The Tip of the Iceberg: Modeling Trade Costs and Implications for Intra-industry Reallocation*

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Abstract

International economics has overwhelmingly relied on Samuelson’s (1954) assumption that trade costs are proportional to value. We build a general equilibrium heterogeneous firms model of trade that allows for both ad valorem and per-unit costs. Using a novel minimum distance estimator we identify per-unit trade costs from the distribution of foreign sales across firms within markets. Estimated average per-unit costs are substantial being, on average, between 35 and 45 percent of the average consumer price. This leads us to reject the pure ad valorem cost assumption. An important theoretical finding is that a per-unit import barrier is more harmful than an equal yield ad valorem barrier, since per-unit barriers distort relative prices both across and within markets. Since a non-negligible share of existing trade barriers are per-unit, standard welfare assessments of trade liberalization may be understated.

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1 Introduction

The costs of international trade are the costs associated with the exchange of goods and services across borders. Trade costs impede international economic integration and may also explain a great number of empirical puzzles in international macroeconomics (Obstfeld and Rogoff 2000). Since Samuelson (1954), economists usually model variable trade costs as an ad valorem tax equivalent (iceberg costs), implying that pricier goods are also costlier to trade. Trade costs change the relative price of domestic to foreign goods and therefore alter the worldwide allocation of production and consumption. Gains from trade typically occur because freer trade allows prices across markets to converge.

In this paper we take a different approach. We depart from Samuelson’s framework and model variable trade costs as comprising both an ad valorem part and a per-unit part. Trade costs are broadly defined to include “...all costs incurred in getting a good to a final user other than the production cost of the good itself” (Anderson and van Wincoop, 2004).1 Even though more expensive varieties of a given product might be costlier to export, those costs are presumably not proportional to the product price. For example, a $200 pair of shoes will typically face much lower ad valorem costs than a $20 pair of shoes.2 A number of trade policy instruments also act like per-unit or specific variable trade costs. According to the World Trade Organization (WTO), 19 percent of U.S. non-agricultural imports are subject to per-unit tariffs.3 Quotas (through the imposition of a quota license price) also act like a per-unit tariff.4 In the U.S. and the European Union, 9.5 and 15.1 percent of the

1 “...Among others this includes transportation costs (both freight costs and time costs), policy barriers (tariffs and non-tariff barriers), information costs, contract enforcement costs, costs associated with the use of different currencies, legal and regulatory costs, and local distribution costs (wholesale and retail)” (Anderson and van Wincoop, 2004).

2 According to UPS rates at the time of writing, a fee of $125 is charged for shipping a one kilo package from Oslo to New York (UPS Standard). They charge an additional 1% of the declared value for full insurance. Given that each pair of shoes weighs 0.2 kg, the ad-valorem shipping costs are in this case 126 and 13.5 percent for the $20 and $200 pair of shoes respectively.

3 2006 data from the WTO are presented in Table 4. We discuss the data in more detail in the appendix. Until the 1950’s, two-thirds of dutiable U.S. imports were subject to per-unit tariffs. This proportion fell to less than 40 percent by the early 1970’s (Irwin, 1998).

4 Demidova et al. (2009) use a trade model with heterogeneous firms to analyze the behavior of
Harmonized System (HS) six-digit subheadings in the schedule of agricultural concessions are covered by tariff quotas. Distribution costs can also be considered, at least in part, as non-ad valorem costs (e.g. Corsetti and Dedola, 2005).

This modeling choice has important consequences when firms are heterogeneous as in Melitz (2003), Chaney (2008), or Eaton et al. (2008). When trade costs are incurred per-unit, trade costs not only alter relative prices (and consumption) across markets but also relative prices within markets. For example, the $200 pair of shoes becomes cheaper relative to the $20 pair in the presence of a per-unit tariff. This additional distortion in relative prices makes a per-unit import tariff more harmful than an equal yield ad valorem tariff. We show that this result holds in models where firms are heterogeneous both in terms of cost efficiency and quality. Another implication of the theory is that falling prices in the manufacturing sector (e.g. due to productivity growth) increase effective trade costs, if not accompanied by falling prices in the transport sector (or falling nominal tariffs). This illustrates the simple point that it is real trade costs, and not nominal ones, that determine the share of imports in total consumption.

The first contribution of this paper is therefore to present a stylized theory of international trade with heterogeneous firms that encompasses both iceberg costs and per-unit costs. We emphasize the different welfare implications of per-unit versus ad valorem trade frictions. The second contribution is to document new firm-level facts about the distribution of exports across markets, that extend the stylized facts in Eaton et al. (2008). The third contribution is to structurally fit the model to Norwegian firm-product-destination level export data, using a novel minimum distance estimator. Using the model as our guide, we show that the magnitude of per-unit trade costs is identified by higher-order moments of the distribution of exports across firms within markets.

Several strong results emerge from the analysis. First of all, per-unit costs are pervasive. The grand mean of per-unit trade costs, expressed relative to the consumer price, is 35–45%, depending on the elasticity of substitution. The pure iceberg model is therefore rejected.

Bangladeshi garments exporters selling their products to the EU and to the U.S. and facing quotas as well as other types of barriers.

Relative prices within markets are independent of iceberg costs when per-unit costs are zero and markups do not depend on an interaction between firm characteristics and iceberg costs.
Second, we show that the costs of per-unit frictions are much higher than the costs of iceberg frictions. We check what level of tariff revenue would be obtained by imposing a per-unit tariff or by imposing a welfare-neutral iceberg tariff.\textsuperscript{6} Using plausible parameter values, we find that iceberg revenue is much higher than per-unit revenue. Since a non-negligible share of existing trade barriers are per-unit, standard welfare assessments of trade liberalization may be understated. Therefore, we conclude that the somewhat technical issue of the functional form of trade costs is quantitatively important for our assessment of the effects of trade distortions. We therefore ask whether the benefit of the iceberg model, in terms of analytical tractability, is worth the costs, in terms of biased welfare effects.

More flexible modeling of trade costs is not new in international economics. Alchian and Allen (1964) pointed out that per-unit costs imply that the relative price of two varieties of some good will depend on the level of trade costs and that relative demand for the high quality good increases with trade costs ("shipping the good apples out"). More recently, Hummels and Skiba (2004) found strong empirical support for the Alchian-Allen hypothesis. Specifically, the elasticity of freight rates with respect to price was estimated to be well below the unitary elasticity implied by the iceberg assumption. Also, their estimates implied that doubling freight costs increases average free on board (f.o.b.) export prices by $80 - 141$ percent, consistent with high quality goods being sold in markets with high freight costs. However, the authors could not identify the magnitude of per-unit costs, as we do here. Also, our methodology identifies all kinds of trade costs, whereas their paper is concerned with shipping costs exclusively. Furthermore, Lugovskyy and Skiba (2009) introduce a generalized iceberg transportation cost into a representative firm model with endogenous quality choice, showing that in equilibrium the export share and the quality of exports decrease in the exporter country size. However, the existing literature has not addressed the crucial combination of per-unit costs and heterogeneous firms, which are the two ingredients that drive the results in our model.

Our work also connects to the papers that quantify trade costs. Anderson and van Wincoop (2004) provides an overview of the literature, and recent contributions are Ander-

\textsuperscript{6}I.e. obtaining the same level of welfare. The condition of welfare neutrality makes the two cases comparable.
son and van Wincoop (2003), Eaton and Kortum (2002), Head and Ries (2001), Hummels (2007), and Jacks, Meissner, and Novy (2008). This strand of the literature either compiles direct measures of trade costs from various data sources, or infers a theory-consistent index of trade costs by fitting models to cross-country trade data. Our approach of using within-market dispersion in exports is conceptually different and provides an alternative approach to inferring trade barriers from data. This is possible thanks to the recent availability of detailed firm-level data. Furthermore, whereas the traditional approach can only identify iceberg trade costs relative to some benchmark, usually domestic trade costs, our method identifies the absolute level of (per-unit) trade costs.

Furthermore, this paper relates to the extensive literature on gains from trade. Most recently, Arkolakis, Costinot, and Rodríguez-Clare (2010) show that gains from trade can be expressed by a simple formula that is valid across a wide range of trade models. Specifically, the total size of the gains from trade is pinned down by the expenditure share on domestic goods and the import elasticity with respect to trade costs. Gains from trade in the presence of per-unit costs are, however, not discussed in their paper. A set of other papers such as Broda and Weinstein (2006), Hummels and Klenow (2005), Kehoe and Ruhl (2009), Klenow and Rodríguez-Clare (1997) and Romer (1994) emphasize welfare gains due to increased imported variety. Although variety gains are present in our model as well, we focus our discussion on the gains from trade due to relative price movements among incumbents.

Our work also connects to the optimal taxation literature, e.g. Suits and Musgrave (1953) and Delipalla and Keen (1992). It is well known that ad valorem taxes welfare dominate equal yield per-unit taxes for a range of imperfect competition models. Our paper shows that the welfare superiority of ad valorem taxes becomes even stronger in the presence of price heterogeneity across firms.

