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

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Abstract

It is quite common in the trade literature to use iceberg transport costs to represent variable trade barriers, both tariffs and shipping costs alike. However, in models with monopolistic competition these are, in fact, not identical trade restrictions which has important consequences for the theoretical model. We illustrate these differences in a gravity model à la Chaney (2008), but the implications are relevant for other trade models including calibrated models focused on welfare analysis. We show theoretically that the elasticity of substitution plays a role in the elasticity of trade flows with respect to tariffs – unlike with iceberg transport costs. Moreover, trade flows are more elastic with respect to ad valorem tariffs than transport costs and find a linear relationship between the elasticities with respect to ad valorem tariffs, iceberg transport costs, and fixed market costs. We empirically validate the latter results using data on U.S. product-level imports.

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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. In models of perfect competition, iceberg transport costs and ad valorem tariffs are equivalent. 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. 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. This will become clearer later.

The purpose of this paper is to make three main points. The first point relates to a key result of Eaton and Kortum (2002) and Chaney (2008). These papers find that the elasticity of trade flows with respect to variable trade costs does not depend on the elasticity of substitution but rather it is equal to a parameter describing the dispersion of firm productivity. However, the variable trade costs in these models are represented by iceberg transport costs and as we will show, the elasticity of substitution does matter with respect to tariffs. At first glance, this may seem like a minor point. However, if the researcher is estimating a gravity model strictly based on the results of these two models and tariffs are used as an explanatory variable, then important cross sector variation would be ignored by not accounting for differences in sector elasticity of substitution. For instance, Yi and Van

\[\text{The different effect on firm profit is shown explicitly in Cole (2011), which has fixed cost heterogeneity with quasi-linear utility and analyzes how iceberg transport costs and ad valorem tariffs affect the mass of varieties and welfare differently. Schröder and Sørensen (2011) additionally illustrate in a Meltiz (2003) type model how tariffs differ from iceberg transport costs. Neither of these papers highlight this difference in a gravity framework. For a welfare analysis on the differences between per-unit trade costs versus iceberg see Sørensen (2012).}\]
Biesebroeck (2012) find that differentiated goods have the most sensitive tariff extensive margin elasticity by investigating China’s induction into the WTO where Chaney (2008) predicts the elasticity of the extensive margin is equal to one and does not depend on the elasticity of substitution. Moreover, if the researcher is calibrating a model of monopolistic competition to investigate the effects of a tariff reduction, their predicted effects will be for non-value based transport costs and not value based costs like ad valorem tariffs or insurance.

The second point of this paper is to show that the elasticity of trade flows with respect to ad valorem tariffs is greater than the elasticity with respect to iceberg transport costs. Thus, in monopolistically competitive models with an active extensive margin, modeling iceberg costs as a generic variable trade cost may not be appropriate. For instance, Crozet and Koenig (2010) use data on French firms to estimate the structural parameters of the Chaney (2008) model and suggest that the elasticity defined by iceberg transport costs can be used to infer the effects of changes in tariff policy. We show that such an approach would result in downward biased conclusions since the tariff elasticity exceeds the transport cost one. Helpman, Melitz, and Rubinstein (2008) also provide a gravity model with heterogeneous firms and estimate the structural parameters. They highlight the importance of accounting for the extensive margin, which is precisely the reason iceberg transport costs are different than ad valorem tariffs. Arkolakis et. al (2012) show that as long as the modeler assumes a CES import demand structure and a gravity equation, there exists a common estimator of the gains from trade. This estimator depends only on the share of expenditure on domestic goods and a gravity-based estimator of the elasticity of imports with respect to variable trade costs (in which iceberg transport costs are used to represent variable trade costs), the

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2We thank an anonymous referee for pointing out that trade costs based on value (e.g. insurance) would have a similar effect as to tariffs in my model.

3MATT: HMR do not explicitly model tariffs using transport iceberg. They just don’t model tariffs period. We need to be careful that we don’t say others have done something that they actually didn’t. They always talk about bilateral distance related costs. They only say at one point average tariffs end up in the estimated fixed effect if not controlled for directly.

