Transportation Cost Heterogeneity: New results for International Trade?

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Abstract

This paper introduces iceberg transportation costs that depend on firm productivity into a model of international trade with monopolistic competition, firm-level heterogeneity, and both constant and variable markups, following the framework of Arkolakis et al. [2019]. Using shipment-level customs data from Chile, I show that larger firms face systematically lower trade costs: a 1% increase in a firm's total imports is associated with a 0.4-0.6 percentage point decline in its iceberg transport cost, measured as freight over CIF. This evidence challenges the standard assumption that trade costs are uniform across firms within a given origin-destination pair. I incorporate a productivity-dependent iceberg cost, $\tau(z) = \tau/z^{\delta}$, into the model and show that it strengthens the selection effect, raising the productivity cutoff for exporting and improving the fit to observed patterns of firm participation and the distribution of export sales. In a counterfactual exercise with a 25% increase in U.S. tariffs, the model with heterogeneous trade costs predicts smaller declines in aggregate exports and in the fraction of exporters than a benchmark with constant iceberg costs, but larger welfare losses, as trade becomes more concentrated in a small set of high-markup firms. These results suggest that ignoring firm-level heterogeneity in transportation costs can bias quantitative assessments of trade policy.

1 Introduction

In recent decades, tariffs and many other policy barriers to trade have fallen substantially, while transportation costs have become a relatively more important determinant of international trade. The COVID-19 pandemic made this particularly salient: spot rates for shipping a 40-foot container on routes from China to the U.S. and China to Europe rose by an order of magnitude relative to their pre-pandemic average. Figure 1 shows that these costs remained roughly stable from 2018 until the onset of the pandemic, but surged to around ten times their average level by the second half of 2021.

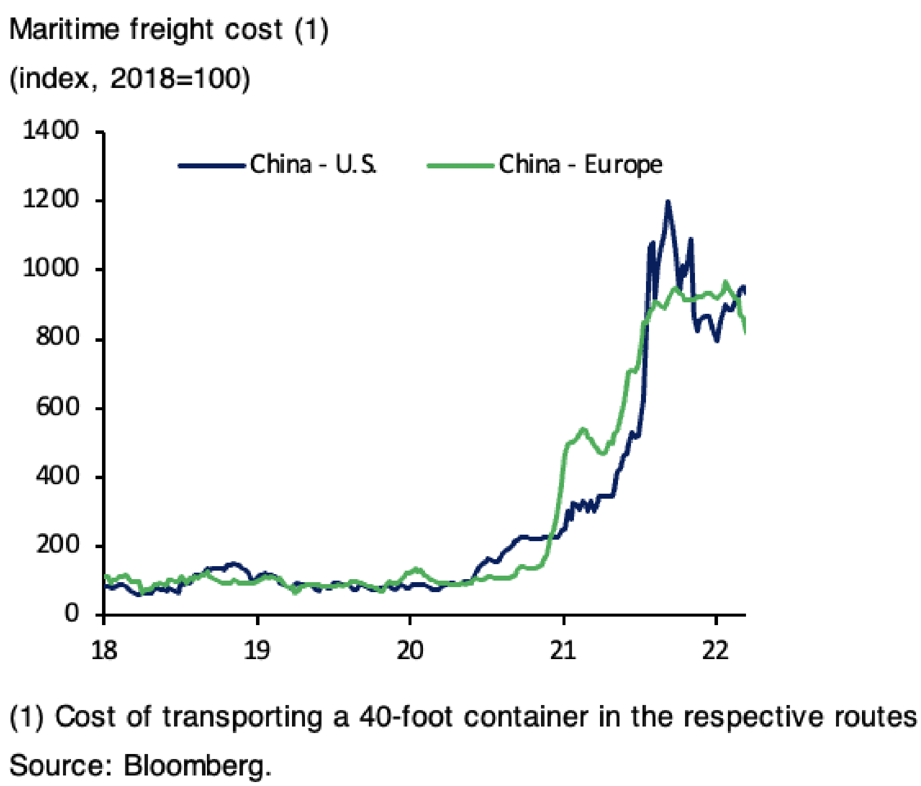


Figure 1: Cost of shipping a 40-foot container from China to the U.S. and Europe

Hummels [2007] argues that transportation costs act as a trade barrier at least as important as tariffs, and often more so. While U.S. average import tariffs declined from about 6% to 1.5% since 1950 (U.S. International Trade Commission), the global average tariff fell from 8.6% to 3.2% between 1960 and 1995 [Clemens and Williamson, 2004]. As tariffs lose prominence, understanding the level and distribution of transportation costs becomes central for analyzing trade flows and welfare.

The case of Chile illustrates this shift particularly clearly. Chile is a small open economy that has pursued an aggressive free-trade strategy. It has negotiated 31 free trade agreements (FTAs) covering 65 economies, which together account for roughly 88% of world GDP. In 2000, around 70% of Chilean imports entered under the General Regime and 30% under FTAs. Two decades later, this pattern has reversed: 80% of imports now benefit from FTAs and only 20% enter under the General Regime. Figure 2 shows this shift in the composition of imports across regimes and documents how effective tariffs have fallen in both regimes. Between 2000 and 2021, tariffs under the General Regime fell from 8% to around 4%, while tariffs under FTAs declined from about 2% to essentially zero. When most trade takes place under FTAs with negligible tariffs, transportation costs become the main variable component of trade frictions.

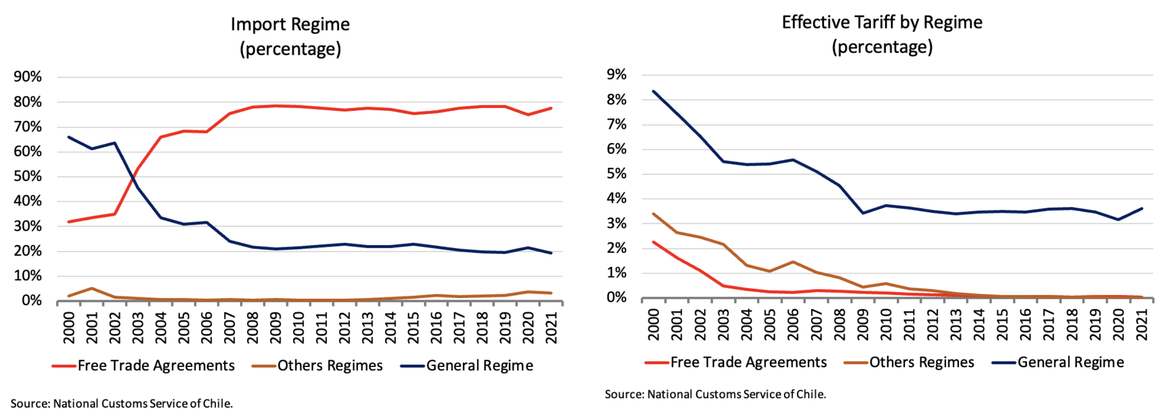


Figure 2: Import regime composition and effective tariffs in Chile

Standard heterogeneous-firm trade models, such as Melitz [2003], typically assume that iceberg trade costs depend only on the origin–destination pair and are identical across firms serving a given route. This assumption is convenient for aggregation, but it rules out systematic heterogeneity in transport costs across firms with different characteristics. In this paper I ask: *Are trade costs really homogeneous across firms on a given route? If not, how does firm-level heterogeneity in transport costs affect trade flows and welfare?*

Using shipment-level customs data for Chile between 2007 and 2017, I show that iceberg transportation costs vary systematically with firm size. Focusing on imports from Shangai in China to San Antonio in Chile, I measure iceberg transport costs as the ratio of freight charges to CIF values and relate this measure to firm size, proxied by total imports. Controlling for weight and experience (years importing in all routes), I find that a 1% increase in a firm's total imports is associated with roughly a 0.41 percentage points decline in its iceberg transport cost. A balanced panel of firms that imported on the Shanghai–San Antonio route in 2007 and are followed through 2017 further shows that shocks to transport costs have highly unequal effects across the firm-size distribution: increases in transport costs reduce both the probability of importing and import volumes substantially more for firms in the bottom three size quintiles than for those in the top two.

Motivated by these facts, I extend a standard heterogeneous-firm trade framework in the spirit of Arkolakis et al. [2019] by allowing iceberg trade costs to depend on firm productivity. In the baseline model, all firms shipping on a given route face the same iceberg factor τ_{ij}. I instead assume that a firm with productivity z faces an effective iceberg cost

$$\tau_{ij}(z) = \frac{\tau_{ij}}{z^{\delta}},$$

so that more productive firms incur lower per-unit trade costs. I embed this specification in an environment with generalized CES (Kimball) preferences, which delivers variable markups and a micro trade elasticity that varies systematically with firm size. Calibrating the productivity elasticity δ to the Chilean estimate of -0.41, I characterize how this modification alters micro and macro trade elasticities and the ACR/ACDR welfare formulas relative to the conventional constant-iceberg-cost benchmark.

The paper makes three contributions. First, on the empirical side, it provides new evidence that iceberg transportation costs decline systematically with firm size and that transport-cost shocks disproportionately affect smaller firms on both the extensive and intensive margins of trade. Second, on the theory side, it introduces productivity-dependent iceberg costs into an ACDR model with generalized CES demand and derives closed-form expressions for micro and macro trade elasticities and welfare that nest the standard ACR and ACDR formulas as special cases. In both CES and generalized CES versions of the model, productivity-dependent trade costs imply smaller gains from trade liberalization and larger welfare losses from higher trade barriers for a given change in trade costs. Third, on the policy side, the framework is used to reassess the effects of recent U.S. tariff increases, showing that ignoring firm-level heterogeneity in transport costs can lead to biased quantitative assessments of the impact of trade policy on aggregate trade flows and welfare.

2 Literature Review

This paper relates to five strands of literature: heterogeneous firm trade models and welfare sufficient statistics, the measurement and determinants of transportation costs, within route freight rate heterogeneity and price discrimination in shipping, firm level heterogeneity in effective policy trade costs, and models with variable markups and micro versus macro trade elasticities.

The first strand builds on heterogeneous firm trade models such as Melitz [2003], in which firms draw productivity, pay fixed and iceberg costs to serve foreign markets, and more productive firms self select into exporting. In these frameworks, iceberg trade costs are typically assumed to depend only on the origin–destination pair and are common across firms serving the same market. Arkolakis et al. [2012] show that, in a broad class of quantitative trade models, welfare gains from trade can be summarized by a small number of sufficient statistics, notably the domestic expenditure share and the trade elasticity. Arkolakis et al. [2019] extend this logic to environments with variable markups, where the micro elasticity faced by individual firms may differ from the macro elasticity governing aggregate trade flows. The present paper maintains the heterogeneous firm structure but relaxes the standard assumption that iceberg trade costs are firm invariant. I allow the effective iceberg cost $\tau_{ij}(z)$ to depend on firm productivity, so that more productive firms face lower per unit trade costs.

A second strand studies the level, structure, and determinants of transportation costs. Hummels [2007] documents the magnitude of freight costs and their importance relative to tariffs. Hummels and Skiba [2004] and Hummels et al. [2009] show that shipping charges depend on product characteristics and value to weight ratios, generating "shipping the good apples out" effects. Brancaccio et al. [2020] endogenize maritime transport costs in a spatial model and show how freight rates depend on the geography of shipping routes and the equilibrium pattern of trade. Relatedly, Allen [2014] emphasizes the role of informational frictions in generating price dispersion across locations. These papers show that transportation costs are not a simple exogenous wedge; they vary systematically with products, routes, market structure, and information. My paper contributes to this literature by focusing on heterogeneity in transport costs across firms within narrowly defined routes and by studying how this heterogeneity changes the aggregate implications of trade cost shocks.

The paper is especially closely related to recent work on within route freight rate heterogeneity and firm size advantages in shipping. Ardelean and Lugovskyy [2023] study price discrimination in liner shipping using Chilean transaction level import data. They show that larger importing firms pay lower freight rates within port to port routes and develop a model in which larger firms request more quotes from carriers and therefore obtain better shipping prices. Their evidence is particularly relevant for the mechanism studied here because it directly challenges the standard assumption that freight rates are uniform across firms within a route. This paper differs from Ardelean and Lugovskyy [2023] in its main object and quantitative use of the evidence. While they focus on the industrial organization of the shipping market and explain why larger importers pay lower freight rates, I take firm size heterogeneity in transportation costs as a disciplined input into a heterogeneous firm trade model. The goal is to study how productivity dependent iceberg costs affect export selection, the distribution of firm sales, micro and macro trade elasticities, markups, and welfare responses to trade policy. Thus, their paper provides a microeconomic foundation for the empirical pattern, while this paper studies its aggregate trade and welfare implications.

