Distorted Trade Barriers: A Dissection of Trade Costs in a "Distorted Gravity" Model*

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Abstract

It is common in the trade literature to use iceberg transport costs to represent both tariffs and shipping costs alike. However, in models with monopolistic competition these are not identical trade restrictions. This difference is driven by how the two costs affect the extensive margin. We illustrate these differences in a gravity model. We show theoretically that trade flows are more elastic with respect to tariffs than transport costs and find a linear relationship between the elasticities with respect to tariffs, iceberg transport costs, and fixed market costs. We empirically validate these results using data on U.S. product-level imports.

JEL classification: F12; F13; F17

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1 Introduction

A common approach in the trade literature is to use iceberg transport costs, shipping more than one unit of output to have one unit arrive as a portion "melts" away, to represent variable trade barriers, both tariffs and shipping costs alike. For many models this equivalence is a reasonable assumption; e.g., in models of perfect competition, iceberg transport costs and ad valorem tariffs are equivalent.[1] In addition, if we are only interested in the intensive margin, then the two trade barriers are equivalent even under monopolistic competition. However, despite the market price being identical under both types of trade barriers in models with monopolistic competition, the *level* of firm profit is not. This has far reaching implications as the level of profit determines firm entry and exit – the extensive margin.[2] It should be noted that this difference is not driven by the fact that tariffs generate income in the destination country (through tariff revenue) and iceberg transport costs generate income in the source country (through an implicit transport sector). The difference in firm profits exists because the firm is able to recoup a portion of its losses in transport via its monopolistic power, whereas tariff revenue is completely captured by the domestic government; i.e. iceberg costs are based on quantity while ad valorem tariffs are based on value.

In this paper we take the difference in variable costs seriously and solve a highly tractable gravity model (based on Chaney 2008) with three costs: fixed costs of production, variable costs based on quantity (iceberg), and variable costs based on value (tariff). Doing this allows us to make several observations. The first observation is that there is a linear relationship

[1] Of course this equivalence hinges on how the researcher deals with the different sources of income either through a transport sector or tariff revenue. The typical approach has been to assume these away.

[2] The different effect on firm profit is shown explicitly in Cole (2011), which has fixed cost heterogeneity with quasi-linear utility and analyzes how iceberg transport costs and ad valorem tariffs affect the mass of varieties and welfare differently. Schröder and Sørensen (2014) additionally illustrate in a Meltiz (2003) type model how tariffs differ from iceberg transport costs. Neither of these papers highlight this difference in a gravity framework. For a welfare analysis on the differences between per-unit trade costs versus iceberg see Sørensen (2014). Felbermayr et al. (2015) illustrates the differences in gains from trade between iceberg transport costs and ad valorem tariffs and finds iceberg costs underestimate the gains from trade liberalization with respect to tariffs. Demidova and Rodríquez-Clare (2009) investigate the optimal import tariff in a Melitz-type model, but do not focus on the differences between iceberg transport costs and ad valorem tariffs.

linking the trade flow elasticities of all three costs. Specifically, we show that the sum of the elasticity with respect to iceberg costs and fixed costs equals the elasticity with respect to tariffs. The second observation is that the elasticity of trade with respect to tariffs is greater (in magnitude) than the elasticity with respect to iceberg transport costs. We provide empirical support for these two results. In addition, we illustrate that the elasticity of substitution matters in a gravity model with heterogenous firms. That is to say, the heterogenous firm literature (see Eaton and Kortum 2002 and Chaney 2008 for example) has shown the trade elasticity with respect to variable costs only depends on a parameter governing the variation in the distribution of firm productivity.[3] However, if variable costs are based on value rather than quantity (e.g. ad valorem tariffs), the elasticity of substitution does not get canceled out by adding up the intensive and extensive margin effects.

We apply our model to data on U.S. imports at the 10-digit HS level for the year 2001. We use ad valorem tariff data from John Romalis's U.S. Tariff Database and calculate the iceberg transport costs from the available import data as reported by the U.S. Census. Since we are not aware of any direct measures of fixed costs of production at the product level, we examine several proxies for fixed costs. Our starting point is the inverse of the elasticity of substitution from Soderbery (2015) which is estimated at the 10-digit HS level using U.S. data giving us product level variation as our other variables. In order to allow for some country level variation as well (our tariffs and transport cost measures vary both across products and countries), we interact the inverse of the elasticity of substitution with four measures from World Bank's Ease of Doing Business Database: the ease of doing business index, cost to export, time to export, and days to export. Our results are consistent across the five proxies. We are able to empirically confirm that tariff and transport cost elasticities are different, with the tariff elasticity being larger when the extensive margin is active, and that the tariff elasticity is equal to the sum of the transport and fixed cost elasticities. We also show our results are robust across several robustness exercises.

[3]For a thorough review of the vast gravity literature see Head and Mayer (2104).

The rest of the paper proceeds as follows. Section 2 sets up the model, while section 3 introduces trade into the model and finds the elasticities of trade flows with respect to both iceberg transport costs and ad valorem tariffs. In section 4 we examine our predictions empirically and section 5 concludes.

2 Setup

We follow Chaney (2008) (henceforth Chaney) very closely, maintaining the notation and setup, with two main exceptions. First, we allow for an ad valorem tariff, s_{ij}^h, to be charged on goods shipped from country i to country j in sector h where $t_{ij}^h = 1 + s_{ij}^h > 1$. Secondly, we allow for the government to sell bonds to the general public in a very specific way. This is a simplifying assumption, but an important one, which we will discuss in greater detail in subsection 2.3.

