PRICE DISCRIMINATION AND COMPETITION IN INTERNATIONAL TRANSPORTATION*

Anna Ignatenko[†]

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Abstract

Using uniquely detailed data, I document large freight price variation across shipments of similar products sharing a container on the same route. I rationalize this using a trade model with economies of scale and price discrimination in transportation. Each mechanism has distinct policy implications. To distinguish them, I test for the effect of competition on freight price variation specific to price discrimination. Using unexpected water level changes to instrument for competition in river transportation, I find increased competition causes steeper discounts for larger shipments. Thus, market power in transportation is less distortionary for larger firms who gain additional cost advantages.

Keywords: price discrimination; quantity discounts; transportation costs; competition; economies of scale; mark-ups

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

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

1 Introduction

The transportation sector is highly concentrated. In 2022, the four largest transport companies accounted for 55% of the global market for maritime transportation (UNCTAD, 2022). This has raised concerns that transport companies can act strategically and exert market power, reducing trade and welfare (Hummels et al., 2009; Brancaccio et al., 2020; Asturias, 2020). If transport companies charge prices far above their marginal costs, it can attenuate gains from investment in transport infrastructure that are commonly estimated assuming perfect competition in transportation (Donaldson, 2018; Asturias et al., 2019; Allen & Arkolakis, 2022). Furthermore, if transport companies vary prices across firms, it can have distributional consequences. Yet, identifying market power of transportation companies is challenging in the absence of detailed freight price data and measures of their marginal costs.

In this paper, I document price discrimination by transport companies as evidence of their market power and uncover its distributional effects on firms. I exploit the extremely detailed customs dataset from Paraguay and its unique geographic location. To my knowledge, this is the first dataset that provides freight charges for transportation of shipments which shared a container between common pick-up and drop-off locations.[1] Such shipments have the same physical costs of transportation, as they traveled the same distance at the same speed with the same transportation conditions (e.g. refrigeration). Yet, surprisingly, within a container, freight prices vary substantially across shipments – the average coefficient of variation is equal to 50%. Importantly, 80% of freight price variation across shipments within a container remains unexplained by differences in shipments' volumes, care and handling costs.[2]

To rationalize this freight price variation, I allow transport companies to have economies or diseconomies of scale and vary mark-ups across firms differing in productivity in a standard model of trade. I show that the patterns of transport companies' mark-up variation depend on the informational environment. If transport companies fully observe firms' demand for transportation, they can engage in (first-degree) price discrimination by offering more productive firms larger quantities for a *higher* per-unit price. If they only know the distribution of firm productivities, they can engage in (second-degree) price discrimination by offering larger quantities for *lower* per-unit prices to encourage more productive firms to reveal their higher willingness-to-pay. If transport companies observe firms' characteristics correlated with their demand elasticities, they can engage in (third-degree) price discrimination by of-

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[1] I use the term "container" loosely, to denote shipments transported simultaneously on the same truck, boat or plane between the same pick-up and drop-off locations. For 90% of shipments that are transported to Paraguay by trucks, this term is used rather precisely.

[2] Although my data covers mainly inland transportation of manufactured products, Brancaccio et al. (2020) report similar freight price variation in dry bulk ocean shipping.

fering *lower* per-unit prices to firms with more elastic demand for transportation. Unlike economies or diseconomies of scale, price discrimination by transport companies results in distributional effects of competition of transport companies.

Testing the model's predictions, I provide evidence of price discrimination in the form of quantity discounts and price discrimination based on firms' observed characteristics. In line with the latter, overall larger exporters and those with long-term transportation contracts are charged lower per-ton freight prices for shipments of the same size within a container. Yet, in line with the former, holding exporter characteristics the same, larger shipments of similar products within a container are charged lower per-ton freight prices. I estimate large quantity discounts: conditional on exporter characteristics, doubling the weight of a shipment of a given product within a container increases its total freight payment by only 50%. These discounts are robust to using volume as a measure of shipment size and are not driven by over-time variation in container capacity, fixed paperwork costs or product-specific handling costs. I show that they give an additional cost advantage to more productive firms within an industry.

To show that quantity discounts are not explained by economies of scale, I identify the causal effect of competition on freight price *variation*. Competition can affect freight price *variation* in the presence of price discrimination, but not in the case of pure economies of scale. To causally identify this effect, I use unexpected changes in the water level in Paraguay river, as a source of exogenous variation in competition in its transportation sector. When the water level unexpectedly for a given season drops, Paraguay's Naval Agency lowers the maximum permitted vessel's draft (the distance between the water line and the keel of a vessel). This exogenously and unexpectedly limits the number of transport companies on the river. Instrumenting for the number of competitors on the river, I find that when faced with more competition, the incumbent transport companies reduce freight prices charged for *larger* shipments more. This is consistent with price discrimination as an underlying mechanism of freight price variation, but not with economies of scale, which implies a uniform change of all freight prices of a given transport company.

While the data that enables the identification of price discrimination and the effects of competition in transportation is from landlocked Paraguay, my results are externally valid. Firstly, as much as landlocked Paraguay, many developed and non-landlocked countries such as Germany, Spain, and Portugal, rely on road transportation in importing. Secondly, I find similar results in maritime transportation, which affects most countries and accounts for 80% of world trade. I construct a similarly detailed dataset on container prices in maritime transportation to Peru and show ocean carriers also offer significant discounts for transportation of larger and more containers. These discounts are larger on more competitive routes.

These findings uncover a new quantitatively important role of transport companies' market power in product markets. Firstly, it is less distortionary for more productive firms within an industry, which amplies differences in firm productivities. Lower mark-ups charged by transport companies for larger shipments generate an additional cost advantage for more productive firms that transport larger quantities within an industry. Exporters to Paraguay at the 75th percentile of the shipment size distribution pay 66% lower freight prices and thus can charge their importers 8% lower prices and have 40% higher sales than those at the 25th percentile. Secondly, by changing transport companies' incentives to price discriminate, competition in transportation has distributional effects. It benefits firms with larger productivity within an industry more through larger reduction of their freight prices.

This paper contributes to several areas of research. Firstly, it contributes to the literature on endogenous transportation costs. It considers the round-trip effect (Ishikawa & Tarui, 2018; Wong, 2022; Ge et al., 2024), technological choices of transport companies(Asturias, 2020), network and scale effects (Heiland et al., 2019; Ganapati et al., 2021), and search frictions (Brancaccio et al., 2020, 2023). Holding these mechanisms fixed, I show that the market power of transport companies makes transportation costs not only endogenous, but also variable across firms. I identify price discrimination based on unobserved firm productivity separately from economies of scale and other sources of cost variation. This contrasts with previous studies that showed the variation in freight prices consistent with the market power of transport companies and economies of scale, but could not distinguish between them due to data limitations (Hummels et al., 2009; Ardelean & Lugovskyy, 2023; Boddin & Stähler, 2024). Yet, this distinction is important because of the unique distributional effect that competition in the transportation sector has in the presence of price discrimination.

Secondly, my findings affect the gains from investments in transport infrastructure that are often estimated under constant and exogenous transportation costs (Duranton et al., 2014; Donaldson & Hornbeck, 2016; Donaldson, 2018; Heiland et al., 2019; Allen & Arkolakis, 2022). On the one hand, when better infrastructure reduces physical transportation costs, transport companies with market power pass through a smaller portion of their cost reductions into the freight prices of more productive firms. By reallocating production from more to less productive firms, this can attenuate the consumer gains from improvements in the infrastructure. On the other hand, if better transport infrastructure increases entry in the transportation sector, it will result in larger reductions of freight prices of more productive firms. This can magnify the consumer gains from investments in transport infrastructure.

Thirdly, studying transportation as an input, I contribute to the literature on input price variation in international trade (Kugler & Verhoogen, 2012; Manova & Zhang, 2012; Bastos et al., 2018; Blaum et al., 2019). It shows that more productive firms purchase inputs of higher quality at higher prices, which gives them an additional quality advantage in their output markets. I uncover two mechanisms through which more productive firms get an additional cost advantage, conditional on input quality: economies of scale and price discrimination in inputs markets. They can bias the estimates of firm productivity (De Loecker, 2011; De Loecker et al., 2016) and suggest competition in inputs markets as an explanation for the growing differences in firm performance (Syverson, 2011; Van Reenen, 2018).

Finally, my findings contribute to the ongoing debate in the industrial organization on how competition affects sellers' incentives to price discriminate. While some studies find that it increases the extent of price discrimination (Borenstein & Rose, 1994; Busse & Rysman, 2005; Seim & Viard, 2011; Boik & Takahashi, 2018; Lewis, 2021), others document precisely the opposite (Gerardi & Shapiro, 2009; Gaggero & Piga, 2011; Lin & Wang, 2015). I exploit the firm-to-firm nature of international transportation, to causally estimate this effect in an input rather than consumer goods' market, as in other studies. My results suggest that competition upstream has distributional implications for firms downstream.

2 Theoretical Framework

I develop a theoretical framework that guides my empirical analysis of market-power and cost-based determinants of freight prices. I treat transportation as an essential input purchased by manufacturers that differ in their exogenous productivities from transport companies with market power and economies of scale. I derive differential testable implications of price discrimination and economies of scale for freight prices faced by firms.

2.1 Technologies and market structures

Consider a standard model of trade with firm heterogeneity as in Melitz (2003). An industry is populated by a continuum of manufacturers each producing a single differentiated product variety. The only input in production is labor, which is inelastically supplied at wage w. Manufacturers' production technology consists of constant marginal and fixed overhead costs $F > 0$. While the fixed costs are common across all manufacturers, marginal costs vary with firm productivity φ drawn from a known distribution with cumulative distribution function $G(\varphi)$. Manufacturers purchase one unit of transportation for each unit of output and face exogenous multiplicative trade costs $\tau \geq 1$ (tariffs).

The only deviation from the standard trade model is that prices for transportation are not exogenous and not necessarily proportional to transported goods' value. They are set endogenously by a transport company that can have both market power and variable marginal costs. When transporting Q units of goods, a transport company incurs total costs $K(Q)$. If $K'(Q) = 0$, its marginal costs are constant; if $K'(Q) < 0$, it has economies of scale; and if $K'(Q) > 0$, it has diseconomies of scale.[3] To focus on transport companies' market power, I first assume it is a monopolist and then introduce competition.

2.2 Manufacturers' profits

Let $\bar{q}(\varphi) \equiv \underset{q \geq 0}{\operatorname{argmax}} \{[p(q) - w\tau/\varphi]\, q\}$ denote the optimal output quantity of a manufacturer with marginal production costs $w\tau/\varphi$ in a market with inverse demand function $p(q)$. If manufacturer φ is offered q units of transportation for payment T, its maximum profit is

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

This profit function has two properties important for the transport company's pricing decisions. Firstly, it is strictly increasing and concave in q for $q \in [0, \bar{q}(\varphi))$: $\frac{\partial \pi(q,\varphi)}{\partial q} \geq 0, \frac{\partial^2 \pi(q,\varphi)}{\partial q^2} < 0$. Secondly, more productive manufacturers benefit more from an increase in transported quantity: $\frac{\partial^2 \pi(q,\varphi)}{\partial q \partial \varphi} \geq 0$.

2.3 Transport company's profit maximization problems

A profit maximization problem that a monopolist transport company solves depends on the information it possess about the manufacturers. I consider three information environments that result in three types of price discrimination: full information, asymmetric information, and imperfect information.

Full information (first-degree price discrimination) implies that the transport company knows each manufacturer's demand and can distinguish between them. Then it gets maximum profits by offering to transport quantities q that maximize their joint surplus and fully extracting it with a fee, T. Formally, under full information, the transport company solves the following problem:

$$\max_{q(\varphi)} \int_{\varphi^*}^{+\infty} T(q(\varphi)) g(\varphi) d\varphi - K(Q), \;\; Q \equiv \int_{\varphi^*}^{+\infty} q(\varphi) g(\varphi) d\varphi \tag{2}$$

$$\text{subject to } \pi(q(\varphi)) \geq T(q(\varphi)) \;\; \forall \varphi.$$

Asymmetric information (second-degree price discrimination) implies that the transport company does not know each manufacturer's productivity but knows their distri-

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[3] In my empirical analysis in Section 4, I allow for fixed transportation costs.

bution. Instead of choosing quantities and payments for each manufacturer, it maximizes profits by offering a single quantity-payment schedule that encourages the manufacturers to reveal their productivities. Formally, the transport company maximizes its *expected* profits by choosing a menu of contracts, (q, T), and the least productive firm, φ^* to serve:

$$\max_{\varphi,^*(q(\varphi),T(\varphi))} \int\limits_{\varphi^*}^{+\infty} T(q(\varphi))g(\varphi)d\varphi - K(Q), \;\; Q \equiv \int\limits_{\varphi^*}^{+\infty} q(\varphi)g(\varphi)d\varphi \tag{3}$$

subject to incentive compatibility and individual rationality constraints:

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

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

The individual rationality (IR) constraints are the same as under full information. Additionally, under asymmetric information, there are incentive compatibility (IC) constraints, which ensure that a manufacturer prefers a contract intended to her than to another firm. To ensure low-productivity firms' incentive compatibility, high-productivity firms are charged higher total payments that are unattained for low-productivity ones. To ensure high-productivity firms' incentive compatibility, they are offered lower per-unit prices.