A fourth related strand studies firm level heterogeneity in effective policy trade costs. Although statutory tariff rates are usually set at the product–origin level, the effective tariff burden faced by a firm may differ across firms because using preferential trade agreements, complying with rules of origin, documenting origin requirements, or obtaining tariff exemptions involves fixed, informational, and sometimes political costs. Larger and more productive firms may be better able to absorb these costs and therefore may face lower effective tariff-inclusive trade costs than smaller firms. Consistent with this view, Hayakawa [2015] finds that firm size matters for the use of FTA schemes, while Cadot et al. [2014] show that preference utilization is related to firm level characteristics and rules of origin constraints. Recent evidence from the U.S.–China trade war also suggests that effective tariff exposure can vary across firms: Cen et al. [2024] show that government linked firms were more likely to obtain tariff exemptions. This literature reinforces the idea that trade policy shocks need not be uniform across firms in practice, even when statutory tariffs are written at the product–country level. In the counterfactual exercise, I therefore model a tariff increase as a change in the tariff-inclusive iceberg cost faced by firms, allowing the effective impact of the policy shock to interact with productivity through the term $\tau_{ij}(z) = \tau_{ij}/z^{\delta}$. This reduced form specification captures the idea that more productive firms are partly insulated from increases in trade barriers, while less productive firms face larger effective increases in delivered costs and are more likely to exit foreign markets.

A fifth related strand studies dynamic or endogenous reductions in trade costs at the firm level. Alessandria et al. [2021] develop a heterogeneous firm model in which firms gradually reduce iceberg costs by investing in exporting, and show that this mechanism helps account for exporter growth and survival. My paper shares with this work the idea that trade costs need not be fixed at the firm level. The difference is that the mechanism emphasized here is not gradual learning or investment in exporting, but a relationship between firm productivity and the effective cost of serving foreign markets. In the model, this relationship is summarized by the specification $\tau_{ij}(z) = \tau_{ij}/z^{\delta}$, which amplifies productivity differences and changes the selection margin.

The final strand involves models with generalized CES demand, variable markups, and the distinction between micro and macro trade elasticities. Following Kimball [1995] and the empirical evidence on variable markups (e.g. Loecker and Warzynski [2012]), Arkolakis et al. [2019] introduce generalized CES preferences into a heterogeneous firm model and show that the elasticity relevant for firm level responses need not coincide with the elasticity relevant for aggregate trade flows and welfare. This distinction is central for my analysis. When iceberg costs depend on productivity, low productivity firms face disproportionately high delivered marginal costs, while high productivity firms face lower effective trade costs. Under generalized CES demand, this mechanism interacts with variable markups and generates stronger heterogeneity in firm level responses to trade cost shocks. The paper therefore builds on Arkolakis et al. [2019] by adding productivity dependent iceberg costs and quantifying how they change selection, markups, aggregate trade elasticities, and welfare.

Finally, the paper connects to empirical work on heterogeneous firm responses to trade cost and exchange rate shocks. Studies such as Bernard et al. [2007] and Baldwin [2013] document that small and large firms respond differently to changes in trade costs and international prices, both on the extensive and intensive margins. The firm level evidence from Chile presented here shows that increases in transportation costs reduce both the probability of importing and import volumes more strongly for smaller firms. This evidence motivates the variable markup version of the model, in which small and large firms differ not only in their exposure to trade costs but also in their demand elasticities and markup responses.

3 Data and Empirical Evidence

This section outlines the data used to estimate the effect of firm size on transportation costs and details the empirical strategy employed in the analysis.

3.1 Data

To study the heterogeneity of transportation costs, I analyze Chilean import data from 2007 to 2017, provided by the National Customs Service of Chile. The dataset includes variables such as the Operation Number, Importing Company Number, Country of Origin, Country of Destination, Mode of Transport, Port of Shipment, Port of Landing, Freight Cost, Total Weight, CIF, and Product Code (HSC).

Focusing on Chilean imports from China, I analyze shipments where the Port of Origin is Shanghai and the Port of Destination is San Antonio, calculating transportation costs as Freight Cost/CIF. Figure 3 compares transportation costs by quintile for February 2020 (just before the COVID-19 pandemic), February 2021, and February 2022. The left column displays transportation costs by quintile of total firm imports (from all origins), serving as a proxy for firm size or productivity. According to the international trade literature, firms involved in international trade tend to be larger and more productive. The right column shows transportation costs by quintile of the import transaction value.

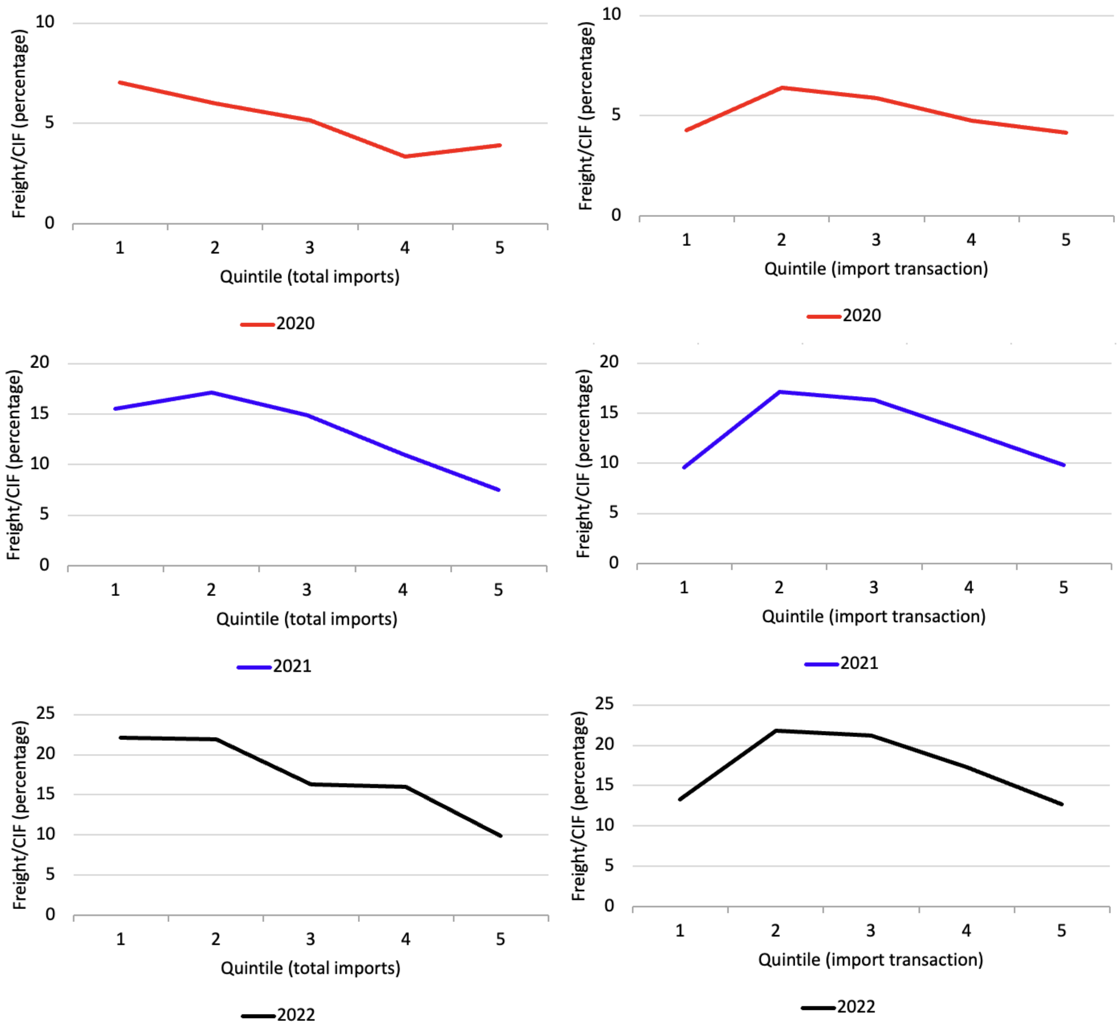


Figure 3: Average Trasnportation Cost by quintile

We can conclude that there is a negative relationship between firm size or productivity and transportation costs, meaning that larger and more productive firms face lower transportation costs. One might hypothesize that this could be related to the fixed costs of transportation, larger firms importing higher, value products should experience lower transportation costs due to the way transportation costs are measured. However, this is not the case. There is no observed relationship between the import value (transaction value) and transportation costs.

3.2 Empirical Strategy

To assess the effect of firm size on transportation costs, I estimate the following regression:

$$y_{i,t} = \alpha + \beta TI_{i,t} + \gamma X_{i,t} + \mu_t + \eta_i + \epsilon_{i,t} \quad (1)$$

Where index i corresponds to the firm and t to the month-year. The dependent variable $y_{i,t}$ corresponds to the transportation cost, measured as the freight cost divided by the import value for firm i in month-year t. The independent variables are as follows: $TI_{i,t}$ which represents the total value of imports from all origins by firm i in month-year t. The vector of controls, denoted by $X_{i,t}$, includes the number of years it has been importing from any country and the weight of the imports. And finally, μ_t represents month-year fixed effects and η_i represents firm or product fixed effects. $\epsilon_{i,t}$ is the unobservable error term.

4 Results

I estimated the OLS regression and applied fixed effects by month-year, and firm fixed effects as shown in Table 1. In Table 2, I included product fixed effects to account for the possibility that larger firms may import different types of products, which could contribute to the observed heterogeneity in transportation costs. Furthermore, in Table 2, I separated transactions into two categories: those with a value less than $14,815 and those between $14,815 and $30,000. The 50% of the transactions are in this range. As discussed in the Data subsection, transaction value could explain some of the heterogeneity, particularly if freight costs have a significant fixed component and larger firms tend to import higher-value products.

In Table 3, I make a robust analysis, using the same regression but for all the combination routes from China to Chile. Applying fixed effects by routes, I find practically the same results, higher total imports of the firm, like a proxy of firm's size or firm's productivity, reduce the transportation cost, practically at the same level. So the results are robust for other routes.

Through these considerations and robust analysis, I found a significant effect: a 1% increase in total imports by the firm from all destinations, serving as a proxy for firm size or productivity, reduces transportation costs, measured as Freight / CIF, between 0.4 and 0.6 percentage points. These results highlight significant heterogeneity in transportation costs across firms and suggest the need to introduce an iceberg cost that depends on firm productivity in an international trade model with firm-level heterogeneity.

This relationship between firm size and productivity is supported by previous research, such as Bernard et al. [2003], which finds that, on average, more efficient suppliers have a greater cost advantage over their competitors, set higher markups, and exhibit higher measured productivity. In addition, more productive firms typically compete with more productive rivals, charge lower prices, and experience higher sales.

Table 1: Effect of Firm's size on Transport Cost

	(1)	(2)	(3)
Freight Cost/CIF	OLS	Year Fixed Effects	Firm Fixed Effects
Total Imports	-0.436***	-0.469***	-0.524***
	(0.008)	(0.008)	(0.027)
Experience (years importing all origins)	-0.249***	-0.146***	0.170
	(0.006)	(0.010)	(0.330)
Total weight	0.546***	0.543***	0.190***
	(0.011)	(0.011)	(0.012)
Constant	9.272***	9.548***	10.999***
	(0.161)	(0.300)	(2.056)
Observations	90,240	90,240	87,577
R-squared	0.078	0.128	0.494
Number of Firms	No	No	3,792
Month-Year FE	No	Yes	Yes
Firm FE	No	No	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2: Effect of Firm's size on Transport Cost

Freight Cost/CIF	(1) Fixed Effects	(2) Fixed Effects	(3) Fixed Effects
Total Imports	-0.380***	-0.571***	-0.288***
	(0.010)	(0.026)	(0.019)
Experience (years importing all origins)	-0.098***	-0.041	-0.007
	(0.011)	(0.033)	(0.020)
Total weight	0.036***	0.453***	2.173***
	(0.013)	(0.039)	(0.057)
Constant	14.349***	29.050***	-5.781***
	(4.697)	(6.262)	(4.095)
Observations	66,898	17,040	17,038
R-squared	0.429	0.440	0.580
Product FE	Yes	Yes	Yes
Month-Year FE	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
*Second column import transaction lower or equal than 14,815.
*Third column import transaction equal or higher than 14,815 and lower than 30,000.

