliminate the existence of quantity discounts at the shipment level. In column (5), I include both exporter and importer fixed effects and still find that a one percent increase in the shipment size increases the total freight payment less than proportionately, by 0.6 percent.

Overall, the estimates in Tables 7 and 8 show that the observed variation in per-ton freight prices across shipments imported to Paraguay by the same carrier, on the same vehicle following the same route at the same time cannot be fully attributed to cost economies and is at least partially driven by the mark-up variation. There is evidence that this mark-up variation arises because of the existence of long-term contracts between buyers and sellers of transportation services, better bargaining position of the larger buyers and quantity discounts offered to larger shipments. Yet, a

Table 7: The relationship between freight and weight with controls for marginal costs

Dependent Variable:	$\log Freight$					
	(1)	(2)	(3)	(4)	(5)	(6)
	All modes	All modes	All modes	Road	River	Air
$\log GrossWeight$	0.438***	0.440***	0.477***	0.460***	0.630***	0.653***
	(0.007)	(0.008)	(0.010)	(0.011)	(0.070)	(0.020)
$\log GrossWeight \times Nonborder$	0.182***	0.200***	0.133***	0.041**	-0.012	0.076***
	(0.008)	(0.009)	(0.012)	(0.018)	(0.070)	(0.016)
$\log TripWeight$	-0.077***					
	(0.006)					
$\log GrossWeight \times \log TripWeight$	0.015***	0.027***	0.033***	0.019**	0.036***	0.057***
	(0.001)	(0.002)	(0.002)	(0.008)	(0.004)	(0.003)
Constant	4.035***	3.367***	3.339***	3.187***	1.744***	4.005***
	(0.059)	(0.030)	(0.039)	(0.081)	(0.091)	(0.029)
Country-Carrier-Month	Y	N	N	N	N	N
Country-Manifest	N	Y	Y	Y	Y	Y
HS2 code	N	N	Y	Y	Y	Y
N obs	256890	218595	119677	56742	13947	28542
N of clusters	44850	38798	25482	11881	5622	8202
R2	0.782	0.833	0.854	0.776	0.867	0.853

Robust standard errors clustered at exporter level in parentheses.
Data at the Bill of Lading (shipment) level.
Nonborder equals 1 for shipments from countries other than Argentina, Brazil and Bolivia, and 0 otherwise.
TripWeight is total gross weight transported by the carrier at a time
* p<0.10, ** p<0.05, *** p<0.01

large shipment size results in a sizable discount even within exporter-carrier (or importer-carrier) pair. This is consistent with the main prediction of the model described in Section 3. The special case of this model (with CES preferences and a Pareto distribution of firm productivities), however, suggests that, in equilibrium, freight payments are a function of both shipment's size and its value. In contrast to the popular "iceberg" assumption, the model of price discrimination, predicts the elasticity less than unity with respect to both value and quantity.

In Table 9, I test for this prediction by adding shipment's value as a control variable together with shipment size as well as the proxies for exporter- and importer- sizes. The first column suggests that, when studying freight variation across similarly valued shipments, larger shipments get an even larger discount. Conditional on the shipment's (FOB) value, a one percent increase, its gross weight increases the freight payment by only 0.3 percent, which implies an increase in the size of the discount relative to that reported in Table 6. Notice that, consistently with the model's prediction, the elasticity of freight payment with respect to value is positive but less than unity. In column (2), I show that both elasticities remain to be less than one, when I estimate them using two instrumental variable: the average monthly exchange rate with the exporters' suppliers and

Table 8: Quantity discounts vs. exporter/importer size effect in transportation

Dependent Variable:			$\log Freight$		
	(1)	(2)	(3)	(4)	(5)
$\log GrossWeight$	0.346***	0.305***	0.407***	0.375***	0.598***
	(0.017)	(0.017)	(0.024)	(0.028)	(0.044)
$\log GrossWeight \times Nonborder$	0.150***	0.165***	0.084**	0.077**	-0.001
	(0.022)	(0.020)	(0.034)	(0.036)	(0.045)
$\log ExporterCarrierWeight$	-0.105***	-0.053***			
	(0.014)	(0.015)			
$\log GrossWeight \times \log ExporterCarrierWeight$	0.014***	0.005***			
	(0.001)	(0.002)			
$\log ImporterCarrierWeight$		-0.076***			
		(0.010)			
$\log GrossWeight \times \log ImporterCarrierWeight$		0.012***			
		(0.002)			
$\log ExporterWeight$			-0.068***	-0.057***	
			(0.014)	(0.011)	
$\log GrossWeight \times \log ExporterWeight$			0.010***	0.008***	
			(0.002)	(0.002)	
$\log ImporterWeight$				-0.022*	
				(0.012)	
$\log GrossWeight \times \log ImporterWeight$				0.005***	
				(0.002)	
Constant	3.844***	4.063***	3.662***	3.782***	2.592***
	(0.057)	(0.063)	(0.102)	(0.140)	(0.185)
Country-Manifest	Y	Y	Y	Y	Y
Exporter	N	N	N	N	Y
Importer	N	N	N	N	Y
N obs	361647	361647	268072	245535	333254
N of clusters	40991	40991	17210	16387	21054
R2	0.864	0.865	0.876	0.879	0.916