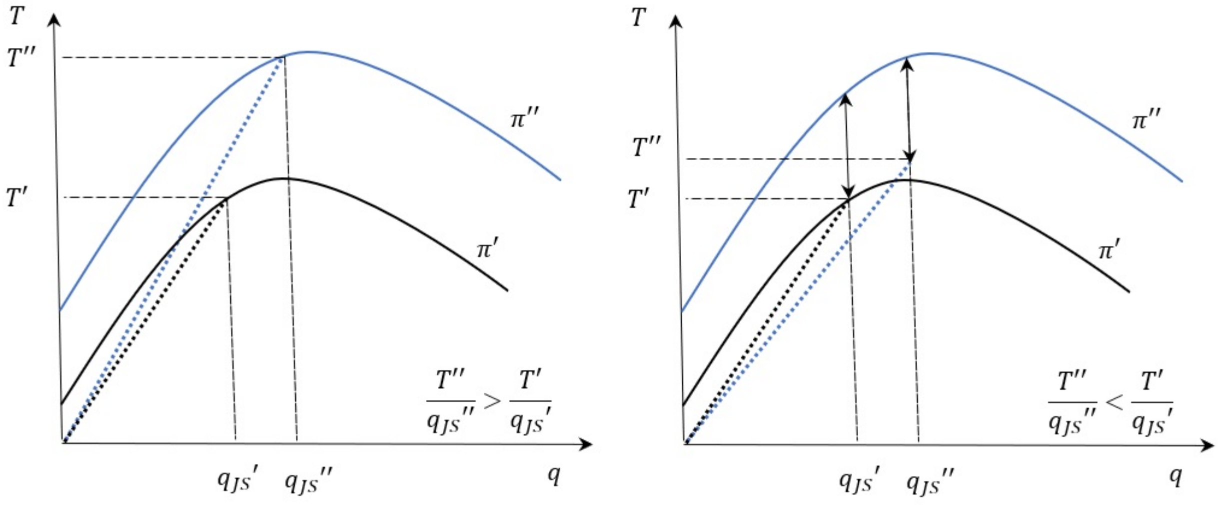
Imperfect information (third-degree price discrimination) implies that the transport company observes manufacturers' characteristics correlated with their demand elasticities. In this environment, it maximizes profits by choosing quantities for each manufacturer and per-unit price is determined from the inverse demand for transportation, $t(q)$:

$$\max_{q(\varphi)} \int_{\varphi^*}^{+\infty} t(q(\varphi))q(\varphi)g(\varphi)d\varphi - K(Q). \tag{4}$$

2.4 Equilibrium freight price variation

I describe and compare patterns of freight price variation under full, asymmetric and imperfect information, and leave all proofs to Appendix A.

Figure 1 illustrates the solutions to the transport company's profit maximization problems under full and asymmetric information in (2) and (3). It depicts profit functions of two manufacturers with productivities $\varphi'' > \varphi'$, and freight prices and quantities offered to them by a transport company with constant marginal costs ($K'(Q) = k$). In Figure 1a, under full information, the transport company offers each manufacturer quantities that equalize their marginal profits with the transport company's marginal costs. Because a more productive manufacturer has higher marginal profits, she is offered larger quantities: $q''_{JS} > q'_{JS}$. By



(a) Full information (b) Asymmetric information

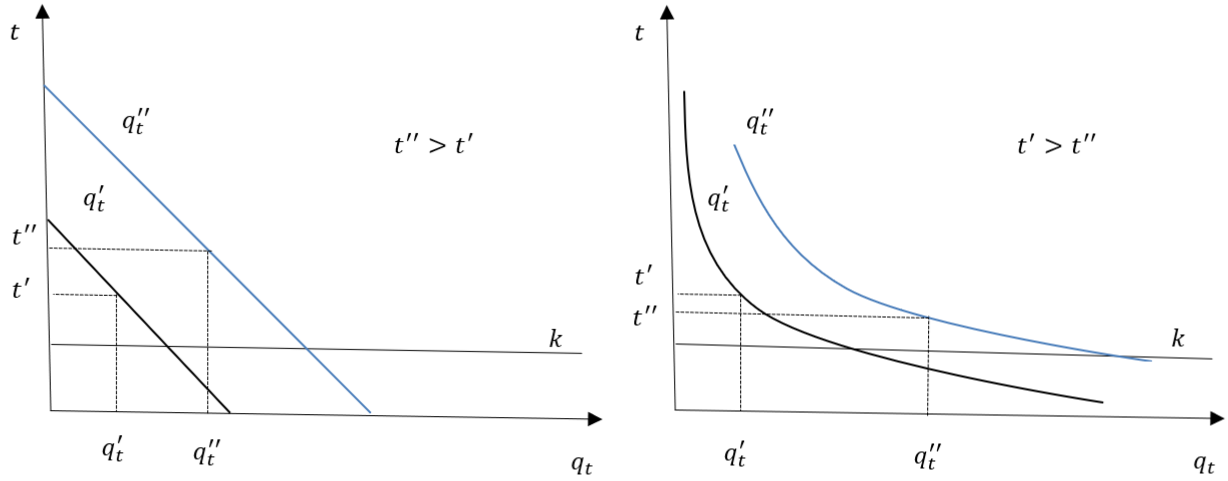
Figure 1. Price discrimination under full and asymmetric information

Notes: π'' and π' are profit functions of high and low productivity manufacturers, respectively, purchasing. q''_{JS} and q'_{JS} are the joint-surplus maximizing quantities of transportation offered to the two manufactures. T'' and T' are freight payments a transport company considers to charge to them. The slopes of the dotted lines from the origin are equal to per-unit freight prices, T''/q''_{JS} and T'/q'_{JS}, at joint-surplus maximizing quantities. (a) is a full information scenario, when the transport company observed manufacturer's productivities, while (b) is an asymmetric information scenario, when the transport company only knows the distribution of manufacturers' productivities.

transporting larger quantities, a more productive manufacturer obtains higher profits that the transport company extracts with a larger freight payment: $T'' > T'$. A more productive manufacturer is also charged more per unit of transportation: $T''/q''_{JS} > T'/q'_{JS}$, as shown by the slope of the dotted line from the origin.

Figure 1b shows that this pattern is reversed when the transport company does not observe firm productivities but knows their distribution. Then the more productive manufacturer can "pretend" to be a less productive one (by splitting the shipment), to pay a lower per-unit freight price. This increases the more productive manufacturer's profits from zero to a positive value depicted with arrows in Figure 1b. To prevent this, the transport company has to reduce the payment for the more productive manufacturer by this value. As a result, in Figure 1b, the more productive firm pays a lower per-unit freight price than the less productive one: $T''/q''_{JS} < T'/q'_{JS}$. Intuitively, under asymmetric information, the transport company offers quantity discounts, to incentivize the more productive firm to reveal its higher willingness-to-pay. To reduce the discounts, it offers a less than efficient quantity to the less productive firm, which lowers the benefits from deviation for the more efficient one.

If, instead, the transport company knows only manufacturer's demand elasticities, it sets



(a) Linear demand (b) CES demand

Figure 2. Price discrimination under imperfect information

Notes: q_t'' and q_t' are derived demands for transportation of high and low productivity manufacturers, respectively. t'' and t' are profit maximizing per-unit prices charged to the two manufacturers, while q'' and q' are their equilibrium purchased quantities. (a) is a linear consumer demand scenario, while (b) is a CES consumer demand scenario.

a per-unit freight price for each of them as a mark-up over its marginal costs. The mark-up is inversely related to the manufacturer's elasticity of demand for transportation, which varies with productivity. Figure 2 illustrates mark-up variation across manufacturers with productivities $\varphi'' > \varphi'$ and derived demand for transportation q_t'' and q_t'. On the one hand, a more productive manufacturer has a larger share of its price dependent on the per-unit freight price, which implies a higher elasticity of demand for transportation. On the other hand, a more productive manufacturer has lower consumer prices and faces less elastic consumers, which implies a lower elasticity of demand for transportation. Under linear demand, in Figure 2a, the latter effect dominates and a more productive manufacturer is charged a higher per-unit price: $t'' > t'$. Under CES demand, in Figure 2b, the former effect dominates and a more productive manufacturer is charged a lower per-unit price: $t'' < t'$.

Therefore, under both asymmetric and imperfect information, price discrimination on the part of a transport company can result in lower per-unit freight prices charged to more productive manufacturers. The key distinction between the two types of price discrimination is that under asymmetric information lower per-unit freight prices are contingent on larger transported quantities. This means that per-unit freight prices can vary across quantities transported by the same manufacturer. In contrast, under imperfect information, per-unit freight prices are set constant for all quantities of a given manufacturer and vary only across them. I use this distinction to empirically separate the two types of price discrimination in

Section 4.

Proposition 1 *If transport companies engage in price discrimination, per-unit freight prices i) increase with quantities under full information (first-degree), and ii) decrease with quantities under asymmetric information (second-degree), and iii) increase or decrease with quantities under imperfect information (third-degree), depending on consumer demand.*

While I obtain these predictions without imposing any specific functional forms, I test them using customs data in an international trade environment. For that, I derive the transport company's pricing rules assuming standard for this environment preferences and distribution of firm productivities.

2.5 Implications for a standard model of trade

In a standard international trade environment, consumers have CES demand, $q(\varphi) = Ap(\varphi)^{-\sigma}$, and firm productivities have Pareto distribution $G(\varphi) = 1 - \varphi^{-\theta}$, where $\theta > \sigma - 1$. Under these assumptions, equilibrium freight payments that solve transport company's profit maximization problems in (2) – (4) are as summarized in Proposition 2.

Proposition 2 *Assume that consumers have CES demand with elasticity $\sigma > 1$, and manufacturers' productivities have Pareto distribution with shape parameter θ, $\theta > \sigma - 1$. Then total freight payment, $T(q)$, a price discriminating transport company charges for transportation of q units, under full (PD1), asymmetric (PD2), and imperfect information (PD3) is:*

$$T(q) = K'(Q)q + \frac{1}{\sigma}Aq^{\frac{\sigma-1}{\sigma}} - F \tag{PD1}$$

$$T(q) = \frac{\theta}{\theta+1}K'(Q)q + \frac{1}{\theta+1}Aq^{\frac{\sigma-1}{\sigma}} - F \tag{PD2}$$

$$T(q) = K'(Q)q + \frac{\sigma-1}{\sigma^2}Aq^{\frac{\sigma-1}{\sigma}} \tag{PD3}$$

These patterns cannot be rationalized by the standard "iceberg" trade cost assumption, under which total freight payment is proportional to the shipment's value: $T(q) = \frac{\tilde{\tau}-1}{\tilde{\tau}}Aq^{\frac{\sigma-1}{\sigma}}$. Therefore, under this assumption, variation in freight payments across shipments is fully explained by their value. In contrast, log-linearizing (PD1) - (PD3) around freight payment charged to the smallest shipment, I show in Appendix A.3 that per-unit freight prices continue to vary with quantities, even conditional on the shipment's value.

Besides price discrimination, freight prices can vary with quantities if a transport company has (dis)economies of scale. The two mechanisms have distinct implications for pass-through of cost reductions due to improved transport infrastructure into consumer prices.

If a transport company charges freight prices equal to its marginal costs, then changes in its transportation costs are fully passed through into consumer prices. Yet, it is incomplete and varies across manufacturers under second- and third-degree price discrimination. Since more productive firms are charged lower mark-ups for transportation, their freight prices fall less when marginal transportation decrease. This can attenuate the aggregate gains from investment in transport infrastructure.

2.6 Competition in the transportation sector

It might seem intuitive that competition in the transportation sector removes transport company's ability to price discriminate. However, it is well established that price discrimination occurs even in non-monopoly settings (see Stole (2007) for a review). Moreover, the effect competition on the extent of price variation is often used to distinguish price discrimination from cost-based price variation (Shepard, 1991; Boik & Takahashi, 2018). Inspired by these studies, I derive differential testable predictions on the effect of competition on freight price *variation* under price discrimination and economies of scale.

To ease the comparison with previous studies, and match the homogeneous nature of transportation services, I start with Cournot competition in the transportation sector.[4] As in Hummels & Skiba (2004), I assume that there are N symmetric transport companies $i = 1, \dots, N$ offering identical transportation services and competing in quantities. Manufacturer with productivity φ transports $Q_i(\varphi)$ with each of the transport companies, where $q(\varphi) = \sum_{i=1}^{N} Q_i(\varphi)$. Transport companies compete for each manufacturer by choosing quantities $Q_i(\varphi)$, simultaneously and independently from each other.

If transport companies do not have market power, they set per-ton freight prices equal to their marginal costs: $t(\varphi) = K'(Q_i), Q_i = \int\limits_{\varphi^*}^{\infty} Q_i(\varphi) g(\varphi) d\varphi$. Under symmetry of the transport companies' costs, in equilibrium, each of them supplies $1/N$th of the total demand for transportation: $Q_i = Q/N$. As the number of transport companies N increases, the output of each transport company falls. If transport companies have economies of scale, this increases their marginal costs and hence per-unit freight prices they charge manufacturers. Therefore, if freight price variation is driven solely by the economies of scale, entry of transport companies increases freight prices of all manufacturers *equally* and does not affect the extent of freight price variation.