There are N potentially asymmetric countries that produce goods using only labor. Country n has a population of L_n. Consumers in each country maximize utility derived from the consumption of goods from $H+1$ sectors. Sector 0 provides a single freely traded homogenous good that pins down the wage in country n, w_n.[4] The other H sectors are made of a continuum of differentiated goods. If a consumer consumes q_0 units of good 0, and $q_h(\omega)$ units of each variety ω of good h, for all varieties in the set Ω_h (determined in equilibrium), she gets a utility U,

$$U \equiv q_0^{\mu_0} \prod_{h=1}^{H} \left(\int_{\Omega_h} q_h(\omega)^{(\sigma_h - 1)/\sigma_h} d\omega \right)^{[\sigma_h/(\sigma_h-1)]\mu_h}, \tag{1}$$

where $\mu_0 + \sum_{h=1}^{H} \mu_h = 1$, and where $\sigma_h > 1$ is the elasticity of substitution between two varieties of good h.

[4]We assume that every country produces a positive amount of q_0.

2.1 Trade Barriers and Technology

There are three types of trade barriers, two of which are variable and one is fixed. The two variable trade barriers are tariffs, t_{ij}^h, and iceberg transport costs, τ_{ij}^h, while the fixed barrier is given by fixed cost of production, f_{ij}^h. Each firm in sector h draws a random unit labor productivity φ from a Pareto distribution with shape parameter γ_h.[5] Following Chaney, we assume the total mass of potential entrants in each sector is proportional to $w_j L_j$. The cost of producing q units of a good and selling them in country j for a firm with productivity φ is[6]

$$c_{ij}^h(p,q) = (t_{ij}^h - 1)pq + \frac{\tau_{ij}^h w_i}{\varphi} q + f_{ij}^h \tag{2}$$

and the total revenue for the same firm is $t_{ij}^h pq$. Therefore the profit is

$$\Pi(p,q,\varphi) = t_{ij}^h pq - (t_{ij}^h - 1)pq - \frac{\tau_{ij}^h w_i}{\varphi} q - f_{ij}^h = pq - \frac{\tau_{ij}^h w_i}{\varphi} q - f_{ij}^h, \tag{3}$$

which collapses to the familiar form found in the literature. The tariff does affect profits, but only through q, the quantity demanded. As is standard in these models, the price a firm charges is a constant markup over marginal cost and the price a consumer pays is the price the firm charges plus the tariff,

$$\hat{p}_{ij}^h(\varphi) = \frac{\sigma_h}{(\sigma_h - 1)} \frac{\tau_{ij}^h w_i}{\varphi} \qquad \text{Firm Price} \tag{4}$$

$$p_{ij}^h(\varphi) = t_{ij}^h \hat{p}_{ij}^h(\varphi) = \frac{\sigma_h}{(\sigma_h - 1)} \frac{t_{ij}^h \tau_{ij}^h w_i}{\varphi} \qquad \text{Consumer Price} \tag{5}$$

Note that the tariff and transport cost have the same effect on the price paid by consumers. However, a tariff equal to transport cost will result in a lower level of profit which will have an effect on the extensive margin. To see this insert the price given by equation

[5] Productivity is distributed over $[1, +\infty)$ according to $P(\tilde{\varphi}_h < \varphi) = G_h(\varphi) = 1 - \varphi^{-\gamma_h}$, with $\gamma_h > \sigma_h - 1$.

[6] For a cleaner equation, we abuse notation and drop the i, j subscripts on p and q. This is also consistent with Chaney.

(4) back into the profit function given by equation (3):

$$\Pi(p,q,\varphi) = t_{ij}^h \left[\frac{\sigma_h}{(\sigma_h - 1)} \frac{\tau_{ij}^h w_i}{\varphi} \right] q - (t_{ij}^h - 1) \left[\frac{\sigma_h}{(\sigma_h - 1)} \frac{\tau_{ij}^h w_i}{\varphi} \right] q - \frac{\tau_{ij}^h w_i}{\varphi} q - f_{ij}^h.$$

As can be seen, everything is the same except the variable cost under an iceberg specification is less than that of a tariff. The reason stems from when the cost is incurred. Through monopolistic power, the firm is able to recoup a portion of its losses in transport by charging a markup over marginal cost (which includes transport costs), whereas tariff revenue is completely captured by the domestic government.

2.2 Demand for Differentiated Goods

The total income spent by workers in country j, Y_j, is the sum of their labor income ($w_j L_j$) and of the dividends they get from their portfolio ($w_j L_j \pi$), where π is the dividend per share of the global mutual fund consisting of aggregated firm profits and government bonds. Tariff inclusive exports from country i to country j in sector h, by a firm with labor productivity φ, are

$$x_{ij}^h(\varphi) = p_{ij}^h(\varphi) q_{ij}^h(\varphi) = \mu_h Y_j \left(\frac{p_{ij}^h(\varphi)}{P_j^h} \right)^{1-\sigma_h} \tag{6}$$

where P_j^h is the ideal price index for good h in country j.[7]

If only those firms above the productivity threshold $\bar{\varphi}_{kj}^h$ in country k and sector h export to country j, the ideal price index for good h in country j, P_j, and dividends per share, π, are defined as

$$P_j^h = \left(\sum_{k=1}^{N} w_k L_k \int_{\bar{\varphi}_{kj}^h}^{\infty} \left(\frac{\sigma_h}{(\sigma_h - 1)} \frac{t_{kj}^h \tau_{ij}^h w_k}{\varphi} \right)^{1-\sigma_h} dG_h(\varphi) \right)^{1/(1-\sigma_h)} \tag{7}$$

[7] We have chosen to include tariffs in the value of exports to be consistent with the calculations of Chaney with respect to iceberg transport costs. The proofs for a model using a gravity equation both *inclusive* and *exclusive* of trade costs is available in an online appendix. Though the elasticities obviously change, our claims do not.