4Additionally, Lawless (2010) deconstructs the gravity equation into the extensive and intensive margins, highlighting the importance of both.
latter being the focus of this paper. Furthermore, Giovanni and Levchenko (2013) use a model similar to Chaney (2008) to investigate the welfare gains from trade liberalization, in particular, the gains from the extensive margin. Finally, Brienlich (2011) uses the Chaney (2008) model (with iceberg trade costs) to test firm level responses to the United States - Canada tariff liberalization of 1989 (CUSFTA)\footnote{MATT: We should explicitly state that these two papers use iceberg to model tariffs as well, if they do so.}

The second point illustrates how the three different elasticities are related to each other. When one correctly treats iceberg transport costs and ad valorem tariffs as different trade costs in a Chaney (2008) type gravity model, an interesting (linear) relationship arises between the elasticities with respect to iceberg costs, ad valorem tariffs, and fixed cost of production. Specifically, we show that the sum of the elasticity with respect to iceberg costs and fixed costs equals the elasticity with respect to tariffs. This has empirical implications in that a restriction on the estimated parameters is warranted. It also means that one only needs to estimate two elasticities to infer the third by appropriately constraining the coefficients.

We apply our model to data on U.S. imports at the 10-digit HS level in the year 2000. We use 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 (2014) 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.
with the tariff one being larger, and that the tariff elasticity is equal to the sum of the transport and fixed cost elasticities.

We want to emphasize that the point of this paper is not to claim the use of iceberg transport costs as a variable trade cost is not valid, nor is it our intention to discredit previous studies. The purpose here is to illustrate that the extensive margin drives a wedge between the longstanding isomorphic relationship of iceberg transport costs and ad valorem tariffs. This produces a necessary caveat when making tariff policy recommendations based on models that use only transport costs as trade barriers. 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) 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 homogeneous good that pins down the wage in country $n$, $w_n$. 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 $\omega$ of good $h$, for all varieties in the set $\Omega_h$ (determined in equilibrium),

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6We assume that every country produces a positive amount of $q_0$. 

she gets a utility $U$,

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

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 $h$.

### 2.1 Trade Barriers and Technology

There are three types of trade barriers: two variable, tariffs, $t_{ij}^h$, and iceberg transport costs, $(\tau_{ij}^h)$, and a fixed cost, $f_{ij}^h$. Each firm in sector $h$ draws a random unit labor productivity $\varphi$ from a Pareto distribution with shape parameter $\gamma_h$. Following Chaney (2008), we assume the total mass of potential entrants in each sector is proportional to $w_i L_j$. The cost of producing $q$ units of a good and selling them in country $j$ for a firm with productivity $\varphi$ is

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

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

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

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

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

8 For a cleaner equation, we abuse notation and drop the $i, j$ subscripts on $p$ and $q$. This is also consistent with Chaney (2008).
the firm charges plus the tariff or,

\[ p = \frac{\sigma_h}{(\sigma_h - 1)} \frac{\tau_{ij}^h w_i}{\varphi} \]

Firm Price \hspace{1cm} (4)

\[ p_{ij}^h(\varphi) = t_{ij}^h p = \frac{\sigma_h}{(\sigma_h - 1)} \frac{t_{ij}^h \tau_{ij}^h w_i}{\varphi} \]

Consumer Price \hspace{1cm} (5)

Note that the tariff and transport cost have the same effect on the price paid by consumers, however the actual level of profit will be lower under an identical tariff which will have an effect on the extensive margin. To see this insert the price (4) back into the profit function (3):

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

and as an illustrative example let \( \frac{w_i}{\varphi} = 100, \sigma_h = 2 \) and both trade restrictions to be equal, \( t_{ij}^h = \tau_{ij}^h = 1.10 \). We decompose the firm’s profit for shipping one unit in Table 1 while only allowing for one trade barrier at a time. 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, whereas tariff revenue is completely captured by the domestic government.

<table>
<thead>
<tr>
<th>Trade Barrier</th>
<th>Revenue</th>
<th>Variable Cost</th>
<th>Fixed Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iceberg ((t_{ij}^h = 1, \tau_{ij}^h = 1.10))</td>
<td>220</td>
<td>110</td>
<td>( f_{ij}^h )</td>
</tr>
<tr>
<td>Tariff ((t_{ij}^h = 1.10, \tau_{ij}^h = 1))</td>
<td>220</td>
<td>0.1(200)+100=120</td>
<td>( f_{ij}^h )</td>
</tr>
</tbody>
</table>
2.2 Demand for Differentiated Goods

The total income spent by workers in country $j$, $Y_j$, is the sum of their labor income ($w_jL_j$) and of the dividends they get from their portfolio ($w_jL_j\pi$), where $\pi$ 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 a labor productivity $\varphi$, are

$$x^h_{ij}(\varphi) = p^h_{ij}(\varphi)q^h_{ij}(\varphi) = \mu_h Y_j \left( \frac{p^h_{ij}(\varphi)}{P^h_j} \right)^{1-\sigma_h} \tag{6}$$

where $P^h_j$ is the ideal price index for good $h$ in country $j$.