In contrast, if transport companies have market power to price discriminate, they can adjust their mark-ups unevenly across manufacturers, in response to competition. First, consider a transport company i that observes manufacturers' characteristics correlated with

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[4] I show that the results hold under price competition in Appendix A.5.

the elasticity of their inverse demand, $t(Q(\varphi))$ and choose quantity $Q_i(\varphi)$ to maximize profits:

$$\max_{Q_i(\varphi)} \int_{\varphi^*}^{\infty} t(Q(\varphi))Q_i(\varphi)g(\varphi)d\varphi - K(Q_i), \;\; Q_i \equiv \int_{\varphi^*}^{\infty} Q_i(\varphi)g(\varphi)d\varphi$$

Taking the first-order condition and using symmetry yields the equilibrium per-unit freight price as a mark-up over marginal costs (see Appendix A.4):

$$t(\varphi) = \frac{1}{1 - \frac{1}{\sigma N}\left(\frac{t(\varphi)+w\tau/\varphi}{t(\varphi)}\right)} K'(Q)$$

Here, the mark-up decreases in manufacturer's productivity, φ, which means that, even if faced with competition, transport companies engage in (third-degree) price discrimination, as in Figure 2b. Moreover, when competition increases (N goes up), transport companies reduce their mark-ups charged to all manufacturers but especially to the less productive ones. I solve for the equilibrium freight price and derive its elasticity with respect to N:

$$\frac{\partial t(\varphi)}{\partial N}\frac{N}{t(\varphi)} = -\frac{\sigma N(K'(Q) + w\tau/\varphi)}{(\sigma N - 1)(\sigma K'(Q)N + w\tau/\varphi)}$$

It is more negative for less productive manufacturers. Hence, their mark-ups fall more with competition than those charged to more productive firms.

Yet, if a transport company only knows the distribution of firm productivities and engages in (second-degree) price discrimination, less productive manufacturers experience a *smaller* reduction in mark-ups when competition increases. To show this, I follow Boik & Takahashi (2018), who prove this in the context of consumer goods' markets. I consider two types of manufacturers – with high ($''$) and low ($'$) productivities, and examine how entry of a rival transport company affects the incumbent's menu of price-quantity contracts. In this setting, transport company i's problem in (3) simplifies to:

$$\max_{(q_i', T_i'),(q_i'', T_i'')} \alpha_i^r T_i' + (1-\alpha_i^r)T_i'' - K(Q_i), \;\; Q_i = \alpha_i^r q_i' + (1-\alpha_i^r)q_i''$$

subject to the incentive compatibility and individual rationality constraints

$$\begin{aligned} \pi(q', \varphi') - T' &\geq \pi(q'', \varphi') - T'' && (IC') \\ \pi(q'', \varphi'') - T'' &\geq \pi(q', \varphi'') - T' && (IC'') \\ \pi(q', \varphi') - T' &\geq 0 && (IR') \\ \pi(q'', \varphi'') - T'' &\geq 0 && (IR''), \end{aligned}$$

where α_i^r is the share of low-productivity firms purchasing from transport company i, under $r = \{\text{monopoly}, \text{competition}\}$.

Under monopoly, it is easy to verify that IR'' and IC' never bind in equilibrium, and the payments are determined by the IR' and IC'' constraints. Intuitively, freight payments set for the high-productivity firms are too high to be considered by the low-productivity ones, which makes IC' satisfied with inequality. This is not necessarily true under competition, which can lower the freight payment offered to the high-productivity firms so much that IC' will bind in equilibrium. Therefore, competition gives rise to three cases: i) neither IC' nor IC'' binds in equilibrium, ii) IC' binds but IC'' does not, and iii) IC'' binds but IC' does not. Boik & Takahashi (2018) show that in all three cases, competition lowers per-unit prices of buyers with higher willingness-to-pay more as long as it increases the quantities offered to the buyer with the lowest willingness-to-pay. In the context of transportation sector, this means that per-unit freight prices of more productive manufacturers fall more with competition, if it increases quantities offered to the least productive firm.

While generating similar patterns of freight price variation, economies of scale and (second- and third-degree) price discrimination result in different responses of freight price variation to competition. Proposition 3 summarizes these differential responses that I test in Section 4.

Proposition 3 *Assume transport companies are symmetric in their costs, offer homogeneous services and compete in quantities. An increase in the number of transport companies leads to larger reduction of freight prices charged to i) more productive manufacturers under second-degree price discrimination, and ii) less productive manufacturers under third-degree price discrimination. It does not affect freight price variation under (dis)economies of scale.*

3 Data

3.1 Unique features of the Paraguayan customs data and context

To disentangle the market-power and cost-based determinants of freight prices, I use freight prices for import shipments from Paraguayan customs dataset. Paraguay is a landlocked country in South America that imports mostly manufactured consumer and intermediate goods (machinery, electronics, and transportation) mainly from adjacent Argentina, Brazil, and Bolivia. They are transported to Paraguay mainly by trucks and river barges, which carry 92% of the country's import shipments directly from the adjacent countries, and 72% of shipments from non-adjacent countries on their last leg, after a transshipment (see Table A1).

Uniquely suited for this study, Paraguay's customs data is much more detailed than other data used in research of the transportation sector. Firstly, it identifies shipments that, on the last leg of travel, were transported simultaneously by the same transport company on board of the same transport between identical pick-up and drop-off locations. When such shipments come from adjacent countries with only one leg of travel, they have identical physical costs of transportation. Therefore, variation in the transport companies' costs related to a transport unit, distance, speed, time and transportation conditions (*e.g.,* refrigeration) cannot explain freight price variation across such shipments. Yet, it can be used to provide evidence of price discrimination on the part of transport companies with market power.

Secondly, for each import transaction, this dataset identifies an exporter, a transport company[5] conducting the transportation, and a transportation contract (bill of lading). The contract describes the transported goods with their 8-digit Harmonized systems code (HS8), their weight, value, and freight charges in US dollars. I use contract identifiers, to aggregate transactions into shipments and compute shipment-level freight charges, and exporter names, to construct proxies for their observed characteristics. This allows me to separately identify (second-degree) price discrimination based on shipment size from (third-degree) price discrimination based on exporter characteristics.

Thirdly, Paraguay's unique geography enables the causal identification of the effect of competition on freight price *variation.* It heavily relies on Paraguay river, which, together with Parana, carries 40% and 80% of its annual imports from adjacent and non-adjacent countries, by weight, respectively. However, this river often becomes unpredictably shallow and unnavigable for standard-sized barges, which lessens competition in the transportation sector. Using this plausibly exogenous variation in the number of transport companies on the river, I test for the differential effects of competition on freight price variation, under price discrimination and economies of scale.

One limitation of this data is that the physical costs of transportation can be controlled for only across shipments transported by land (roads, rivers, and air) from the adjacent to Paraguay countries. For shipments from non-adjacent countries, maritime transportation accounts for about 20-40% of their freight payments. Yet, the maritime transport companies and routes that these shipments follow until their last leg are unknown and cannot be controlled for. To overcome this limitation, I construct a similarly detailed dataset for containerized maritime transportation in Peru. From maritime shipping contracts, I identify the number of containers an exporter transports to Peru with a given transport company on

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[5] I cleaned and standardized company names using methods of textual analysis, similar to those in Bernard et al. (2018) (see Appendix B). The data also contains importers' identifiers, which I use to show that transportation is organized by the exporters.

board of a given vessel between two ports at a time. I merge this data with freight charges recorded in Peru's customs data, using shipping contracts' identifiers. This allows me to study freight price variation across shipments that were transported simultaneously by the same maritime transport company on the same ship between the same ports.

3.2 Summary statistics

Between 2013 and 2018, Paraguayan customs annually recorded 0.8 million import transactions from 25 800 exporters transported by 306 transport companies. I define a shipment as a collection of import transactions listed on the same transportation contract, which results in 108 500 import shipments, per year. Then, for conciseness, somewhat loosely, I define shipments that were listed on the same cargo manifest as shipments that shared a container on the last leg of travel. By definition of a cargo manifest, these shipments were transported simultaneously by the same transport company on board of the same transport between identical pick-up and drop-off locations, on the last leg of travel. When transported on trucks from adjacent countries with only one leg of travel (90% of shipments), such shipments are very likely to precisely share a container from their origin to destination.

Table 1 presents the key characteristics of thus defined shipments and containers, as well as exporters and transport companies responsible for their transportation. **Shipments** imported to Paraguay vary substantially in size, content and payments charged for their transportation. An average import shipment weighs 38 ton, contains 2 distinct HS2 product categories, is worth 51 000 US dollars and costs an exporter 4000 US dollars to transport to Paraguay. Yet, the median one is 6 times lighter, 3 times cheaper, and 4 times less expensive to transport. The high degree of heterogeneity in shipment characteristics can explain large variation in their freight charges through both market-power and cost-based mechanisms.

To disentangle them, I consider shipments that shared a **container** on the last leg of travel and therefore had identical physical transportation costs related to distance, speed, transport unit, and transportation conditions. An average container consists of 2 shipments from 2 exporters. Shipments sharing a container are, on average, almost 3 times smaller by weight and 30% smaller by value than in the full sample. Shared containers are used by most exporters (80%) and account for 20%, 30%, and 50% of all containers by count, annually imported weight and value, respectively. In most shared containers (83%), exporters do not share an importer, which means that their transportation is arranged by the exporters.[6]

Heterogeneous shipments are exported by **exporters** that also vary substantially in their sizes, shipment frequencies, and economic activity, which could affect their demand for trans-

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[6] If transportation to Paraguay was arranged by importers, exporters sharing a container would have also shared an importer in charge of the transportation.

Table 1. Shipments, containers, exporters and transporters in Paraguay

	All		**Shared container**	
	Mean	Median	Mean	Median
Shipments				
Weight, ton	38	6	13	1
Value, ’000 $	51	19	39	11
Freight, ’000 $	4	1	3	1
# HS2	2	1	2	1
Containers				
Weight, ton	78	18	92	14
# Shipments	2	1	7	4
# Exporters	2	1	5	3
Exporters				
Weight/year, ton	156	3	19	1
# Shipments/year	5	1	2	1
# Transporters/year	2	1	1	1
Intermediary, %-share	0.1	0	0.8	0
Transport companies				
Weight/year, ton	9879	1954	10278	2806
# Shipments/year	282	98	373	156
# Exporters/year	120	18	398	93

portation. While an average exporter transports 148 ton and has 5 shipments per year, while the median one transports only 3 ton and one shipment per year. Exporters that at least once share a container are, on average, 15% smaller by annually exported weight but have similar shipment frequency as those in the full sample. Based on their names, 10% of exporters are intermediaries (wholesalers and trading companies), who are less likely to share containers and can negotiate freight prices differently than manufacturers.

Although the **transport companies** that transport goods to Paraguay differ in size, the largest among them are large enough to have at least some market power. An average company transports 282 shipments and 9879 ton per year, which corresponds to 0.3% of annual imports by weight, but the four largest ones altogether transport 25% of annually imported weight. Therefore, in line with the theory, the market structure in the Paraguayan transportation sector can be characterized as an oligopoly with a competitive fridge. It consists of three segments: road transportation with 256 trucking companies per year, river transportation with 64 transporters per year, and air transportation with 29 airlines per year. Trucking companies range from small one-person enterprises with 7 transportation units to large companies with 891 transportation units in their fleet.[7] River transporters range from a few international carriers to many South American and local companies.[8]

The observed transporter-exporter **relationships** suggest that freight prices are likely

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[7] Information provided by the Department of National Transportation of Paraguay.

[8] Examples include international PO Maritime and Imperial Shipping, and regional UABL and Paranave.

Table 2. Determinants of Freight/Ton and Freight/Value

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

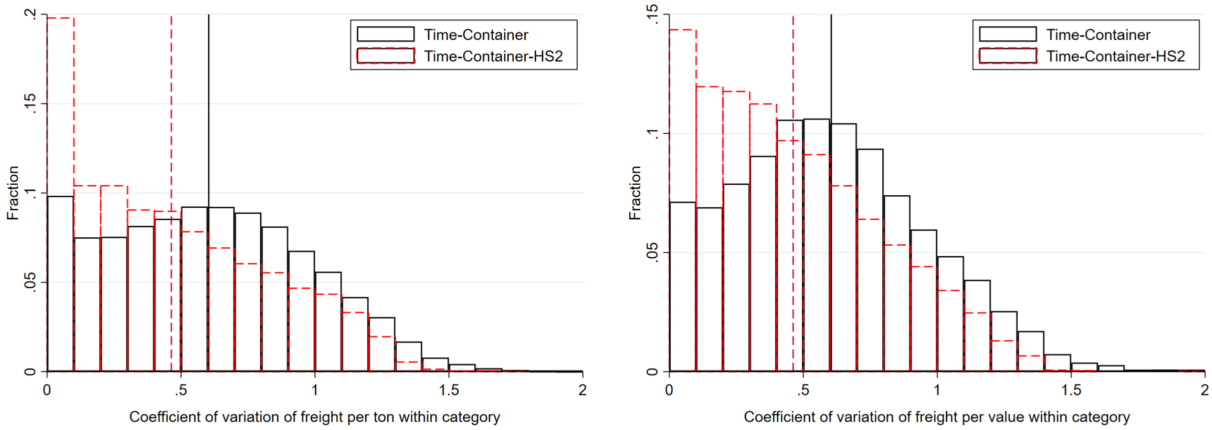
Notes: HS2 stands for a 2-digit Harmonized system's code of a product.

set within both long-term and spot-market contracts. In a year, on average, a transport company contracts with 120 exporters, while an exporter contracts with 2 transport companies. An exporter's main transport company, on average, transports around 80% and 90% of the exporter's annual shipments by count and weight, respectively. Similarly, a transport company's main exporter accounts for around 46% and 40% of the company's annual shipments by count and weight, respectively. While transport companies can observe characteristics of their main exporters, they may have limited information about exporters in the spot market. Therefore, they can engage in both second- and third-degree price discrimination.