$$\pi = \frac{\sum_{h=1}^{H} \sum_{k,l=1}^{N} w_k L_k \left(\int_{\bar{\varphi}_{kl}^h}^{\infty} \left[\pi_{kl}^h(\varphi) + b_{kl}^h(\varphi) \right] dG(\varphi) \right)}{\sum_{n=1}^{N} w_n L_n} \tag{8}$$

where

$$\pi_{kl}^h(\varphi) = \left(\frac{1}{(\sigma_h - 1)} \right) \frac{\tau_{kl}^h w_k}{\varphi} q_{kl}^h(\varphi) - f_{kl}^h \tag{9}$$

are the net profits that a firm with productivity φ in country k and sector h earns from exporting to country l, and

$$b_{kl}^h = \frac{(t_{kl} - 1) p_{kl}^h(\varphi) q_{kl}^h(\varphi)}{t_{kl} \sigma_h} = \left(\frac{(t_{kl} - 1)}{\sigma_h - 1} \right) \frac{\tau_{kl}^h w_k}{\varphi} q_{kl}^h(\varphi) \tag{10}$$

is the return on country bond investments. This government bond activity plays an important simplifying role that needs more explanation, but first note that b_{kl}^h is less than the tariff revenue generated in country l for sector h, which is

$$\text{Tariff Revenue} = \frac{(t_{kl} - 1) p_{kl}^h(\varphi) q_{kl}^h(\varphi)}{t_{kl}} = \sigma_h b_{kl}^h$$

since $\sigma_h > 1$. This means that only a specific portion of tariff revenue is returned to consumers through bond returns.

2.3 Home Government and Tariff Revenue

It is important to note why the particular treatment of government tariff revenue was chosen. An inherent part of the iceberg transport cost assumption is that output is lost to the economy whereas tariffs create revenue for the government. This makes comparing the two trade restrictions problematic, particularly since our argument is that tariffs affect the extensive margin differently than typical transport costs regardless of any demand effects driven by tariff revenue. Therefore, we require the government to "redistribute" tariff revenue back to world consumers in a particular way. This is done for two reasons: it allows for a very reasonable point of comparison between the two trade barriers and it maintains the high tractability of Chaney's model.

Though it is not explicitly modeled with iceberg transport costs in the literature, there is in fact a transport sector that receives income. It takes labor to produce the output which is "lost" in transport and this labor receives a wage. Given the assumption of sector 0 (the numeraire), this wage is identical across sectors. From a worker's perspective, it doesn't matter which sector (s)he is employed in, including the numeraire. Therefore, we assume that whatever government income from tariff revenue is not used to pay bond holders is spent on the numeraire.

In addition to their wage, a worker receives income from a global mutual fund that redistributes firm profits. This is a very nice assumption that Chaney uses to get zero profits without having the additional complexities of a free entry condition. Since firm profits are lower with a tariff than an identical iceberg transport cost, dividends from this fund are lower and tractability is severely threatened. Therefore, we assume that governments are active in the bond market and keep a budget that results in a specific level of bond payments described by equation (10). Combining firm profits, (9), with government bond payments, (10), results in the following equation:

$$r_{ij}^h(\cdot) = \pi_{kl}^h + b_{kl}^h = \left(\frac{1}{(\sigma_h - 1)}\right) \frac{t_{kl}^h \tau_{kl}^h w_k}{\varphi} q_{kl}^h(\varphi) - f_{kl}^h,$$

which is identical to the dividends received in the Chaney model that only included iceberg transport costs. This means that the income, associated with each variety in existence, consumers receive is identical regardless of how the modeler chooses to represent trade barriers.

3 Trade with Heterogeneous Firms

In this section, we characterize the equilibrium with trade. Due to the independence of sectors, we only consider sector h and drop the h superscript. The profits firm φ earns when exporting from country i to j are[8]

$$\pi_{ij} = \frac{\mu Y_j}{t_{ij}\sigma}\left[\frac{\sigma}{(\sigma-1)}\frac{w_i t_{ij}\tau_{ij}}{\varphi P_j}\right]^{1-\sigma} - f_{ij}.$$

Define the threshold $\bar{\varphi}_{ij}$ from $\pi_{ij}(\bar{\varphi}_{ij}) = 0$ as the productivity of the least productive firm in country i able to export to country j:

$$\bar{\varphi}_{ij} = \lambda_1 \left(\frac{f_{ij}t_{ij}^{\sigma}}{Y_j}\right)^{\frac{1}{(\sigma-1)}} \frac{w_i\tau_{ij}}{P_j} \tag{11}$$

where $\lambda_1 = \left(\frac{\sigma}{\sigma-1}\right)\left(\frac{\sigma}{\mu}\right)^{1/(\sigma-1)}$ is a constant. It is easy to see that tariffs affect the threshold firm differently than iceberg transport costs and that, all else equal, a tariff would correspond to a higher threshold (and productivity) than an identical transport cost.

Recalling that $Y_k = w_k L_k(1+\pi)$ so $w_k L_k = \frac{Y_k}{(1+\pi)}$, the price index can be written as

$$P_j = \lambda_2 Y_j^{\frac{(\sigma-1)-\gamma}{\gamma(\sigma-1)}}\theta_j \tag{12}$$

where

$$\lambda_2^{\gamma} = \left(\frac{\gamma-(\sigma-1)}{\gamma}\right)\left(\frac{\sigma}{\mu}\right)^{\frac{\gamma-(\sigma-1)}{(\sigma-1)}}\left(\frac{\sigma}{(\sigma-1)}\right)^{\gamma}\left(\frac{1+\pi}{Y}\right)$$
$$\theta_j^{-\gamma} = \sum_{k=1}^{N}\left(\frac{Y_k}{Y}\right)(w_k\tau_{ij})^{-\gamma}\, t_{kj}^{1+\frac{\sigma\gamma}{1-\sigma}} f_{kj}^{1+\frac{\gamma}{1-\sigma}}.$$

The term θ_j is a measure of country j's remoteness from the rest of the world. Using the general equilibrium price index, (12), we can solve for firm level exports, the productivity thresholds, and total world profits:

[8] Note that in order for firm profits to be affected in the same way regardless of the trade barrier, income Y_j would have to be a constant multiple of t_{ij}.