Finally, our work relates to a recent paper by Berman, Martin, and Mayer (2009). They also introduce a model with heterogeneous firms and per-unit costs, but in their model the per-unit component is interpreted as local distribution costs that are independent of firm productivity. Their research question is very different, however, as their paper analyzes the

7 Helpman, Melitz and Rubinstein (2008) develop a gravity model that controls both for firm heterogeneity and fixed costs of exporting and make predictions about the response of trade to changes in trade costs.
reaction of exporters to exchange rate changes. They show that, in response to currency
depreciation, high productivity firms optimally raise their markup rather than the volume,
while low productivity firms choose the opposite strategy.

The rest of the paper is organized as follows. Section 2 presents the model and proposes
a simple method for comparing the effect of per-unit costs and iceberg costs on welfare.
Section 3 lays out the econometric strategy and presents the baseline estimates as well as
an extensive number of robustness checks. Finally, Section 4 concludes.

2 Theory

In this section, we present a stylized theory of international trade that encompasses both
iceberg and per-unit costs. We keep the model as parsimonious as possible with the purpose
of showing that this simple modification has important consequences when firms are hetero-
geneous.\footnote{In the special case where iceberg is the only type of variable trade cost, our model collapses to Chaney (2008).}
We show that, when firms are heterogeneous, there is an additional mechanism
through which ad valorem barriers welfare dominate equal yield per-unit barriers in models
with imperfect competition. We also show how the volume distribution of exports (within
a market, across firms) depends on the magnitude of per-unit costs. These properties will
be used in the econometric section below to identify the magnitude of per-unit trade costs.

2.1 The Basic Environment

We consider a world economy comprising $N$ asymmetric countries and multiple final goods
sectors indexed by $k = 1, \ldots, K$. Each country $n$ is populated by a measure $L_n$ of workers.
Each sector $k$ consists of a continuum of differentiated goods.\footnote{In the econometric section, a sector $k$ is interpreted as a product group according to the harmonized
system nomenclature, at the 8 digit level (HS8). A differentiated good within a sector $k$ is interpreted as a
firm observation within an HS8 code.}

Preferences across varieties within a sector $k$ have the standard CES form with an
elasticity of substitution $\sigma > 1$.\footnote{Following Chaney (2008), preferences across sectors are Cobb-Douglas.}
Each variety enters the utility function symmetrically.
These preferences generate, in country $n$, for every variety within a sector $k$, a quantity

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\footnote{Following Chaney (2008), preferences across sectors are Cobb-Douglas.}
demanded function $x_{in}^k = (p_{in}^k)^{-\sigma} (P_n^k)^{\sigma-1} \mu_k Y_n$, where $p_{in}^k$ is the consumer price of a variety produced in country $i$, $P_n^k$ is the consumption-based price index in sector $k$, $Y_n$ is total expenditure, and $\mu_k$ is the share of expenditure in sector $k$. We assume that workers are immobile across countries, but mobile across sectors, firms produce one variety of a particular product, and technology is such that all cost functions are linear in output. Finally, market structure is monopolistic competition.

2.2 Variable Trade Costs

Unlike much of the earlier trade literature (e.g. Melitz, 2003, Chaney, 2008, Eaton et al., 2008),\textsuperscript{11} the economic environment also consists of a transport sector, whose services are used as an intermediate input in final goods production, in order to transfer the goods from a firm’s plant to the consumer’s hands. Transport services are freely traded and produced under constant returns to scale.

$\phi_{mk_{in}}$ units of labor are necessary for transferring one unit of a sector-$k$ good from a plant in $i$ to its final destination in $n$, using shipping services from country $m$. The sector is perfectly competitive, so there is a global shipping service price $w_m \phi_{mk_{in}}$ for each product and route, where $w_m$ is the wage in country $m$.\textsuperscript{12} Relative wages between any two pair of countries $i$ and $n$ are then pinned down in all markets, as long as each country produces the shipping service, and are equal to $w_i/w_n = \phi_n/\phi_i$. By normalizing the price on a particular shipping route to one, say from $i$ to $n$ for product $k$, all nominal wages are pinned down.

Firms need labor and transport services in production. Technology is assumed to be Leontief, so demand for the shipping service is proportional to the quantity produced (not proportional to value).

Additionally, the economic environment consists of a standard iceberg cost $\tau_{in}^k$, so that

\textsuperscript{11}Hummels and Skiba (2004) and Lugovskyy and Skiba (2009) introduce more general trade costs functions.

\textsuperscript{12}Hummels, Lugovskyy, and Skiba (2009) find evidence for market power in international shipping. An extension of our model with increasing returns in shipping would generate lower per-unit trade costs for more efficient firms. In other words, per-unit trade costs would become more like ad valorem costs, since they would be correlated with the price of the good shipped. We focus on perfect competition here in order to isolate the pure per-unit cost case (although the model also allows for pure iceberg costs).
\( \tau_{in}^k \) units of the final good must be shipped in order for one unit to arrive. The presence of iceberg costs ensures that any correlation between product value and shipping costs is captured by the model.

### 2.3 Prices and Quantities

A firm owns a technology associated with productivity \( z \). A firm in country \( i \), operating in sector \( k \), can access market \( n \) only after paying a sector- and destination-specific fixed cost \( f_{in}^k \) in units of the numéraire. For notational convenience, let \( t_{in}^k \equiv \phi_i \tau_{in}^k \), i.e. \( t_{in}^k \) is the labor unit requirement of the shipping service if using a domestic shipping company.\(^{13}\)

Profits are then\(^{14}\)

\[
x_{in}^k(z) \left[ p_{in}^k(z) - w_i \left( \frac{\tau_{in}^k}{z} + t_{in}^k \right) \right] - f_{in}^k.
\]

Given market structure and preferences, a firm with efficiency \( z \) maximizes profits by setting its consumer price as a constant markup over total marginal production cost,\(^{15}\)

\[
p_{in}^k(z) = \frac{\sigma}{\sigma - 1} w_i \left( \frac{\tau_{in}^k}{z} + t_{in}^k \right).
\]

Relative prices within markets are now altered as long as \( t_{in}^k > 0 \). Specifically, the relative price of two varieties with efficiencies \( z_1 \) and \( z_2 \) within a sector \( k \) is

\[
\frac{p_{in}^k(z_1)}{p_{in}^k(z_2)} = \frac{\left( \frac{\tau_{in}^k}{z_1} + t_{in}^k \right)}{\left( \frac{\tau_{in}^k}{z_2} + t_{in}^k \right)}.
\]

In general, both iceberg and per-unit costs will affect within-market relative prices. Relative prices are unaffected by trade frictions only in the special case with \( t_{in}^k = 0 \).

As in many of the previous trade models, the quantity sold by a firm is linear (in logs) in the price charged to the consumer. Specifically, using (1), the quantity sold by a firm

\(^{13}\)The firm is indifferent between using a domestic or foreign shipping supplier, since the costs are the same, \( w_i \phi_i \tau_{in}^k = w_i \phi_i t_{in}^k = w_i t_{in}^k \).

\(^{14}\)As a convention, we assume that per unit costs are paid on the "melted" output.

\(^{15}\)The corresponding producer price is \( \tilde{p}_{in}^k(z) = \left( p_{in}^k - w_i t_{in}^k \right) / \tau_{in}^k = \frac{\sigma}{\sigma - 1} \left[ 1 + z t_{in}^k / (\sigma \tau_{in}^k) \right] w_i / z \).

Note that the markup over production costs is no longer constant. All else equal, a more efficient firm will charge a higher markup, since the perceived elasticity of demand that such a firm faces is lower. In other words, the markup is higher for more efficient firms since, due to the presence of per-unit trade costs, a larger share of the consumer price does not depend on the producer price. This mechanism is explored theoretically and empirically in Berman et al. (2009).
with efficiency $z$ is

$$x_{in}^k(z) = \left( \frac{\sigma}{\sigma - 1} w_i \right)^{-\sigma} \left( \frac{\tau_{in}^k}{z} + t_{in}^k \right)^{-\sigma} \left( P_n^k \right)^{\sigma - 1} \mu_k Y_n.$$  

However, while in previous models the sensitivity of quantity sold (and value of sales) to iceberg trade cost depended only on the elasticity of substitution $\sigma$, in our model the effect is more complex. The elasticity of the quantity sold to each type of variable trade cost also depends on the per-unit trade cost, on the iceberg trade cost, and on the efficiency of the firm itself. The elasticity of the quantity sold by a firm with efficiency $z$ with respect to per-unit and ad valorem trade cost is,

$$\varepsilon_{t_{in}^k} = -\sigma \left( \frac{\tau_{in}^k}{z^{t_{in}^k}} + 1 \right)^{-1}$$

and

$$\varepsilon_{\tau_{in}^k} = -\sigma \left( \frac{t_{in}^k}{\tau_{in}^k} + 1 \right)^{-1} \frac{\tau_{in}^k - 1}{\tau_{in}^k}.$$  

The following proposition summarizes a series of important properties of the model.

**Proposition 1** When per-unit trade costs are positive,

- $|\varepsilon_{t_{in}^k}|$ is increasing in $z$ while $|\varepsilon_{\tau_{in}^k}|$ is decreasing in $z$ and $|\varepsilon_{t_{in}^k}| > |\varepsilon_{\tau_{in}^k}|$ if $z > \left( \tau_{in}^k - 1 \right) / t_{in}^k$.
- $|\varepsilon_{t_{in}^k}|$ is increasing in $t_{in}^k / (\tau_{in}^k - 1)$ while $|\varepsilon_{\tau_{in}^k}|$ is decreasing in $t_{in}^k / (\tau_{in}^k - 1)$.
- both $|\varepsilon_{t_{in}^k}|$ and $|\varepsilon_{\tau_{in}^k}|$ have an upper bound equal to $\sigma$.