Robust standard errors clustered at exporter level in parentheses.

Data at the Bill of Lading (shipment) level.

Nonborder equals 1 for shipments from countries other than Argentina, Brazil and Bolivia, and 0 otherwise.

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

the average value of other shipments containing similar products. Columns (3) - (6) demonstrate that the negative overall exporter/importer- size effect on per-ton freight prices also holds after controlling for the shipment's value.

Table 9: The relationship between transportation price and shipment size, with controls for value

Dependent Variable:	$\log Freight$					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	OLS	OLS	OLS	OLS
$\log GrossWeight$	0.317***	0.410***	0.321***	0.380***	0.355***	0.342***
	(0.015)	(0.048)	(0.018)	(0.018)	(0.022)	(0.022)
$\log GrossWeight \times Nonborder$	0.158***		0.082***	0.112***	0.052**	0.073***
	(0.018)		(0.019)	(0.018)	(0.024)	(0.025)
$\log FOBValue$	0.292***	0.180***	0.307***	0.290***	0.295***	0.320***
	(0.019)	(0.073)	(0.012)	(0.012)	(0.014)	(0.017)
$\log FOBValue \times Nonborder$	-0.106***		-0.092***	-0.084***	-0.093***	-0.110***
	(0.020)		(0.015)	(0.014)	(0.017)	(0.019)
$\log TripWeight \times \log GrossWeight$				0.033***		
				(0.002)		
$\log ExporterWeight$					-0.015***	
					(0.005)	
$\log ImporterWeight$					0.005	
					(0.003)	
Constant	1.801***		1.784***	1.587***	1.897***	1.601***
	(0.137)		(0.107)	(0.100)	(0.136)	(0.088)
Country-Manifest	Y	Y	Y	Y	Y	Y
HS2 code	N	N	Y	Y	Y	Y
Exporter, Importer	N	N	N	N	N	Y
N obs	361647	45520	228463	228463	158954	208910
N of clusters	40991	12213	27716	27716	13399	15088
R2	0.873	0.556	0.897	0.899	0.912	0.943
Kleibergen-Paap rk Wald F		7.69				
Cragg-Donald Wald F		32.34				

Standard errors in parentheses

Robust standard errors clustered at exporter level in parentheses.

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

5 An Implication: The effect of competition on freight prices

In this section, I investigate empirically how competition in transportation industry affects the average freight prices and freight prices charged for shipments of different sizes. Recall that the model developed in Section 3 and extended to feature competition among freight carriers predicts that entry into the sector incentives the incumbent carrier to offer larger discounts to exporters transporting larger shipments. Notice that this prediction is specific to the environments, in which freight carriers have the power to set different mark-ups to different exporters, conditional on any cost economies associated with larger shipments. In contrast, if the entirety of the documented quantity discounts is purely driven by economies of scale, then we do not expect competition in the market to change the size of the discounts in anyway. Therefore, establishing whether competition has an effect of freight prices offers yet another test of the role of price discrimination as opposed to cost differences in explaining the observed freight price variation.

To test the model's predictions with respect to competition as a determinant of freight prices and a cause of their variation, I first formulate my empirical strategy and discuss my approach to the endogeneity of entry and freight prices.

5.1 Empirical Specification

Assuming a log-linear representation, the main prediction of the model with respect to competition can be formulated by extending the empirical model of Section 4.1 as:

$$\log T_{fcy} = \beta_0 + \gamma \log Q_{cy} + \rho \log \nu_{fcy} + \beta_1 \log q_{fcy} + \beta_2 \log N_y + \beta_3 \log q_{fcy} \times \log N_y + \log k_{cy} + \epsilon_{fcy}, \tag{29}$$

where $\log N_y$ denotes the number of carriers on the market at period y,[12] and the rest of the notation is the same as before.