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

$$P^h_j = \left( \sum_{k=1}^{N} w_k L_k \int_{\varphi^h_{kj}}^{\infty} \left( \frac{\sigma_h}{(\sigma_h - 1)} R^h_k \right)^{1-\sigma_h} dG_h(\varphi) \right)^{1/(1-\sigma_h)} \tag{7}$$

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

where

$$\pi^h_{kl}(\varphi) = \left( \frac{1}{(\sigma_h - 1)} \right) \frac{\tau^h_{kl} w_k}{\varphi} q^h_{kl}(\varphi) - f^h_{kl} \tag{9}$$

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

$$b^h_{kl} = \frac{(t_{kl} - 1)p^h_{kl}(\varphi)q^h_{kl}(\varphi)}{t_{kl}\sigma_h} = \left( \frac{(t_{kl} - 1)}{(\sigma_h - 1)} \right) \frac{\tau^h_{kl} w_k}{\varphi} q^h_{kl}(\varphi) \tag{10}$$

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

$$
\text{Tariff Revenue} = \frac{(t_{kl} - 1)p^h_{kl}(\varphi)q^h_{kl}(\varphi)}{t_{kl}} = \sigma_h b^h_{kl}
$$

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 (which are based on quantity) regardless of any demand effects driven by tariff revenue. Therefore, we require the government to “re-distribute” 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 Chaney’s (2008) 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 the sector 0 (the numeraire), this wage is identical across sectors which means, 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 not used to pay bond holders is spent on the numeraire. It is often an assumption in the literature to simply have the government throw tariff revenue away. For our purposes, either assumption yields the same result, but the latter would require an additional “full-employment” assumption.
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 (2008) 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 the firm profits, (9), with government bond payments, (10), results in the following equation:

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

which is identical to the dividends received in the Chaney (2008) 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 \( \varphi \) earns when exporting from country \( i \) to \( j \) are:\(^{10}\)

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

\(^{10}\)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 multiple of \( t_{ij} \).
Define the threshold $\bar{\phi}_{ij}$ from $\pi_{ij}(\bar{\phi}_{ij}) = 0$ as the productivity of the least productive firm in country $i$ able to export to country $j$:

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

where $\lambda_1 = \left( \frac{\sigma}{\sigma - 1} \right)^{1/(\sigma - 1)}$ 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. Moreover, there is empirical evidence that supports this; Yi and Van Biesebroeck (2012) find that differentiated goods (goods with a lower elasticity of substitution) have the most sensitive tariff extensive margin elasticity by investigating China’s induction into the WTO.\footnote{MATT: We can put our own evidence here, correct?}

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

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

where

$$\lambda_2 = \left( \frac{\gamma - (\sigma - 1)}{\gamma} \right) \left( \frac{\sigma}{\mu} \right)^{\frac{\gamma - (\sigma - 1)}{\gamma(\sigma - 1)}} \left( \frac{\sigma}{\sigma - 1} \right)^{\gamma} \left( 1 + \pi \right)$$

$$\theta_j = \sum_{k=1}^{N} \left( \frac{Y_k}{Y} \right) (w_k \tau_{ij})^{-\gamma} \frac{1 + \frac{\gamma}{\gamma - 1}}{t_{kj}^{1 + \frac{\gamma}{\gamma - 1}}} \frac{1 + \frac{\gamma}{\gamma - 1}}{f_{kj}^{1 + \frac{\gamma}{\gamma - 1}}}.$$ The term $\theta_j$ is a measure of country $j$’s remoteness from the rest of the world such that $\tau_{ij}$ represents the physical distance and $t_{ij}$ represents its remoteness as a result of unilateral trade policy. Using the general equilibrium price index, (12), we can solve for firm level exports, the productivity thresholds and total world profits:
\[ x_{ij}(\varphi) = \begin{cases} 
\lambda_3 \left( \frac{Y_i}{Y_j} \right)^{\frac{(\sigma-1)}{\sigma}} \left( \frac{\theta_j}{\tau_{ij}} \right)^{\frac{1}{\sigma}} \varphi^{\sigma-1}, & \text{if } \varphi \geq \varphi_{ij} \\
0, & \text{otherwise,} 
\end{cases} \] (13)

where \( \lambda_3, \lambda_4, \) and \( \lambda_5 \) are constants.\(^{12}\)