Table 3: Effect of Firm's size on Transport Cost

Freight/CIF	(1) Shanghai–San Antonio	(2) China (all routes)
Total Imports	-0.380***	-0.410***
	(0.010)	(0.003)
Experience (years importing all origins)	-0.098***	-0.060***
	(0.019)	(0.003)
Total weight	0.036***	0.027***
	(0.035)	(0.004)
Constant	14.349***	12.964***
	(4.697)	(0.050)
Observations	66,898	735,924
R-squared	0.429	0.388
Route FE	No	Yes
Product FE	Yes	Yes
Month-Year FE	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.1 Explanation of the fact: Better match or second-degree price discrimination?

The fact told us that larger import firms face lower transportation costs. But what is the explanation of this? Is it due to larger firms matching with more productive transportation firms or is it because transportation firms give lower prices to biggest import firms, due to the fact that bigger firms do more shipments trips?

I analyze this including in the regression the information of the relation with the transportation firm. The first column of Table 4 shows that the hypothesis of a better match is rejected because when I incorporated a fixed effect of the transportation firm, the effect of total import in the transportation cost practically does not change and continues to be significant. If the explanation of a better match would be correct, the effect of total imports should be non-significant because the cause of the lower transportation cost would be the relation with a more productive transportation firm, not the fact to be a bigger importer.

Column 2 of the same table gives the answer. I can see that the explanation for why larger firms face a lower transportation cost is related to the fact that larger firms make a higher number of import transactions with the same transportation firms. Supporting the hypothesis of second-degree price discrimination or nonlinear pricing. This occurs when prices differ depending on the number of units of the good bought, but not across consumers. That is, each consumer faces the same price schedule, but the schedule involves different prices for different amounts of the good purchased. Quantity discounts or premia are the obvious examples (Varian [1985]). So, in this case, the transportation firm cannot observe the buyer's willingness to pay or productivity. But it offers a menu of price-quantity bundles. Buyers choose the bundle that gives them the highest utility. Larger buyers (with higher demand or productivity) tend to choose bigger bundles with lower per-unit prices.

Table 4: Effect of Firm's size on Transport Cost

Freight Cost/CIF	(1) Fixed Effects	(2) Fixed Effects
Total Imports	-0.358***	
	(0.011)	
Experience (years importing all origins)	-0.079***	-0.140***
	(0.011)	(0.011)
Total weight	0.015	-0.020
	(0.013)	(0.013)
Transactions (by transportation firm)		-0.055***
		(0.003)
Constant	12.230***	7.913***
	(0.188)	(0.139)
Observations	66,756	66,756
R-squared	0.437	0.430
Product FE	Yes	Yes
Month-Year FE	Yes	Yes
Trans. Firm FE	Yes	Yes

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

5 Firm-Level Evidence on Intensive and Extensive Margin Responses

To discipline the heterogeneity in transport-cost elasticities in the model, I assemble a balanced panel of Chilean importers that were already active in 2007. This construction fixes the composition of firms ex ante, so that subsequent changes in importing activity can be interpreted as intensive and extensive margin responses of the same set of firms to shocks in transportation costs, rather than to entry and exit of new firms.

For each firm, I compute total imports and assign the firm to a quintile of the 2007 size distribution. Quintiles 1–3 (Q1–Q3) are interpreted as "smaller" firms, while quintiles 4–5 (Q4–Q5) correspond to larger firms. Using transaction-level customs data, I then construct a quarterly measure of the ad–valorem transport cost paid by firms in each quintile on this route, defined as:

$$\text{Transport Cost}_{q,t} = \frac{\text{Freight}_{q,t}}{\text{CIF}_{q,t}},$$

where $\text{Freight}_{q,t}$ and $\text{CIF}_{q,t}$ denote the total freight charges and CIF value for all imports of quintile q in quarter t. This yields a panel of firm–quarter observations where the transport-cost variable varies over time and across size quintiles, but is common to all firms within a given quintile in a given quarter.

I measure the extensive margin of importing with a dummy variable $\text{Imported}_{i,t}$ that equals one if firm i records at least one import transaction in quarter t, and zero otherwise. The intensive margin is captured by the value of imports per firm and quarter, $\text{ImportTransaction}_{i,t}$. I estimate panel regressions of the form

$$y_{i,t} = \alpha + \beta_1 \, \text{TC}_{q(i),t} + \beta_2 \, \text{TC}_{q(i),t} \times \mathbf{1}\{i \in Q1\text{–}Q3\} + \delta_t + \varepsilon_{i,t},$$

where $y_{i,t}$ is either the import dummy or the import value, $\text{TC}_{q(i),t}$ is the transport-cost index for the quintile $q(i)$ to which firm i belongs, and δ_t are quarter-year fixed effects that absorb common seasonal and macroeconomic shocks. The interaction term $\text{TC}_{q(i),t} \times \mathbf{1}\{i \in Q1\text{–}Q3\}$ allows the elasticity with respect to transport costs to differ between smaller (Q1–Q3) and larger (Q4–Q5) firms. Standard errors are robust to heteroskedasticity.

Table 5: Extensive and Intensive Margin 2007-2017

	(1)	(2)
Dependent Variable	Imported (dummy)	Import Transaction
Transport Cost	-0.020***	-0.378***
	(0.000)	(0.002)
TC*Dummy(Q1,Q2,Q3)	-0.020***	-0.052***
	(0.000)	(0.001)
Constant	0.928***	14.126***
	(0.002)	(0.020)
Observations	1,403,072	464,381
R-squared	0.215	0.463
Year-Quarter FE	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5 reports the main coefficients. In the extensive-margin regression (column 1), the coefficient on TC is -0.020 and statistically significant at the 1% level. This implies that, for firms in the top two quintiles (Q4–Q5), an increase in the transport-cost index is associated with a lower probability of importing on the route. The interaction term TC $\times$ $\mathbf{1}\{Q1\text{–}Q3\}$ is also negative (-0.020) and significant, indicating that smaller firms in Q1–Q3 react more strongly: their total effect is $\beta_1 + \beta_2 = -0.040$, so the sensitivity of their importing probability to changes in transport costs is exactly double that of larger firms. In other words, an increase in the transport-cost index reduces the probability of importing significantly more for small firms than for large firms, confirming that higher transport costs disproportionately raise the likelihood of exit from importing among smaller importers.

The intensive-margin regression (column 2) shows an even stronger asymmetry. For firms in Q4–Q5, the coefficient on TC is -0.378, implying that an increase in transport costs is associated with a sizable reduction in import values among continuing importers. For smaller firms in Q1–Q3, the additional interaction effect is -0.052, so that their total response is $\beta_1 + \beta_2 \approx -0.430$, which is substantially larger in absolute value than the response of larger firms. Hence, conditional on remaining active, smaller firms cut their import volumes more aggressively when transport costs rise.

Overall, these results provide direct micro evidence that transport-cost shocks hit smaller importers disproportionately, both on the extensive margin (probability of importing) and on the intensive margin (import volumes). This pattern is especially informative for the generalized CES (Kimball) version of the model, in which the *micro* elasticity of demand and the markup elasticity ρ_d vary systematically with firm size. In that environment, smaller (low-productivity) firms face more elastic demand, charge lower markups, and therefore experience a larger quantity response when their marginal cost increases, while larger firms face less elastic demand and adjust quantities less. The empirical finding that firms in the bottom three quintiles (Q1–Q3) are both more likely to stop importing and, conditional on continuing, reduce their import volumes almost twice as much as firms in Q4–Q5 is exactly the pattern implied by variable markups and size-dependent demand elasticities. By contrast, under CES preferences the demand elasticity is constant and all firms face the same intensive-margin response to a given change in marginal cost, so heterogeneity would operate only through the extensive margin. The strong size gradient in both margins documented here thus supports the generalized CES specification and the interpretation that productivity-dependent trade costs and variable markups are key to understanding how transport-cost shocks propagate across firms.

6 Model: ACDR with iceberg costs dependent on firm productivity

In this section, I incorporate transportation costs that depend on firm productivity into a model with monopolistic competition, firm-level heterogeneity, and variable vs. constant markups, following the framework of Arkolakis et al. (2019). The key departure from the standard model is that iceberg trade costs are decreasing in firm productivity, consistent with the empirical evidence that larger firms face lower iceberg costs.

Environment and preferences

Consider a world economy consisting of countries $i = 1, \ldots, n$, a single factor of production (labor), and a continuum of differentiated goods indexed by $\omega \in \Omega$. Individuals are perfectly mobile across the production of different goods within a country but immobile across countries. Let L_i denote the population and w_i the wage in country i.

All consumers share the same preferences and income y, which derives from wages and, possibly, domestic firm profits. If a consumer with income y faces a schedule of prices $p \equiv \{p(\omega)\}_{\omega \in \Omega}$, her Marshallian demand for any variety ω is

$$q_\omega(p, y) = Q(p, y)\, D\left(\frac{p_\omega}{P(p, y)}\right), \tag{2}$$

where $D(\cdot)$ is strictly decreasing, and $Q(p, y)$ and $P(p, y)$ are aggregate demand shifters that firms take as given. The function $Q(p, y)$ affects the level of demand, while $P(p, y)$ affects both the level and the elasticity of demand.

The demand system is completed by assuming that $Q(p, y)$ and $P(p, y)$ jointly solve

$$\int_{\omega \in \Omega} \left[H\left(\frac{p_\omega}{P}\right)\right]^\beta \left[p_\omega Q D(p_\omega, P)\right]^{1-\beta} d\omega = y^{1-\beta}, \tag{3}$$

$$Q^{1-\beta} \left[\int_{\omega \in \Omega} p_\omega Q D(p_\omega, P)\, d\omega\right]^\beta = y^\beta, \tag{4}$$

with $\beta \in (0, 1)$ and $H(\cdot)$ strictly increasing and strictly concave.

Three properties of this demand system are important. First, the own-price elasticity $\partial \ln D(p_\omega / P(p, y)) / \partial \ln p_\omega$ varies with prices, so markups are variable under monopolistic competition. Second, the demand for any good ω depends on other prices only through the aggregate shifters $Q(p, y)$ and $P(p, y)$. Third, β governs (non-)homotheticity: when $\beta = 1$, $P(p, y)$ is independent of y and $Q(p, y)$ is proportional to y; when $\beta = 0$, preferences are generally non-homothetic unless $D(\cdot)$ is isoelastic (CES).

There exists a threshold a such that $D(x) = 0$ for all $x \geq a$. Without loss of generality, I normalize $a = 1$, so that $P(p, y)$ coincides with the choke price. In the absence of fixed costs of accessing domestic and foreign markets, the case I focus on, this assumption implies that the appearance or disappearance of "cutoff" goods has no first-order effect on welfare at the margin.

It is convenient to write demand so as to highlight both the symmetry across goods and the role of the aggregate shifters. I thus write

$$q_\omega(p, y) \equiv q(p_\omega, Q(p, y), P(p, y)), \tag{5}$$

with

$$q_\omega(p_\omega, Q, P) = Q\, D\left(\frac{p_\omega}{P}\right). \tag{6}$$

Firms, productivity, and iceberg costs

Firms compete under monopolistic competition. Entry may be restricted or free. Under restricted entry, there is an exogenous measure of firms N_i with the right to operate in each country i. Under free entry, ex ante identical firms pay a fixed cost $F_i > 0$ units of labor to enter and choose to do so until aggregate profits net of entry costs, $w_i F_i$, are driven to zero. I denote by N_i the equilibrium measure of firms in country i.

Upon entry, the production of any differentiated good exhibits constant returns to scale. Each firm in country i draws its productivity z from a Pareto distribution,

$$G_i(z) = 1 - \left(\frac{b_i}{z}\right)^\theta, \qquad z \geq b_i, \quad \theta > 0, \tag{7}$$

with lower bound $b_i > 0$ and common shape parameter θ across countries.

The key innovation of the model is the treatment of iceberg trade costs. In standard heterogeneous-firm trade models, each firm from country i that wishes to sell in j faces a constant iceberg cost $\tau_{ij} \geq 1$. Here I instead assume that iceberg costs decrease with firm productivity according to

$$\tau_{ij}(z) = \frac{\tau_{ij}}{z^{\delta}}, \qquad \delta \geq 0, \tag{8}$$

where τ_{ij} is a baseline bilateral trade cost and δ governs how strongly transport costs vary with productivity. When $\delta = 0$, $\tau_{ij}(z) = \tau_{ij}$ and I recover the standard assumption of homogeneous iceberg costs. When $\delta > 0$, more productive firms (z high) face lower iceberg costs, in line with the empirical evidence that bigger firms pay lower transportation charges.

Producing one unit of the good requires w_i/z units of labor, and delivering it to destination j requires $\tau_{ij}(z)$ units to arrive. The constant marginal cost of supplying one unit to country j is therefore:

$$c_{ij}(z) = \frac{w_i}{z}\,\tau_{ij}(z) = \frac{w_i \tau_{ij}}{z^{1+\delta}}. \tag{9}$$

Relative to the standard case $c_{ij}(z) = (w_i\tau_{ij})/z$ ($\delta = 0$), productivity differences are now amplified by the factor $z^{-\delta}$: low-productivity firms face disproportionately higher trade costs, while high-productivity firms enjoy disproportionately lower trade costs.