3.3 Freight price variation across shipments

I document large variation of freight prices across shipments that cannot be explained by standard proxies for physical costs of transportation in Table 2. Column (1) that distance between countries, common border, common language and colonial ties explain only 17% of per-ton freight price variation across shipments. Accounting for their unobserved country-level determinants with country fixed effects explains only 27% of this variation. Adding HS2 product fixed effects to control for the type of transported goods in shipments with only one HS2 category increases the explained share of variation to 60%. Further accounting for transportation mode on the last leg increases the explained share of per-ton freight price variation to 78%. Even accounting for the differences in costs across transport companies on the last leg leaves 15% of per-ton freight price variation unexplained.

Table 2 shows that the observed variation in per-ton freight prices is not explained by variation in shipment's value, as implied by the "iceberg" trade cost assumption. Under this standard in international trade assumption, transportation costs are directly proportional to the product's price with coefficient of proportionality constant on a given route. It implies that the ratio of freight payment and shipment's value is constant on a given route. In contrast, column (2) of Table 2 reports that observed and unobserved country-country route



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

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

Figure 3. Large within-container variation of Freight/Ton and Freight/Value

Notes: Coefficient of variations are calculated for each category (Date-Container or Date-Container-HS2) by dividing standard deviation of freight-per-ton or freight-per-value by their means. Unit values 3 times larger and 3 times smaller than the median in each category were excluded as outliers, for illustrative purposes. Vertical lines show average coefficients across all categories.

characteristics explain at most 7% of variation in freight-per-value ratios. Accounting for HS2 product codes for shipments containing only one product type and for transportation mode on the lest leg increases the explained share of this variation to only 33%. Even controlling for the transport company on the last leg leaves a half of freight-per-value variation unexplained.

Per-ton freight price variation remains to be large even when variation in physical costs of transportation is controlled for at the most disaggregated level. Figure 3a shows that freight prices vary substantially even across shipments that shared a container on their last leg of travel. It plots the distribution of the coefficients of variation of per-ton freight prices across shipments sharing a container. In violation of the Law of One Price, which predicts zero variation in freight prices across such shipments for all containers, I find the average coefficient of variation of 60%. Accounting for differences in volumes and handling costs across shipments with only one product type using HS2 fixed effects only slightly reduces the average coefficient of variation to 45%. This variation in per-ton freight prices cannot be rationalized by the "iceberg" trade cost assumption. Figure 3b shows that, in violation of this assumption, the freight-per-value ratio within a container is far from zero for most containers, with the average coefficient of variation of 60%. It remains large with the average coefficient of variation of 45%, even when shipment's HS2 product category is accounted for.

4 Empirical Results

I provide evidence of price discrimination on the part of transport companies in the documented within-container freight price variation. I test distinct implications of various types of price discrimination derived in Section 2 and summarized in Propositions 1 – 3.

4.1 Identification strategy

First, I examine whether patterns of freight price variation across shipments are consistent with various types of price discrimination, as summarized in Proposition 1. For that, I estimate the log-linear relationship between shipment's total freight payment and shipped quantities:

$$\log Freight_{icd}(\varphi) = \beta \log Weight_{icd}(\varphi) + \psi_{icd} + \varepsilon_{icd}(\varphi), \tag{5}$$

where i, c, d, and φ denote transport company (transporter), route, date, and manufacturer, respectively. I use transporter-route-date fixed effects, ψ_{icd}, to capture variation in the transport company's marginal costs, and shipment's gross weight (inclusive of packaging) as a measure of shipped quantities. If the fixed effects fully absorb variation in the transport company's marginal costs, then estimated $\beta \neq 0$ reflect variation in its mark-ups. According to Proposition 1, $\beta > 1$ if the transport company (first-degree) price discriminates under full information, and $\beta < 1$, if it (second- or third-degree) price discriminates under asymmetric or imperfect information.

Next, I show that price discrimination by transport companies cannot be rationalized by the standard "iceberg" trade cost assumption. I estimate the relationship between shipment's total freight payment and shipped quantities, conditional on shipment's value:

$$\log Freight_{icd}(\varphi) = \beta_q \log Weight_{icd}(\varphi) + \beta_p \log Value_{icd}(\varphi) + \psi_{icd} + \varepsilon_{icd}(\varphi) \tag{6}$$

Because, under the "iceberg" trade cost assumption, freight payments are proportional to the shipment's value, $\beta_q = 0$ and $\beta_p = 1$. In contrast, the equilibrium freight payments under price discrimination in Proposition 2, log-linearized around the freight payment for the smallest shipment, imply $\beta_p < 1$ and $\beta_q \neq 1$. Specifically, as above, $\beta_q < 1$ under second- and third-degree price discrimination, and $\beta_q > 1$, under first-degree price discrimination.

Finally, I distinguish price discrimination from shipment-level economies or diseconomies of scale. To test for their differential implied effects of competition on freight price variation in Proposition 3, I estimate equation:

$$\log Freight_{icd}(\varphi) = \beta \log Weight_{icd}(\varphi) + \beta_n \log N_{cd} \times \log Weight_{icd}(\varphi) + \psi_{icd} + \varepsilon_{icd}(\varphi), \tag{7}$$

Table 3. Mechanisms of freight price variation

	β, β_q	β_p	β_n
(1^{st}-degree) Price discrimination, full information	> 1	< 1	
(2^{nd}-degree) Price discrimination, asymmetric information	< 1	< 1	< 0
(3^{rd}-degree) Price discrimination, imperfect information	< 1	< 1	> 0
Economies of scale	< 1	0	0
Iceberg trade cost assumption	< 1	1	0

where N_{cd} denotes the number of transport companies on route c at time d. The effect of competition on freight price *variation* is captured by β_n, while its effect on price levels is absorbed by the transporter-route-time fixed effects. If freight price variation is entirely driven by shipment-level economies of scale, then the number of transport companies on a route should affect freight prices of all shipments equally and $\beta_n = 0$. In contrast, if the incumbent transport company price discriminates through quantity discounts, it lowers freight prices for larger shipments more, when competition increases ($\beta_n < 0$). If it price discriminates based on exporter's observed characteristics, it lowers freight prices for smaller shipments more, when competition increases ($\beta_n > 0$).

Addressing endogeneity. I use the estimates of β, β_p, and β_n, to distinguish various forms of price discrimination from each other and from economies of scale, as shown in Table 3. When estimating them, I address several standard sources of endogeneity. Firstly, I address *simultaneity* bias driven by unobserved quality of transportation. I use container fixed effects and product-type fixed effects to absorb much of variation in transportation quality due to the differences in traveled distance, speed, transportation and handling conditions. Secondly, I alleviate the *omitted variable* bias driven by unobserved differences in transport company's costs across shipments within a container, such as paperwork costs and costs of capacity. Thirdly, I account for a potential *measurement error bias* in my estimates using instrumental variables. Finally, I address endogeneity of entry using unexpected changes in the water level in the river to instrument for the number of transport companies.

4.2 Evidence of price discrimination in transportation

Table 4 presents the results of estimating the relationship between freight payment and shipped quantities in equation (5) using a simple OLS. In column (1), I use year-transporter-country fixed effects to proxy for the transport company's marginal costs and distinguish shipments in shared and non-shared containers. I find large per-unit discounts offered to larger shipments: doubling the shipment's weight results in only 55% higher freight payment. Shipments of the same weight are charged 34% more for transportation in shared relative to non-shared containers. However, transport companies offer 10% larger quantity discounts for transportation in shared than non-shared containers.

Although the results in column (1) are consistent with (second- and third-degree) price discrimination, they could also be explained by variation in transportation conditions, speed, and distance across shipments of different sizes. To rule out this explanation, in column (2), I study freight price variation across shipments that shared a container on the last leg, using container fixed effects. I estimate the relationship between freight payments and shipment size separately for shipments from adjacent and non-adjacent countries. This is because container fixed effects fully absorb variation in the physical costs of transportation only for shipments from the adjacent countries with only one leg of travel. I find that even when transported within the same container at the same time on the same route, larger shipments get substantial discounts. Doubling the weight of a shipment from an adjacent country increases in its freight payment only by 44%. For shipments from non-adjacent countries, the discounts are slightly smaller, but they could be explained by differences in maritime transportation costs that cannot be accounted for.

I show that these large within-container quantity discounts are not due to transportation indivisibilities and differences in handling costs across shipments within a container. If transportation services are priced per volume, then even when charged the same per-volume price, firms with more densely packed shipments get lower per-ton freight prices (see Holmes & Singer (2018)). Moreover, if certain products within a container require special handling, they can be charged higher per-ton freight prices. To account for the shipment's density and handling costs, in column (3), I include HS2 product fixed effects for shipments containing only one HS2 product type and still find large discounts for heavier shipments. Since heavier shipments from same HS2 category have higher total volume, this is equivalent to volume discounts. I show this explicitly using a subsample of shipments from Chile to Paraguay, for which Chilean customs data reports both weight and volume (Table A5).

Next, I demonstrate that, in line with the theory, these discounts benefit more productive exporters that export more rather than intermediaries or exporters from high-demand industries. In column (4), I include a dummy variable for an exporting intermediary, and find that although they pay 10% lower freight prices for shipments of the same size, this does not change the discounts offered to larger shipments. In column (5), I control for the exporter's NACE industry to account for differences in demand conditions that could lead to variation in shipment sizes. The results suggest that, since within-industry, larger shipments are exported by more productive firms, they benefit from lower per-ton freight prices.

I argue that these within-container quantity discounts are, at least partly, explained by price discrimination rather than economies of scale. Following Proposition 3, I test for

Table 4. Patterns of freight price variation across shipments

Dependent Variable:	$\log Freight_{icd}(\varphi)$				
	(1)	(2)	(3)	(4)	(5)
$\log Weight_{icd}(\varphi)$	0.552***	0.440***	0.446***	0.446***	0.443***
	(0.024)	(0.024)	(0.026)	(0.026)	(0.037)
Shared	0.338***				
	(0.127)				
$\log Weight_{icd}(\varphi) \times Shared$	-0.051***				
	(0.015)				
$\log Weight_{icd}(\varphi) \times NonAdj$		0.091*	0.101*	0.103**	0.180***
		(0.051)	(0.053)	(0.052)	(0.055)
$Intermediary(\varphi)$				-0.098*	
				(0.057)	
Year-Transporter-Country	✓				
Container-Country		✓			
Container-Country-HS2			✓	✓	✓
Exporter's industry					✓
N obs	416492	88225	88225	88225	40128
N clusters	425	348	348	348	304
Adj. R^2	0.792	0.920	0.932	0.932	0.935

Standard errors clustered at exporter- and transporter- levels in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Notes: Shipment is identified with its Bill of Lading. φ, i, c, and d denote exporter, transport company, route, and date. $NonAdj$ is one for shipments *not* from Brazil, Argentina and Bolivia, and zero otherwise. Container denotes shipments transported together on board of the same transport on the same route on the last leg. *Shared* denotes containers shared by multiple exporters. HS2 is a 2-digit HS classification code. Constant is not shown.

the differential effects of competition on freight price *variation* under price discrimination and pure economies of scale. In Table 5, I estimate equation (7), using the number of transport companies on the routes to Paraguay in a given month of the year, as a measure of competition.[9] I include HS2-month fixed effects, to account for seasonality in the types of goods transported to Paraguay, and monthly gas prices, as well as Paraguay's and exporter's currency exchange rates, to control for variation in the transport companies' costs.

Column (1) of Table 5 shows that, as competition increases, incumbent transport companies expectedly lower freight prices for all shipments of a given product from a given exporter. What is less expected, but consistent with price discrimination, they reduce their freight prices for larger shipments more. This uneven effect of competition is implied by the negative coefficient on the interaction term ($\beta_n < 0$) estimated in column (2). This rules out economies of scale as the sole explanation for freight price variation, which implies an even

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[9] This measure of competition (unlike HHI or CR4), directly follows from the model in Section 2.6.

Table 5. The effect of competition of transport companies on freight prices

Dependent Variable:	$\log Freight_{icmy}(\varphi)$				
	(1) OLS	(2) OLS	(3) IV	(4) Reduced form	(5) First stage
$\log Weight_{icmy}(\varphi)$	0.782***	0.675***	0.673***	0.674***	-0.013
	(0.006)	(0.003)	(0.003)	(0.003)	(0.008)
$\log N_{my}$	-0.378***				
	(0.102)				
$\log \hat{W}eight_{icmy}(\varphi) \cdot \log \hat{N}_{my}$		-0.024*	-0.116**		
		(0.013)	(0.051)		
$\log \hat{W}eight_{icmy}(\varphi) \cdot \log \hat{D}_{my}$				-0.014**	0.122***
				(0.006)	(0.019)
$\log Gas\ Price_{my}$	1.342***				
	(0.268)				
$\log Currency(\varphi)/\$_{my}$	0.360**				
	(0.173)				
$\log Guarani/\$_{my}$	-0.423*				
	(0.254)				
Transporter×Exporter×Year	✓				
Transporter×Country×Month×Year		✓	✓	✓	✓
HS2×Month	✓	✓	✓	✓	✓
N obs	41129	98175	93668	93668	93668
N clusters	1457	1281	1196	1196	1196
Adj. R^2	0.929	0.792	0.666	0.791	0.214
First-stage F			46.8		

Standard errors clustered at the month-year-transporter level in parentheses.
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

Notes: φ, i, c, and d denote exporter, transport company, route, and date of shipment. N_{my} and D_{my} are, respectively, the number of transport companies on the river and maximum permitted vessel's draft. $\hat{x}$ denotes x's deviation from its average in month m. HS2 is a 2-digit product code in HS classification. Constant is not shown.

change of *all* freight prices of the incumbent transport companies ($\beta_n = 0$).