**Proof.** See Appendix A.1.  

The first statement in Proposition 1 emphasizes an asymmetry that affects most of the results in this paper. The higher the efficiency of a firm, the higher the elasticity of quantities to per-unit trade costs, and the lower the elasticity of quantities to iceberg costs. In other words, a reduction in $t_{in}^k$ will benefit the high efficiency firms disproportionately more than the low productivity firms, in terms of increased quantities sold. As a consequence, factors of production are reallocated from low to high efficiency firms. The intuition is simple once  

$^{16}$The following elasticities are computed without accounting for changes in the price index.
we consider the optimal price (1). The share of per-unit trade costs in the consumer price is
greater for efficient firms than for less efficient ones.\textsuperscript{17} The opposite holds for iceberg costs.

Moreover, when per-unit costs are initially greater than iceberg costs (i.e. when $t_{in}^k$ is
greater than $(\tau_{in}^k - 1) / z$, the iceberg cost converted to labor units for a firm with efficiency
$z$) a given firm is more sensitive to changes in per-unit costs than to changes in iceberg
costs. This is the case for all the firms lying to the right of the $(\tau_{in}^k - 1) / t_{in}^k$ thresholds
in Figure (1).\textsuperscript{18} The second statement in Proposition 1 points out that the asymmetric
effect outlined above becomes stronger when per-unit costs are initially high relative to
iceberg costs. Finally, the third statement says that the limit sensitivity of quantity sold to
per-unit and ad valorem trade cost is the same and it equals the sensitivity (to ad valorem
trade costs) in a model without per-unit trade cost. Figure (1) summarizes the qualitative
relationships between the elasticities, firm’s efficiency, and the variable trade costs.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{elasticity.png}
\caption{Elasticity of quantity sold to per-unit and ad-valorem trade cost as a function of $t$, $\tau - 1$ and $z$.}
\end{figure}

\textsuperscript{17}In the limit, infinitely efficient firms charge a consumer price that is a fixed markup on per unit trade
costs only.

\textsuperscript{18}In this respect, our model enriches the predictions about sorting of firms that characterize the heterogeneous trade literature. Less efficient firms are more sensitive to ad valorem trade costs while more efficient firms are more sensitive to per-unit costs.
2.4 Import Shares

Before we close the model and solve the general equilibrium, we emphasize a simple theoretical implication of per-unit trade costs: Falling prices in the manufacturing sector (e.g. due to productivity growth) increases effective trade costs, if not accompanied by falling prices in the transport sector (or falling nominal tariffs). In other words, what matters for the degree of economic integration is technological progress in transport relative to other activities.\(^{19}\)

This can be seen most easily by calculating the import share for a variety produced with efficiency \(z\), compared to a domestic variety with the same efficiency,\(^{20}\)

\[
\frac{p_{in}^k x_{in}^k}{p_{nn}^k x_{nn}^k} = \left(\frac{\tau_{in} t_{in} w_{i}}{w_{n}} + \frac{\sigma - 1}{\sigma} \frac{\bar{t}_{in}}{w_{n}}\right)^{1-\sigma} = \left(\frac{\tau_{in} t_{in} w_{i}}{w_{n}} + \frac{\bar{t}_{in}}{p_{0}}\right)^{1-\sigma},
\]

where \(\bar{t}_{in} = t_{in} w_{i} \sigma / (\sigma - 1)\) and \(p_{0}\) is defined as the frictionless price in market \(n\), i.e. \(p_{0} = [\sigma / (\sigma - 1)] w_{n} / z\). This illustrates that it is real trade costs, and not nominal ones, that determine the import share. Furthermore, the elasticity of the import share with respect to \(p_{0}\) is positive, so that lower prices in the manufacturing sector yield a lower import share.\(^{21}\)

We emphasize that this mechanism not only operates in the model presented in this paper, but will be present in a wide range of models (e.g. models with a quality differentiation, or with different market structures).

2.5 Entry and Cutoffs

We assume that the total mass of potential entrants in country \(i\) is proportional to \(w_{i} L_{i}\) so that larger and wealthier countries have more entrants. This assumption, as in Chaney (2008), greatly simplifies the analysis and it is similar to Eaton and Kortum (2002), where the set of goods is exogenously given. Without a free entry condition, firms generate net profits that have to be redistributed. Following Chaney, we assume that each consumer

\(^{19}\)In Paul Krugman’s blog post "A Globalization Puzzle" (http://krugman.blogs.nytimes.com/2010/02/21/a-globalization-puzzle), he hypothesizes that technological progress biased against transport can help explain the fall in trade in the inter-war period.

\(^{20}\)Assuming that \(\tau_{nn} = 1\) and \(t_{nn} = 0\).

\(^{21}\)The elasticity is \(\sigma \bar{t}_{in} / p_{0} < 0\).
owns \( w_i \) shares of a totally diversified global fund and that profits are redistributed to them in units of the *numéraire* good. The total income \( Y_i \) spent by workers in country \( i \) is the sum of their labor income \( w_i L_i \) and of the dividends they earn from their portfolio \( w_i L_i \pi \), where \( \pi \) is the dividend per share of the global mutual fund.

Firms will enter market \( n \) only if they can earn positive profits there. Some low productivity firms may not generate sufficient revenue to cover their fixed costs. We define the productivity threshold \( z_{in}^k \) from \( \pi_{in}^k (z_{in}^k) = 0 \) as the lowest possible productivity level consistent with non-negative profits in export markets,

\[
z_{in}^k = \left[ \lambda_k^k \left( \frac{f_{in}^k}{Y_n} \right)^{1/(1-\sigma)} \frac{P^k_n}{w_i \tau_{in}} - \frac{f_{in}^k}{\tau_{in}} \right]^{-1},
\]

with \( \lambda_k^i \) a constant.\(^{22}\)

### 2.6 Closing the Model

Following Chaney (2008) and others, we assume that productivity shocks are drawn from a Pareto distribution with density \( dF (z) \), shape parameter \( \gamma \), and support \([1, +\infty)\).\(^ {23}\) The price index in sector \( k \) of country \( n \) is then

\[
(P_n^k)^{1-\sigma} = \sum_i w_i L_i \int_{z_{in}^k}^{\infty} (P_{in}^k)^{1-\sigma} dF (z) dz.
\]

We can summarize an equilibrium with the following set of equations:

\[
\begin{align*}
P_n^k &= h \left( z_{1n}^k, z_{2n}^k, \ldots, z_{Nn}^k \right) \quad \forall \ n \\
z_{in}^k &= f \left( P_n^k, \pi \right) \quad \forall \ i, n \\
\pi &= g \left( z_{11}^k, \ldots, z_{1N}, \ldots, z_{21}^k, \ldots, z_{2N}, \ldots, z_{NN}^k \right)
\end{align*}
\]

The first equation states that the price index is a function the endogenous entry cutoffs (all exogenous variables are suppressed). The second states that the cutoffs are a function of the price index and the dividend share \( \pi \) (\( \pi \) is part of income \( Y_n \)). The third states that the dividend share is a function of all entry cutoffs. We show why this is so in Appendix A.2.1.

\(^{22}\)Specifically, \( \lambda_k^i = (\sigma / \mu_k)^{1/(1-\sigma)} (\sigma - 1) / \sigma \).

\(^{23}\)Unlike in earlier models (e.g. Chaney, 2008), we do not need to impose the condition \( \gamma > \sigma - 1 \) for the size distribution of firms to have a finite mean, as long as per-unit trade costs are positive. When \( t > 0 \) even the most productive firms have finite revenue.
All in all, this constitutes a system of $N(N+1)+1$ equations and $N(N+1)+1$ unknowns. It is not possible to find a closed-form solution for the price index when $t_{in}^k > 0$. In Appendix A.2 we show how to solve the model numerically.

### 2.7 Welfare and Trade Costs

In this section we show that per-unit frictions lead to higher welfare losses than comparable iceberg frictions. In the literature on optimal taxation (e.g. Suits and Musgrave, 1953, and Delipalla and Keen, 1992) it is well known that ad valorem taxes welfare dominate equal yield per-unit taxes for a range of imperfect competition models. Here we show that in models of firm heterogeneity, per unit frictions become even more harmful than ad valorem frictions.

The intuition for our result is as follows. In the presence of heterogeneous prices, relative prices of imported goods become distorted in the presence of a per-unit barrier. As a consequence, relative consumption of imported goods also becomes distorted. An iceberg barrier introduces a deadweight loss due a distortion in imported goods relative to domestic goods. A per-unit barrier also features a distortion in consumption among imported goods.\(^{24}\)

The fundamental problem in comparing welfare effects is that changes in per-unit trade costs are not directly comparable to changes in iceberg costs. E.g. it makes little sense to compare a one percent increase in $\tau_{in}$ to a one percent increase in $t_{in}$. One way to deal with this is the following.\(^{25}\)

- Start with a frictionless equilibrium and impose either (A) a per-unit import barrier $t$ on imports from $m$ to $n$ or (B) an ad valorem barrier $\tau$ on imports from $m$ to $n$.