Monopolistic competition, pricing, and export cutoffs

Goods markets are perfectly segmented across countries and parallel trade is prohibited, so firms set a market-specific monopoly price in each destination. Consider a firm from i selling in some destination j at marginal cost c and facing aggregate demand shifters (Q_j, P_j). Under monopolistic competition, the firm chooses price p to maximize destination-specific profits:

$$\pi(c, Q_j, P_j) = \max_{p} \big(p - c\big)\, q(p, Q_j, P_j), \tag{10}$$

taking Q_j and P_j as given. The associated first-order condition can be written as:

$$\frac{p-c}{p} = -\frac{1}{\partial \ln q(p, Q_j, P_j)/\partial \ln p}, \tag{11}$$

which states that markups are inversely related to the demand elasticity.

Define the firm-level markup as $m \equiv p/c$. Using $q(p, Q_j, P_j) = Q_j D(p/P_j)$ and the fact that $D(\cdot)$ is strictly decreasing, one can rewrite the first-order condition as

$$m = \frac{\varepsilon_D(m/v)}{\varepsilon_D(m/v) - 1}, \tag{12}$$

where

$$\varepsilon_D(x) \equiv -\frac{\partial \ln D(x)}{\partial \ln x}$$

is the demand elasticity and

$$v \equiv \frac{P_j}{c}$$

is a market-specific measure of the firm's efficiency relative to other firms in that market. Under my cost specification, this relative efficiency term is:

$$v(z) = \frac{P_j}{c_{ij}(z)} = \frac{P_j z^{1+\delta}}{w_i \tau_{ij}}. \tag{13}$$

Given v, the markup m is determined as the unique solution of

$$m = \mu(v), \tag{14}$$

where $\mu(\cdot)$ is increasing in the effective price index P_j and increasing in productivity z. For a firm with marginal cost c and relative efficiency v, the optimal price in market j is then $p(c, v) = c\,\mu(v)$.

Given this pricing rule, total sales by a firm with marginal cost c and relative efficiency v in a market with aggregate shifter Q_j and population L_j are

$$x(c, v, Q_j, L_j) = L_j Q_j\, c\,\mu(v)\, D\left(\frac{\mu(v)}{v}\right), \tag{15}$$

and profits in that market are

$$\pi(c, v, Q_j, L_j) = \left(\frac{\mu(v) - 1}{\mu(v)}\right) x(c, v, Q_j, L_j). \tag{16}$$

Let P_j be the choke price in country j. Only firms with $c_{ij}(z) \leq P_j$ can profitably serve that market. Using $c_{ij}(z) = w_i \tau_{ij}/z^{1+\delta}$, the export productivity cutoff z^*_{ij} is implicitly defined by

$$P_j = \frac{w_i \tau_{ij}}{(z^*_{ij})^{1+\delta}}, \tag{17}$$

so that

$$z_{ij}^* = \left(\frac{w_i \tau_{ij}}{P_j}\right)^{\frac{1}{1+\delta}}. \tag{18}$$

Relative to the standard ACDR case with homogeneous iceberg costs ($\delta = 0$), where $z_{ij}^* = w_i \tau_{ij}/P_j$, a higher $\delta > 0$ implies a higher export cutoff for given (w_i, τ_{ij}, P_j). Intuitively, because low-productivity firms face disproportionately high iceberg costs, they are driven out of international trade, strengthening the selection effect.

Bilateral trade flows, profits, and equilibrium

Let X_{ij} denote total sales by firms from i in country j. Only firms with $z \geq z_{ij}^*$ serve market j, so

$$X_{ij} = N_i \int_{z_{ij}^*}^{\infty} x\left(c_{ij}(z),\, \left(\frac{z}{z_{ij}^*}\right)^{1+\delta},\, Q_j,\, L_j\right) dG_i(z), \tag{19}$$

Substituting $c_{ij}(z) = w_i \tau_{ij}/z^{1+\delta}$, the Pareto distribution for z, and performing the change of variables $v = (z/z_{ij}^*)^{1+\delta}$, one obtains (see Appendix for details)

$$X_{ij} = \chi(\delta)\, N_i\, b_i^{\theta}\, (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}}\, L_j\, Q_j\, P_j^{\frac{\theta+1+\delta}{1+\delta}}, \tag{20}$$

where $\chi(\delta) > 0$ is a constant that depends on the demand system and on δ.

Let Π_{ij} denote aggregate profits of firms from i in country j (gross of any entry costs). Using the profit expression above, the Pareto distribution, and the same change of variables, aggregate profits can be written as:

$$\Pi_{ij} = \pi(\delta)\, N_i\, b_i^{\theta}\, (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}}\, L_j\, Q_j\, P_j^{\frac{\theta+1+\delta}{1+\delta}}, \tag{21}$$

where $\pi(\delta) > 0$ is another constant. It follows that profits are a constant share of sales:

$$\Pi_{ij} = \zeta(\delta)\, X_{ij}, \qquad \zeta(\delta) \equiv \frac{\pi(\delta)}{\chi(\delta)} \in (0, 1). \tag{22}$$

Aggregate income in country j is the sum of wages and profits, which must equal the total sales of firms from j:

$$Y_j \equiv y_j L_j = \sum_i X_{ij}. \tag{23}$$

With free entry, the measure of entrants in country i satisfies

$$N_i = \frac{1}{w_i F_i} \sum_j \Pi_{ij}, \tag{24}$$

so expected profits across all markets equal the entry cost.

Labor market clearing in country i requires that the total wage bill equals total sales of firms from i:

$$w_i L_i = \sum_j X_{ij}. \tag{25}$$

A trade equilibrium consists of price schedules $\{p_i(\omega)\}$, measures of firms $\{N_i\}$, and wages $\{w_i\}$ such that (i) firms optimally set monopoly prices in each market given their marginal costs $c_{ij}(z)$ and aggregate demand shifters (Q_j, P_j), (ii) free entry (or restricted entry) conditions hold, and (iii) labor markets clear in every country. Given these conditions, trade is necessarily balanced: using the budget constraint of the representative consumer and aggregating demand across varieties, one obtains:

$$\sum_i X_{ji} = \sum_i X_{ij}. \tag{26}$$

6.1 Micro and macro trade elasticities under CES (constant markups)

It is useful to distinguish between a *micro* trade elasticity, the sensitivity of a single firm's exports to changes in trade costs, holding its productivity fixed, and a *macro* trade elasticity, which describes the response of aggregate exports to the same shock once the entry and exit of exporters are taken into account.

Consider first the case of CES demand with elasticity $\sigma > 1$ and constant markups. Under CES, the firm-level markup is:

$$m = \mu = \frac{\sigma}{\sigma - 1},$$

independent of productivity or destination. With productivity-dependent iceberg costs:

$$\tau_{ij}(z) = \frac{\tau_{ij}}{z^{\delta}}, \qquad c_{ij}(z) = \frac{w_i \tau_{ij}}{z^{1+\delta}},$$

the price charged by a firm with productivity z from i in market j is a constant markup over marginal cost:

$$p_{ij}(z) = \mu\, c_{ij}(z) \propto \frac{\tau_{ij}}{z^{1+\delta}}.$$

Demand for this variety is CES,

$$q_{ij}(z) \propto \left(\frac{p_{ij}(z)}{P_j}\right)^{-\sigma},$$

so revenue (exports of firm z to j) is

$$x_{ij}(z) = p_{ij}(z)\, q_{ij}(z) \;\propto\; p_{ij}(z)^{1-\sigma} \;\propto\; \left(\frac{\tau_{ij}}{z^{1+\delta}}\right)^{1-\sigma}.$$

The *micro* trade elasticity for a firm with productivity z is defined as

$$\varepsilon^{\text{CES}}_{\text{micro}}(z) \equiv \left.\frac{\partial \ln x_{ij}(z)}{\partial \ln \tau_{ij}}\right|_{z, Q_j, P_j}. \tag{27}$$

Using the expression above,

$$\varepsilon^{\text{CES}}_{\text{micro}}(z) = \frac{\partial \ln x_{ij}(z)}{\partial \ln \tau_{ij}} = 1 - \sigma = -(\sigma - 1),$$

which is independent of z. In the CES case with constant markups, all surviving exporters face the same micro elasticity, and this elasticity depends only on the curvature of demand.

The *macro* trade elasticity is defined at the level of aggregate bilateral exports,

$$\varepsilon_{\text{macro}} \equiv \frac{\partial \ln X_{ij}}{\partial \ln \tau_{ij}}, \tag{28}$$

where X_{ij} aggregates over all firms with $z \geq z^*_{ij}$. With productivity-dependent iceberg costs and Pareto productivity, aggregate exports take the form

$$X_{ij} = \chi(\delta)\, N_i\, b_i^{\theta}\, (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}}\, L_j\, Q_j\, P_j^{\frac{\theta+1+\delta}{1+\delta}},$$

so that

$$\varepsilon_{\text{macro}} = \frac{\partial \ln X_{ij}}{\partial \ln \tau_{ij}} = -\frac{\theta}{1+\delta}. \tag{29}$$

Comparison with the baseline model (constant transportation costs). In the original Melitz–CES model with *homogeneous* iceberg costs (the special case $\delta = 0$), marginal cost is $c_{ij}(z) = w_i \tau_{ij}/z$, and the micro elasticity is

$$\varepsilon^{\text{CES}}_{\text{micro, baseline}}(z) = 1 - \sigma,$$

identical for all exporters. The macro trade elasticity is

$$\varepsilon_{\text{macro, baseline}} = -\theta,$$

so aggregate exports vary with trade costs according to $X_{ij} \propto \tau_{ij}^{-\theta}$. Introducing productivity-dependent iceberg costs with $\delta > 0$ leaves the micro CES elasticity *unchanged*: conditional on continuing to export, each firm's exports still respond with elasticity $1 - \sigma$ to changes in τ_{ij}. However, the macro elasticity becomes

$$\varepsilon_{\text{macro}} = -\frac{\theta}{1 + \delta},$$

so aggregate trade becomes less elastic in absolute value as δ increases. Intuitively, making trade costs fall with productivity strengthens selection (low-z firms are already screened out), so a given change in τ_{ij} has a smaller proportional effect on total exports, even though the intensive-margin response of each surviving firm is the same as in the baseline model.

6.2 Micro and macro trade elasticities under generalized CES (variable markups)

In the generalized CES environment of Arkolakis et al. (2019), the demand elasticity is not constant and markups vary with the relative efficiency term $v(z) = P_j/c_{ij}(z)$. This generates systematic heterogeneity in firm-level responses to trade costs, even conditional on continuing to export.

As before, for a firm with productivity $z \geq z^*_{ij}$ exporting from i to j, destination-specific exports are

$$x_{ij}(z) \equiv x(c_{ij}(z), v(z), Q_j, L_j)\,,$$

with marginal cost

$$c_{ij}(z) = \frac{w_i \tau_{ij}}{z^{1+\delta}}, \qquad v(z) = \frac{P_j}{c_{ij}(z)} = \frac{P_j z^{1+\delta}}{w_i \tau_{ij}}.$$

The *micro* trade elasticity of firm z is

$$\varepsilon_{\text{micro}}(z) \equiv \left. \frac{\partial \ln x_{ij}(z)}{\partial \ln \tau_{ij}} \right|_{z,\, Q_j,\, P_j} = \frac{\partial \ln x_{ij}(z)}{\partial \ln c_{ij}(z)}. \tag{30}$$

Using the ACDR revenue representation

$$x(c, v, Q_j, L_j) = L_j Q_j \, c \, \mu(v) \, D\left(\frac{\mu(v)}{v}\right),$$

and defining

$$\eta(x) \equiv \frac{\partial \ln D(x)}{\partial \ln x} < 0, \qquad \phi(v) \equiv \frac{\partial \ln \mu(v)}{\partial \ln v},$$

one can show (by differentiating $\ln x$ with respect to $\ln c$) that

$$\varepsilon_{\text{micro}}(z) = \left[1 + \eta\left(\tfrac{\mu(v(z))}{v(z)}\right)\right] \left[1 - \phi\big(v(z)\big)\right], \tag{31}$$

with $v(z) = P_j z^{1+\delta}/(w_i \tau_{ij})$. Unlike in the CES case with constant markups, the micro elasticity now depends on productivity z: low-productivity firms have higher marginal costs, set higher prices relative to P_j, and typically operate in a region of the demand curve where demand is more elastic and markups are lower. As a result, even *conditional on continuing to export*, low-productivity (smaller) firms exhibit a more negative $\varepsilon_{\text{micro}}(z)$ than high-productivity (larger) firms. This pattern is consistent with the micro evidence in my data, where conditional on survival smaller chilean importers reduce their trade volumes by more when transportation costs increase.