From the analysis of quantity discounts in the previous section, we expect β_1 to be positive and less than unity, and focus on establishing the sign of the coefficients β_2 and β_3. Specifically, through competition, an increase in the number of carriers is expected to reduce the average freight prices ($\beta_2 < 0$). The sign of the coefficient on the interaction term, β_3, will help distinguishing between competitive and non-competitive pricing. In a perfectly competitive market, the per-ton prices should not depend on the number of carriers, in which case, $\beta_3 = 0$. On the other hand, if the model of competitive second-degree price discrimination discussed above is correct, then the extent of quantity discounting is predicted to increase with competition, in which case, $\beta_3 < 0$.

To obtain an unbiased estimator of β_3, it remains to solve the problem of endogenous entry due to reverse causality: for example, a shock to the local demand conditions can cause the number of carriers to change. In order to solve this problem, we need an instrumental variable that is

[12] I estimate this specification separately for road and river modes of transportation, but, for brevity, I omit the mode's subscripts here.

correlated with carrier's entry decisions, and affects freight prices only through its effect on the level of competition at a given point in time. a given period of time. To construct such an instrumental variable, I exploit the variation in natural conditions that exogenously limit the number of entrants in the river segment of transportation. Specifically, I make use of the fact that although Paraguay river is mostly navigable all year round, the level of water in it varies substantially both within and across years. When the water level in the upstream portion of the river drops below approximately 9 feet (3 meters), the standard (Mississippi-type barge) can no longer be used in transportation of goods, which exogenously limits the number of carriers on the market. Figure 7 shows that low-water episodes are not rare in the region and happen in about 50% of times. Apart from the actual measured water levels in the river, this Figure also plots the maximal permitted vessel draft (the distance between the surface of the water and the lowest point of the vessel) set ahead by the General Naval Prefecture of Paraguay based on the predicted hydrological conditions. The difference between the two series questions the predictability of the extremely low or high water-level episodes, which suggests that water level is likely to satisfy the exclusion restriction.

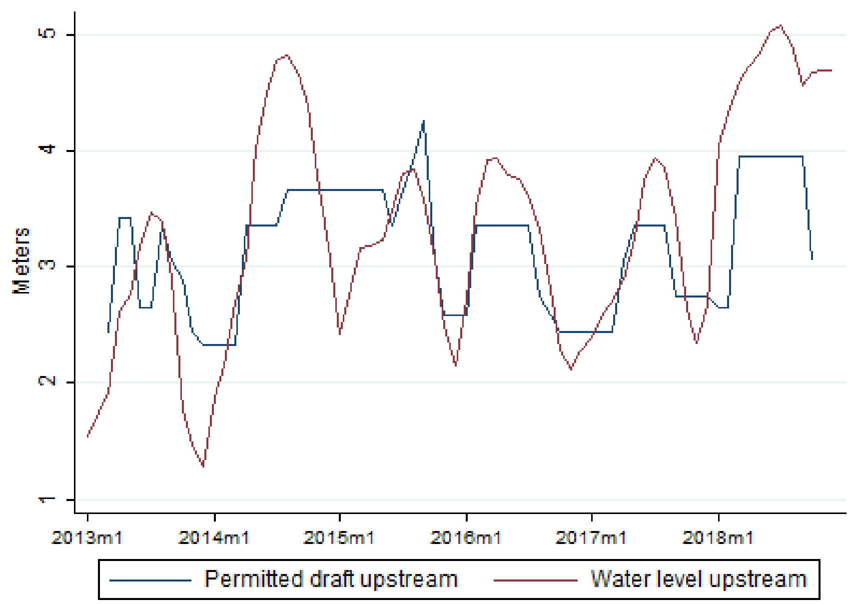


Figure 7: Variation in water levels and permitted vessel draft upstream of Paraguay river
Data Source: La Dirección de Meteorología e Hidrología

To test, whether the water level is also a valid instrument for the number of carrier in a given month, I estimate the following first-stage equation:

$$\log q_{fcy} \times \log N_y = \alpha_0 + \gamma \log Q_{cy} + \rho \log \nu_{fcy} + \alpha_1 \log q_{fcy} + \alpha_3 \log q_{fcy} \times LowWater + \log k_{cy} + \eta_{cy} + \epsilon_{fcy} \tag{30}$$

where $LowWater$ is an indicator variable, which is equal to one when the water level is less than 3 meters, and zero, otherwise. Notice that since we are interested in the effect of competition on the extent of quantity discounts, we use the water-level variable to instrument for the interaction of $\log q_{fcy} \times \log N_y$, and absorb the level of competition $\log N_y$ within a carrier-country-month fixed effect, η_{cy}. If low water level indeed restricts the number of entrants, then we show see the coefficient $\alpha_3 < 0$. If true, then this instrument is valid and we proceed to the second stage, which estimates the effect of competition on the extent of the discounts using only exogenous variation in entry.