In the remaining columns of Table 5, I demonstrate that this effect of competition on freight price *variation* is not due to endogenous entry. I use unexpected weather-motivated restrictions on vessel entry in Paraguay river as a source of plausibly exogenous variation in the number of transport companies on the river. It bears a half of the country's imports but often becomes unnavigable for standard barges that require a water level of at least three meters.[10] To avoid river blockages, Paraguay's Naval Agency issues monthly decrees setting maximum permitted vessel's draft (distance between the keel and the waterline) upstream.

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[10] See World Bank's report: Southern Cone Inland Waterways Transportation Study

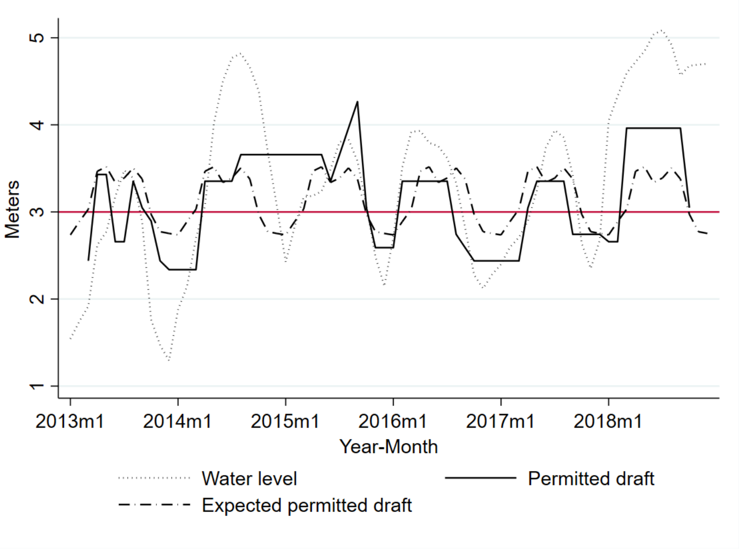

Figure 4. Maximum permitted vessel's draft in Paraguay river closely follows water level and is not fully predictable by seasonal trends

Notes: Maximum permitted vessel's draft in meters set out by Paraguay's Naval agency and water levels from La Dirección de Meteorología e Hidrología upstream of the Paraguay river from over time.

Figure 4 shows that it closely follows the water level in the river upstream, which means that its over-time variation is driven by exogenous weather rather than demand conditions. Moreover, the maximum permitted draft often deviates from its average levels expected for a given month of the year. Hence, as an instrument for competition, deviations of the maximum permitted draft from its monthly average across years satisfy the exclusion restriction.

I identify the causal effect of competition on the extent of *variation* in freight prices of the *incumbent* transport companies. I interact demeaned (log) exporter's weight transported by a transport company in a given month-year with (log) deviations of the maximum permitted draft to instrument for its interaction with the number of transport companies in that period. The first-stage results in column (5) show that this instrument is relevant: when the maximum permitted draft unexpectedly increases relative to its average level in this month, more transport companies operate on the river. The reduced-form results in column (4) show that freight prices decrease when the maximum permitted draft suddenly increases. The IV estimates in column (3) confirm that, in response to entry, the incumbent transport companies offer larger freight price reductions to larger shipments.[11]

This differential effect of competition on freight prices across shipments cannot be explained by entry of transport companies with smaller (larger) barges when the water level

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[11] In Table A4, I obtain similar results using deviations of the dummy variable for high permitted draft (more than 3 meters) from its monthly average, as an instrument.

Table 6. Evidence of quantity discounts, conditional on shipment's value

Dependent Variable:	$\log Freight_{icd}(\varphi)$				
	(1) OLS	(2) OLS	(3) IV	(4) Reduced form	(5) First stage
$\log Weight_{icd}(\varphi)$	0.377***	0.271***	0.471***		
	(0.017)	(0.014)	(0.060)		
$\log Value_{icd}(\varphi)$		0.215***	0.038	0.453***	0.880***
		(0.015)	(0.049)	(0.017)	(0.038)
$\log Weight_{-icq}(\varphi)$				0.023***	0.048***
				(0.004)	(0.007)
Container×Country	✓	✓	✓	✓	✓
N obs	86162	86162	86162	86162	86162
N clusters	259	259	259	259	259
Adj. R^2	0.810	0.824	0.405	0.784	0.864
First-stage F			50.5		

Standard errors clustered at exporter- and transporter levels in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Notes: Shipment is identified with its Bill of Lading. φ, i, c, and d denote exporter, transport company, route, and date of shipment. $Weight_{-icq}(\varphi)$ is gross weight shipped by transport companies other than i to exporter φ's importer in quarter q. Container identifies shipments transported simultaneously on board of the same vehicle following the same route on the last leg of transportation. Constant is not shown.

drops (rises). This is because this effect is estimated using variation in freight prices of the same incumbent transport company. It also cannot be explained by the change in the incumbent transport companies' costs driven by the change in the water level. Although when the water level is high, they could potentially use barges of larger size, this could lower freight prices for all shipments equally, in absence of price discrimination. This mechanism is accounted for by transporter-month-year fixed effects in Table 5 and cannot explain larger freight price reductions for bigger shipments transported in a given month of the year.

The presented evidence of price discrimination in transportation has important implications for international trade, as it cannot be rationalized by the commonly used "iceberg" trade cost assumption. To show this, in Table 6, I estimate the relationship between shipments' freight payments and shipped quantities, conditional on their values. Under the "iceberg" trade cost assumption, variation in the freight payment should be fully explained by variation in the value of shipped products. In contrast, in column (2), I find that per-ton freight prices still decrease in shipment's weight, even conditional on its value. Both estimated freight payment elasticities with respect to shipment's weight and value are less than one ($\beta_q < 1$ and $\beta_p < 1$), in line with price discrimination. In column (3), I treat shipment's value as a control and I instrument shipment's weight with the quarterly weight its exporter

Table 7. Price discrimination under asymmetric and imperfect information

Dependent Variable:	$\log Freight_{icd}(\varphi)$			
	(1)	(2)	(3)	(4)
$\log Weight_{icd}(\varphi)$	0.453***	0.462***	0.606***	0.516***
	(0.030)	(0.031)	(0.054)	(0.075)
$\log Weight_{icd}(\varphi) \times NonAdjacent$	0.099	0.098	0.046	0.073
	(0.065)	(0.064)	(0.086)	(0.090)
$\log Weight_{y}(\varphi)$	-0.013***			
	(0.005)			
$\log Weight_{iy}(\varphi)$		-0.026***		
		(0.008)		
Container×HS2	✓	✓	✓	✓
Exporter×Transporter×Year			✓	✓
Contracts	All	All	All	Spot
N obs	88848	88848	59913	16371
N clusters	350	350	315	213
Adj. R^2	0.932	0.932	0.962	0.969

Standard errors clustered at exporter- and transporter- levels in parentheses.
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

Notes: Shipment is identified with its Bill of Lading. φ, i, c, and d denote exporter, transport company, route, and date of shipment. $Weight_y(\varphi)$ and $Weight_y(\varphi)$ are exporter's total weight and weight transported with transport company i in year y. *NonAdjacent* equals one for shipments *not* from Brazil, Argentina and Bolivia, and zero otherwise. Container identifies shipments transported simultaneously on board of the same transport on the same route on the last leg of travel. HS2 is a 2-digit HS classification code. "Spot" denotes shipments of transport companies with less than 20% share in their exporters' annually exported weight. Constant is not shown.

transports with alternative transport companies. Although this results in smaller estimates of quantity discounts, they remain to be significant and unexplained by shipment's value.

4.3 Mechanisms of price discrimination in transportation

I distinguish price discrimination under asymmetric information in a form of quantity discounts from price discrimination based on observed exporter characteristics in Table 7. If a transport company observes exporters' annually transported weight, it can price discrimination by charging lower freight prices for *all* shipments of overall larger exporters. Since overall larger exporters have larger shipments, this can explain the documented within-container quantity discounts. To test for this mechanism, in column (1), I use total weight annually exported to Paraguay as a measure of exporter's overall size. As Ardelean & Lugovskyy (2023), I find that overall larger exporters pay lower per-ton freight prices for shipments of the same size. Yet, accounting for this effect does not eliminate within-container quantity discounts. This is in line with price discrimination under asymmetric information, which predicts price variation even across units of the same buyer.

Alternatively, a transport company might have long-term contracts with some exporters and offer them lower freight prices than in the spot market. If long-term contracts require to transport more with a transport company, this can explain the within-container quantity discounts. To rule this out, in column (2), I use total weight annually transported by an exporter with a given transport company as a proxy for a long-term contract between them. Although exporters annually transporting more with the transport company pay lower freight prices for shipments of the same weight, it does not reduce quantity discounts. In column (3), I include exporter-transporter-year fixed effects to absorb differences in their unobserved contracts, and estimate only 30% smaller within-container quantity discounts. To estimate quantity discounts in a spot market for transportation, in column (4), I use shipments transported by transport companies with less than 20% share in their exporters' annually exported weight. I find that in thus defined spot market, within-container quantity discounts are 13% smaller than in the full sample. Hence, long-term contracts can explain only 13-30% of the estimated within-container quantity discounts.

4.4 Robustness

Here, I demonstrate that the presented evidence of price discrimination is robust to alternative measures of shipment size; more detailed controls for transportation conditions and handling; over-time variation in container capacity; fixed shipment costs; and transportation organized by importers rather than exporters.

Differences in transportation conditions and handling costs across shipments in the main analysis are accounted for with container-HS2 fixed effects. They also absorb **variation in shipment's density**, which could bias the estimates of volume discounts. In Figure A10, I show that within-container quantity discounts are robust to using more disaggregated HS4 and HS6 product fixed effects. Using maritime freight price data from Peru, in Table A6, I show that measuring shipment size with weight, volume or container count, yields similar quantity discounts, especially after controlling for HS2 category.

Variation in container's capacity over time can explain within-container freight price variation through opportunity costs of container capacity rather than price discrimination. If transportation of larger shipments is arranged earlier, when the container is less full, their per-ton freight prices can be lower because of the lower opportunity costs of capacity. However, using information on shipping and shipping order dates for shipments from Peru, I find no evidence that transportation of larger shipments is arranged earlier (Figure A8a). Moreover, freight prices do not vary with how long in advance an exporter arranges transportation, on average (Figure A8b). Therefore, accounting for over-time variation in container's capacity in Table A3 does not eliminate within-container quantity discounts.

Fixed shipment costs such as paperwork and border compliance costs could explain within-container discounts offered to larger shipments through economies of scale. In this case, the discounts should be larger on routes where fixed shipment cost are larger. However, in Figure A9, I show that my estimates of within-container discounts are not sensitive to the number of hours documentary and border compliance takes in an exporter's country.

Transportation organized by importers rather than exporters could slightly change the interpretation of my results. To address this concern, I use information on who arranges transportation – exporters or importers, of shipments from Chile to Paraguay available in Chile's customs data. In Table A5, I find the same quantity discounts within exporter-route across shipments with exporter-organized transportation as in the full sample.[12]

5 Quantifying the Effects of Market Power

5.1 Amplified differences in firm productivities and prices

My findings suggest that besides raising transportation costs for all firms, market power of transport companies amplifies differences in their exogenous productivities. This, in turn, increases differences in consumer prices across firms within an industry. Using estimates in Section 4, I quantify the distributional effects of market power in the transportation sector.

I first estimate an additional cost advantage more productive firms get by shipping in larger quantities through price discrimination in the transportation sector. I apply the estimated freight price elasticity with respect to quantity of -0.56 to the ratios of shipment sizes at the 75th and 25th percentiles, $(q75/q25)$ in each HS8-country category. I calculate the %-difference in freight prices faced by firms with shipment sizes at the 75th and 25th percentiles as $(1 - (q75/q25)^{-0.56}) \times 100\%$ and plot their distribution in Figure 5. It shows that in most markets, firms exporting larger shipments get a substantial cost advantage through quantity discounts in transportation. On average, firms with shipments at the 75th percentile of their size distribution face 66% lower freight prices than those with shipments at the 25th percentile. How does this affect the initial differences in their consumer prices?

To answer this question, I first derive consumer price elasticity with respect to shipment size. Since consumer price, p^{cif}, is a sum of a producer, p^{fob}, and per-unit freight prices t,

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[12] While Ardelean & Lugovskyy (2023) report that transportation of most import shipments to Chile is organized by the importers, I show it depends on the firms' sizes. Using Peru's data, I find the probability that it is exporter-organized increases with exporter size and decreases with importer size (Table A7).