Turning to aggregate exports, recall from Section 6 that with productivity-dependent iceberg costs, Pareto productivity and generalized CES demand, bilateral exports can be written as:

$$X_{ij} = \chi(\delta) \, N_i \, b_i^{\theta} \, (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}} \, L_j \, Q_j \, P_j^{\frac{\theta+1+\delta}{1+\delta}},$$

for some constant $\chi(\delta) > 0$ that depends on the demand system and on δ. From this expression, the *macro* trade elasticity is:

$$\varepsilon_{\text{macro}} = \frac{\partial \ln X_{ij}}{\partial \ln \tau_{ij}} = -\frac{\theta}{1+\delta}. \tag{32}$$

This elasticity is independent of the generalized CES parameters and of the exact pattern of micro responses, and it can be interpreted as combining (i) the heterogeneous intensive-margin elasticities $\varepsilon_{\text{micro}}(z)$ across all exporters with (ii) the extensive-margin effect coming from changes in the export cutoff z_{ij}^*.

Comparison with the baseline model (constant transportation costs). In the baseline generalized CES model with *homogeneous* iceberg costs ($\delta = 0$, $c_{ij}(z) = w_i\tau_{ij}/z$), the structure of the micro elasticity is the same,

$$\varepsilon_{\text{micro, baseline}}(z) = \left[1 + \eta\left(\tfrac{\mu(v_0(z))}{v_0(z)}\right)\right]\left[1 - \phi\big(v_0(z)\big)\right], \qquad v_0(z) = \frac{P_j z}{w_i\tau_{ij}},$$

so low-productivity firms are already more fragile to changes in trade costs than highly productive firms, conditional on exporting. The macro trade elasticity in that baseline case is

$$\varepsilon_{\text{macro, baseline}} = -\theta,$$

so aggregate exports vary according to $X_{ij} \propto \tau_{ij}^{-\theta}$, independently of the details of demand and markups.

Introducing productivity-dependent iceberg costs, $\tau_{ij}(z) = \tau_{ij}/z^{\delta}$ with $\delta > 0$, leaves the *form* of the micro elasticity unchanged but modifies the argument from $v_0(z) = P_j z/(w_i\tau_{ij})$ to $v(z) = P_j z^{1+\delta}/(w_i\tau_{ij})$. This amplifies heterogeneity across firms: because $v(z)$ grows faster in z, the wedge between low and high productivity firms in terms of demand curvature and markups becomes larger, and small firms' micro elasticities become even more negative relative to those of large firms. At the macro level, the trade elasticity changes from $-\theta$ in the baseline model to $-\theta/(1+\delta)$ in the heterogeneous-cost model, reflecting the fact that selection has already removed many low-productivity exporters before a change in τ_{ij} occurs. Thus, relative to the original model, the new specification delivers stronger heterogeneity in micro elasticities across firms and a macro elasticity that is smaller in absolute value.

Micro vs. macro trade elasticities: summary

For reference, the table below summarizes the micro and macro trade elasticities in the baseline model with homogeneous iceberg costs ($\delta = 0$) and in the extended model with productivity-dependent iceberg costs $\tau_{ij}(z) = \tau_{ij}/z^{\delta}$, for both CES and generalized CES demand.

	Micro elasticity $\varepsilon_{\text{micro}}$	Macro elasticity $\varepsilon_{\text{macro}}$
Baseline model: homogeneous iceberg costs ($\delta = 0$)		
CES (constant markups)	$1-\sigma = -(\sigma-1)$	$-\theta$
Generalized CES (variable markups)	$\left[1+\eta\left(\frac{\mu(v_0(z))}{v_0(z)}\right)\right]\left[1-\phi\big(v_0(z)\big)\right]$ with $v_0(z) = \dfrac{P_j z}{w_i \tau_{ij}}$	$-\theta$
Extended model: productivity-dependent iceberg costs ($\delta > 0$)		
CES (constant markups)	$1-\sigma = -(\sigma-1)$	$-\dfrac{\theta}{1+\delta}$
Generalized CES (variable markups)	$\left[1+\eta\left(\frac{\mu(v(z))}{v(z)}\right)\right]\left[1-\phi\big(v(z)\big)\right]$ with $v(z) = \dfrac{P_j z^{1+\delta}}{w_i \tau_{ij}}$	$-\dfrac{\theta}{1+\delta}$

Economically, the table highlights three key points. First, in all cases the *micro* elasticity is an intensive-margin object: it describes how the exports of a given firm respond to a change in trade costs, conditional on remaining an exporter. Under CES with constant markups, this elasticity is the same for all firms and depends only on the demand elasticity σ. Under generalized CES with variable markups, it is heterogeneous in productivity z and depends on demand curvature and markup adjustment.

Second, the *macro* elasticity is an aggregate object that combines the intensive responses of all exporters with entry and exit at the export cutoff. With a Pareto productivity distribution, macro elasticities take a simple closed form that depends only on the tail parameter θ and on the exponent δ governing how trade costs vary with productivity.

Third, introducing productivity-dependent iceberg costs ($\delta > 0$) leaves the CES micro elasticity unchanged but makes the macro elasticity less elastic in absolute value, $-\theta \to -\theta/(1+\delta)$, and amplifies the heterogeneity of micro elasticities under generalized CES by making low-productivity firms particularly fragile to changes in transportation costs.

7 Calibration of the productivity elasticity of transport costs

In the model, the effective iceberg transport cost for a firm i shipping from country i to destination j is

$$\tau_{ij}^{\text{eff}}(z_i) = \frac{\tau_{ij}}{z_i^{\delta}}, \tag{33}$$

where τ_{ij} is a baseline bilateral trade cost, z_i is firm-level productivity, and $\delta > 0$ governs how strongly higher productivity reduces per-unit trade frictions. Taking logs,

$$\ln \tau_{ij}^{\text{eff}}(z_i) = \ln \tau_{ij} - \delta \ln z_i, \tag{34}$$

so that

$$\frac{\partial \ln \tau_{ij}^{\text{eff}}(z_i)}{\partial \ln z_i} = -\delta. \tag{35}$$

By construction, δ is the (minus) elasticity of the iceberg factor with respect to firm productivity.

From the semi-elasticity to the elasticity δ. To map the regression coefficient into the model parameter δ, note that the model relationship in (35) can be written locally as

$$\Delta \ln \tau_{ij}^{\text{eff}}(z_i) \approx -\delta\, \Delta \ln z_i. \tag{36}$$

Using a first-order approximation,

$$\Delta \ln \tau_{ij}^{\text{eff}}(z_i) \approx \frac{\Delta \tau_{ij}^{\text{eff}}}{\bar{\tau}}, \tag{37}$$

where $\bar{\tau}$ is the mean iceberg factor in the data. Combining these expressions gives

$$\frac{\Delta \tau_{ij}^{\text{eff}}}{\bar{\tau}} \approx -\delta\, \Delta \ln z_i \quad \Rightarrow \quad \frac{\partial \tau_{ij}^{\text{eff}}}{\partial \ln z_i} \approx -\delta\, \bar{\tau}. \tag{38}$$

On the empirical side, the regression (1) implies

$$\frac{\partial \tau_{i,t}}{\partial \ln \text{Total Imports}_i} = \beta_{\text{size}}. \tag{39}$$

Interpreting firm size as a proxy for productivity ($\Delta \ln z_i \approx \Delta \ln \text{Total Imports}_i$) and identifying the model iceberg factor with its empirical counterpart ($\tau_{ij}^{\text{eff}} \simeq \tau_{i,t}$), we can equate the model-implied slope in (38) with the empirical slope in (39):

$$\beta_{\text{size}} \approx -\delta\,\bar{\tau} \quad \Rightarrow \quad \delta \approx -\frac{\beta_{\text{size}}}{\bar{\tau}}. \tag{40}$$

The average transport-cost share in the sample is about 68%, so the mean iceberg factor is

$$\bar{\tau} \approx 1 + 0.68 = 1.68. \tag{41}$$

Using the China-all-routes estimate (Table 3) $\beta_{\text{size}} = -0.410$, equation (40) yields

$$\delta = -\frac{-0.410}{1.68} \approx 0.24. \tag{42}$$

For the Shanghai–San Antonio route alone (Table 3) ($\beta_{\text{size}} = -0.380$), the implied value is $\delta \approx 0.23$. In the baseline calibration, I set

$$\delta = 0.24, \tag{43}$$

which lies between these two estimates and is directly disciplined by the firm-level relationship between iceberg costs and size.

Economic interpretation. The calibrated value $\delta \approx 0.24$ has a straightforward interpretation. From (35), it implies that a 1% increase in firm productivity (or, empirically, in firm size) reduces the iceberg transport cost by about 0.24%:

$$\frac{\partial \ln \tau_{ij}^{\text{eff}}(z_i)}{\partial \ln z_i} = -\delta \approx -0.24. \tag{44}$$

Equivalently, doubling productivity ($z_i \times 2$) lowers the iceberg factor by a factor

$$2^{-\delta} = 2^{-0.24} \approx 0.85, \tag{45}$$

that is, by roughly 15%. A firm that is twice as productive as another otherwise similar firm therefore faces an iceberg transport cost about 15% lower. This calibration makes explicit how the semi-elasticity estimated in the data (a reduction of about 0.4 percentage points in the iceberg cost for a 1% increase in total imports) translates into the structural parameter δ in the model.

8 New Model, New Results

In this section, I analyze how the results of the model change when incorporating an iceberg cost that depends on firm productivity. Starting from the calibrated economy of Arkolakis et al. [2019], I compare the outcomes of the standard model with those of the new model, where transportation costs vary with firm productivity.

I rely on numerical simulations, focusing on a world economy with two symmetric countries. I normalize country size to $L = 1$ and set the fixed entry cost to $F = 1$. In all simulations, I use the demand system estimated in Arkolakis et al. [2019], with parameter values $\alpha = 0$ and $\gamma = -0.221$ for the CES case and $\alpha = 1.5$ and $\gamma = -0.253$ for the generalized CES case. Trade costs and the parameters of the firm-level productivity distribution are calibrated to match the US imports-to-expenditure ratio and the trade elasticity. The values of all calibrated parameters are reported in Table 6.

Table 6: Calibration

Parameter	Value	Target/Choice Calibration
		Panel A: Demand
α (CES)	0	Arkolakis et al. [2019]
γ (CES)	-0.221	Arkolakis et al. [2019]
α (gen. CES)	1.5	Arkolakis et al. [2019]
γ (gen. CES)	-0.253	Arkolakis et al. [2019]
		Panel B: Pareto productivity distribution
θ	5	Trade Elasticity (Arkolakis et al. [2019])
τ	1.68	Imports/expenditure = 7% (OECD Input-Output Database, 2000)
δ (CES)	0.295	Imports/expenditure = 7% (OECD Input-Output Database, 2000)
δ (gen. CES)	0.59	Imports/expenditure = 7% (OECD Input-Output Database, 2000)

For the baseline calibration with a Pareto distribution, this implies a Pareto shape parameter of $\theta = 5$. In the standard model, the iceberg cost is set to 1.68, calibrated to match the 7% imports-to-total-expenditure ratio. To ensure comparability, the iceberg cost remains at 1.68 in the new model. However, the elasticity of the iceberg factor with respect to firm productivity, δ, is calibrated separately for different utility specifications: in the generalized CES case, $\delta = 0.59$, while in the CES case, $\delta = 0.295$, to match the 7% imports-to-total-expenditure ratio too.

Tables 7 and 8 present the results of both models. The new model, incorporating the productivity-dependent iceberg cost, yields a fraction of exporting firms that aligns more closely with empirical observations. Specifically, in the generalized CES utility case, 0.9% of total firms export while maintaining an export share of 7% of total expenditure, whereas in the CES utility case, 2.4% of firms export. These results are consistent with the findings of Bernard et al. [2007], who report that among the 5.5 million firms operating in the United States in 2000, only 4% were exporters.