Applying this empirically strategy to each transport mode separately, in the next subsection, I estimate the effect of competition on the extent of quantity discounts in road and river transportation segments of the market.

5.2 The empirical effects of competition on quantity discounts

I start exploring how competition in transportation industry affects the extent of quantity discounts offered to the larger shipment using simple OLS. The first two columns of Tables10 and 11 report the results of estimating specification (29) using data from river and road transportation segments, respectively. Consistently with the model's prediction, an increase in the number of carriers is associated with a reduction in per-ton freight prices, on average. Specifically, a one percent increase in the number of carriers serving Paraguay, on average, reduces the per-ton freight prices of a given carriers by 0.13% - in the river segment, and by 0.5% - in the road segment of transportation. In addition, columns (2) of these Tables provides some evidence that a given carrier reduces the freight prices charged to the exporters with larger shipments more than to those with smaller shipments.

To further investigate this effect, I now take the instrumental variable approach to address the potential endogeneity of entry of carriers. In columns (3) of each Table, I estimate the reduced form to check that the level of water in Paraguay river affects the freight prices. The positive coefficient on the interaction of the shipment's size and the low-water level dummy means that, indeed, in periods of low water level, when competition is expected to be lower in both segments of the market, a given carrier reduces the size of the discount offered to the larger shipments. Notice that this effect is estimated in the specification with controls for the time-varying components of costs (oil prices), and taking into account a potential selection of short-distant shipments and shipments of some specific products at times of low water levels.

Next, in Table 12, I explore the validity of the low water level instrument by estimating the first-stage specification (30) for each transport mode separately. Notice that for both transportation segments, I use the same measure of competition, which is a count of carriers in river segments in a given month. Column (1) shows that the dummy for the low water level month is statistically significantly and negatively correlated with the number of river carriers in that month. A potential threat to endogeneity here is that low water levels also restrict the total amount of cargo that can be transported at at time, which would increase river carriers' transport costs if there are substantial cost economies. Notice that this is not a concern for the road transportation segment, where carriers' costs are independent of the river level, given that road and river transportation are substitutes on the last leg of travel. To assess the sensitivity of my first-stage results to this potential issue in the river segment, in columns (2) and (4) of Table 12 I add controls for the capacity restrictions set by the Naval prefecture in a form of barge configurations, and it only improves the validity of my instrument. And finally, in columns (3) and (6), I experiment with a different version of my water-level instrument by computing it as an indicator for the permitted maximum draft being below 3 meters, which also appear to be a valid instrument for the number of river carriers.

With this in mind, we can now return to Tables10 and 11, where in the last two columns I estimate specification (29) using the low water level dummy as an instrument for the number of carriers in a month. The coefficient on the interaction term between shipment's size and the number of river carrier in a month is negative and statistically significant. It means that competition increases the extent of quantity discounts offered by the incumbent carrier in transportation industry. This result is consistent with the model's prediction, and confirms again that the observed large variation of freight prices across shipments is not cost-based but is driven by mark-up variation.

These results have two important implications. Firstly, unsurprisingly competition can substantially reduce the freight prices faced by exporters, on average, which makes policies directed at inducing competition in transportation industry a viable alternative to the investment in transport infrastructure. Secondly, competition reduces freight prices for larger exporters relatively more than for smaller exporters, thus exacerbating their advantage in the market. Although I document these effects in a specific market for transportation services, they apply equally well to other internationally traded inputs where sellers have an opportunity to engage in price discrimination. In the next section, I discuss the general implications of my finding for international economics.

6 Discussion and 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 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.

Table 10: The effect of competition on quantity discounts in river transportation