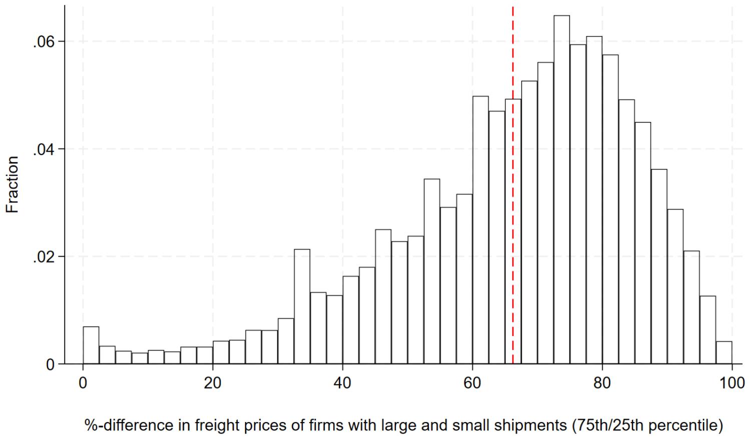

Figure 5. Exporter cost variation due to quantity discounts in transportation

Notes: %-differences in freight prices across firms are calculated for each HS8-product-country category. For illustrative purposes, categories with less than 10 shipments are dropped; categories with %-differences above 98 are assigned the value of 98. The vertical line shows average across all categories.

its elasticity with respect to shipment size, q is a weighted average of the elasticities of its components:

$$\frac{\partial p^{cif}}{\partial q}\frac{q}{p^{cif}} = \frac{\partial p^{fob}}{\partial q}\frac{q}{p^{fob}}\frac{p^{fob}}{p^{cif}} + \frac{\partial t}{\partial q}\frac{q}{t}\frac{t}{p^{cif}}, \tag{8}$$

where weights are shares of producer and freight prices in the consumer price, respectively. Thus, consumers purchasing from firms with larger shipments pay lower prices because these firms have lower transportation costs which also results in lower producer prices.

To quantify the direct contribution of quantity discounts in transportation to consumer price variation, I calculate the second component of consumer price elasticity in (8). For that, I multiply the estimated freight price elasticity with respect to shipment size by the share of freight prices in consumer prices in each HS8-country category. Applying it to the 75th/25th-percentile ratio of shipment sizes in each HS8 category, I find the %-differences in consumer prices charged by firms at the 75th and 25th percentiles of the shipment size distribution and plot their distribution in Figure 6. It shows that, due to quantity discounts in transportation, firms with shipments at the 75th percentile of their size distribution, on average, have 8% lower consumer prices relative to those at the 25th percentile. This gives a larger competitive advantage to firms with large shipments, which get 40% higher sales, assuming a standard value of 5 for the elasticity of substitution between products.

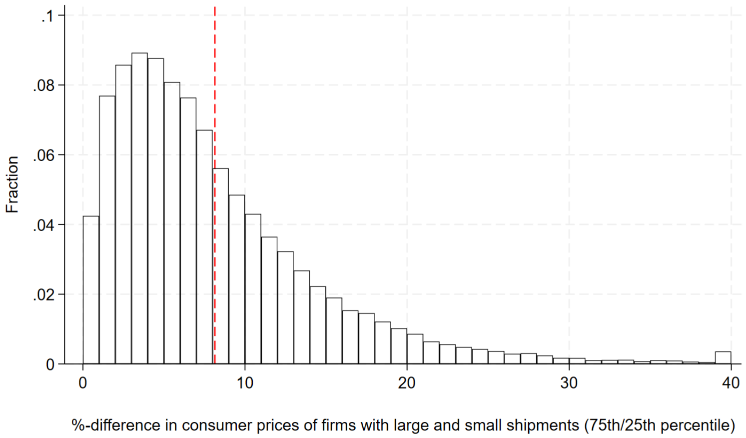

Figure 6. Consumer price variation due to quantity discounts in transportation

Notes: %-differences in consumer prices across firms are calculated for each HS8-product-country category. For illustrative purposes, categories with less than 10 shipments are dropped; categories with %-differences above 40 are assigned the value of 40. The vertical line shows average across all categories.

5.2 Freight price variation around the world

While evidence on price discrimination and distributional effects of competition in transportation is based on data from landlocked Paraguay, my findings are externally valid for two reasons. Firstly, in-land transportation, the focus of this study, is as important in many developed and large economies with ocean access, as it is in Paraguay. To show this, I collected data on the value share of imports transported by roads for 41 countries and plot it against their (log) GDP in Figure 7.[13] It shows that roads carry a larger share of imports to Germany, Spain and Portugal, than to Paraguay and other landlocked countries. Moreover, they carry 15-30% of imports to the US, Turkey, and Colombia, where maritime transportation is the main mode of transportation of imports.

Secondly, I find similar patterns of price discrimination and the effects of competition in maritime transportation, which carries 80% of the world trade (UNCTAD (2022)) and affects most countries. I construct a novel dataset on maritime container freight prices from Peru with the level of detail similar to the Paraguayan customs dataset. I combine shipment-level freight payments recorded in Peru's customs data with information from Peru's maritime bills of lading on the size and number of containers an exporter transports with a given transport company on a given vessel between two ports. This allows me to estimate the relationship between shipment's freight payments and size across shipments on board of the same vessel between the same ports at the same time.

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[13] I use data from UN Comtrade, Schott (2008)) and individual countries' customs data.

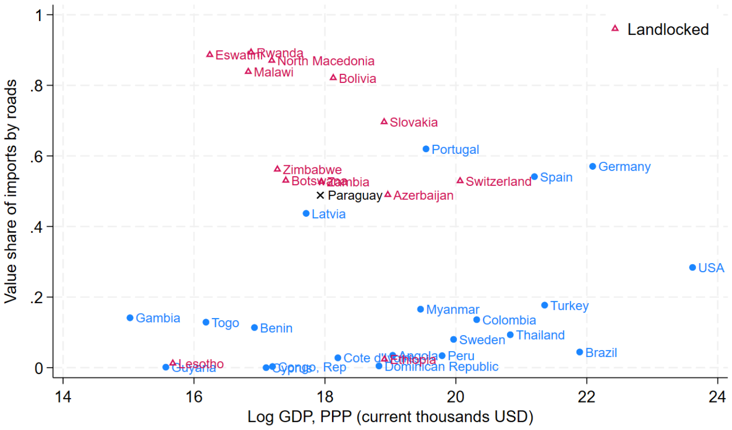

Figure 7. Roads carry a large share of imports in a wide range of countries

Table 8 presents evidence of price discrimination in maritime transportation in Peru. Column (1) shows maritime transport companies in Peru offer discounts to larger shipments and exporters with larger annually transported quantity, by weight, similar to those in Paraguay. Column (2), suggests that these discounts are robust to using the number of 20- and 40- foot containers as a measure of shipment size and annually exported volume (in 20-foot container equivalent units, TEU) as a measure of exporter size. Although a 40-foot container is twice as big by volume as a 20-foot container, transportation of a 40-foot container costs only 40% more. Moreover, doubling the number of 40-foot (20-foot) containers of a given size increases the freight payment by only 70% (90%). Column (3) shows that these discounts are offered to exporters, rather than importers, by estimating them using shipments whose transportation is organized by the exporters.[14].

In column (4) of Table 8, I show that maritime transport companies also respond to competition by increasing the discountss offered for transportation of a larger number of containers on a given vessel and route. I find that a one percent increase in the number of transport companies above average lowers the freight payment elasticity with respect to the number of containers per shipment from 0.7 to 0.6.[15] This is equivalent to a 15% reduction in the average discounts offered to larger shipments. Therefore, by studying smaller economies served by fewer transport companies, this paper underestimates the distributional effects of market power of transport companies in larger markets.

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[14] I infer this information from incoterms, as in Ardelean & Lugovskyy (2023).

[15] This is quantitatively similar to the causal effect of competition in transportation to Paraguay in Table 5.

Table 8. Evidence of price discrimination in maritime transportation in Peru

Dependent Variable:	$\log Freight_{icd}(\varphi)$			
	(1) All	(2) All	(3) Exporter organized	(4) Exporter organized $20Foot = 0$
$\log Weight_{icd}(\varphi)$	0.532*** (0.019)			
$\log Weight_{y}(\varphi)$	-0.049*** (0.008)			
$\log Containers_{icd}(\varphi)$		0.717*** (0.028)	0.749*** (0.035)	0.733*** (0.041)
$\log Containers_{icd}(\varphi) \times 20Foot$		0.170*** (0.046)	0.146*** (0.046)	
$20Foot$		-0.419*** (0.025)	-0.399*** (0.028)	
$\log TEU_{y}(\varphi)$		-0.039*** (0.006)	-0.056*** (0.009)	-0.070*** (0.014)
$\log Containers_{icd}(\varphi) \times \log \hat{N}_{cy}$				-0.090*** (0.028)
Transporter-Vessel-Route-Date	✓	✓	✓	✓
N obs	8904	8904	3841	1685
N clusters	27	27	23	20
Adj. R^2	0.702	0.732	0.785	0.796

Robust standard errors clustered at the exporter and transporter levels in parentheses.
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

Notes: Shipment is identified as a combination of transporter, exporter, date, port of departure, customs of receipt. $Weight_{icd}(\varphi)$ and $Containers_{icd}(\varphi)$, denote, respectively, gross weight (incl. packaging) and the number of containers transported by transport company i from exporter φ at time d on route c. $Weight_{y}(\varphi)$ and $TEU_{y}(\varphi)$ are, respectively, weight and volume exported to Peru by exporter φ in year y. $20Foot$ is equal to one for shipments consisting of 20-foot containers, and zero otherwise. Constant is not shown.

6 Conclusions

This paper documents price discrimination and strategic response to competition by transport companies that uncover their market power. It overcomes a major empirical challenge faced by previous researchers – the unavailability of freight price data and detailed measures of physical costs of transportation. Drawing this information from a uniquely detailed customs dataset, I isolate price discrimination from economies of scale in freight price variation across shipments sharing a container between their pick-up and drop-off locations. I show that both mechanisms benefit larger, more productive, firms.

Yet, economies of scale and price discrimination in transportation have very different implications for policies aimed at reducing firms' transportation costs. As one of such policies, investments in transport infrastructure can encourage entry of new transport companies and reduce marginal costs of the existing ones. My findings imply that, on the one hand, more productive firms experience a lower pass-through of this cost reduction into their freight prices. On the other hand, they benefit more through lower freight prices charged by incumbent in response to entry of new transport companies. Accounting for these mechanisms in the estimates of gains from investments in transport infrastructure is a promising avenue for future research.

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A Online Theoretical Appendix

A.1 Proof of Proposition 1

A.1.1 Freight price variation under full information

In the environment with full information, quantities for each manufacturer φ are determined from $\frac{\partial(\pi(q(\varphi))}{\partial q} = K'(Q)$. Since manufacturer's marginal profits increase in firm productivity, more productive manufacturers are offered larger quantities, q^*. The freight payment is then determined from the constraint as the manufacturer's profits from selling these quantities: $T(q^*(\varphi)) = \pi(q^*(\varphi))$. Then per-unit freight prices are $\pi(q^*(\varphi))/q^*$. They increase in quantity if $\frac{\partial\pi(q^*)}{\partial q^*} > \frac{\pi(q^*)}{q^*}$ or, equivalently, $\frac{\pi(q^*)}{q^*} < K'(Q)$.

A.1.2 Freight price variation under asymmetric information

In the environment with asymmetric information, I first simplify profit maximization problem in (3). Following Varian (1989), I re-write it as:

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

where $V(\varphi) \equiv \pi(q(\varphi), \varphi) - T(q(\varphi))$. Integrating the last term by parts obtains

$$\int_{\varphi^*}^{+\infty} V(\varphi)g(\varphi)d\varphi = V(\varphi)(G(\varphi)-1)\Big|_{\varphi^*}^{+\infty} - \int_{\varphi^*}^{+\infty} V'(\varphi)(G(\varphi)-1)d\varphi.$$

The (IR) constraint for the least productive firm implies that the first term on the right-hand side is equal to zero. Now, consider the second term, and take the derivative of $V(\varphi)$ with respect to φ:

$$V'(\varphi) = \underbrace{\left(\frac{\partial\pi(q(\varphi),\varphi)}{\partial q} - \frac{\partial T(q(\varphi))}{\partial q}\right)}_{=0 \text{ by (IC) constraint}} \frac{dq}{d\varphi} + \frac{\partial\pi(q,\varphi)}{\partial\varphi} = \frac{\partial\pi(q,\varphi)}{\partial\varphi}$$

Substituting it back in the integral of $V(\varphi)$, leaves us with

$$\int_{\varphi^*}^{+\infty} V(\varphi)g(\varphi)d\varphi = -\int_{\varphi^*}^{+\infty} \frac{\partial\pi(q,\varphi)}{\partial\varphi}\left(G(\varphi)-1\right)d\varphi$$

This results in the following simplified profit maximization problem:

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

subject to the following IC and IR constraints:

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

$$\pi(q(\varphi^*), \varphi^*) = T(q(\varphi^*)) \tag{10}$$

The first-order condition with respect to q determines quantities offered to each manufacture as:

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

The first-order condition with respect to φ^* determines the range of firms served by the transport company as:

$$\pi(q(\varphi^*), \varphi^*) g(\varphi^*) - K'(Q(\varphi^*)) q(\varphi^*) - \frac{(1 - G(\varphi^*))}{g(\varphi^*)} \frac{\partial \pi(q(\varphi^*), \varphi^*)}{\partial \varphi} = 0 \tag{12}$$

Then payments for the chosen quantities for the chosen range of firms are determined from the binding IC and IR constraints.

Given (11), if $(1 - G(\varphi))/g(\varphi)$ decreases in φ,[16] more productive manufacturers are offered larger quantities and hence are charged higher total freight payments. The binding IC constraint $\frac{\partial T(q)}{\partial q} = \frac{\partial \pi(q,\varphi)}{\partial q}$ and the profit-function properties imply that firms with larger quantities are charged lower marginal prices. Hence, more productive firms pay lower marginal freight prices.