Table 7: Results: Old Model / New Model (CES)

Model	Old	New
FracExporters	0.07	0.02
ExportShare	0.07	0.07
p^*	5.57	5.55
z_d	0.28	0.22
z_x	0.37	0.46
N	0.16	0.16
MeanMarkupNonexporters	0.07	0.06
MeanMarkupExporters	0.19	0.23

Table 8: Results: Old Model / New Model (generalized CES)

Model	Old	New
FracExporters	0.07	0.01
ExportShare	0.07	0.07
p^*	5.44	5.41
z_d	0.18	0.18
z_x	0.31	0.48
N	0.17	0.17
MeanMarkupNonexporters	0.10	0.06
MeanMarkupExporters	0.21	0.27

Moreover, the results confirm that in both cases of the new model, the export cutoff productivity is higher than in the original model, as predicted by the theoretical framework. Since less productive exporting firms in the original model now face higher iceberg costs, they are driven out of international trade. Consequently, firms must be more productive to engage in exporting under the new model.

Another important conclusion from Tables 7 and 8 is the change in mean markups for both non-exporting and exporting firms. In both cases—under CES and generalized CES utility functions—the introduction of a productivity-dependent iceberg cost reduces the mean markup for non-exporting firms. Specifically, in the CES case, the average markup falls from 7.4% to 5.9%, while in the generalized CES case, it reduces from 10% to 6.3%. This occurs because, under the new model, the least productive firms that previously exported are now unable to do so.

For exporting firms, markups increases. In the CES case, the mean markup increases from 18.6% to 22.8% and in the case of variable markups, generalized CES, from 21.5% to 27.0%. This is because firms must be more productive to export, which reduces their marginal cost and increases their markups.

Figures 4 and **??** illustrate the distribution of sales—normalized by mean sales—across markets for French firms at the 5th, 25th, 50th, 75th, and 95th percentiles. As first documented by Eaton et al. [2004], the data reveal significant heterogeneity: compared to the mean exporter, firms at the 5th, 50th, and 95th percentiles sell less than 1/100th, around 1/10th, and three times as much, respectively.

The new model, which incorporates a transport cost that depends on firm productivity, better replicates the observed distribution of firm exports compared to the original model with a constant iceberg cost. The main improvement occurs among the smallest exporters. In the new model, these less productive firms face higher transport costs, which reduces their export sales relative to the original model. This adjustment aligns more closely with the empirical distribution observed in the data, improving the model's fit, particularly for the lower end of the distribution.

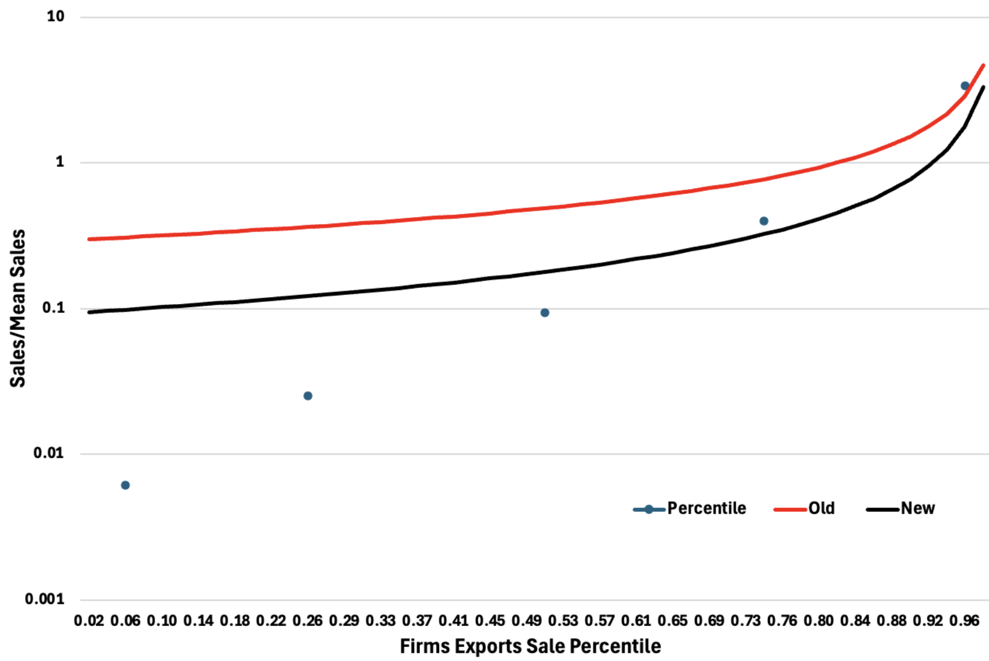


Figure 4: Distribution of Firm Export Sales (CES)

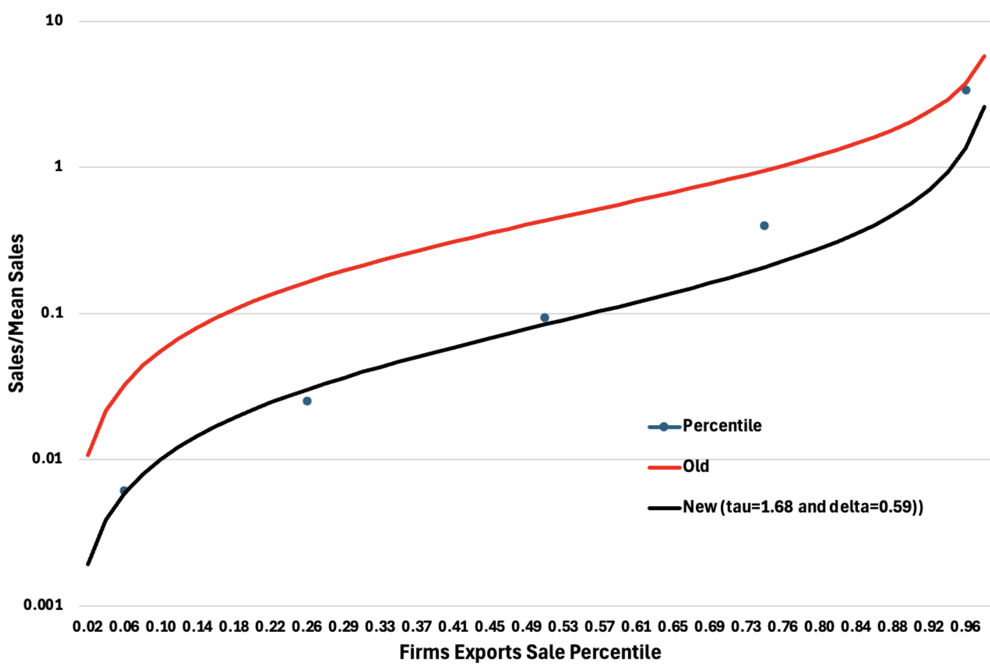


Figure 5: Distribution of Firm Export Sales (generalized CES)

9 Welfare and Policy Implications

This section summarizes how the welfare implications of trade cost changes differ between the benchmark model with a constant iceberg cost and the extended model in which iceberg costs depend on firm-level productivity. I first lay out the relevant theoretical expressions for welfare under CES and generalized CES preferences, and then discuss the quantitative results obtained from the calibrated model.

9.1 Theoretical Benchmarks

Throughout this section I follow the ACDR convention and define $\varepsilon^{\text{macro}}$ as a positive quantity equal to the absolute value of the signed elasticity in Section 6.1: $\varepsilon^{\text{macro}} \equiv -\partial \ln X_{ij}/\partial \ln \tau_{ij} = \theta/(1+\delta) > 0$.

Let λ_{jj} denote the domestic expenditure share, θ the shape parameter of the Pareto productivity distribution, and τ_{ij} the bilateral iceberg trade cost between countries i and j. In the original model, the iceberg cost is constant across firms, so that serving market j requires $\tau_{ij} \geq 1$ units to deliver one unit of the good. In the extended model, the effective iceberg cost depends on firm productivity z according to

$$\tau_{ij}(z) \;=\; \frac{\tau_{ij}}{z^{\delta}}, \qquad \delta \geq 0,$$

so that more productive firms face lower trade costs. With a simple one-factor technology, this implies a marginal cost of exporting

$$c_{ij}(z) \;=\; \frac{w_i \tau_{ij}(z)}{z} \;=\; \frac{w_i \tau_{ij}}{z^{1+\delta}}.$$

CES preferences. Under CES preferences, all firms face the same demand elasticity and charge the same markup. With constant iceberg costs and Pareto productivity, bilateral exports obey:

$$X_{ij} \;\propto\; (w_i \tau_{ij})^{-\theta},$$

so that the macro trade elasticity is $\varepsilon^{\text{macro}} \;=\; -\partial \ln X_{ij}/\partial \ln \tau_{ij} \;=\; \theta$. Arkolakis, Costinot and Rodríguez-Clare (ACR) show that welfare can then be written solely in terms of the domestic expenditure share:

$$\Delta \ln W_{\text{const}} \;=\; -\frac{1}{\theta}\, \Delta \ln \lambda_{jj}.$$

In the productivity–dependent model, marginal cost becomes $c_{ij}(z) = w_i\tau_{ij}/z^{1+\delta}$, which strengthens the cost advantage of high-productivity firms. Under Pareto productivity this implies

$$X_{ij} \;\propto\; (w_i\tau_{ij})^{-\theta/(1+\delta)},$$

so that the effective macro trade elasticity is attenuated to

$$\varepsilon^{\text{macro}}(\delta) \;=\; -\frac{\partial \ln X_{ij}}{\partial \ln \tau_{ij}} \;=\; \frac{\theta}{1+\delta} \;<\; \theta \quad \text{for } \delta > 0.$$

The ACR-style welfare formula retains its structure but with the modified elasticity:

$$\Delta \ln W_{\text{het}} \;=\; -\frac{1}{\varepsilon^{\text{macro}}(\delta)}\,\Delta \ln \lambda_{jj} \;=\; -\frac{1+\delta}{\theta}\,\Delta \ln \lambda_{jj}.$$

Relative to the constant-iceberg case, a given change in λ_{jj} is then associated with a larger underlying change in trade costs and a larger welfare response.

Generalized CES (Kimball) preferences. With generalized CES (Kimball) preferences, the demand elasticity is no longer constant and markups vary systematically across firms. Following Arkolakis, Costinot, Donaldson, and Rodríguez-Clare (ACDR), two elasticities are relevant for welfare:

1. The macro trade elasticity: $\varepsilon^{\text{macro}} = -\partial \ln X_{ij}/\partial \ln \tau_{ij}$,
2. The micro markup elasticity ρ_d, which measures how domestic markups respond to changes in firm size or marginal cost.

ACDR show that, to a first-order approximation, welfare satisfies:

$$\Delta \ln W \;\approx\; -\frac{1-\eta}{\varepsilon^{\text{macro}}}\,\Delta \ln \lambda_{jj}, \qquad \eta \equiv \frac{\rho_d}{1+\varepsilon^{\text{macro}}}.$$

The parameter $\eta \in [0,1]$ captures how much trade-induced changes in markups dampen the gains from trade: when $\rho_d = 0$ (constant markups), $\eta = 0$ and the formula collapses to the CES/ACR case; when $\rho_d > 0$, markup adjustment reduces the welfare impact of a given change in λ_{jj}.

In the original generalized CES model with constant iceberg costs and Pareto productivity, the macro trade elasticity is again $\varepsilon^{\text{macro}} = \theta$, so that:

$$\Delta \ln W_{\text{const}} \;\approx\; -\frac{1-\eta^{\text{const}}}{\theta}\,\Delta \ln \lambda_{jj}, \qquad \eta^{\text{const}} = \frac{\rho_d}{1+\theta}.$$

Introducing productivity dependent iceberg costs leaves the micro demand system and hence ρ_d unchanged, but alters the mapping from trade costs to trade flows: as above, bilateral exports now satisfy $X_{ij} \propto (w_i \tau_{ij})^{-\theta/(1+\delta)}$, so that

$$\varepsilon^{\text{macro}}(\delta) = \frac{\theta}{1+\delta}.$$

The ACDR welfare formula becomes:

$$\Delta \ln W_{\text{het}} \;\approx\; -\frac{1-\eta(\delta)}{\varepsilon^{\text{macro}}(\delta)}\,\Delta \ln \lambda_{jj}, \qquad \eta(\delta) = \frac{\rho_d}{1+\varepsilon^{\text{macro}}(\delta)} = \frac{\rho_d}{1+\theta/(1+\delta)}.$$

Relative to the constant iceberg case, both the macro trade elasticity in the denominator and the markup adjustment term $\eta(\delta)$ change, so the net effect on the coefficient in front of $\Delta \ln \lambda_{jj}$ is a quantitative question.

9.2 Quantitative Results

I evaluate these welfare formulas numerically using the calibrated model. For each specification, I consider a symmetric economy and compute welfare for a range of iceberg costs τ around the baseline value $\tau^{\text{base}} = 1.68$. For each τ, I solve for the general equilibrium, compute the associated utility level, and evaluate the exact expenditure needed to attain that utility. Welfare is reported as $W(\tau)/W(\tau^{\text{base}})$ and plotted against $d\ln\tau$.