- Make (A) and (B) comparable by requiring that welfare in $n$ is identical in the two

\(^{24}\)In our model, the consumer price is a constant mark-up over total variable costs (including trade costs), but the producer price (f.o.b. price) is a variable mark-ups. Arkolakis, Costinot and Rodriguez-Clare (2010) show that a model with monopolistic competition, firm heterogeneity and variable mark-ups (due to a translog expenditure function), does not lead to larger gains from trade than a model with constant mark-ups. This suggests that the welfare effect in this paper is not related to variable mark-ups.

\(^{25}\)For simplicity, in this subsection, we consider one sector only and drop the $k$ subscript.
situations. This amounts to requiring that the price index in country n is identical.\textsuperscript{26} From this, we obtain a function $\tilde{\tau}(t)$ that maps per-unit costs to welfare-neutral iceberg costs.

- Now ask how much is collected in import tariffs in (A) and (B). We suspect that revenue is higher in (B), as the price distortions are less severe in this case. If this is the case, the flip side is that welfare gains from reducing per-unit frictions are higher than gains from reducing iceberg frictions.\textsuperscript{27}

In Appendix A.3 we derive the function $\tilde{\tau}(t)$, relative tariff revenues $G_B/G_A$ and the relative entry hurdles $\bar{z}_B/\bar{z}_A$. They are\textsuperscript{28}:

$$\tilde{\tau}^\gamma = (1 + \bar{z}_At)^{\gamma-\sigma+1} \frac{\int_1^\infty z^{\sigma-1}dF(z)}{\int_1^\infty (1/z + \bar{z}_At)^{1-\sigma}dF(z)},$$

$$\frac{G_B}{G_A} = \frac{\sigma}{\bar{z}_A} \frac{\tilde{\tau} - 1}{\tau - 1} \frac{\tilde{\tau}^{-\gamma-1}}{1 + \bar{z}_At} \frac{\int_1^\infty (1/z + \bar{z}_At)^{-\sigma}dF(z)}{\int_1^\infty (1/z + \bar{z}_At)^{1-\sigma}dF(z)}$$

(3)

and

$$\frac{\bar{z}_B}{\bar{z}_A} = \frac{\tau}{1 + \bar{z}_At}$$

where $\bar{z}_K$ is the entry hurdle faced by firms in m entering n in equilibrium $K$.\textsuperscript{29}

Relative revenue is related to only three variables: $\bar{z}_t$, $\sigma$, and $\gamma$. $\bar{z}_At$ is simply per-unit costs relative to production unit costs of the least efficient exporter, and serves as a convenient measure of the distortion imposed by per-unit costs.\textsuperscript{30}

\textsuperscript{26}Welfare also depends on income from profits, but as in Chaney (2008), income from profits is constant.

\textsuperscript{27}Alternatively, one could require that tariff revenue is equal in (A) and (B), and then calculate welfare in (A) relative to welfare in (B). However, this approach will not produce analytical solutions, and one must therefore rely on simulation of the full equilibrium.

\textsuperscript{28}Compared to the expressions in Appendix A.2, we simplify notation by calling the variable of integration $z$, instead of $\bar{z}_A$ and $\bar{z}_B$. Also, we define $\bar{z}_A = \bar{z}_{A,mn}$.

\textsuperscript{29}Here we assume that $\gamma > \sigma - 1$, since equilibrium (B) is not defined otherwise.

\textsuperscript{30}The fact that we can express the $G$ ratio as a function of $t\bar{z}_A$ instead of $t$ and $\bar{z}_A$ separately makes the calculations much simpler, since we do not have to evaluate the effect of $t$ on $\bar{z}_A$ (which involves calculating the price index).
We now show how the ratio relates to different combinations of these variables. In Figure 2 we plot $\bar{z}_A t$ on the x-axis and $G_B/G_A$ as well as $\bar{z}_B/\bar{z}_A$ on the y-axis. The four graphs show four different choices of $\sigma$ and $\gamma$, $\sigma = 4, 6, 8$; and $\gamma = \sigma - 1, \sigma + 1$.\(^{31}\)

For all parameter values, $G_B/G_A > 1$, implying that iceberg tariffs generate more revenue than per-unit tariffs, holding welfare constant.\(^{32}\) For example, in the top left and right graphs, if the per-unit barrier is 20 percent of production costs for the least efficient exporter, then the alternative strategy of imposing a welfare-neutral iceberg cost will increase tariff revenue by roughly 90 – 100 percent.\(^{33}\)

### 2.7.1 Robustness of the Welfare Effect

One concern is that the welfare effect is only valid in models with heterogeneity in terms of cost efficiency. For example, if high price firms have a large market share, one might hypothesize that $t$-barriers are less harmful, since in this case the small (low price) firms are hit the hardest by a $t$-barriers (their price increase by more, in percent, than the large firms).

In this section we show the welfare result is robust to an extension of the model where firms are heterogeneous both in terms of efficiency and quality.\(^{34}\) However, the magnitude of the effect becomes smaller when high price firms have a very large market share.

Consider an extended CES utility function of the following type,

$$U = \left( \int_{\omega \in \Omega} \left[ x(\omega) q(\omega) \right]^{(\sigma-1)/\sigma} d\omega \right)^{\sigma/({\sigma-1})},$$

where $q(\omega)$ is the quality of variety $\omega$ and $\Omega$ is the set of available varieties. In Appendix

\(^{31}\) The values for $\gamma$ chosen here are higher than the ones estimated in the next section (see Table 1). The reason is that the $G$ ratio is defined only when $\gamma > \sigma - 1$. Figure 2 shows that the $G$ ratio increases for lower $\gamma$, so using the estimated value for $\gamma$ instead would presumably increase the $G$ ratio even more.

\(^{32}\) We have tried a range of different parameter values, and have not succeeded in generating a $G_B/G_A$ ratio less than one.

\(^{33}\) Decreasing the level of heterogeneity (increasing $\gamma$) will decrease the gains from iceberg tariffs relative to per-unit tariffs. Also note that the $\bar{z}_B/\bar{z}_A > 1$ in all four graphs, implying that an iceberg barrier decreases the set of imported varieties relative to a per-unit barrier. This occurs because high price (high cost) firms close to the entry hurdle are less affected by per-unit barriers than iceberg barriers.

\(^{34}\) Johnson (2009) proposes a model where firms are heterogeneous both in terms of unit costs and quality.
Figure 2: Relative tariff revenue $G_B/G_A$ ($A = t$ barriers, $B = \tau$ barriers)

Figure 3: Quality heterogeneity and relative tariff revenue $G_B/G_A$ ($A = t$ barriers, $B = \tau$ barriers)
A.4 we show that $G_B/G_A$ is then

$$
\frac{G_B}{G_A} = \frac{\sigma - 1}{\sigma - 1} \frac{\tilde{\tau} - 1}{\tilde{\tau}} \int_{\Omega_{Bmn}} q(\omega)^{\sigma - 1} \left[ \frac{p(\omega)}{q(\omega)} \right]^{1 - \sigma} d\omega \tag{4}
$$

where

$$
\tilde{\tau}^{1 - \sigma} = \frac{\int_{\Omega_{Amn}} \left( \frac{p(\omega) + \bar{t}}{q(\omega)} \right)^{1 - \sigma} d\omega}{\int_{\Omega_{Bmn}} \left( \frac{p(\omega)}{q(\omega)} \right)^{1 - \sigma} d\omega},
$$

$p(\omega)$ is the frictionless price and $\bar{t} = w_m t \sigma / (\sigma - 1)$.

Equation (4) is a function of the distribution of prices and qualities, as well as the elasticity of substitution $\sigma$, and the target additive tariff $\bar{t}$. In Figure 3 we evaluate equation (4) under four different distributions of prices and qualities. The x-axis shows the additive barrier $t$. The y-axis shows the $G_B/G_A$ ratio given this magnitude of protection. In graphs (1)-(3), we assume that prices are inversely Pareto distributed (which follows from Pareto distributed efficiency). In graph (1), quality is constant, and is therefore similar to the top left graph in Figure 2. In graphs (2) and (3), higher prices translate to higher quality, with the functional form $q = p^\eta$, $\eta = 0.5$ and $\eta = 3/2$ in graph (2) and (3) respectively. In these two cases, the $G_B/G_A$ ratio becomes smaller, but it still remains larger than one. In graph (4) we assume that prices are constant across all firms. In this case, $G_B/G_A = \sigma / (\sigma - 1)$. It is interesting to note that this is the same outcome as in Suits and Musgrave (1953), who solve a similar problem in a partial equilibrium model with one monopolist.

We have evaluated the $G_B/G_A$ ratio for a range of different combinations of parameter values, and we always find that $G_B/G_A > 1$. The ratio increases when price dispersion is high and decreases when large firms charge high prices. All in all, we conclude that the qualitative theoretical result in this paper extends to models with heterogeneity along other

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35The calculations are performed using $\sigma = 6$, $\gamma = \sigma - 1$, and 100,000 random draws. Since efficiency is distributed along $[1, \infty]$, prices are distributed along $<0,1]$. $t$ on the x-axis can therefore be interpreted as additive barriers relative to the maximum price. As we discuss in the appendix, we assume that $\Omega_{Amn} = \Omega_{Bmn}$. Results for other choices of $\sigma$ and $\gamma$ are available upon request.