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, \( \varphi_{ij} \). This difference translates into the following gravity equation:

Total (tariff inclusive) exports, \( X_{ij}^h \), in sector \( h \) from country \( i \) to country \( j \) are given by

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

Exports are a function of country size (\( Y_i \) and \( Y_j \)), workers’ productivity (\( w_i \)), the bilateral trade costs, variable (\( \tau_{ij}^h, \tau_{ij}^h \)) and fixed (\( f_{ij}^h \)), and the measure of \( j \)'s remoteness from the rest of the world (\( \theta_j^h \)).\(^{13}\) It can easily be seen that tariffs and trade costs enter the gravity

\[ \lambda_3 = \sigma \lambda_4^{1-\sigma} \]

\[ \lambda_4 = \left[ \left( \frac{\sigma}{\mu} \right) \left( \frac{\gamma}{\gamma - (\sigma - 1)} \right) \frac{1}{(1 + \lambda_5)} \right]^\frac{1}{\sigma} \]

\[ \lambda_5 = \frac{\sum_{h=1}^{H} \left( \sum_{h=1}^{H} \frac{\mu_h}{\sigma_h} \right) \mu_h}{1 - \sum_{h=1}^{H} \left( \sum_{h=1}^{H} \frac{\mu_h}{\sigma_h} \right) \frac{\mu_h}{\sigma_h}} \]

\(^{12}\)The proof of equation (14) is available in the appendix. Furthermore, following Chaney (2008), 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 (as in Chaney 2008):

\[ \text{Tari} \equiv -\frac{d\ln X_{ij}}{d\ln t_{ij}} = (\sigma - 1) + \frac{\sigma \gamma}{\sigma - 1} - 1, \]

\[ \text{Iceberg} \equiv -\frac{d\ln X_{ij}}{d\ln \tau_{ij}} = (\sigma - 1) + [\gamma - (\sigma - 1)] = \gamma, \]

\[ \text{Fixed Cost} \equiv -\frac{d\ln X_{ij}}{d\ln f_{ij}} = 0 + \frac{\gamma}{\sigma - 1} - 1 = \frac{\gamma}{\sigma - 1} - 1. \]

There are three conclusions from these elasticities that warrant particular attention. The first is that the elasticity with respect to tariffs is equal to the sum of the elasticity with respect to iceberg and fixed costs:

\[ \zeta + \xi = \vartheta. \]

This 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 also follows from point one – trade flows are more elastic with respect to changes in

\[ ^{14}\text{As in Chaney (2008), we report the negative of the elasticities.} \]
tariffs than transport costs\(^{15}\),

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

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. Additionally, the shape parameter of the firms’ productivity distribution plays an important role. When a sector has a high \( \gamma \), 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. Therefore, if one wishes to use estimates of trade flow elasticities derived from data on distance, for instance, in order to assess the impact of tariff policy, the theory suggests that this estimate will underestimate the effect. In particular, this is the case for industries that are not very competitive (low \( \sigma \)) and are more homogeneous in productivity (high \( \gamma \)).

The third conclusion is that the elasticity of substitution (\( \sigma \)) does play a role in the elasticity of trade flows with respect to variable costs (contrary to the broad claim by Chaney (2008) and Eaton and Kortum (2002)) when the variable cost is a function of product value; e.g. ad valorem tariffs\(^{16}\). However, the claim by Chaney (2008) 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\(^{17}\)

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

\(^{15}\)It should be noted that the estimated elasticities are derived from exports that include the tariff in the value. If a researcher was using data that does not include tariffs, then the difference would be even greater as \( \vartheta = \frac{\sigma \gamma}{\sigma - 1} \), but again this is by construction that the intensive margin is more elastic.

\(^{16}\)Though not explicitly shown in this model, due to the specific treatment of income, it is intuitive that other trade costs such as insurance would have a similar effect.

\(^{17}\)This claim reverses the prediction of Krugman (1980).
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;

1. 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.

2. Each country has free entry into the industry and no additional barriers to entry outside of the model.

3. 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 otherwise.

4 Empirical Application

We examine our model empirically using U.S. 10-digit HS imports data sourced from the U.S. Census’ Imports of Merchandise for the year 2000. 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 tariffs rates the U.S. assessed on 2000. While the Census data allows one to calculate ad-valorem tariffs as it provides information on duties collected and the dutiable value (as has been done by Beseděs and Prusa 2013, among others), we prefer to use the U.S. Tariff Database in this application as it provides us with actual tariffs the U.S. assesses, the rates which firms react to. In our application we only use data on products with positive tariffs, as our model applies to instances where trade costs are positive.\textsuperscript{18} The Census data allows us to calculate the ad-valorem transportation 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 (2014), 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

\textsuperscript{18}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 (results available on request).
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.