In the CES case, the original constant iceberg model and the productivity dependent model display similar qualitative behavior: welfare rises when trade costs fall and declines when trade costs increase. Quantitatively, however, the model with $\tau(z) = \tau/z^{\delta}$ (for the calibrated value of δ) exhibits *smaller gains* from trade liberalization and *larger losses* from protection for a given change in $\ln\tau$. In Figure **??**, the welfare curve for the productivity dependent model lies systematically below the constant-τ curve: starting from the same baseline, a reduction in τ yields a smaller increase in $W(\tau)/W(\tau^{\text{base}})$, while an increase in τ leads to a slightly larger decline.

The same qualitative pattern appears under generalized CES preferences. When I solve the model with Kimball demand and variable markups, both the original and the productivity dependent specifications produce welfare gains from lower trade costs and welfare losses from higher trade costs. Yet, again, the welfare response is systematically weaker on the upside and stronger on the downside in the model with $\tau(z) = \tau/z^{\delta}$: relative to the constant iceberg benchmark, liberalization generates smaller gains, while increases in τ lead to somewhat larger welfare losses, like we can observe in Figure **??**.

The intuition is common across both demand systems. In the model with productivity dependent iceberg costs, the export sector is more strongly selected: relatively few, very productive firms account for most trade, while many low-productivity firms face very high effective trade costs. When trade costs increase, a given proportional rise in τ triggers a large wave of exit among marginal and mid-productivity exporters and shifts market shares toward very high-markup firms, so welfare falls more than in the constant-τ benchmark. By contrast, when trade costs fall, most of the new exporters are low-productivity firms that remain small even after entering, while already highly efficient exporters experience only limited changes in markups and quantities. As a result, the variety and pro-competitive gains from a reduction in τ are smaller than in the constant-τ model. This asymmetry generates larger welfare losses from trade protection and smaller welfare gains from trade liberalization in the productivity-dependent iceberg cost model.

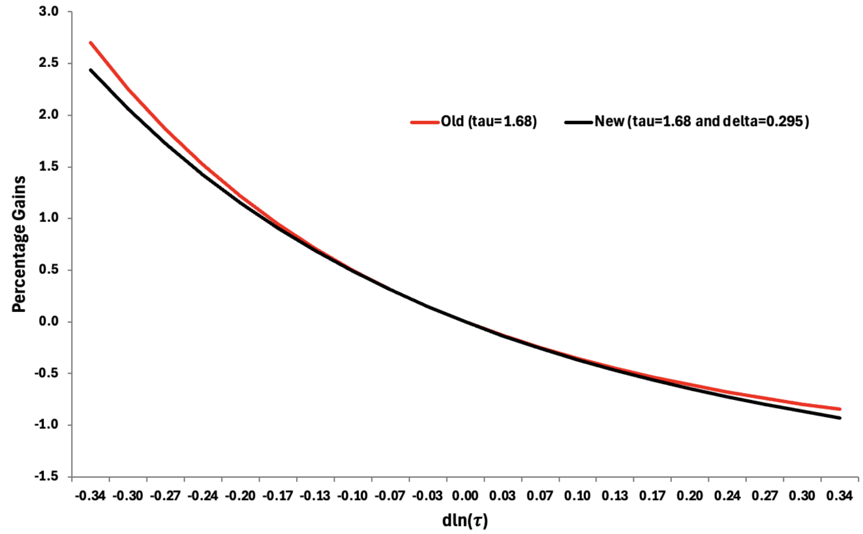


Figure 6: Welfare gains relative to baseline (τ =1.68), CES

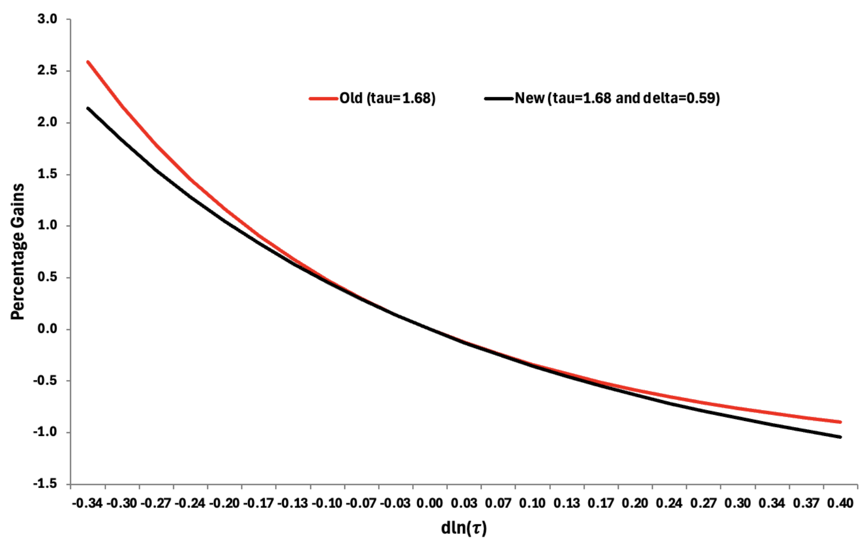
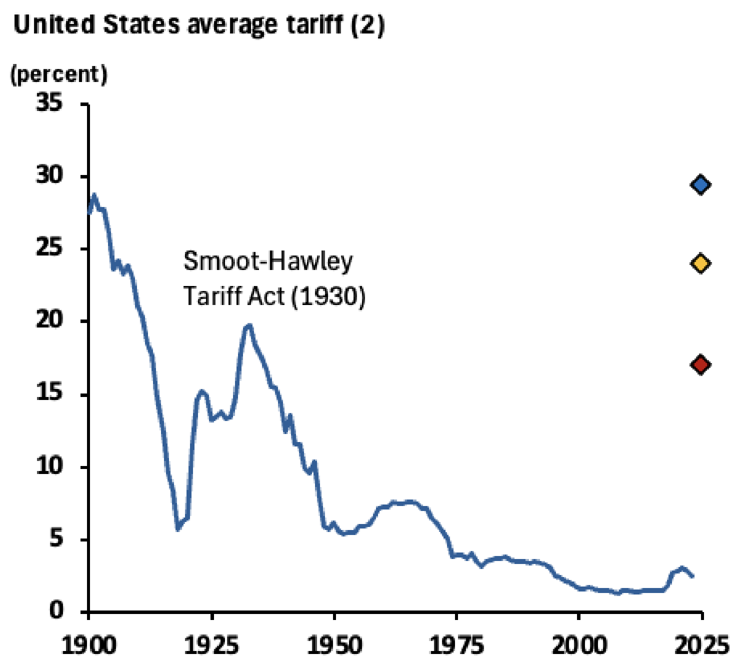


Figure 7: Welfare gains relative to baseline (τ =1.68), generalized CES

9.3 Policy Application: How Does the Effect of US Tariff Change?

The new government of the United States under President Donald J. Trump has increased import tariffs on foreign products, reaching the highest level since 1930, with the Smoot-Hawley Tariff Act., like we can observe in Figure ??.



(2) The yellow diamond corresponds to the average tariff after the April 2 announcements. The blue diamond corresponds to the average tariff as of April 12, after the increase to 145% of the tariff on China. The red diamond corresponds to the average tariff as of June 11 (statistical closing date of this Report). Sources: June 2025 IPoM, Central Bank of Chile, US International Trade Commission, and Tax Foundation.

Figure 8: United States average tariff

In this case, I study the effect of a 25% increase in tariffs within a model featuring variable markups (generalized CES) is analyzed. Since tariffs are imposed on all companies, regardless of their productivity, the new cost of the iceberg in the original model is $\tau_{ij} \equiv \tau_{ij} + 0.25$, while in the new model it becomes $\tau_{ij}(z) \equiv (\tau_{ij} + 0.25)/z^{\delta}$.

Table 9: Effect of US tariffs: Old Model

Model	Old	Old (25% tariffs)	Comparison Old
FracExporters	0.07	0.04	-0.50
ExportShare	0.07	0.04	-0.48
p^*	5.44	5.47	0.01
z_d	0.18	0.18	-0.01
z_x	0.31	0.35	0.14
N	0.17	0.17	0.00
MeanMarkupNonexporters	0.10	0.11	0.07
MeanMarkupExporters	0.21	0.24	0.14

Table 10: Effect of US tariffs: New Model

Model	New	New (25% tariffs)	Comparison New
FracExporters	0.01	0.01	-0.36
ExportShare	0.07	0.05	-0.35
p^*	5.41	5.45	0.01
z_d	0.18	0.18	-0.01
z_x	0.48	0.52	0.09
N	0.17	0.17	-0.01
MeanMarkupNonexporters	0.06	0.06	0.00
MeanMarkupExporters	0.27	0.28	0.02

In Tables 9 and 10, we can observe the effects of US tariffs. By comparing both models, the impact of a 25% tariff increase on goods imported from the US shows a reduction of 50% in the percentage of exports and 48% in the number of firms that export in the original model. In contrast, in the new model, exports decrease by 35% and the number of exporting firms decreases by 36%. These results can be explained by the fact that in the original model, the least productive firms that export still do so, whereas in the new model, these firms are excluded from exporting due to higher iceberg costs. As a result, when tariffs increase for all firms, the productivity of the export cutoff increases by 14% in the original model, compared to just 9% in the new model. This leaves more firms engaged in international trade in the original model than in the new one, as some firms were already excluded in the latter model before the tariff increase. This explains why the export share decreases less in the new model (35%) than in the original model (48%).

10 Conclusion

In recent years, transportation costs have become increasingly important in international trade. In this paper I have shown that transportation costs are highly heterogeneous across firms operating on the same international route. Using shipment-level customs data for Chile, I document that iceberg transport costs, measured as the ratio of freight charges to CIF values, decline systematically with firm size. Along the Shanghai-San Antonio route, a 1% increase in a firm's total imports is associated with approximately a 0.4-0.6 percentage point reduction in its iceberg transport cost. A balanced panel of firms that imported in 2007 and are followed through 2017 further reveals that transport-cost shocks have disproportionate effects across the firm-size distribution: increases in transport costs reduce both the probability of importing and import volumes significantly more for firms in the bottom three size quintiles than for those in the top two.

Motivated by these empirical facts, I extend a standard heterogeneous-firm trade framework in the spirit of Arkolakis, Costinot, Donaldson, and Rodríguez-Clare by allowing iceberg trade costs to depend on firm productivity as $\tau_{ij}(z) = \tau_{ij}/z^{\delta}$. Embedding this structure in an environment with generalized CES (Kimball) preferences delivers variable markups and a micro trade elasticity that varies systematically with firm size. Calibrating the productivity elasticity δ to the Chilean estimate of -0.41, I derive the implied micro and macro trade elasticities and show how they map into extended ACR/ACDR welfare formulas under both CES and generalized CES demand. The constant-iceberg-cost benchmark emerges as a special case when $\delta = 0$ and markups are constant.

The quantitative analysis highlights several implications of productivity-dependent transport costs for the structure of trade and the transmission of trade-cost shocks. First, by making effective trade costs fall steeply with productivity, $\tau_{ij}(z)$ generates much stronger selection into exporting: the set of exporters is smaller and more productive on average, and a relatively small number of very productive firms account for a large share of aggregate trade. Second, because many low- and mid-productivity firms operate close to the export cutoff, moderate changes in iceberg costs induce sizable adjustments along the extensive margin for these marginal exporters. Third, in the generalized CES case, surviving high-productivity exporters face relatively inelastic demand and charge higher markups, so changes in trade costs are accompanied by nontrivial shifts in the markup distribution and in the composition of varieties consumed.

These features give rise to welfare responses that differ in important ways from the constant-iceberg-cost benchmark. For a given percentage increase in iceberg trade costs, the model with productivity-dependent iceberg costs yields larger welfare losses than the constant-cost model, even though the export share and the fraction of exporters fall by a smaller percentage. Intuitively, the same change in aggregate trade flows comes with more damaging composition and markup effects: marginal and mid-productivity exporters experience sharp declines in profitability and either exit or contract, while market shares shift toward very high-markup firms. By contrast, a reduction in iceberg costs from the calibrated level leads to smaller welfare gains than in the constant-cost benchmark, because most new entrants are low-productivity firms that remain small, and already highly efficient exporters adjust markups and quantities less than when iceberg costs are homogeneous. Taken together, these results imply that productivity-dependent trade costs amplify the welfare losses from trade protection and attenuate the gains from trade liberalization relative to what a constant iceberg cost model would suggest.