A.1.3 Freight price variation under imperfect information

In the environment with imperfect information, quantity for manufacturer φ is determined by the first-order condition for profit maximization in ():

$$t'(q_t(\varphi)) q_t(\varphi) + t(q_t(\varphi)) - K'(Q) = 0,$$

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[16] This function is decreasing in φ for a large class of distribution functions, such as uniform, normal, Pareto, exponential, logistic and others with nondecreasing density.

where $t(q_t)$ is inverse derived demand for transportation. From here, per-unit freight price $t(\varphi)$ can written as a multiplicative mark-up over marginal costs:

$$t(\varphi) = \frac{1}{1 + \varepsilon_t(\varphi)} K'(Q), \tag{13}$$

where $\varepsilon_t(\varphi) \equiv \frac{\partial t(q_t)}{\partial q_t} \frac{t(q_t)}{q_t}$ is the inverse derived demand elasticity.

To understand how per-ton freight prices vary across manufacturers, I derive the elasticity of each manufacturer's inverse demand for transportation. Since manufacturers use one unit of transportation for each unit of output, their demand for transportation is determined by quantities they decide to sell. Manufacturer φ's optimal quantities are determined from the following maximization problem, taking per-unit freight price t as given:

$$\max_q \left(p - \frac{w\tau}{\varphi} - t \right) q \tag{14}$$

Rearranging the first-order condition yields the following inverse derived demand for transportation:

$$t = \left[\varepsilon^p(q_t) + 1 \right] p(q_t) - \frac{w\tau}{\varphi},$$

where $\varepsilon^p \equiv \frac{\partial p}{\partial q} \frac{q}{p}$ is consumer's inverse demand elasticity. From here, the elasticity of the inverse derived demand for transportation can be derived as

$$\varepsilon_t(\varphi) = \varepsilon^p(\varphi) \frac{p(\varphi)}{t(\varphi)} \left[\Gamma(\varphi) + \varepsilon^p(\varphi) + 1 \right],$$

where $\Gamma(\varphi) \equiv \frac{\partial \varepsilon^p(\varphi)}{\partial q(\varphi)} \frac{q(\varphi)}{\varepsilon^p(\varphi)}$ is the elasticity of the consumer's inverse demand. Therefore, the inverse demand for transportation is, by absolute value, higher and freight prices are lower for manufacturers with higher consumer's demand elasticity ε^p and lower share of transportation costs in their price, $t(\varphi)/p(\varphi)$. Under CES demand, consumers' demand elasticity is constant across firms, but more productive firms have a larger share of their price dependent on the freight prices and sells more. This results in a negative relationship between freight price and quantity. In contrast, under linear demand, more productive manufacturers face more elastic consumers, which results in a positive relationship between freight prices and manufacturer's productivity.

A.2 Proof of Proposition 2

Proposition 2 follows from the profit maximization conditions in Appendix A.1 - A.4, under CES demand $q = Ap(\varphi)^{-\sigma}$ and Pareto distribution of firm productivities $G(\varphi) = 1 - \varphi^{\theta}$.

In the environment with full information, the solution for the first-order condition $\frac{\partial \pi}{\partial q} = K'(Q)$ is

$$q = A\left[\frac{\sigma}{\sigma-1}\right]^{-\sigma}\left[K'(Q)+\frac{w\tau}{\varphi}\right]^{-\sigma}.$$

Then marginal production costs of manufacturer φ can be expressed as $\frac{w\tau}{\varphi} = \frac{\sigma-1}{\sigma} - K'(Q)$. Using this expression in the equilibrium total freight payment yields (PD1):

$$T(q) = \pi(q) = \left(p - w\tau/\varphi\right)q - F = K'(Q)q + \frac{1}{\sigma}Aq^{\frac{\sigma-1}{\sigma}} - F.$$

In the environment with asymmetric information, quantities offered to manufacturer φ are determined from:

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

Here, the right-hand side indeed decreases in manufacturer's productivity φ. Because marginal profits on the left-hand side decrease in quantities, this confirms that more productive manufacturers are offered larger quantities. Using the expression for marginal profits given CES demand yields the following relationship between quantities and firm productivity, φ:

$$q = A\left[\frac{\sigma}{\sigma-1}\right]^{-\sigma}\left[K'(Q)+\frac{w\tau}{\varphi}\left(1+\frac{1}{\theta}\right)\right]^{-\sigma}.$$

Then, marginal production costs of manufacture φ as a function of q can be expressed as

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

Using it in the marginal freight price, which is equal to the manufacturer's marginal profits due to the binding IC constraint, yields

$$\frac{\partial T}{\partial q} = K'(Q) + \frac{w\tau}{\varphi\theta} = \frac{1}{1+\theta}\left[\frac{\sigma-1}{\sigma}A^{1\sigma}q^{-1/\sigma}\right] + \frac{\theta}{1+\theta}K'(Q).$$

Integrating this expression using the conditions in (12) and (10), yields the total freight payment in (PD2):

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

In the environment with imperfect information, I first derive firm's inverse demand for transportation by solving maximization problem in (14):

$$t(q,\varphi) = \frac{\sigma-1}{\sigma}q^{-1/\sigma}A^{1/\sigma} - w\tau/\varphi. \tag{15}$$

Then its elasticity with respect to quantity is

$$\frac{\partial t}{\partial q}\frac{q}{t} = -\frac{\frac{\sigma-1}{\sigma^2}A^{1/\sigma}q^{-1/\sigma}}{\frac{\sigma-1}{\sigma}q^{-1/\sigma}A^{1/\sigma} - w\tau/\varphi}.$$

Using this expression in the transport company's first-order condition (13) and solving for the equilibrium per-ton freight price, t, yields:

$$t(\varphi) = \frac{\sigma}{\sigma-1}K'(Q) + \frac{w\tau}{\varphi}\frac{1}{\sigma-1}.$$

Plugging this into the manufacturer's inverse demand for transportation in (15), I solve for the manufacturer's production costs as a function of quantity:

$$\frac{w\tau}{\varphi} = \left(\frac{\sigma-1}{\sigma}\right)^2 q^{-1/\sigma}A^{1/\sigma} - K'(Q).$$

Using this expression to solve for $T(q) = t(q)q$, yields (PD3):

$$T(q) = K'(Q)q + \frac{\sigma-1}{\sigma^2}A^{1/\sigma}q^{\frac{\sigma-1}{\sigma}}.$$

A.3 Freight price variation, conditional on shipment value

I show that variation in per-ton freight price with quantity under price discrimination remains, even conditional on shipment's value, and thus cannot be rationalized by the "iceberg" trade cost assumption. I log-linearize total freight payments in (PD1) – (PD3) around the one charged for the smallest shipment of size, q^*:

$$\log\frac{T(q)}{T(q^*)} = \frac{K'(Q)q^*}{T(q^*)}\log\frac{q}{q^*} + \frac{1}{\sigma}\frac{p^*q^*}{T(q^*)}\log\frac{pq}{p^*q^*} \tag{PD1'}$$

$$\log\frac{T(q)}{T(q^*)} = \frac{\theta}{\theta+1}\frac{K'(Q)q^*}{T(q^*)}\log\frac{q}{q^*} + \frac{1}{\theta+1}\frac{p^*q^*}{T(q^*)}\frac{pq}{p^*q^*} \tag{PD2'}$$

$$\log\frac{T(q)}{T(q^*)} = \frac{K'(Q)q^*}{T(q^*)}\log\frac{q}{q^*} + \frac{\sigma-1}{\sigma^2}\frac{p^*q^*}{T(q^*)}\log\frac{pq}{p^*q^*} \tag{PD3'}$$

These expressions can be generalized as the log-linear relationship estimated in equation (6):

$$\log T_{icd}(\varphi) = \beta_q \log q(\varphi) + \beta_p \log p(\varphi)q(\varphi) + \psi_{icd},$$

where $\beta_p < 1$ in all (PD1') – (PD3'), while $\beta_q > 1$ in (PD1') and $\beta_q < 1$ in (PD2') and (PD3'). Hence, conditional on shipment's value, $p(\varphi)q(\varphi)$, per-ton freight prices continue to increase in quantity under first-degree price discrimination, and decrease in quantity under second- and third-degree price discrimination.

A.4 Proof of Proposition 3

In the environment with imperfect information and CES demand, manufacturer's inverse demand for transportation is derived in (15) as

$$t(q,\varphi) = \frac{\sigma-1}{\sigma} q(\varphi)^{-1/\sigma} A^{1/\sigma} - w\tau/\varphi, \tag{16}$$

where in the competitive environment $q(\varphi) = \sum_{i=1}^{N} Q_i(\varphi)$. Its elasticity with respect to quantity can be derived as

$$\frac{\partial t(\varphi)}{\partial Q_i(\varphi)} \frac{Q_i(\varphi)}{t(\varphi)} = -\frac{w\tau/\varphi + t(\varphi)}{\sigma t(\varphi)}$$

Taking the first-order condition under Cournot competition and using $Q = NQ_i(\varphi)$, under symmetry, results in equilibrium per-unit freight price:

$$t(\varphi) = K'(Q) \frac{1}{1 + \frac{\partial t}{\partial Q_i(\varphi)} \frac{Q_i(\varphi)}{t} \frac{1}{N}}. \tag{17}$$

Using (A.4), yields the equilibrium per-ton freight price

$$t(\varphi) = \frac{\sigma N}{\sigma N - 1} K'(Q) + \frac{1}{\sigma N - 1} \frac{w\tau}{\varphi}.$$

Its elasticity with respect to N implies that mark-ups charged to more productive manufacturers with larger shipments fall less in response to competition.

In the environment with asymmetric information, Proposition 3 follows directly from Boik & Takahashi (2018), which contains its proof.

A.5 Price competition in transportation

The results in Proposition 3 can arise when transport companies offer differentiated services and compete in prices. In the environment with asymmetric information, the effects of competition on mark-ups charged to different buyers in Boik & Takahashi (2018) do not depend on the mode of competition.

In the environment with asymmetric information, Stole (2007) uses the set-up in Holmes (1989) to show that the effect of competition on price discrimination is generally ambiguous. Following Holmes (1989), I show that mark-ups charged to manufacturers with greater productivity can decrease more with competition if they have lower switching or search costs.

Under Bertrand oligopoly, mark-up is a function of buyer's industry-demand elasticity, $\varepsilon^I(t_i(\varphi))$ and cross-price elasticity, $\varepsilon^C(t_i(\varphi))$:

$$\frac{t_i^O(\varphi) - K'(Q)}{t_i^O(\varphi)} = \frac{1}{\varepsilon^I(t_i(\varphi)) + \varepsilon^C(t_i(\varphi))}$$

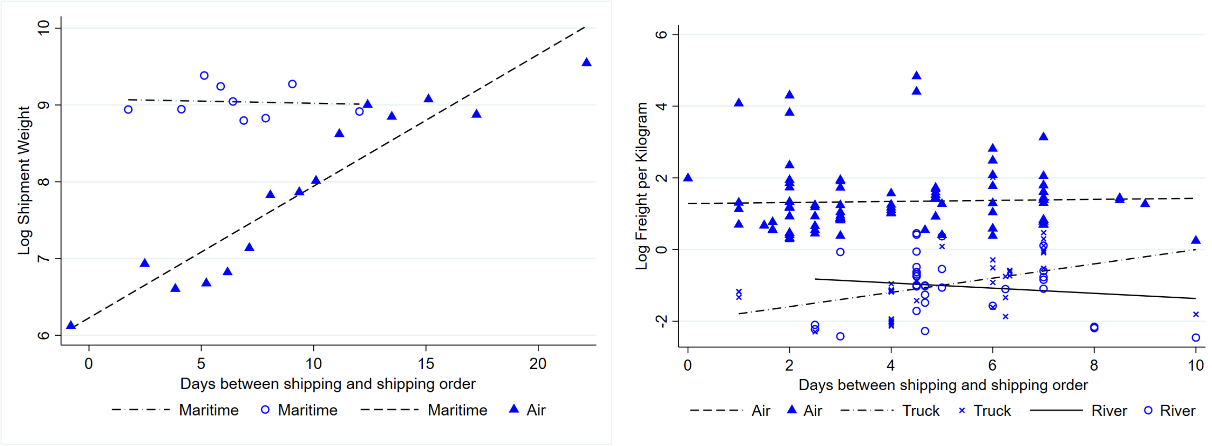
In contrast, under monopoly, mark-up is an inverse of industry-demand elasticity, $\varepsilon^I(t_i(\varphi))$. Therefore, moving from monopoly to oligopoly lowers mark-ups of all buyers. However, if buyers differ in their cross-price elasticities, their mark-ups will be lowered unevenly. Specifically, if more productive manufacturers have higher cross-price elasticity, transport companies will reduce their mark-ups more, in response to competition. This can be the case if more productive manufacturers can switch to alternative transport companies easier than less productive ones.

B Online Data Appendix

B.1 Procedures used to clean and standardize firm names

First, I cleaned declared foreign manufacturers' names from commonly used legal abbreviations (Ltd., Limited, Incorportated, LLC, GMBH, Group, Company, Holding, etc), names of their countries (reported separately in the data) and names of largest cities. I also removed word indicators of trade intermediaries (exp, imp, trading, etc.). Then, to correct spelling mistakes in manufacturers' names, I calculated a similarity score between every two cleaned company names, using Stata's *matchit* function. This similarity score ranges from 0 to 1, where a score of 1 implies a perfect similarity between two strings, according to the chosen string matching technique. I started with the strictest *token* technique, for which I used the threshold similarity score value of 0.9 to identify the two names as the same. This resulted in clusters of firms with very similar names, to which I assign a common name. Then to these common names I sequentially applied other techniques in the order of their strictness: *circular fourgram-*, *threegram-*, *fivegram-*, and *bigram-*. Each time I assigned a common name to firms with a similarity score above 0.75 and proceeded by matching the resulting names with another method. This procedure allowed me to substantially reduce the number of unique manufacturers' names from 255 278 to 89 365.