$$x_{ij}(\varphi) = \begin{cases} \lambda_3 \left(\frac{Y_j}{Y}\right)^{\frac{(\sigma-1)}{\gamma}} \left(\frac{\theta_j}{w_i \tau_{ij} t_{ij}}\right)^{\sigma-1} \varphi^{\sigma-1}, \text{ if } \varphi \geq \bar{\varphi}_{ij} \\ 0 \text{ otherwise,} \end{cases} \tag{13}$$

$$\bar{\varphi}_{ij} = \lambda_4 \left(\frac{Y}{Y_j}\right)^{\frac{1}{\gamma}} \left(\frac{w_i \tau_{ij}}{\theta_j}\right) \left(f_{ij} t_{ij}^{\sigma}\right)^{\frac{1}{(\sigma-1)}}$$

$$Y_i = (1 + \lambda_5) w_i L_i$$

$$\pi = \lambda_5$$

where $\lambda_3,\ \lambda_4$, and λ_5 are constants.[9]

It is important to note how tariffs and transport costs enter into the equilibrium firm level of exports and productivity thresholds. Since the price consumers pay is identical under the two trade costs, the quantity of each variety sold is identical $x_{ij}(\varphi)$ – what changes is the number of varieties, $\bar{\varphi}_{ij}$. This difference translates into the following gravity equation: Total (trade cost inclusive) exports, X_{ij}^h, in sector h from country i to country j are given by

$$X_{ij}^h = \mu_h \left(\frac{Y_i Y_j}{Y}\right) \left(\frac{w_i \tau_{ij}^h t_{ij}^{h\, \frac{\sigma_h}{\sigma_h - 1} - \frac{1}{\gamma_h}}}{\theta_j}\right)^{-\gamma_h} f_{ij}^{-\left[\frac{\gamma_h}{(\sigma_h-1)} - 1\right]}. \tag{14}$$

Exports are a function of country size (Y_i and Y_j), workers' productivity (w_i), the bilateral trade costs, variable ($t_{ij}^h,\ \tau_{ij}^h$) and fixed (f_{ij}^h), and the measure of j's remoteness from the rest of the world (θ_j^h).[10] It can easily be seen that tariffs and trade costs enter the gravity

[9]

$$\begin{aligned} \lambda_3 &= \sigma \lambda_4^{1-\sigma} \\ \lambda_4 &= \left[\left(\frac{\sigma}{\mu}\right)\left(\frac{\gamma}{\gamma - (\sigma - 1)}\right) \frac{1}{(1 + \lambda_5)}\right]^{\frac{1}{\gamma}} \\ \lambda_5 &= \frac{\sum_{h=1}^{H} \left(\frac{\sigma_h - 1}{\gamma_h}\right) \frac{\mu_h}{\sigma_h}}{1 - \sum_{h=1}^{H} \left(\frac{\sigma_h - 1}{\gamma_h}\right) \frac{\mu_h}{\sigma_h}} \end{aligned}$$

[10]The proof of equation (14) is available in the online appendix. Furthermore, following Chaney, we also assume that country i is small enough and/or remote enough, so that $\partial\theta_j/\partial t_{ij} \approx 0$ and $\partial\theta_j/\partial\tau_{ij} \approx 0$

function differently which is purely driven by the extensive margin. This point is made more clearly by separating out the trade elasticities into the two margins. We additionally report the elasticity with respect to fixed costs:

$$\text{Tariff:} \quad \rightarrow \vartheta \equiv -\frac{d\ln X_{ij}}{d\ln t_{ij}} = \underbrace{(\sigma-1)}_{\text{Intensive}} + \underbrace{\frac{\sigma\left[\gamma-(\sigma-1)\right]}{\sigma-1}}_{\text{Extensive}} = \frac{\sigma\gamma}{\sigma-1} - 1, \tag{15}$$

$$\text{Iceberg:} \quad \rightarrow \zeta \equiv -\frac{d\ln X_{ij}}{d\ln \tau_{ij}} = \underbrace{(\sigma-1)}_{\text{Intensive}} + \underbrace{\left[\gamma-(\sigma-1)\right]}_{\text{Extensive}} = \gamma \tag{16}$$

$$\text{Fixed Cost:} \quad \rightarrow \xi \equiv -\frac{d\ln X_{ij}}{d\ln f_{ij}} = \underbrace{0}_{\text{Intensive}} + \underbrace{\frac{\gamma}{\sigma-1} - 1}_{\text{Extensive}} = \frac{\gamma}{\sigma-1} - 1. \tag{17}$$

There are three conclusions from these elasticities that warrant particular attention.

Result 1. *The elasticity with respect to tariffs is equal to the sum of the elasticity with respect to fixed and iceberg costs:*

$$\xi + \zeta = \vartheta. \tag{18}$$

Result 1 means that if the researcher believed this model completely and took it to the data, she should test that the estimated coefficients satisfy this restriction. If the restriction is not satisfied then the parameters should be restricted accordingly. The second conclusion is straightforward to see by comparing equation (15) with (16) and follows from Result 1.

Result 2. *Trade flows are more elastic with respect to changes in tariffs than transport costs,*

$$\vartheta - \zeta = \frac{\gamma-(\sigma-1)}{\sigma-1} > 0. \tag{19}$$

The difference between trade elasticities depends on two things: the elasticity of substitution and dispersion of productivity among firms in equilibrium. With respect to the elasticity of substitution, the intuition is as follows: For highly competitive industries where a firm's markup is quite low, the ability of a firm to recoup some of its transport costs is also lower and thus the wedge between profit values is smaller. The shape parameter of the firms' productivity distribution also plays an important role. When a sector has a high γ, the smaller, less productive firms are producing relatively more of the sector's output. Since changes in tariffs have a greater impact on whether these firms are producing or not, it will then also have a greater impact on the industry's aggregate trade flow.