Finally, I use the framework to reassess the effects of recent U.S. tariff increases. The policy counterfactuals show that when iceberg costs are allowed to depend on firm productivity, a given tariff shock can generate smaller changes in aggregate trade flows but larger welfare losses compared with the constant cost benchmark. Ignoring heterogeneity in transport costs across firms may therefore lead to biased quantitative assessments of the consequences of trade policy. More generally, the evidence and mechanisms documented in this paper suggest that the distribution of trade costs across firms, not just their average level, is crucial for understanding how shocks to tariffs and transportation costs propagate through the economy.

References

G. Alessandria, H. Choi, and K. J. Ruhl. Trade adjustment dynamics and the welfare gains from trade. *Journal of International Economics*, 131:103458, 2021.

T. Allen. Information frictions in trade. *Econometrica*, 82(6):2041–2083, 2014.

A. Ardelean and V. Lugovskyy. It pays to be big: Price discrimination in maritime shipping. *European Economic Review*, 153:104403, 2023.

C. Arkolakis, A. Costinot, and A. Rodríguez-Clare. New trade models, same old gains? *American Economic Review*, 102(1):94–130, 2012.

C. Arkolakis, A. Costinot, D. Donaldson, and A. Rodríguez-Clare. The elusive pro-competitive effects of trade. *The Review of Economic Studies*, 86(1):46–80, 2019.

R. Baldwin. Trade and industrialization after globalization's second unbundling: How building and joining a supply chain are different and why it matters. In *Globalization in an age of crisis: Multilateral economic cooperation in the twenty-first century*, pages 165–212. University of Chicago Press, 2013.

A. B. Bernard, J. Eaton, J. B. Jensen, and S. Kortum. Plants and productivity in international trade. *American economic review*, 93(4):1268–1290, 2003.

A. B. Bernard, J. B. Jensen, S. J. Redding, and P. K. Schott. Firms in international trade. *Journal of Economic perspectives*, 21(3):105–130, 2007.

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

O. Cadot, A. Graziano, J. Harris, and C. V. Martincus. Do rules of origin constrain export growth? firm-level evidence from colombia. 2014.

L. Cen, L. Cohen, J. Wu, and F. Zhang. Who benefits from trade wars? Technical report, National Bureau of Economic Research, 2024.

M. A. Clemens and J. G. Williamson. Why did the tariff–growth correlation change after 1950? *Journal of Economic Growth*, 9:5–46, 2004.

J. Eaton, S. Kortum, and F. Kramarz. Dissecting trade: Firms, industries, and export destinations. *American Economic Review*, 94(2):150–154, 2004.

K. Hayakawa. Does firm size matter in exporting and using fta schemes? *The Journal of International Trade & Economic Development*, 24(7):883–905, 2015.

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

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

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

M. S. Kimball. The quantitative analytics of the basic neomonetarist model, 1995.

J. D. Loecker and F. Warzynski. Markups and firm-level export status. *American economic review*, 102(6):2437–2471, 2012.

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

H. R. Varian. Price discrimination and social welfare. *The American Economic Review*, 75 (4):870–875, 1985.

A Appendix

A.1 Bilateral trade flows X_{ij} with productivity-dependent iceberg costs

I assume that firm productivity z in country i follows a Pareto distribution:

$$G_i(z) = 1 - \left(\frac{b_i}{z}\right)^{\theta}, \qquad z \geq b_i, \tag{46}$$

where $b_i > 0$ is the lower bound of the productivity distribution and $\theta > 0$ is the shape parameter. The corresponding density is

$$g_i(z) = \theta b_i^{\theta} z^{-(\theta+1)}. \tag{47}$$

As shown in the main text, the marginal cost of a firm with productivity z from country i serving market j is

$$c_{ij}(z) = \frac{w_i \tau_{ij}}{z^{1+\delta}}, \tag{48}$$

and the export productivity cutoff z_{ij}^* is defined by $c_{ij}(z_{ij}^*) = P_j$, so

$$z_{ij}^* = \left(\frac{w_i \tau_{ij}}{P_j}\right)^{\frac{1}{1+\delta}}. \tag{49}$$

Using the firm-level revenue expression

$$x(c, v, Q_j, L_j) = L_j Q_j \, c \, \mu(v) \, D\!\left(\frac{\mu(v)}{v}\right), \tag{50}$$

and denoting by $v(z) \equiv P_j / c_{ij}(z)$ the relative efficiency term, aggregate exports from i to j are

$$X_{ij} = N_i \int_{z_{ij}^*}^{\infty} x(c_{ij}(z), v(z), Q_j, L_j) \; g_i(z) \, dz. \tag{51}$$

Substituting $c_{ij}(z) = w_i \tau_{ij} / z^{1+\delta}$ and $g_i(z) = \theta b_i^{\theta} z^{-(\theta+1)}$, we obtain

$$X_{ij} = N_i L_j Q_j \theta b_i^{\theta} \int_{z_{ij}^*}^{\infty} \frac{w_i \tau_{ij}}{z^{1+\delta}} \, \mu\big(v(z)\big) \, D\!\left(\frac{\mu(v(z))}{v(z)}\right) z^{-(\theta+1)} dz. \tag{52}$$

Using $c_{ij}(z_{ij}^*) = P_j$, or

$$P_j = \frac{w_i \tau_{ij}}{(z_{ij}^*)^{1+\delta}}, \tag{53}$$

it is convenient to change variables by setting

$$u \equiv \frac{z}{z_{ij}^*}, \qquad z = u z_{ij}^*, \qquad dz = z_{ij}^* du. \tag{54}$$

Note that

$$v(z) = \frac{P_j}{c_{ij}(z)} = \frac{P_j z^{1+\delta}}{w_i \tau_{ij}} = \left(\frac{z}{z_{ij}^*}\right)^{1+\delta} = u^{1+\delta}, \tag{55}$$

and thus $v(z)$ can be written as $u^{1+\delta}$, with μ and D evaluated at $\mu(u^{1+\delta})$ and $\mu(u^{1+\delta})/u^{1+\delta}$.

Rewriting the integral in terms of u,

$$X_{ij} = N_i L_j Q_j \theta b_i^\theta \int_1^\infty \frac{w_i \tau_{ij}}{(u z_{ij}^*)^{1+\delta}} \, \mu\big(u^{1+\delta}\big) \, D\left(\frac{\mu(u^{1+\delta})}{u^{1+\delta}}\right) (u z_{ij}^*)^{-(\theta+1)} z_{ij}^* du \tag{56}$$

$$= N_i L_j Q_j \theta b_i^\theta w_i \tau_{ij} \, (z_{ij}^*)^{-(\theta+1+\delta)} \int_1^\infty \mu\big(u^{1+\delta}\big) \, D\left(\frac{\mu(u^{1+\delta})}{u^{1+\delta}}\right) u^{-(\theta+2+\delta)} du. \tag{57}$$

Using $P_j = w_i \tau_{ij} / (z_{ij}^*)^{1+\delta}$, we can write

$$w_i \tau_{ij} \, (z_{ij}^*)^{-(1+\delta)} = P_j, \tag{58}$$

so that

$$w_i \tau_{ij} \, (z_{ij}^*)^{-(\theta+1+\delta)} = P_j (z_{ij}^*)^{-\theta}. \tag{59}$$

It is also convenient to write $(z_{ij}^*)^{-\theta}$ in terms of $(w_i \tau_{ij})$ and P_j:

$$z_{ij}^* = \left(\frac{w_i \tau_{ij}}{P_j}\right)^{\frac{1}{1+\delta}} \quad \Rightarrow \quad (z_{ij}^*)^{-\theta} = \left(\frac{w_i \tau_{ij}}{P_j}\right)^{-\frac{\theta}{1+\delta}} = (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}} P_j^{\frac{\theta}{1+\delta}}. \tag{60}$$

Combining these expressions, we obtain

$$X_{ij} = N_i L_j Q_j \theta b_i^\theta P_j (z_{ij}^*)^{-\theta} \int_1^\infty \mu\big(u^{1+\delta}\big) \, D\left(\frac{\mu(u^{1+\delta})}{u^{1+\delta}}\right) u^{-(\theta+2+\delta)} du \tag{61}$$

$$= N_i L_j Q_j \theta b_i^\theta (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}} P_j^{1+\frac{\theta}{1+\delta}} \int_1^\infty \mu\big(u^{1+\delta}\big) \, D\left(\frac{\mu(u^{1+\delta})}{u^{1+\delta}}\right) u^{-(\theta+2+\delta)} du. \tag{62}$$

Define the constant

$$\chi(\delta) \equiv \theta \int_1^\infty \mu\big(u^{1+\delta}\big) \, D\left(\frac{\mu(u^{1+\delta})}{u^{1+\delta}}\right) u^{-(\theta+2+\delta)} du > 0. \tag{63}$$

Using the fact that $1 + \theta/(1 + \delta) = (\theta + 1 + \delta)/(1 + \delta)$, we can rewrite X_{ij} as

$$X_{ij} = \chi(\delta)\, N_i\, b_i^\theta\, (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}}\, L_j\, Q_j\, P_j^{\frac{\theta+1+\delta}{1+\delta}}, \tag{64}$$

which is the expression reported in the main text.

A.2 Aggregate profits Π_{ij} with productivity-dependent iceberg costs

Aggregate profits of firms from i in market j (gross of any entry costs) are given by

$$\Pi_{ij} = N_i \int_{z_{ij}^*}^{\infty} \pi(c_{ij}(z), v(z), Q_j, L_j)\ g_i(z)\, dz, \tag{65}$$

where

$$\pi(c, v, Q_j, L_j) = \left(\frac{\mu(v) - 1}{\mu(v)}\right) x(c, v, Q_j, L_j) = L_j Q_j\, c\, \big(\mu(v) - 1\big)\, D\left(\frac{\mu(v)}{v}\right). \tag{66}$$

Proceeding as in the previous subsection, with $c_{ij}(z) = w_i \tau_{ij}/z^{1+\delta}$ and $g_i(z) = \theta b_i^\theta z^{-(\theta+1)}$, we obtain

$$\Pi_{ij} = N_i L_j Q_j \theta b_i^\theta \int_{z_{ij}^*}^{\infty} \frac{w_i \tau_{ij}}{z^{1+\delta}} \big(\mu(v(z)) - 1\big)\, D\left(\frac{\mu(v(z))}{v(z)}\right) z^{-(\theta+1)} dz. \tag{67}$$

Using again the change of variables $u = z/z_{ij}^*$, $z = u z_{ij}^*$, $dz = z_{ij}^* du$ and $v(z) = u^{1+\delta}$, we can rewrite this as

$$\Pi_{ij} = N_i L_j Q_j \theta b_i^\theta w_i \tau_{ij}\, (z_{ij}^*)^{-(\theta+1+\delta)} \int_1^{\infty} \big(\mu(u^{1+\delta}) - 1\big)\, D\left(\frac{\mu(u^{1+\delta})}{u^{1+\delta}}\right) u^{-(\theta+2+\delta)} du. \tag{68}$$

Using the same step as for X_{ij},

$$w_i \tau_{ij}\, (z_{ij}^*)^{-(\theta+1+\delta)} = P_j (z_{ij}^*)^{-\theta} = (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}} P_j^{1+\frac{\theta}{1+\delta}},$$

we can write

$$\Pi_{ij} = N_i L_j Q_j \theta b_i^\theta (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}} P_j^{1+\frac{\theta}{1+\delta}} \int_1^{\infty} \big(\mu(u^{1+\delta}) - 1\big)\, D\left(\frac{\mu(u^{1+\delta})}{u^{1+\delta}}\right) u^{-(\theta+2+\delta)} du. \tag{69}$$

Define the constant

$$\pi(\delta) \equiv \theta \int_1^{\infty} \big(\mu(u^{1+\delta}) - 1\big)\, D\left(\frac{\mu(u^{1+\delta})}{u^{1+\delta}}\right) u^{-(\theta+2+\delta)} du > 0. \tag{70}$$

Then aggregate profits can be written as

$$\Pi_{ij} = \pi(\delta)\, N_i\, b_i^{\theta}\, (w_i \tau_{ij})^{-\frac{\theta}{1+\delta}}\, L_j\, Q_j\, P_j^{\frac{\theta+1+\delta}{1+\delta}}. \tag{71}$$

Comparing this expression with that for X_{ij}, we see that aggregate profits are a constant fraction of aggregate exports:

$$\Pi_{ij} = \zeta(\delta)\, X_{ij}, \qquad \zeta(\delta) \equiv \frac{\pi(\delta)}{\chi(\delta)} \in (0,1). \tag{72}$$

This result is the analogue of the constant profit share in Arkolakis et al. (2019), now derived under productivity-dependent iceberg costs $\tau_{ij}(z) = \tau_{ij}/z^{\delta}$.