Dependent Variable:			log $Freight$		
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	Reduced form	IV	IV
log $GrossWeight$	0.408***	0.500***	0.499***	0.486***	0.489***
	(0.085)	(0.089)	(0.089)	(0.089)	(0.090)
log $\#Carriers$	**-0.133*****				
	(0.018)				
log $GrossWeight$ × log $\#Carriers$		**-0.030*****		**-0.200****	**-0.192****
		(0.012)		(0.089)	(0.081)
log $GrossWeight$ × $LowWater$			0.013**		
			(0.006)		
log $GrossWeight$ × $Nonborder$	-0.224***	-0.234***	-0.235***	-0.224***	-0.224***
	(0.052)	(0.052)	(0.052)	(0.054)	(0.054)
log $GrossWeight$ × log $OilPrice$	0.111***	0.013	0.014	0.009	0.005
	(0.005)	(0.009)	(0.009)	(0.010)	(0.011)
log $GrossWeight$ log $Distance$	0.051***	0.047***	0.046***	0.046***	0.046***
	(0.010)	(0.011)	(0.011)	(0.011)	(0.011)
Constant	1.836***	1.370***	1.369***		
	(0.084)	(0.064)	(0.064)		
Carrier-Country-Year	Y	N	N	N	N
Carrier-Country-Month	N	Y	Y	Y	Y
HS4 code	Y	Y	Y	Y	Y
Barge-configuration restrictions	N	N	N	N	Y
N obs	62142	57381	57381	57381	56178
N of clusters	11799	10823	10823	10823	10660
R2	0.811	0.855	0.855	0.664	0.664

Robust standard errors clustered at exporter level in parentheses.

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

Table 11: The effect of competition on quantity discounts in road transportation

Dependent Variable:	log $Freight$				
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	Reduced form	IV	IV
log $GrossWeight$	0.327***	0.324***	0.321***	0.332***	0.351***
	(0.054)	(0.055)	(0.055)	(0.055)	(0.056)
log $\#Carriers$	**-0.515*****				
	(0.053)				
log $GrossWeight$ × log $\#RiverCarriers$		-0.005		**-0.171***	**-0.187****
		(0.013)		(0.088)	(0.080)
log $GrossWeight$ × $LowWater$			0.012*		
			(0.006)		
log $GrossWeight$ × $Nonborder$	-0.024	-0.032	-0.032	-0.034	-0.032
	(0.022)	(0.021)	(0.021)	(0.021)	(0.021)
log $GrossWeight$ × log $OilPrice$	0.091***	-0.008	-0.009	-0.012	-0.017
	(0.005)	(0.019)	(0.019)	(0.020)	(0.022)
log $GrossWeight$ × log $Distance$	0.036***	0.041***	0.041***	0.040***	0.038***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Constant	4.599***	1.716***	1.715***		
	(0.343)	(0.118)	(0.118)		
Carrier-Country-Year	Y	N	N	N	N
Carrier-Country-Month	N	Y	Y	Y	Y
HS4 code	Y	Y	Y	Y	Y
Barge-configuration restrictions	N	N	N	N	Y
N obs	236579	229333	229333	229333	223567
N of clusters	16956	15916	15916	15916	15692
R2	0.751	0.794	0.794	0.498	0.496

Robust standard errors clustered at exporter level in parentheses.

Data at the Bill of Lading (shipment) level.

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

Table 12: First stage regressions

Dependent Variable:	$\log GrossWeight \times \log \#RiverCarriers$					
		River			Road	
	(1)	(2)	(3)	(4)	(5)	(6)
$\log GrossWeight \times LowWater$	-0.039***	-0.047***		-0.049***	-0.057***	
	(0.006)	(0.006)		(0.005)	(0.004)	
$\log GrossWeight \times LowMaxDraft$			-0.073***			-0.080***
			(0.006)			(0.004)
$\log GrossWeight$	-0.078	-0.079	-0.063	0.055*	0.095***	0.104***
	(0.054)	(0.053)	(0.052)	(0.031)	(0.030)	(0.029)
$\log GrossWeight \times Nonborder$	0.061**	0.054**	0.050**	-0.007	-0.006	-0.006
	(0.026)	(0.025)	(0.024)	(0.010)	(0.010)	(0.009)
$\log GrossWeight \times \log OilPrice$	-0.028***	-0.052***	-0.052***	-0.018**	-0.055***	-0.055***
	(0.009)	(0.009)	(0.009)	(0.008)	(0.007)	(0.007)
$\log GrossWeight \times \log Distance$	-0.002	-0.000	0.000	-0.009**	-0.011***	-0.010**
	(0.007)	(0.007)	(0.007)	(0.004)	(0.004)	(0.004)
Constant	0.081**	0.074**	0.069**	-0.027	-0.034	-0.033
	(0.036)	(0.035)	(0.035)	(0.027)	(0.024)	(0.024)
Carrier-Month	Y	Y	Y	Y	Y	Y
HS4 code	Y	Y	Y	Y		Y
Barge-configuration restrictions	N	Y	Y	N	Y	Y
N obs	57381	56178	56178	229333	223567	223567
N of clusters	10823	10660	10660	15916	15692	15692
R2	0.984	0.985	0.985	0.981	0.981	0.981

Robust standard errors clustered at exporter level in parentheses.

Data at the Bill of Lading (shipment) level.

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

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