The third conclusion is that the elasticity of substitution (σ) does play a role in the elasticity of trade flows with respect to variable costs (contrary to the broad claim by Chaney and Eaton and Kortum 2002) when the variable cost is a function of product value; e.g. ad valorem tariffs. However, the claim by Chaney that the elasticity of trade flows is decreasing in the elasticity of substitution is not only maintained by using tariffs, but is strengthened by it.

Result 3. *The elasticity of trade flows with respect to ad valorem tariffs is decreasing in the elasticity of substitution,*

$$\frac{d\vartheta}{d\sigma} = \frac{-\gamma}{(\sigma - 1)^2} < 0. \tag{20}$$

It is crucial to point out how important the extensive margin is for the last two results; equations (19) and (20). If, for example, there was no entry and exit in the export sector, the tariff elasticity would be identical to the iceberg trade cost elasticity. Moreover, the magnitude would be increasing in the elasticity of substitution which is the prediction of Krugman (1980). Therefore, as we move from the theory to the empirics, the reader should keep in mind where a tractable (and simplified) theoretical model may fail us in the real world. In particular, the theory assumes that the extensive margin is able to react to changes in trade costs in line with the intensive margin. This can fail for various reasons. One such reason is if productivity is distributed by a discrete distribution instead of continuous. In this case, the zero profit condition (equation 11) becomes a non-negative profit condition and it is possible for the least productive exporting firm to make positive ex post profits and the next firm down in the productivity ladder would make negative profits if it exported. Therefore, a sufficiently small change in trade costs would have no effect on the extensive margin. Another possibility is that there are additional barriers to entry outside of the current model. Finally, in terms of timing, the model assumes firms can enter and exit the foreign market as quickly as an incumbent firm can adjust its production. This is particularly important in a time series model as the effect of the extensive margin would lag behind that of the intensive margin.

4 Empirical Application

We examine our model empirically using U.S. 10-digit HS imports data sourced from the U.S. Census' Imports of Merchandize for the year 2001. To conduct an empirical investigation, in addition to trade data, we need three more pieces of information: tariffs, transportation costs, and fixed costs of production. We use John Romalis's U.S. Tariff Database (Feenstra, Romalis, and Schott 2002) as the source of tariff rates the U.S. assessed in 2001. While the Census data allow us to calculate the average collected tariff as it provides information on duties collected and the dutiable value of imports (as has been done by Besedeš and Prusa 2016, among others), we prefer to use the U.S. Tariff Database as it provides us with actual tariffs the U.S. assesses, the rates which firms react to. We use the product-level value of imports inclusive of collected duties as well as charges for freight and insurance given our model.[11] We restrict our sample to products with positive tariffs, as our model applies to instances where trade costs are positive.[12] We further restrict the sample by dropping

[11]We note that our results are qualitatively unchanged if we use imports exclusive of collected duties and charges for freight and insurance.

[12]The inclusion of imports of zero-tariff products which face positive transport and fixed costs would bias the elasticity of trade with respect to tariffs downward given there would be a number of observations with a zero tariff. Our results reported below are qualitatively unchanged if we include all zero-tariff observations along with a dummy variable which identifies them.

observations with unreasonably high transportation costs, which we define as transport costs equal to the value of imports.[13] The Census data allow us to calculate the ad valorem transport cost for every country-product pair observed in the data. We use the ratio of import charges (all freight, insurance, and other charges exclusive of the tariff charged) and imports as the iceberg-melt factor.

The most difficult data to obtain for our exercise are data on fixed costs of production at the country-product level. We are not familiar with any source of data providing such information, so we resort to several proxies for fixed costs. Assuming constant marginal costs (as is the case in our model following equation 2) and increasing returns to scale in production, the elasticity of substitution is directly related to fixed costs, with a lower elasticity implying higher fixed costs. Our first proxy for fixed costs is the inverse of the elasticity of substitution that we source from Soderbery (2015), who provides estimates of the elasticity of substitution at the 10-digit HS level. We use the inverse of the elasticity of substitution so that a higher value corresponds to higher fixed costs. One potential difficulty with respect to using the elasticity of substitution as a proxy for fixed costs is that it only varies across the 10-digit HS product codes, but not countries. In order to introduce variation across countries we interact the inverse of the elasticity of substitution with data from World Bank's Ease of Doing Business Database which have been used to proxy for fixed costs: the ease of doing business index, cost to export, documents to export, and time to export. We use each measure for the earliest year available which is 2011 for the ease of doing business index and 2005 for the remaining three measures. As we will show, our results are not particularly sensitive with respect to any of these four measures.

4.1 Benchmark Results

We estimate a gravity equation using OLS with the log of U.S. imports of product h from country i ($\ln X_i^h$) as our dependent variable and regress it on the log of tariffs ($\ln t_i^h$), trans-

[13]There are 931 such observations.

portation costs ($\ln \tau_i^h$), and fixed costs ($\ln f_i^h$). We include country-product pair fixed effects as a proxy for multilateral resistance terms (r_i). Since our explanatory variable vary either at the 10- or 8- digit HS level, we define the country-product pair fixed effects at the 6-digit HS level. We estimate

$$\ln X_i^h = \beta_0 + \beta_1 \ln t_i^h + \beta_2 \ln \tau_i^h + \beta_3 \ln f_i^h + r_i + \epsilon_i^h \tag{21}$$

where $|\beta_1| = \vartheta$, $|\beta_2| = \zeta$, $|\beta_3| = \xi$, and ϵ_i^h is the error term. The results from our basic specification using all available data are shown in Table 1. The last two rows in the table report the p-values resulting from testing whether estimated coefficients satisfy restriction (18), that the elasticity of trade flows with respect to tariffs and transport costs add up to the elasticity with respect to fixed costs, and restriction (19), that the elasticity with respect to tariffs exceeds the elasticity with respect to transport costs. In the latter case we conduct a test on the equality of the two estimates and report the p-value from the one-sided test.