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 (\( \ln t_i^h \)), transportation costs (\( \ln \tau_i^h \)), and fixed costs (\( \ln f_i^h \)) as the dependent variables. We include country level fixed effects as a proxy for multilateral resistance terms (\( r_i \)). We estimate

\[
\ln X_i^h = \beta_0 + \beta_1 \ln t_i^h + \beta_2 \ln \tau_i^h + \beta_3 \ln f_i^h + r_i + \epsilon_i^h
\]

where \(|\beta_1| = \vartheta\), \(|\beta_2| = \zeta\), \(|\beta_3| = \xi\), and \( \epsilon_i^h \) is the error term. The results from our basic specification using all available data are shown in Table 2. 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 tariff and transport costs add up to the elasticity with respect to fixed costs, and and restriction 19, that the elasticity with respect to tariffs exceeds the elasticity with respect to transport costs (in the case of the latter we report p-values from the one-sided test).

We first note that our estimated coefficients are largely consistent across the five difference proxies of fixed costs we use. Our estimates imply that the elasticity of U.S. imports with respect to tariffs is between -0.561 and -0.589, with respect to transport costs between -0.477 and -0.480, and with respect to fixed costs between -0.131 and -0.135. However, we are more interested in ascertaining whether the implied restrictions are satisfied than in the size of the estimated coefficients. Let us first focus on Result 1. In every specification we cannot reject the hypothesis that the elasticities with respect to transport costs and fixed costs add up to the elasticity with respect to tariffs. 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.
Table 2: Full Sample

<table>
<thead>
<tr>
<th>Fixed cost proxy</th>
<th>Elasticity of substitution interacted with</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elasticity of substitution</td>
</tr>
<tr>
<td>Tariff rate (−θ)</td>
<td>-0.561***</td>
</tr>
<tr>
<td></td>
<td>(0.07361)</td>
</tr>
<tr>
<td>Transport cost (−ζ)</td>
<td>-0.477***</td>
</tr>
<tr>
<td></td>
<td>(0.03267)</td>
</tr>
<tr>
<td>Fixed cost (−ξ)</td>
<td>-0.131***</td>
</tr>
<tr>
<td></td>
<td>(0.02690)</td>
</tr>
<tr>
<td>Constant</td>
<td>10.186***</td>
</tr>
<tr>
<td></td>
<td>(0.19482)</td>
</tr>
</tbody>
</table>

| Observations                            | 72,970                       | 69,471                  | 69,100         | 69,100             | 69,100        |
| Number of countries                     | 179                          | 151                     | 144            | 144                | 144           |
| R²                                      | 0.074                        | 0.078                   | 0.078          | 0.078              | 0.078         |

Test p-values

| Result 1 \( ϕ = ζ + ξ \) | 0.6008 | 0.8016 | 0.7697 | 0.7697 | 0.7697 |
| Result 2 \( ϕ > ζ \)     | 0.1350 | 0.0782 | 0.0827 | 0.0827 | 0.0827 |

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%.

However, we note that the trade elasticity is very close to being equal to the sum of the other two elasticities. As far as Result 2 is concerned note that in every specification the tariff elasticity is estimated to be larger than the transport cost elasticity (in absolute value). Note however, that only when we proxy for fixed costs using both the elasticity of substitution and ease of doing business data do we get some evidence of the tariff elasticity being significantly higher than the transport cost elasticity. But even in those cases, we have significance only at the 10% level.

However, as discussed at the end of section 3 it is possible that the extensive margin differs across products with products where there is a lot of entry and exit and products with 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. For each product we calculate net entry (exit-entry)
and re-estimate our model for the high net entry sample and the low net entry sample. We define high net entry sample as those products with net entry below the 10th and above the 90th percentile of observed net entry which corresponds to net entry less than -2 and more than 5 (the former implies that the number of exits in 2000 was by at least 3 larger than the number of entries and the latter implies that the number of entries exceeded exits by at least 6). Table 3 collects the results from estimating our model using the high net entry sample.