I identify a foreign manufacturer with its unique name (cleaned and standardized) and country from which it exports to Paraguay. Each location of a multinational firm is treated as a separate firm. To alleviate the impact of errors in names' cleaning on the results, I use only manufacturers with at least 1000 recorded transactions throughout the sample



(a) Transportation of larger shipments is not always arranged earlier

(b) Freight prices not significantly affected by advance shipping order

Figure A8. Freight payments and capacity constraints across shipment sizes

Notes: Binned scatter plots obtained from combining data on shipments exported from Peru to Paraguay from Peru's customs data with data on their freight payments from Paraguay's customs data.

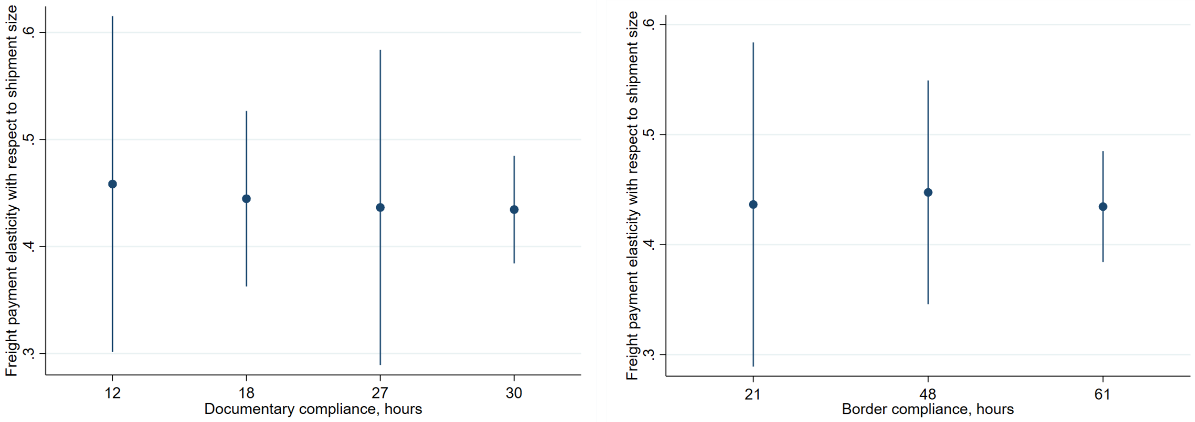
period in my analysis. For these manufacturers, I manually checked that the cleaning and standardization procedure performed on their names only remove spelling mistakes. They account for 75% of the total number of transactions in my sample.

I apply similar procedures to clean and standardize reported transport company names. I first cleaned them from commonly used legal abbreviations (EIRL, SA, SRL, Group, Company, TRANSP, etc.), their country names, and large cities' names. Then I manually remove typos in the resulting transport companies' names. By doing this, I reduce the number of unique transport companies' names from 2700 to 1700.

To minimize the role of the names' cleaning procedure's errors in the results, I use only transport companies with more than 500 transactions in my analysis. For these transport companies, I manually checked that the cleaning and standardization procedures performed on their names correctly remove spelling mistakes. Transport companies reported in more than 500 transactions in the sample account for 83% of the total number of Paraguay's import transactions between 2013 and 2018.

B.2 Additional results

B.2.1 Figures



(a) Within-container quantity discounts are not affected by time costs of paperwork

(b) Within-container quantity discounts are not affected by border compliance hours

Figure A9. Average quantity discounts are not driven by fixed transportation costs

Notes: Figures plot shipment's freight payment elasticities with respect to weight depending on country's documentary compliance costs (in hours) in (a) and border compliance costs (in hours) in (b). All coefficient are estimated off shipments from adjacent countries using container-country-HS2 fixed effects.

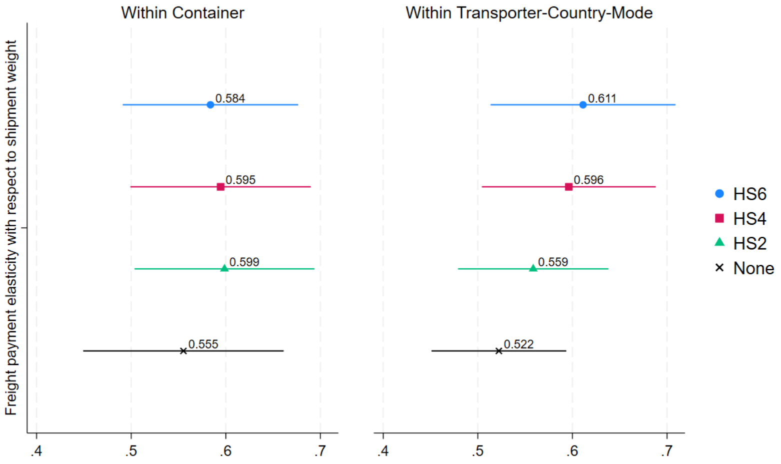


Figure A10. Quantity discounts identified with more disaggregated product types to control for density

B.2.2 Tables

Table A1. Modes of transportation of Paraguayan imports, 2013 - 2018

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

Table A2. Evidence of quantity discounts in maritime transportation in Peru

Dependent Variable:	$\log Freight_{icd}(\varphi)$			
	(1)	(2)	(3)	(4)
$\log Weight_{icd}(\varphi)$	0.797***	0.743***		
	(0.047)	(0.042)		
$\log Weight_{i}(\varphi)$	-0.059***	-0.067***		
	(0.015)	(0.016)		
$\log TEU_{icd}(\varphi)$			0.681***	
			(0.051)	
$\log TEU_{i}(\varphi)$			-0.023**	-0.020**
			(0.011)	(0.009)
$\log Containers_{icd}(\varphi)$				0.709***
				(0.088)
$20Foot$				-0.264***
				(0.068)
$\log Containers_{icd}(\varphi) \times 20Foot$				0.027
				(0.147)
Constant	0.611	1.271**	7.340***	7.690***
	(0.485)	(0.449)	(0.070)	(0.059)
Carrier×Vessel×Route	✓	✓	✓	✓
N obs	781	781	781	781
N clusters	22	22	22	22
Adj. R^2	0.910	0.882	0.830	0.835

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

Standard errors clustered at exporter- and transporter- levels in parentheses.

Table A3. The effect of earlier arrangement of transportation from Peru to Paraguay

Dependent Variable:		$\log Freight_{icd}(q)$		
	(1)	(2)	(3)	(4)
$N^{daysadvance}(\varphi)$	-0.139***	0.016		0.024
	(0.045)	(0.028)		(0.022)
$\log Weight_{icd}(q)$			0.407***	0.411***
			(0.048)	(0.050)
Constant	1.036***	0.132	4.228***	4.061***
	(0.316)	(0.207)	(0.270)	(0.319)
Year	✓			
Year-Mode		✓		
Container			✓	✓
N obs	825	825	140	140
N clusters	120	120	44	44
Adj. R^2	0.060	0.627	0.861	0.862

Standard errors clustered at exporter- and transporter-levels in parentheses.

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

Notes: Shipment is identified with its Bill of Lading identifier. φ, i, c, and d denote exporter, transport company, route, and date of shipment. $N^{daysadvance}(\varphi)$ is the average number of days between shipping order and shipping dates of exporter φ in a year. Container identifies shipments on board of the same vehicle between the same pick-up and drop-off locations at the same time on the last leg of travel to Paraguay.

Table A4. The effect of competition of transport companies on freight prices

Dependent Variable:	$\log Freight_{icm}(\varphi)$				
	(1) OLS	(2) IV	(3) OLS	(4) OLS	(5) I stage
$\log Weight_{icmy}(\varphi)$	0.782***	0.675***	0.675***	0.675***	-0.002
	(0.006)	(0.003)	(0.003)	(0.003)	(0.008)
$\log N_{my}$	-0.378***				
	(0.102)				
$\log \hat{W}eight_{icmy}(\varphi) \cdot \log \hat{N}_{my}$		-0.024*	-0.117*		
		(0.013)	(0.060)		
$\log \hat{W}eight_{icmy}(\varphi) \cdot \hat{1}_{D_{my}\geq 3}$				-0.013**	0.109***
				(0.006)	(0.020)
$\log$ *Gas Price*$_{my}$	1.342***				
	(0.268)				
$\log$ *Currency*$(\varphi)/\$_{my}$	0.360**				
	(0.173)				
$\log$ *Guarani*$/\$_{my}$	-0.423*				
	(0.254)				
Constant	4.183*	1.850***		1.849***	0.013
	(2.196)	(0.028)		(0.028)	(0.076)
Transporter-Exporter-Year	✓				
Transporter-Country-Month		✓	✓	✓	✓
HS2-Month	✓	✓	✓	✓	✓
N obs	41129	98175	98175	98175	98175
N clusters	1457	1281	1281	1281	1281
Adj. R^2	0.929	0.792	0.667	0.792	0.184
First-stage F		21.2			

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

Notes: $Freight_{icmy}(\varphi)$ and $Weight_{icmy}(\varphi)$ denote total freight payment and gross weight (incl. packaging), respectively, transported from exporter φ in country c by transport company i in month-year my. N_{my} denotes the number of transport companies on the river. $1_{D_{my}\geq 3}$ is a dummy variable equals to one when permitted maximum vessel's draft in month-year my is above 3 meters and zero otherwise. $\hat{x}$ denotes x's deviation from its average in month m. HS2 is a 2-digit product code in HS classification.

Table A5. Quantity vs. volume discounts in transportation from Chile to Paraguay

Dependent Variable:	$\log Freight_{icd}(\varphi)$			
	(1)	(2)	(3)	(4)
$\log Weight_{icd}(\varphi)$	0.443***	0.432***		
	(0.014)	(0.039)		
$\log TEU_{icd}(\varphi)$			0.440***	0.432***
			(0.014)	(0.039)
Constant	3.950***	4.363***	8.064***	8.387***
	(0.117)	(0.252)	(0.050)	(0.129)
Transporter-Route-Date	✓	✓	✓	✓
Exporter organized		✓		✓
N obs	1982	150	1982	150
N clusters	402	58	402	58
Adj. R^2	0.867	0.898	0.862	0.898

Standard errors clustered at exporter-, transporter- levels in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Notes: Shipment is defined as a combination of exporter, transport company, date, port of lading and destination. Exporter-organized shipments are those with incoterms CFR, CIF, SCL, and DDP, as in Ardelean & Lugovskyy (2023). Route is defined as port of lading–destination. $Freight_{icd}(\varphi)$, $Weight_{icd}(\varphi)$ and $TEU_{icd}(\varphi)$ denote, respectively, freight payment, gross weight (incl. packaging) and volume (in twenty-foot equivalent units) of a shipment transported from exporter φ by transport company i at time d on route c.

Table A6. Quantity, volume, container count discounts in maritime transportation to Peru

Dependent Variable:	$\log Freight_{icd}(\varphi)$			
	(1)	(2)	(3)	(4)
$\log Weight_{icd}(\varphi)$	0.797***	0.743***		
	(0.047)	(0.042)		
$\log Weight_{y}(\varphi)$	-0.059***	-0.067***		
	(0.015)	(0.016)		
$\log TEU_{icd}(\varphi)$			0.681***	
			(0.051)	
$\log TEU_{y}(\varphi)$			-0.023**	-0.020**
			(0.011)	(0.009)
$\log Containers_{icd}(\varphi)$				0.709***
				(0.088)
20Foot				-0.264***
				(0.068)
$\log TEU_{i}(\varphi)$				0.027
				(0.147)
Constant	0.611	1.271**	7.340***	7.690***
	(0.485)	(0.449)	(0.070)	(0.059)
Transporter×Vessel×Port×Receipt	✓	✓	✓	✓
× HS2		✓		
N obs	781	781	781	781
N clusters	22	22	22	22
Adj. R^2	0.910	0.882	0.830	0.835

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

Robust standard errors clustered at the exporter- and transporter- levels in parentheses.

Notes: Shipment is identified with its Bill of Lading identifier. φ, i, c, d, and y denote exporter, transport company, route, date, and year, respectively. TEU stands for 20-foot container equivalent units.

Table A7. Exporters and importers organizing transportation to Peru

Dependent Variable:	$\mathbb{P}r$ [*Exporter-organized shipment*]			
	(1)	(2)	(3)	(4)
log *Annual Exporter-Transporter TEU*	0.038***		0.046***	0.046***
	(0.005)		(0.005)	(0.005)
log *Annual Importer-Transporter TEU*		0.011**	-0.017***	-0.017***
		(0.005)	(0.005)	(0.006)
log *Shipment TEU*				0.001
				(0.007)
Constant	0.390***	0.467***	0.415***	0.415***
	(0.014)	(0.015)	(0.019)	(0.018)
Transporter-Vessel-Route-Date	✓	✓	✓	✓
N obs	59313	59313	59313	59313
N clusters	31	31	31	31
Adj. R^2	0.417	0.404	0.419	0.419

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

Standard errors clustered at the transporter-level in parentheses.

Notes: Shipment is defined with its declaration number. Exporter-organized shipments are those with incoterms CFR, CIF, SCL, and DDP, as in Ardelean & Lugovskyy (2023). Route is defined as port of departure-port of receipt.