We first note that our estimated coefficients are largely consistent across the five different proxies of fixed costs we use. Our estimates imply that the elasticity of U.S. imports with respect to tariffs is between -0.125 and -0.141, with respect to transport costs between -0.319 and -0.320, and with respect to fixed costs between -0.047 and -0.051. However, we are more interested in ascertaining whether the implied restrictions are satisfied than in the size of the estimated coefficients. Since we only use a proxy for fixed costs, and not direct measures of fixed costs, our preference is that we test whether the coefficient satisfy the predicted relationship, rather than appropriately constraining estimated coefficients. Let us first focus on Result 1. In every specification we can reject the hypothesis that the elasticities with respect to transport costs and fixed costs add up to the elasticity with respect to tariffs. As far as Result 2 is concerned note that in every specification the tariff elasticity is estimated to be smaller than the transport cost elasticity (in absolute value). It would seem then that our data do not support the model. We now turn to the possible explanation, alluded to above, that our empirical results may depend on how active the extensive margin is for every product.

As discussed at the end of section 3 it is possible that the extensive margin differs across products with some products having a lot of entry and exit and some having little entry and exit. For the latter group of products, we should observe no differences in tariff and transport cost elasticities, while the difference should be significant for products where there is a lot of activity along the extensive margin. In order to examine the extent to which the extensive margin affects our results we split our sample according to the extent of activity on the extensive margin. We use U.S. Census Imports of Merchandize data for the year 2000 to calculate how active is the extensive margin for every product. We measure the activity by calculating the net entry in 2001 relative to 2000. Products with active extensive margins will be those that either had more entry than exit or more exit than entry. How active must the extensive margin be for the predicted difference to be observed is an empirical question since the model is silent on it. In Table 2 we report two classifications of active extensive margin. The first one classifies as active products those 10-digit HS codes with net entry below the 20$^{\text{th}}$ percentile and above the 80$^{\text{th}}$ percentile. As can be seen from Table 2 such a definition does not isolate products with sufficiently active extensive margin.

The second definition we use are products with net entry below the 10$^{\text{th}}$ and above the 90$^{\text{th}}$ percentile. Under this definition of an active extensive margin, our data support our theoretical predictions. For products with an active extensive margin, the elasticity with respect to tariffs is larger (in absolute value) than and statistically significantly different from the elasticity with respect to transport costs, both when using the elasticity of substitution as a proxy for fixed costs (-0.572 vs. -0.274 with a p-value of 0.0497) and its interaction with the ease of doing business index (-0.584 vs. -0.269 with a p-value of 0.0405). In addition, the tariff elasticity is not statistically significantly different from the sum of the the transport and fixed costs elasticities (p-values of 0.2436 and 0.1999 for the two measures of fixed costs). If we restrict the sample for products with even more active extensive margin (using the $5^{\text{th}} - 95^{\text{th}}$ percentile definition, for example), then the difference between the tariff and transport cost elasticities grows even more (-0.936 vs. -0.128 with a p-value of 0.0004), though in such a case the tariff elasticity is also statistically significantly different from the sum of the transport and fixed cost elasticities (p-value of 0.0007). Note also that in the remainder of the sample, characterized as not having an active extensive margin (bottom panel of Table 2), there is no statistically significant difference between the tariff and transport elasticities, as the model predicts.

Unfortunately, our data preclude us from examining Result 3 empirically, that the elasticity of trade with respect to tariffs is decreasing in the elasticity of substitution, as rigourously as we would like. We use the elasticity of substitution as a proxy for fixed costs giving us product level variation. For this reason we are reluctant to also use it as the elasticity of substitution given the difficulty that would create in interpreting our results. We did explore splitting the subsample of observations for products with an active extensive margin (using the $10^{\text{th}} - 90^{\text{th}}$ percentile definition) at the median value of the elasticity of substitution and then reestimating our specification for the low-elasticity-of-substitution subsample (below the median) and the high-elasticity-of-substitution-subsample. Doing so results in an estimate of the tariff elasticity of -0.872 in the low-elasticity sample and -0.682 in the high-elasticity sample, providing potential evidence that tariff elasticities indeed decreases with the elasticity of substitution. Unfortunately, given standard errors of 0.187 and 0.197, the two estimates are not statistically different from each other.

4.2 Robustness

4.2.1 Tariff measures

In assessing the robustness of our results we first turn our attention to the tariff data. The U.S. Census data on imports in 2001 consists of 251,920 observations. The largest sample we use in Table 1 consists of 45,918 observations. Some 95% of the remaining 200,602 observations are not used due to them being associated with either zero tariffs or missing tariff information, while the remainder either do not have observations on fixed costs or transport costs or have unreasonably high transport costs. The large number of observations with zero tariffs is at odds with the observation that the U.S. Census data report positive duty collected for 150,688 observations or almost 60%. This discrepancy likely stems from rules of origins not having been satisfied for some imports resulting in them receiving the MFN treatment, rather than the preferred duty-free entry or from some exporters not taking advantage of preferential access to the U.S., either out of ignorance or unwillingness to file the necessary paperwork.

In order to examine the sensitivity of our results to this behavior, we offer the top two panels in Table 3 where we replicate the main regressions from Tables 1 and 2 with the elasticity of substitution as a measure of fixed costs, while using two different measures of tariffs. In the top panel we supplement the Romalis Tariff Database with U.S. 2001 MFN tariffs rates for every observation where our original tariff data report a tariff of zero and the Census data report positive duties collected. We do so under the assumption that if an exporter does not file the necessary paperwork to obtain preferential access to the U.S. market or does not satisfy rules of origin, their exports will receive MFN treatment. The middle panel uses the Census data to calculate the average assessed tariff by taking a ratio of collected duties and the dutiable value of imports. The former approach increases our sample size to 68,162, and the latter to 120,541 observations, almost a half of all observed in 2001. In the latter approach the unused observations either have no duties collected resulting in a zero tariff or are missing other information.