<table>
<thead>
<tr>
<th>Table 3: High Net Entry Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed cost proxy</strong></td>
</tr>
<tr>
<td><strong>Elasticity of substitution interacted with</strong></td>
</tr>
<tr>
<td>Elasticity of substitution</td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>Tariff rate ((-\vartheta))</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Transport cost ((-\zeta))</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Fixed cost ((-\xi))</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Observations</td>
</tr>
<tr>
<td>Number of countries</td>
</tr>
<tr>
<td>R^2</td>
</tr>
</tbody>
</table>

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%.

Differences in the extensive margin across products play an important role. Limiting our sample to just those products where there is more activity along the extensive margin, improves our results. Not only does the difference between the trade and transport cost elasticities grow, it is significant at at least the 5% level in every specification. In addition, we again cannot reject the hypothesis that the trade elasticity is equal to the sum of the transport cost and fixed cost elasticities. To fully confirm the important role played by the extensive margin, Table 4 collects the results from estimating our specifications on the remaining sample of products characterized by low net entry. Not that in this sample Result
1 still holds, but not Result 2, confirming the theoretical prediction that when there is not much activity along the extensive margin the elasticity of trade flows with respect to tariffs equals that with respect to transport costs.

<table>
<thead>
<tr>
<th>Table 4: Low Net Entry Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed cost proxy</strong></td>
</tr>
<tr>
<td>Elasticity of substitution</td>
</tr>
<tr>
<td>Elasticity of substitution</td>
</tr>
<tr>
<td>Interacted with</td>
</tr>
<tr>
<td>Tariff rate (-\theta)</td>
</tr>
<tr>
<td>-0.492***</td>
</tr>
<tr>
<td>0.07535</td>
</tr>
<tr>
<td>Transport cost (-\zeta)</td>
</tr>
<tr>
<td>-0.450***</td>
</tr>
<tr>
<td>0.03341</td>
</tr>
<tr>
<td>Fixed cost (-\xi)</td>
</tr>
<tr>
<td>-0.086***</td>
</tr>
<tr>
<td>0.02268</td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>10.314***</td>
</tr>
<tr>
<td>0.20099</td>
</tr>
<tr>
<td>Observations</td>
</tr>
<tr>
<td>57,149</td>
</tr>
<tr>
<td>Number of countries</td>
</tr>
<tr>
<td>178</td>
</tr>
<tr>
<td>(R^2)</td>
</tr>
<tr>
<td>0.06089</td>
</tr>
<tr>
<td>Test p-values</td>
</tr>
<tr>
<td>Result 1 (\varphi = \zeta + \xi)</td>
</tr>
<tr>
<td>0.5993</td>
</tr>
<tr>
<td>Result 2 (\varphi &gt; \zeta)</td>
</tr>
<tr>
<td>0.2906</td>
</tr>
</tbody>
</table>

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%.

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. 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 elasticity of substitution given the difficulty that would create in interpreting our results.

5 Conclusion

It is common in the trade literature to simply assume iceberg transport costs as a general proxy for many types of trade restrictions (in particular ad valorem tariffs). When perfect competition is assumed the two trade barriers are analogous. However, in the often used
model of monopolistic competition, this is no longer the case, particularly if there is a lot of activity on the extensive margin. By using the Chaney (2008) framework, we illustrate that trade flows are more elastic in response to changes in tariffs than iceberg transport costs and are a function of the elasticity of substitution. Since it is quite common to use distance to represent trade restrictions in gravity equations, it is important to understand this difference between tariffs and transport costs when anticipating the affects of tariff policy. Furthermore, we illustrate an interesting linear relationship between the elasticity with respect to all three trade costs. We find that the elasticity with respect to tariffs is equal to the sum of the elasticity with respect to iceberg and fixed costs. We validate our model empirically using data on U.S. imports showing that the tariff elasticity exceeds the transport cost one, especially when there is a lot of activity along the extensive margin, and that the tariff elasticity is equal to the sum of the the transport cost and fixed cost elasticities.

The contribution of this paper is not limited to strictly empirical tests of “gravity” models. The researcher’s decision on how to model trade costs in a monopolistically competitive framework (which has been the predominant workhorse model for international trade for the past 30 years) has important implications for calibrated models seeking to estimate the effects of trade liberalization and empirical studies explaining the decision of firms to become exporters as well. In the end, trade costs in the real world can be diverse and difficult to encapsulate easily in a unified theoretical framework. Ultimately, it is an empirical question, but this paper adds a more complete theoretical picture.