36In their framework, $G_B/G_A = p/MR(x)$, where $MR(x)$ is marginal revenue net of tax. Since in our model $MR(x) = p[1 - 1/\sigma]$, $G_B/G_A$ simply becomes $\sigma / (\sigma - 1)$. 

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17
dimensions than cost efficiency, although the *quantitative* effect may differ depending on the distribution of prices and market shares.

### 2.8 The Export Volume Distribution

In this section we examine some properties of the distribution of exports, across firms for a given product-destination pair. We will make extensive use of these properties further below when we estimate the model. We first derive the theoretical exports volume distribution for every destination \( n \) and product \( k \).\(^{37}\) Given that productivity among potential entrants is distributed Pareto, the productivity distribution among exporters of product \( k \) to destination \( n \) is also Pareto with cumulative distribution function \( F(z|z_{k}^{n}) = 1 - (z/z_{k}^{n})^{-\gamma} \). The Pareto shape coefficient \( \gamma \) is assumed to be equal across products and destinations. Then the exports volume cumulative distribution function (CDF), conditional on \( z > z_{k}^{n} \), is\(^{38}\)

\[
Q(x|z_{k}^{n}) = \Pr(X < x|Z > z_{k}^{n}) = 1 - \left( A_{n}^{k} x^{-1/\sigma} - B_{n}^{k} \right)^{\gamma},
\]

where \( A_{n}^{k} \) and \( B_{n}^{k} \) are two clusters of parameters,

\[
A_{n}^{k} = \frac{\sigma - 1}{\sigma} \frac{z_{k}^{n}}{\mu_{k}^{1/\sigma} Y_{n}^{1/\sigma} \tau_{n}^{1/w}},
\]

\[
B_{n}^{k} = \frac{t_{n}^{k}}{\tau_{n}^{k}/z_{k}^{n}}.
\]

#### 2.8.1 Properties of the Distribution

As with the scale parameter for the Pareto distribution, \( A_{n}^{k} \) will affect the location of the distribution. For example, an increase in market size \( Y_{n} \) will shift the probability density function to the right, so that it becomes more likely to sell greater quantities.

Since \( B_{n}^{k} = t_{n}^{k}/(\tau_{n}^{k}/z_{k}^{n}) \), \( B_{n}^{k} \) simply measures per-unit trade costs \((t_{n}^{k})\) relative to the unit costs of the least efficient firm, inclusive ad valorem costs \((\tau_{n}^{k}/z_{k}^{n})\). When \( t_{n}^{k} = 0 \implies B_{n}^{k} = 0 \), the distribution is identical to Pareto with shape parameter \( \gamma/\sigma \). This is similar to

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\(^{37}\)Source country subscripts are dropped because Norway is always the source in the data.

\(^{38}\)The cdf is well-behaved when \((1 + B_{n}^{k})^{-\sigma} - x_{\text{min}}^{k} < 0\) and \( x_{\text{max}}^{k} - (B_{n}^{k})^{-\sigma} < 0 \) where \( x_{\text{min}}^{k} \) is the minimum export volume and \( x_{\text{max}}^{k} \) is maximum export volume.
Chaney (2008), where the sales distribution preserves the shape of the underlying efficiency distribution and the sales distribution is identical across markets. When $t_n^k > 0$, $B_n^k$ will affect the dispersion of quantity sold. This can be seen by finding the inverse CDF:

$$x_n^k(\vartheta) = Q^{-1}(\vartheta) = \left[\frac{(1-\vartheta)^{1/\gamma} + B_n^k}{A_n^k}\right]^{-\sigma}.$$

Dispersion, as measured by the ratio between the $\vartheta_{2}^{th}$ and $\vartheta_{1}^{th}$ percentiles ($0 < \vartheta_1 < \vartheta_2 < 1$) is then

$$D(\vartheta_2, \vartheta_1; B_n^k, \gamma, \sigma) \equiv \frac{x_n^k(\vartheta_2)}{x_n^k(\vartheta_1)} = \left[\frac{(1-\vartheta_1)^{1/\gamma} + B_n^k}{(1-\vartheta_2)^{1/\gamma} + B_n^k}\right]^{-\sigma}. \quad (6)$$

When $t_n^k = 0$, this ratio is constant across destinations. When $t_n^k > 0$, the ratio declines as $B_n^k$ goes up. That is, exports volume becomes less dispersed with higher per-unit costs. The intuition is that higher per-unit costs will hit the high productivity/low cost firms harder than firms with low productivity/high cost, since more trade costs will force the high productivity firms to increase their price by more than the low productivity firms, in percentage terms. This will translate into a larger reduction in quantity sold for the high productivity firms relative to the low productivity firms, so that dispersion will decrease.

The following proposition summarizes our findings:

**Proposition 2** When per-unit costs are positive ($t_n^k > 0$), dispersion, as measured by the ratio between the $\vartheta_{2}^{th}$ and $\vartheta_{1}^{th}$ percentiles, is decreasing in $t_n^k$ and increasing in $\tau_n^k$. Moreover, when per-unit costs are zero ($t_n^k = 0$), then dispersion is invariant to a change in variable trade costs $\tau_n^k$.

**Proof.** See Appendix A.5.

In Appendix A.5 we prove this proposition allowing for trade costs to alter the entry cutoffs and the price index.

In Figure 4 we plot the theoretical exports volume complementary cumulative distribution function, on log scales. The value of the complementary CDF is on the horizontal axis, while quantity exported is on the vertical axis. The solid line represents the case when $B_n^k = t_n^k / (\tau_n^k/z_n^k) = 0$. The gradient is then equal to $-\sigma / \gamma$. The dotted line represents the case when per-unit costs are positive. As $B_n^k$ increases, the complementary CDF becomes
more and more concave. The concavity reflects the fact that large firms (low cost firms) are hit harder by per-unit costs than small firms (high cost firms).

![Figure 4: The Export Volume Distribution](image)

The properties of the exports volume distribution also survive, under some assumptions, in a framework where firms are heterogeneous both in terms of unit costs and quality.\textsuperscript{39} In Appendix A.6 we also investigate whether departures from the CES framework in models with ad valorem costs can generate predictions similar to those of our model. We show that for a popular class of linear demand systems (and with zero per-unit costs), dispersion in exports will increase in ad valorem costs - the opposite of the case with per-unit costs.\textsuperscript{40}

We provide additional information about the properties of the distribution in Section 3.4.

\textsuperscript{39}More specifically, the result that dispersion decreases with per-unit trade costs carries through as long as the relationship between production unit costs and quality is not too convex (as we show in Appendix A.5.1). In our particular dataset, as we will show below, this is the case for an overwhelming majority of product-destination pairs.

\textsuperscript{40}In Appendix A.6.1, we also consider an extension of our model where firms have to sustain marketing costs in order to promote their products and reach consumers, following Arkolakis (2008). It turns out that, in the extended model, as long as the market penetration effect is not too strong compared to the per-unit trade cost effect, we can interpret our results as a lower bound on the true magnitude of the ad valorem equivalent of per-unit trade costs.
3 Estimating the Model

In this section we structurally estimate the magnitude of per-unit trade costs. We showed in the theory section that per-unit costs introduce curvature in the export volume CDF, leading to less dispersion in exports volume as per-unit trade costs increase. When per-unit trade costs are zero, dispersion in exports volume is unaffected by (ad valorem) trade costs. This is the identifying assumption that allows us to recover estimates of trade costs consistent with our model.\textsuperscript{41} The econometric strategy consists of using a minimum distance estimator that matches the empirical distribution of exports volume (per product-destination) to the theoretical distribution.\textsuperscript{42}

Our approach of estimating trade costs from an economic model is very different from the earlier literature.\textsuperscript{43} First, most studies model trade costs as ad valorem exclusively, omitting the presence of per-unit costs. A notable exception is Hummels and Skiba (2004), who distinguish between them and find evidence for the presence of per-unit shipping costs.\textsuperscript{44} Compared to our work, they study freight costs exclusively, whereas we consider all types of international trade costs. Second, our methodology utilizes within-market dispersion in exports volume to achieve identification of trade costs, whereas earlier studies utilize cross-country variation in trade. Third, whereas the traditional approach can only identify trade costs relative to some benchmark, usually domestic trade costs, our method identifies the absolute level of trade costs (although conditional on a value of the elasticity of substitution). Fourth, we do not impose trade cost symmetry ($\tau_{kn}$ and $\tau_{nk}$ can differ from, respectively, $\tau_{ni}$ and $\tau_{ni}$).

\textsuperscript{41}In Section 3.2 below, we provide evidence that is consistent with the identifying assumption.
\textsuperscript{42}We choose to use data for export volume (quantities) instead of export sales for the following reasons. First, a closed-form solution for the sales distribution does not exist. Second, using quantities instead of sales avoids measurement error due to imperfect imputation of transport/insurance costs. Third, we avoid transfer pricing issues when trade is intra-firm (Bernard, Jensen and Schott 2006).
\textsuperscript{43}Anderson and van Wincoop (2004) provide a comprehensive summary of the literature.
\textsuperscript{44}They find an elasticity of freight rates with respect to price around 0.6, well below the unitary elasticity implied by the iceberg assumption on shipping costs.
3.1 Data

The data consist of an exhaustive panel of Norwegian non-oil exporters in the 1996-2004 period. Data come from customs declarations. Every export observation is associated with a firm, a destination and a product id and for every export observation we observe the quantity transacted and the total value.\footnote{Firm-product-year observations are recorded in the data as long as the export value is NOK 1000 ($\approx$ USD 148) or higher. The unit of measurement is kilos for all the products. Moreover, 27.5\% of the products are additionally measured in quantities, while 4.7\% are additionally measured in other units ($m^3$, carat, etc.). In the baseline estimation we use kilos unless a different unit is available.} Since identification in the empirical model is based solely on cross-sectional variation, we chose to work, in our baseline specification, with the 2004 cross-section, the most recent available to us. The product id is based on the Harmonized System 8-digit (HS8) nomenclature, and there are 5,391 active HS8 products in the data. 203 unique destinations are recorded in the data set.