All results in Table 3 are similar to our earlier results. Estimates for the entire sample depart from our model's predictions. However, once we restrict the sample to products with an active extensive margin,[14] we obtain results along the lines of our benchmark results: tariff elasticity exceeds transport elasticity, and is equal to the sum of transport and fixed

[14]The definition of active extensive margin is more restrictive with these two exercises. With Romalis Tariff Database tariffs active extensive margin is defined as products with net entry below the 7^{th} and above the 87^{th} percentile, while for tariffs based on Census data it is below the 4^{th} and above the 97^{th} percentile.

cost elasticities. This is particularly reassuring in the case of results in the middle panel where we use assessed tariff rather than posted ad valorem tariffs for two reasons. Firstly, these results indicate that in instances where posted tariffs are not available, assessed tariffs available in the data are a valid substitute. Secondly, while tariffs should at least in theory be levied on the sale value of goods when they cross borders, in practice they may be levied on the assessable value as that the importer declares. If the latter is predominantly the case, then tariffs calculated as the ratio of the collected duty and dutiable value (which is reported and declared by the importer) is a more accurate measure of the size of the tariff. As the bottom panel of Table 3 shows, our results when using tariffs defined on the declared value are very much in line with our predictions. It also may be the case that if tariffs depend on the declared value, that the appropriate measure of volume of imports is the declared value, rather than the sales value. The bottom panel uses the dutiable or declared value as the independent variable showing that our results for products with an active extensive margin support the model.

4.2.2 Imports exclusive of tariffs and import charges

Our model above is derived for imports inclusive of all tariff and import charges, the latter of which reflect the cost of insurance and freight. The qualitative predictions of our model also hold if we use imports exclusive of tariff and import charges. The derivation of the model under such a condition can be found in an online appendix.[15] In Table 4 we provide the same regressions as in Table 3 but using import values exclusive of tariff and import charges. Our results are qualitatively unchanged, with all estimated elasticity somewhat larger, and both relationships among elasticities holding according to the model.

[15]In the online appendix, we show that $\vartheta = \frac{\sigma\gamma}{\sigma-1}$, $\zeta = \gamma + 1$, and $\xi = \frac{\gamma}{\sigma-1} - 1$. It can be readily seen that our three results hold in this case as well.

5 Conclusion

In this paper, we took seriously the fact that variable costs based on value (ad valorem tariff) are fundamentally different than variable costs based on quantity (iceberg) in the context of a gravity model. We have presented a highly tractable model that allows for all three types of costs (two variable and one fixed). We have two main results in which we find strong empirical support for products with an active extensive margin. The first is the linear relationship between the three elasticities; i.e. the sum of the elasticities of trade with respect to fixed and iceberg transport cost is equal to that of ad valorem tariffs. The second result is that the elasticity of trade with respect to tariffs is greater in magnitude than the elasticity of trade with respect to iceberg transport costs. This latter result is driven by the extensive margin both in the theory and empirical testing. We additionally show that if the variable cost is based on value (e.g. ad valorem tariff), then the elasticity of substitution plays a role in the overall trade elasticity, which decreases with the elasticity of substitution.

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Table 1: Full Sample

	Fixed cost proxy				
		Elasticity of substitution interacted with			
	Elasticity of substitution	Ease of doing business	Cost to export	Documents to export	Time to export
Tariff rate ($-\vartheta$)	-0.125**	-0.137***	-0.141***	-0.141***	-0.141***
	(0.05053)	(0.05075)	(0.05077)	(0.05077)	(0.05077)
Transport cost ($-\zeta$)	-0.319***	-0.320***	-0.320***	-0.320***	-0.320***
	(0.02284)	(0.02306)	(0.02311)	(0.02311)	(0.02311)
Fixed cost ($-\xi$)	-0.051***	-0.047***	-0.047***	-0.047***	-0.047***
	(0.01788)	(0.01811)	(0.01814)	(0.01814)	(0.01814)
Constant	11.249***	11.362***	11.523***	11.281***	11.324***
	(0.15236)	(0.15595)	(0.18171)	(0.15233)	(0.15385)
Observations	45,918	45,053	44,762	44,762	44,762
R^2	0.02047	0.02071	0.02070	0.02070	0.02070
Test hypotheses and p-values					
Result 1: $\vartheta = \zeta + \xi$	0.0000	0.0001	0.0001	0.0001	0.0001
Result 2: $\vartheta = \zeta$	0.9997	0.9993	0.9991	0.9991	0.9991

The dependent variable is log of imports. Country fixed effects are included, robust standard errors clustered on countries are in parenthesis with *, **, *** denoting significance at 10%, 5%, and 1%.

Table 2: The Role of Extensive Margin

	Active Extensive Margin (High Net Entry)			
	$< 20^{\text{th}}$ or $> 80^{\text{th}}$ pctile		$< 10^{\text{th}}$ or $> 90^{\text{th}}$ pctile	
	Elasticity of substitution	Ease of doing business	Elasticity of substitution	Ease of doing business
Tariff rate ($-\vartheta$)	-0.126	-0.143	-0.572***	-0.584***
	(0.11190)	(0.11239)	(0.16275)	(0.16233)
Transport cost ($-\zeta$)	-0.332***	-0.335***	-0.274***	-0.269***
	(0.04180)	(0.04233)	(0.05601)	(0.05621)
Fixed cost ($-\xi$)	-0.090***	-0.087***	-0.085**	-0.081**
	(0.03012)	(0.03080)	(0.03796)	(0.03890)
Constant	11.259***	11.476***	10.048***	10.236***
	(0.32979)	(0.32962)	(0.46889)	(0.46954)
Observations	22,390	21,840	13,690	13,295
R^2	0.023	0.024	0.024	0.024
Test p-values				
Result 1: $\vartheta = \zeta + \xi$	0.0187	0.0278	0.2436	0.1999
Result 2: $\vartheta = \zeta$	0.9508	0.9365	0.0497	0.0405