References


A Mathematical Appendix

A.1 Deriving the Gravity Equation

 Aggregate Exports in sector $h$ from country $i$ to country $j$ is

$$X_{ij}^h = w_i L_i \int_{\varphi_{ij}}^{\infty} x_{ij}^h(\varphi) dG(\varphi).$$

Using the specific assumption about the distribution $G$, this becomes

$$X_{ij}^h = w_i L_i \int_{\varphi_{ij}}^{\infty} \lambda_3^h \left( \frac{Y_j}{Y} \right)^{\frac{\sigma_h-1}{\gamma_h}} \left( \frac{\theta_j}{w_i t_{ij} \tau_{ij}^h} \right)^{\sigma_h-1} \varphi^{\sigma_h-1} \frac{\varphi^{-\gamma_h-1}}{\gamma_h} d\varphi.$$

Solving this integral yields:

$$X_{ij}^h = \left( \frac{Y_j}{Y} \right)^{\frac{\sigma_h-1}{\gamma_h}} \left( \frac{\theta_j}{w_i t_{ij} \tau_{ij}^h} \right)^{\sigma_h-1} w_i L_i \lambda_3^h \frac{\gamma_h}{\gamma_h - (\sigma_h - 1)} \left[ \lambda_4^h \left( \frac{Y_j}{Y} \right)^{\frac{1}{\gamma_h}} \left( \frac{w_i t_{ij}^h}{\theta_j} \right)^{\frac{1}{\sigma_h-1}} \right]^{\sigma_h-1-\gamma_h}$$

$$= \lambda_3^h \left( \frac{Y_j}{Y} \right)^{\frac{\sigma_h-1}{\gamma_h}} \frac{\gamma_h}{\gamma_h - (\sigma_h - 1)} \left( \frac{w_i L_i Y_j}{Y} \right)^{\frac{1}{\gamma_h}} \left( \frac{w_i t_{ij}^h}{\theta_j} \right)^{\frac{1}{\sigma_h-1}} f_{ij}^{\sigma_h-1-\gamma_h}$$

$$= \sigma_h \left( \frac{Y_j}{Y} \right)^{\frac{\sigma_h-1}{\gamma_h}} \frac{\gamma_h}{\gamma_h - (\sigma_h - 1)} \left( \frac{w_i L_i Y_j}{Y} \right)^{\frac{1}{\gamma_h}} \left( \frac{w_i t_{ij}^h}{\theta_j} \right)^{\frac{1}{\sigma_h-1}} f_{ij}^{\sigma_h-1-\gamma_h}$$

$$= \mu_h \left( \frac{Y_j}{Y} \right)^{\frac{\sigma_h-1}{\gamma_h}} \left( \frac{w_i t_{ij}^h}{\theta_j} \right)^{\frac{1}{\sigma_h-1}} f_{ij}^{\sigma_h-1-\gamma_h}$$

Therefore, total $X_{ij}^h$ in sector $h$ from country $i$ to country $j$ are given by

$$X_{ij}^h = \mu_h \left( \frac{Y_j}{Y} \right) \left( \frac{w_i t_{ij}^h}{\theta_j} \right)^{\frac{\sigma_h}{\gamma_h} - \frac{1}{\gamma_h}} f_{ij}^{\sigma_h-1-\gamma_h}. \ (A-9)$$
A.2 Deriving Elasticities

Totally differentiating (A-9) for a specific sector $h$ and assuming $df_{ij} = 0$ yields the following elasticities:

\[
\frac{d \ln X_{ij}}{d \ln t_{ij}} = \frac{-dX_{ij}/dt_{ij}}{X_{ij}/t_{ij}} = -\frac{t_{ij}}{X_{ij}} \left( w_i L_i \int_{\bar{\phi}_{ij}}^{\infty} \frac{\partial x_{ij}(\varphi)}{\partial t_{ij}} dG(\varphi) \right) + \frac{t_{ij}}{X_{ij}} \left( w_i L_i x(\bar{\varphi}_{ij}) G'(\bar{\varphi}_{ij}) \frac{\partial \bar{\varphi}_{ij}}{\partial t_{ij}} \right)
\]

Intensive margin

\[
\frac{d \ln X_{ij}}{d \ln \tau_{ij}} = \frac{-dX_{ij}/d\tau_{ij}}{X_{ij}/\tau_{ij}} = -\frac{\tau_{ij}}{X_{ij}} \left( w_i L_i \int_{\bar{\phi}_{ij}}^{\infty} \frac{\partial x_{ij}(\varphi)}{\partial \tau_{ij}} dG(\varphi) \right) + \frac{\tau_{ij}}{X_{ij}} \left( w_i L_i x(\bar{\varphi}_{ij}) G'(\bar{\varphi}_{ij}) \frac{\partial \bar{\varphi}_{ij}}{\partial \tau_{ij}} \right)
\]