In 2004, 17,480 firms were exporting and the total export value amounted to NOK 232 billion ($\approx$ USD 34.4 billion), or 48 percent of the aggregate manufacturing revenue. On average, each firm exported 5.6 products to 3.4 destinations for NOK 13.3 million ($\approx$ USD 2.0 million). On average, there are 3.0 firms per product-destination (standard deviation 7.8). As we will see, we utilize the distribution of export quantity across firms within a product-destination in the econometric model. We therefore choose to restrict the sample to product-destinations where more than 40 firms are present.\footnote{Also, the likelihood function is relatively CPU intensive, and this restriction saves us a significant amount of processing time.} In the robustness section, we evaluate the effect of this restriction by estimating the model on an expanded set of destination-product pairs.\footnote{Specifically, we lower the threshold to 10 firms per product-destination pair.} Below, extreme values of quantity sold, defined as values below the 1\textsuperscript{st} percentile or above the 99\textsuperscript{th} percentile for every product-destination, are eliminated from the data set. All in all, this brings down the total number of products to 121 and the number of destinations to 21.\footnote{Exports to all possible combinations of these products and destinations amount to 26.2\% of total export value. Lowering the threshold to 10 firms, as we do in the robustness section, increases the share of total exports used in estimation to 58.9\%.}

Before presenting the formal econometric model, we show some descriptive statistics that
suggest how dispersion is related to trade costs. In Figure 5, we first calculated the ratio between the 90th and the 10th percentile of exports quantity for each product-destination. Second, we averaged the ratios across products for every destination, using exports value for each product as weights. Third, we plotted the mean ratio against distance (a proxy for trade costs), in logs. The relationship is clearly negative, indicating that trade costs tend to narrow the dispersion in exports quantity. Regressions that include the usual gravity-type right hand side variables and product fixed effects will give the same result. The relationship is also robust to other measures of dispersion, such as the Theil index or the coefficient of variation.

Figure 5: P90/P10 Ratio of Export Quantity, Weighted Average Across Products

We also investigate why the percentile ratios are falling with trade costs (as proxied by distance). Our theory predicts that firms in the top of the distribution are hit harder

49 In order to show the pattern for as many destinations as possible, we have based these calculations on the unrestricted sample, i.e. using all product-destinations with more than one firm present.

50 Specifically, a regression that includes distance, population, real GDP per capita (all in logs) and an indicator function for contiguity, together with product fixed effects yields an estimate of the distance coefficient of −.667 (t-stat = −27.10), with standard errors clustered at the product level. Separate regressions for each product with 6 destinations or more yields a negative distance coefficient for 92 percent of the products. Alternative regressions where the dependent variable is the coefficient of variation or the Theil index yield estimates of −.204 (t-stat = −23.99) and −.406 (t-stat = −23.34), respectively.
than firms in the bottom of the distribution as per-unit trade costs increase. An alternative way of checking the validity of this prediction, is to investigate how export percentiles (not ratios) are correlated with trade costs (as proxied by distance). We construct export percentiles (from P03 to P99 with intervals of 3) for every product-destination pair and regress each of them on a product fixed effect, distance, GDP, and GDP per capita (all in logs).\footnote{Standard errors are clustered by HS8 product. Product-destinations are included if the number of firms per product-destination > 40, as in the baseline model.} The product fixed effect ensures that we are only using variation within a product category, across markets, to identify the distance effect. Figure 6 shows the results. The solid line shows the estimated distance coefficient (indicated on the y-axis) when the dependent variable is the $n^{th}$ export percentile (indicated on the x-axis). The dotted lines show the 95 percent confidence interval. All the export percentiles are negatively related to distance, but as we move from the lower to the higher percentiles, the distance estimate is decreasing. Hence, there is a tendency of the upper percentiles to be hit harder by trade costs, just as predicted by the model.

![Figure 6: The Impact of Trade Costs on the Export Distribution](image_url)
3.2 Prices and Quantities Within a Market

The theoretical prediction of a negative correlation between per-unit trade costs and export dispersion relies on the assertion that firms in the top of the export quantity distribution charge lower prices than firms in the bottom of the distribution.\(^{52}\) We show in Appendix A.5.1 that this pattern will emerge even in models of quality heterogeneity, under certain parameter restrictions. The identifying assumption is therefore consistent with recent findings, e.g. Baldwin and Harrigan (2007) and Johnson (2009), that more able firms also charge higher prices. From an empirical point of view, the correlation between price and quantity sold is something we can easily check in the data, as prices can be approximated by unit values. In the data, we find that the average correlation between unit value and (quantity) market share is \(-.59\) (the unweighted average over product-destination pairs, using only the pairs that we estimate on) and that 96.7 percent of the correlations are negative.\(^{53}\) The histogram of the correlation coefficients is shown in Figure 7. If the negative relationship between quantity and price is weaker than our model suggests, possibly due to quality heterogeneity within an HS8 category, then the link between per-unit trade costs and dispersion will also be weaker. In that case, our estimate of per-unit trade costs will be biased downward, since our model will interpret high dispersion as low trade costs. However, the strong negative correlations for most of the products in our sample indicate that the bias is relatively small.

3.3 Estimation

We use a minimum distance estimator that matches empirical dispersion in exports volume (per product-destination) to simulated dispersion in exports volume. Specifically, denote the empirical ratio between the \(\hat{\vartheta}_2^{th}\) and \(\hat{\vartheta}_1^{th}\) percentiles for product \(k\) in destination \(n\) as

\[^{52}\text{To fix ideas, this would be equivalent to IKEA selling a higher number of beds than Crate and Barrel. We emphasize that we are referring to a negative correlation between the price charged and the quantity/volume of items sold as opposed to the value of sales. The former is much more empirically likely than the latter.}\]

\[^{53}\text{Using an alternative dataset (see Section 3.6) of Portugal-based exporters, we find that the average correlation between unit value and export quantity is \(-.36\) and 97.5 percent of the correlations are negative. Manova and Zhang (2009), using data on Chinese trading firms, also find a negative correlation between firm f.o.b. export prices and quantity sold (see Table 4, column 2).}\]
$\tilde{D}_n^k (\vartheta_2, \vartheta_1)$ and stack a set of $(\vartheta_2, \vartheta_1)$ ratios in the $M \times 1$ column vector $\tilde{D}_n^k$. Denote its simulated counterpart $D (\vartheta_2, \vartheta_1; B_n^k, \gamma, \sigma)$, as defined in equation (6), and stack a set of $(\vartheta_2, \vartheta_1)$ ratios in the $M \times 1$ column vector $D (B_n^k, \gamma, \sigma)$. Define the criterion function as the squared difference between $\ln D (B_n^k, \gamma, \sigma)$ and $\ln \tilde{D}_n^k$:

$$d (\Psi) = \sum_{n} \sum_{k \in \Omega_n} \left[ \ln D (B_n^k, \gamma, \sigma) - \ln \tilde{D}_n^k \right]' \left[ \ln D (B_n^k, \gamma, \sigma) - \ln \tilde{D}_n^k \right],$$

where $\Psi$ is the vector of coefficients to be estimated (defined below), $N$ is the total number of destinations and $\Omega_n$ is the set of products sold in market $n$. We minimize $d (\Psi)$ with respect to $\Psi$ and denote $\hat{\Psi}$ the equally weighted minimum distance estimator.\footnote{Theory suggests that for overidentified models it is best to use optimal GMM. In implementation, however, the optimal GMM estimator may suffer from finite-sample bias (Altonji and Segal 1996). Furthermore, it is difficult to calculate the optimal weighting matrix in our context, as it would necessitate evaluating the variance of the percentile ratios for every product-destination (see e.g. Cameron and Trivedi, 2005, section 6.7).}

We model $B_n^k$ as the product of sector and destination fixed effects,

$$B_n^k = \beta_k b_n,$$

and normalize $\beta_1 = 1$.\footnote{The normalization is similar to the one adopted in the estimation of two-way fixed effects in the employer-} This decomposition enables us to identify the share of trade costs that is due to product characteristics and the share that is due to market characteristics.

Figure 7: Histogram of the Correlation Coefficient between Quantity (logs) and Price (logs)
Also, note that even though $\beta_k$ is estimated relative to some normalization, the estimates of the $B$ values are invariant to the choice of normalization. Finally, we condition the criterion function on a guess of $\sigma$ (see next section). The coefficient vector then consists of $\Psi = (\beta_k, b_n, \gamma)$, in total $K + N$ parameters.