	Inactive Extensive Margin (Low Net Entry)			
	$> 20^{\text{th}}$ and $< 80^{\text{th}}$ pctile		$> 10^{\text{th}}$ and $< 90^{\text{th}}$ pctile	
	Elasticity of substitution	Ease of doing business	Elasticity of substitution	Ease of doing business
Tariff rate ($-\vartheta$)	-0.338***	-0.347***	-0.214***	-0.222***
	(0.06985)	(0.07006)	(0.05486)	(0.05513)
Transport cost ($-\zeta$)	-0.300***	-0.301***	-0.313***	-0.316***
	(0.03402)	(0.03410)	(0.02702)	(0.02729)
Fixed cost ($-\xi$)	0.055**	0.060**	0.000	0.005
	(0.02568)	(0.02584)	(0.02135)	(0.02153)
Constant	10.671***	10.467***	10.980***	10.951***
	(0.21499)	(0.21827)	(0.16808)	(0.17185)
Observations	23,533	23,217	32,230	31,760
R^2	0.022	0.022	0.020	0.020
Test p-values				
Result 1: $\vartheta = \zeta + \xi$	0.1254	0.1729	0.2530	0.1960
Result 2: $\vartheta = \zeta$	0.9456	0.9347	0.3135	0.2798

The dependent variable is log of imports. Country fixed effects are included, robust standard errors clustered on countries are in parenthesis with *, **, *** denoting significance at 10%, 5%, and 1%.

Table 3: Different Measures of Tariffs

	Romalis (2001) along with MFN tariffs		
	All	Extensive margin	
	observations	Active	Inactive
Tariff rate ($-\vartheta$)	-0.069	-0.464***	-0.189***
	(0.04292)	(0.14299)	(0.04542)
Transport cost ($-\zeta$)	-0.322***	-0.268***	-0.329***
	(0.01987)	(0.05111)	(0.02315)
Fixed cost ($-\xi$)	-0.065***	-0.075**	-0.049***
	(0.01513)	(0.03105)	(0.01829)
Constant	11.485***	10.527***	11.098***
	(0.12698)	(0.39827)	(0.13739)
Observations	68,162	19,231	48,934
R^2	0.019	0.018	0.021
Test p-values			
Result 1: $\vartheta = \zeta + \xi$	0.0000	0.4481	0.0005
Result 2: $\vartheta = \zeta$	0.9999	0.1066	0.9966

	Tariffs based on Census data		
	All	Extensive margin	
	observations	Active	Inactive
Tariff rate ($-\vartheta$)	0.121***	-0.262**	0.124***
	(0.02359)	(0.12167)	(0.02358)
Transport cost ($-\zeta$)	-0.253***	-0.048*	-0.282***
	(0.01233)	(0.02832)	(0.01274)
Fixed cost ($-\xi$)	-0.086***	-0.184***	-0.071***
	(0.01036)	(0.03748)	(0.01091)
Constant	11.321***	12.062***	11.332***
	(0.04568)	(0.22113)	(0.04662)
Observations	120,541	10,252	110,289
R^2	0.015	0.010	0.017
Test p-values			
Result 1: $\vartheta = \zeta + \xi$	0.0000	0.8089	0.0000
Result 2: $\vartheta = \zeta$	1.0000	0.0440	1.0000

	Tariffs based on Census data with dutiable value as the independent variable		
	All	Extensive margin	
	observations	Active	Inactive
Tariff rate ($-\vartheta$)	0.056**	-0.289**	0.057**
	(0.02338)	(0.12972)	(0.02301)
Transport cost ($-\zeta$)	-0.261***	-0.053*	-0.291***
	(0.01197)	(0.02740)	(0.01235)
Fixed cost ($-\xi$)	-0.085***	-0.201***	-0.070***
	(0.01029)	(0.03742)	(0.01084)
Constant	10.997***	11.570***	11.018***
	(0.04541)	(0.23299)	(0.04592)
Observations	120,541	10,252	110,289
R^2	0.016	0.013	0.018
Test p-values			
Result 1: $\vartheta = \zeta + \xi$	0.0000	0.7838	0.0000
Result 2: $\vartheta = \zeta$	1.0000	0.0376	1.0000

The dependent variable is log of imports. Country fixed effects are included, robust standard errors clustered on countries are in parenthesis with *, **, *** denoting significance at 10%, 5%, and 1%.

Table 4: Imports exclusive of tariff and import charges

		Active extensive margin		Inactive extensive margin	
	All observations	Elasticity of substitution	Ease of doing business	Elasticity of substitution	Ease of doing business
Tariff rate ($-\vartheta$)	-0.182***	-0.602***	-0.615***	-0.274***	-0.281***
	(0.05043)	(0.16305)	(0.16265)	(0.05514)	(0.05542)
Transport cost ($-\zeta$)	-0.366***	-0.311***	-0.306***	-0.363***	-0.366***
	(0.02372)	(0.05868)	(0.05887)	(0.02773)	(0.02801)
Fixed cost ($-\xi$)	-0.051***	-0.086**	-0.082**	0.001	0.006
	(0.01795)	(0.03815)	(0.03910)	(0.02142)	(0.02160)
Constant	11.016***	10.059***	9.232***	10.743***	10.712***
	(0.15236)	(0.47105)	(0.62015)	(0.16918)	(0.17292)
Observations	45,918	13,295	5,360	32,230	31,760
R^2	0.027	0.029	0.02257	0.02657	0.027
Test p-values					
Result 1: $\vartheta = \zeta + \xi$	0.0001	0.2639	0.2173	0.1740	0.2326
Result 2: $\vartheta = \zeta$	0.9994	0.0545	0.0444	0.9246	0.9111

The dependent variable is log of imports. Country fixed effects are included, robust standard errors clustered on countries are in parenthesis with *, **, *** denoting significance at 10%, 5%, and 1%.