Extensive margin

Using the definition of equilibrium individual exports from equation (13), and assuming that country $i$ is small enough and/or remote enough, so that $\partial \theta_j / \partial t_{ij} \approx 0$ and $\partial \theta_j / \partial \tau_{ij} \approx 0$, we get

\[
\frac{\partial x_{ij}(\varphi)}{\partial t_{ij}} = -(\sigma - 1) \frac{x_{ij}(\varphi)}{t_{ij}} \quad \text{and} \quad \frac{\partial x_{ij}(\varphi)}{\tau_{ij}} = -(\sigma - 1) \frac{x_{ij}(\varphi)}{\tau_{ij}}.
\]

Integrating over all exporters, we get

\[
\text{Elasticity of the intensive margin w.r.t. tariffs} = -\frac{t_{ij}}{X_{ij}} \left( w_i L_i \int_{\bar{\phi}_{ij}}^{\infty} \frac{\partial x_{ij}(\varphi)}{\partial t_{ij}} dG(\varphi) \right)
\]

\[
= (\sigma - 1) \frac{t_{ij}}{X_{ij}} \left( w_i L_i \int_{\bar{\phi}_{ij}}^{\infty} x_{ij}(\varphi) dG(\varphi) \right)
\]

\[
= (\sigma - 1) \frac{X_{ij}}{t_{ij}}
\]

\[
= (\sigma - 1).
\]

Now, define $x_{ij} = \lambda_{ij} \varphi^{\sigma-1}$ and note that $G'(\varphi) = \varphi^{-\gamma-1}/\gamma$. Aggregate exports can be written in the following way

\[
X_{ij} = w_i L_i \lambda_{ij} \int_{\bar{\phi}_{ij}}^{\infty} \varphi^{\sigma-1} \varphi^{-\gamma-1}
\]

\[
= \frac{\gamma}{\gamma - (\sigma - 1)} w_i L_i \lambda_{ij} \bar{\varphi}^{(\sigma-1)-\gamma}
\]

\[
= \frac{1}{\gamma - (\sigma - 1)} w_i L_i x_{ij}(\bar{\varphi}) G'(\bar{\varphi}) \bar{\varphi}.
\]

\[19\] The focus of this paper is to compare the effects of iceberg transport costs with that of an ad valorem tariff, thus analyzing changes in fixed costs would not add anything to the paper and would be exactly that found in Chaney (2008).
We therefore get the simple solution for the elasticity:

\[
\text{Elasticity of the extensive margin w.r.t. tariffs} = \frac{t_{ij}}{X_{ij}} \left( w_i L_i x_{ij}(\bar{\varphi}) G'(\bar{\varphi}) \frac{\partial \bar{\varphi}}{\partial t_{ij}} \right)
\]

\[
= \frac{t_{ij}}{X_{ij}} \left( \frac{w_i L_i x_{ij}(\bar{\varphi}) G'(\bar{\varphi}) \varphi}{t_{ij}} \right)
\]

\[
= (\gamma - (\sigma - 1)) \frac{t_{ij}}{X_{ij}} \left( \frac{X_{ij}}{t_{ij}} \frac{\sigma}{\sigma - 1} \right)
\]

\[
= \frac{\sigma \gamma}{\sigma - 1} - \sigma.
\]

Similarly for iceberg transport costs:

\[
\text{Elasticity of the intensive margin w.r.t. iceberg costs} = -\frac{\tau_{ij}}{X_{ij}} \left( \int_{\hat{\varphi}_{ij}}^{\infty} \frac{\partial x_{ij}(\varphi)}{\partial \tau_{ij}} dG(\varphi) \right)
\]

\[
= (\sigma - 1) \frac{\tau_{ij}}{X_{ij}} \left( \frac{w_i L_i \int_{\hat{\varphi}_{ij}}^{\infty} x_{ij}(\varphi) dG(\varphi)}{\tau_{ij}} \right)
\]

\[
= (\sigma - 1) \frac{\tau_{ij}}{X_{ij}} \frac{X_{ij}}{\tau_{ij}}
\]

\[
= (\sigma - 1).
\]

The elasticity with respect to fixed costs (as is with iceberg transport costs) is identical to that of Chaney (2008).