We choose the following percentile ratio moments: (.95, .05), (.90, .10), (.75, .25), (.60, .40), (.20, .10), (.30, .20), (.40, .30), (.50, .40), (.60, .50), (.70, .60), (.80, .70), (.90, .80); in total $M = 12$ moments per product-destination.\footnote{We experimented with other combinations of moments as well and the results remained largely unchanged.}

As the covariance matrix of the vector of empirical percentile ratios ($\tilde{D}_k^n$) is unknown, the standard error of the estimator is not available using standard formulas. Instead, we employ a nonparametric bootstrap (empirical distribution function bootstrap). Specifically, we sample with replacement within each product-destination pair, obtaining the same number of observations as in the original sample. After performing 500 bootstrap replications, we form the standard errors by calculating the standard deviation for each coefficient in $\Psi$.

### 3.4 Identification

Recall that Figure 4 showed that per-unit costs (or $B_k^n$) introduced curvature in the complementary CDF. The set of percentile ratio moments enables us to trace out this curvature, which will pin down $B_k^n$. The Pareto shape parameter $\gamma$ is identified by the gradient of the CDF that is common across markets for a given product. We emphasize that with only one moment, $B_k^n$ and $\gamma$ are not separately identified, as one percentile ratio will give information only about the slope of the CDF. As a consequence, variability in dispersion alone (e.g. variability in the P90/P10 ratio) will not generate a positive estimate of per-unit costs. Instead, per-unit costs are identified by the non-linearity in the complementary CDF - that large (low price) firms are hit harder by per-unit costs (embedded in $B_k^n$) than small employee literature (see Abowd, Creecy, and Kramarz 2002). We also need to ensure that all products and destinations belong to the same mobility group. The intuition is that if a given product is sold only in a destination where no other products are sold, then one cannot separate the product from the destination effect.
(high price) firms.\(^{57}\)

As is usual in trade models, the elasticity of substitution \(\sigma\) is not identified. The criterion function \(d(\Psi)\) is therefore conditional on a guess of \(\sigma\). In the results section we report estimates based on different values of \(\sigma\). In the baseline specification, we assume a common \(\gamma\) across all products, but a model with product-specific \(\gamma\) values is also identified. We estimate a model with heterogeneity in \(\gamma\) and \(\sigma\) in the robustness section.

As noted above, \(B_{kn}^k = t_{kn}^k / (\tau_{kn}^k / \bar{z}_{kn}^k)\) simply measures per-unit trade costs \(t_{kn}^k\) relative to the unit costs of the least efficient exporter, inclusive of ad valorem costs \((\tau_{kn}^k / \bar{z}_{kn}^k)\). A more common measure of trade costs is trade costs relative to price. First, using the first-order condition from the firm’s maximization problem, we can re-express firm-level consumer prices as

\[
p_{kn}^k(\tilde{z}) = \frac{\sigma w_{tn}^k}{\sigma - 1} \left( \frac{1}{\tilde{z}B_{kn}^k} + 1 \right),
\]

where \(\tilde{z}\) is productivity measured relative to the cutoff \((z = \tilde{z}z_{kn}^k)\).\(^{58}\) Second, consider the average price (charged by Norwegian exporters) of product \(k\) in destination \(n\):

\[
p_{kn}^k = \frac{1}{1 - F(\tilde{z}_{kn}^k)} \int_{\tilde{z}_{kn}^k}^{\bar{z}_{kn}^k} p_{kn}^k(z) dF(z)
\]

\[
= \left( \frac{\bar{z}_{kn}^k}{\tilde{z}_{kn}^k} \right)^\gamma \int_{\tilde{z}_{kn}^k}^{\bar{z}_{kn}^k} p_{kn}^k(z) \gamma z^{-\gamma - 1} dz
\]

\[
= \int_{1}^{\bar{z}_{kn}^k} p_{kn}^k(\tilde{z}) dF(\tilde{z}),
\]

where we used the substitution \(z = \tilde{z}z_{kn}^k\) in the last equality. Third, inserting equation (7) and solving for \(wt_{kn}^k/p_{kn}^k\) yields:

\[
\frac{wt_{kn}^k}{p_{kn}^k} = \frac{\sigma - 1}{\sigma} \frac{B_{kn}^k(\gamma + 1)}{\gamma + B_{kn}^k(\gamma + 1)}.
\]

The ratio \(wt_{kn}^k/p_{kn}^k\) measures (per-unit) trade costs relative to the average consumer price.\(^{59}\) Given our estimate of \(B_{kn}^k\) and \(\gamma\), the expression on the right hand side can be easily computed. Note that integrating over productivities allows us to express trade costs only as a

\(^{57}\)An implication is that a linear empirical CDF (in logs) will result in an estimate of zero per-unit trade costs.

\(^{58}\)Note that \(\tilde{z}\) is distributed like a Pareto with scale parameter 1 and shape parameter \(\gamma\).

\(^{59}\)Note that this measure of the relevance of per-unit trade costs does not require us to disentangle \(t_{kn}^k\) from \(\tau_{kn}^k\).
Table 1: Estimates of per-unit trade costs relative to consumer price

<table>
<thead>
<tr>
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<th>$\sigma = 4$</th>
<th>$\sigma = 6$</th>
<th>$\sigma = 8$</th>
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<td>.35 (.01)</td>
<td>.36 (.01)</td>
<td>.45 (.01)</td>
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<tr>
<td>Trade costs, median</td>
<td>.33 (.01)</td>
<td>.34 (.01)</td>
<td>.43 (.01)</td>
</tr>
<tr>
<td>Trade costs, st. dev.</td>
<td>.12 .12 .12</td>
<td>.13 .13 .13</td>
<td>.45 .45 .45</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>1.03 (.03)</td>
<td>1.31 (.03)</td>
<td>1.50 (.03)</td>
</tr>
<tr>
<td>Criterion $f$</td>
<td>558.43</td>
<td>539.22</td>
<td>531.37</td>
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<td>21</td>
<td>21</td>
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<tr>
<td># of Products ($K$)</td>
<td>121</td>
<td>121</td>
<td>121</td>
</tr>
</tbody>
</table>

Note: The mean, median, and standard deviation of trade costs estimates are computed considering all destination-product pairs used. Standard errors in parentheses.

function of $B_n^k$, $\gamma$ and $\sigma$. This is due to the fact that a Pareto density is parameterized only by the cutoff ($z_n^k$) and the shape parameter ($\gamma$). Our estimates of $B_n^k$ and $\gamma$ are therefore sufficient to obtain a meaningful measure of per-unit trade costs.

### 3.5 Results

Table 1 summarizes the results.\(^{60}\) We apply the methodology described in the previous section in order to back out a simple measure of per-unit costs from the model. Estimated per-unit trade costs $wt_n^k/p_n^k$, measured relative to the consumer price, averaged over products and destinations, are 0.36 (s.e. 0.01), conditional on $\sigma = 6$, which we use as our baseline case.\(^{61}\) Estimated trade costs drop to 0.35 for $\sigma = 4$ and rise to 0.45 for $\sigma = 8$. These estimates are similar to those found in the existing literature, where international trade barriers are typically estimated in the range of 40 – 80 percent for a 5 – 10 elasticity estimate (Anderson and van Wincoop 2004).\(^{62}\)

Furthermore, 99 and 95 percent of the $\beta_k$ and $b_n$ coefficients respectively (the product

\(^{60}\)The estimates of $\beta_k$ and $b_n$ are available on the authors’ homepages.

\(^{61}\)It is estimated to 3.79 in Bernard, Eaton, Jensen, and Kortum (2004). In summarizing the literature, Anderson and van Wincoop (2004) conclude that $\sigma$ is likely to be in the range of five to ten.

\(^{62}\)Earlier estimates of international trade barriers are not directly comparable to our estimate of $wt_n^k/p_n^k$, however, as earlier studies define trade barriers as the ratio of total (ad valorem) trade barriers relative to domestic trade barriers $\tau_{in}/\tau_{ii}$.
and destination fixed effects embedded in $B^k_n$) are significantly different from zero at the 0.05 level. Since $B^k_n$ is greater than zero only when per-unit costs $t^k_n > 0$, our findings suggest that the standard model with only iceberg costs is rejected.\footnote{We also test the hypothesis that all $t^k_n = 0$ formally. Let $n_T$ be the number of observations, $\Psi^{\text{res}}$ the vector of restricted coefficients (all $B^k_n = 0$), and $\Psi^{\text{unres}}$ the vector of unrestricted coefficients. Then the likelihood ratio statistic $2n_T [d(\Psi^{\text{res}}; \sigma) - d(\Psi^{\text{unres}}; \sigma)]$, is $\chi^2(r)$ distributed under the null, where $r$ is the $K + N - 1$ restrictions. The null is rejected at any conventional p-value.} The estimate of $\gamma$, the Pareto coefficient, is 1.31 (s.e. 0.03) in the baseline case.

Figure 8 shows $wt^k_n/p^k_n$ for every destination, averaged over products, on the vertical axis and distance (in logs) on the horizontal axis. Estimated trade costs are clearly increasing in distance. Note that our two-way fixed effects approach enables us to construct $wt^k_n/p^k_n$ even for product-destination pairs that are not present in the data. This implies that there is no selection bias in Figure 8, since all products are included in every destination. The robust relationship between distance and trade costs also emerges when regressing trade costs on a product fixed effect and a set of gravity variables (distance, contiguity, GDP, and GDP per capita, all in logs).\footnote{The full set of results is available upon request.} The distance coefficient is then 0.07 (s.e. 0.001), meaning that doubling distance yields a 7% increase in trade costs.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure8.png}
\caption{Per-unit Trade Costs Relative to Consumer Price, Averaged Across Products, Conditional on $\sigma = 6$}
\end{figure}
Figure 9 shows the distribution of estimated trade costs from Norway to the U.S. across products. This figure exploits the variability retrieved from the $\beta_k$ variables. As expected, per-unit trade costs are heterogeneous, with values ranging from roughly 10 to 70 percent of the product value.\textsuperscript{65} Figure 10 shows the relationship between estimated trade costs and actual average weight/unit and weight/value in logs.\textsuperscript{66} Since weight/unit and weight/value should be positively correlated with actual trade costs, we expect to see a positive relationship between these measures and estimated trade costs. Indeed, the figures indicate an upward sloping relationship. The correlation between weight/unit (weight/value) and trade costs $wt^k/p^k$ (averaged over destinations) is 0.59 (0.22).

Most of the estimates in the product dimension also make intuitive sense. For example, tractors (HS 87019009) and self-propelled front-end shovel loaders (HS 84295102) are among the products with estimated trade costs above the 95th percentile (taking the average over all destinations). Toys (HS 95039000) and CDs (HS 85243901) are among the products with estimated trade costs below the 5th percentile (taking the average over all destinations).

It is also of interest to study the importance of product and destination characteristics on trade costs. Since the expression for $wt^k_n/p^k_n$ is a monotonically increasing function of $B^k_n$, a straightforward indicator of the importance of product and destination characteristics is the dispersion in $\beta_k$ and $b_n$ respectively. In the baseline case, the 90-10 percentile ratio of $\beta_k$ and $b_n$ is 5.40 and 1.63, respectively, suggesting that product characteristics are 3 – 4 times as important for trade costs compared to destination characteristics.

Furthermore, the decomposition of product and destination effects allows us to study whether costly destinations are associated with products with lower transport costs. Or in other words, that the product mix in a given destination is a selected sample influenced by the costs of shipping to that market. A simple indicator is the correlation between the

\textsuperscript{65}Densities for ln$B^k_n$ for other markets are simply shifted left or right compared to the density for the U.S. This is by construction, since it is only the destination fixed effect $b_n$ that is different in the construction of the density for alternative markets.

\textsuperscript{66}Since only a subset of products has quantities measured in units, the number of products in the graph is lower than what is used in the estimation. Average weight/unit and weight/value are obtained by dividing total weight (summed over firms and destinations) over total units, or value (summed over firms and destinations).
Figure 9: The density of trade costs, conditional on $\sigma = 6$. Norway to the U.S.

Figure 10: Trade Costs and Actual Weight per Unit or Weight per Value (logs)
destination fixed effect $b_n$ and the product fixed effect, averaged over the products actually exported there. Formally, we correlate $b_n$ with $(1/K_n) \sum_{k \in \Omega_n} \beta_k$, where $K_n$ is the number of products exported to destination $n$ and $\Omega_n$ is the set of products exported to $n$. The results indicate that there is not much support for the hypothesis. The correlation is slightly positive but not significantly different from zero.

We also investigate whether the unweighted average of trade costs is different from the weighted average.\textsuperscript{67} When using export values per product-destination as weights, the weighted average of trade costs is 0.27. This suggests that product-destinations associated with high costs have below average exports.

Finally, Figure 11 shows actual and simulated percentile ratios (95/05, 90/10, 75/25, and 60/40), for all product-destination pairs. Most observations lie close to the 45 degree line, although the fit of the model is declining closer to the median. Overall, this leads us to conclude that the model is able to fit the data quite well.

\textsuperscript{67} We focus mainly on the unweighted average because otherwise we would have a selection problem when comparing trade costs across destinations.
3.6 Robustness

3.6.1 Variations of the Baseline Model

Next we present some re-estimations of the model that address several issues. The results are summarized in Table 2. One concern is our reliance on the Pareto distribution. Even though the Pareto is known to approximate the US firm size distribution quite well (e.g. Luttmer 2007), one could argue that dispersion is decreasing with trade costs due to extensive margin effects. As is well known, the fractal nature of the Pareto distribution implies that a percentile ratio is independent of truncation. As a consequence, movements in the entry cutoff do not affect the percentile ratio (when $t = 0$). However, under other distributions this may no longer be the case. For example, with the lognormal distribution and $t = 0$, dispersion will decrease with higher entry hurdles simply because the density is truncated from below, not due to intensive margin reallocation. One way of controlling for this, is to estimate the model on a subsample where the set of exporters is identical in every destination (for each product). Specifically, we take the three most popular destinations, Sweden, Denmark, and Germany, and extract the firms that are present in all three markets, for each product. Since this procedure reduces the sample size dramatically, we are forced to lower the threshold of firms present in a product-destination pair, from 40 to 10, resulting in three destinations and 11 products. With only 10 or more firms per product-destination, we must also reduce the number of estimating moments per product-destination, so we choose four moments: The (95, 05), (90, 10), (75, 25) and (60, 40) percentile ratios. The results are shown in column (R1) in Table 2. Although the sample size is much smaller, the trade cost estimates are nearly unchanged and estimated with high precision. Therefore, we conclude that truncation of the export distribution is not driving our results, nor are other types of selection effects.

Second, a concern is that quality heterogeneity within an HS8 product group might bias our results, something we briefly discussed in Section 3.2. One way to check whether this is an issue, is to re-estimate the model on homogeneous goods exclusively. If the results become very different, there is reason for concern. We use the Rauch (1999) classification of differentiated and homogeneous goods and choose products that are classified as non-
Table 2: Robustness: Alternative specifications

<table>
<thead>
<tr>
<th></th>
<th>(R1)</th>
<th>(R2)</th>
<th>(R3)</th>
<th>(R4)</th>
<th>(R5)</th>
<th>(R6)</th>
<th>(R7)</th>
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<tr>
<td>Trade costs, mean</td>
<td>.34</td>
<td>.36</td>
<td>.43</td>
<td>.44</td>
<td>.36</td>
<td>.34</td>
<td>.27</td>
</tr>
<tr>
<td></td>
<td>(.03)</td>
<td>(.02)</td>
<td>(.02)</td>
<td>(.01)</td>
<td>(.02)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Trade costs, median</td>
<td>.31</td>
<td>.36</td>
<td>.42</td>
<td>.44</td>
<td>.33</td>
<td>.34</td>
<td>.17</td>
</tr>
<tr>
<td></td>
<td>(.03)</td>
<td>(.02)</td>
<td>(.02)</td>
<td>(.01)</td>
<td>(.02)</td>
<td>-</td>
<td>-</td>
</tr>
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<td>.10</td>
<td>.14</td>
<td>.16</td>
<td>.13</td>
<td>.09</td>
<td>.26</td>
</tr>
<tr>
<td></td>
<td>(.19)</td>
<td>(.10)</td>
<td>(.09)</td>
<td>(.04)</td>
<td>(.05)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(\gamma)</td>
<td>1.16</td>
<td>1.28</td>
<td>1.36</td>
<td>1.26</td>
<td>1.40</td>
<td>.98</td>
<td>2.32</td>
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<tr>
<td></td>
<td>(.19)</td>
<td>(.10)</td>
<td>(.09)</td>
<td>(.04)</td>
<td>(.05)</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Criterion (f)</td>
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<td>300.1</td>
<td>6067.2</td>
<td>109.7</td>
<td>493.8</td>
<td>131.1</td>
<td>456.0</td>
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<td>17</td>
<td>42</td>
<td>6</td>
<td>24</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td># of Products ((K))</td>
<td>11</td>
<td>43</td>
<td>826</td>
<td>40</td>
<td>116</td>
<td>19</td>
<td>118</td>
</tr>
</tbody>
</table>

Notes: R1: For each product, the set of exporters is identical in every destination; R2: Only homogeneous goods, using Rauch (1999) classification; R3: Only product-destinations with >10 firms; R4: Only products with quantities measured in units; R5: 2003 cross-section; R6: Portuguese data; R7: Heterogeneity in \(\sigma\) and \(\gamma\). \(\sigma=6\) used in all specifications except in R7. Four moments are used in R1, R2, and R3, otherwise 12.

In R7 the value for \(\gamma\) is an average across all products. Standard errors in parentheses.

differentiated.\(^{68}\) The number of products declines quite substantially in this case, so as in (R1), we set the firm threshold to more than 10 firms per product-destination and restrict the set of moments to four. Estimates are reported in column (R2), and the results are reassuring. The grand mean of trade costs (conditional on \(\sigma = 6\)) is identical to the baseline case.

Third, we investigate whether the choice of truncating the data set to only product-destinations with more than 40 firms affects the results. We choose product-destinations with more than 10 firms present, resulting in 42 destinations and 826 products.\(^{69}\) Again, the lower threshold forces us to reduce the number of moments used in estimation, so as

\(^{68}\)Goods classified as “goods traded on an organized exchange” or “reference priced” in the Rauch (1999) database. We use Jon Haveman’s concordances at http://www.macalester.edu/research/economics/page/haveman/Trade.Resources/TradeData.html to convert SITC to HS codes.

\(^{69}\)Exports to all possible combinations of these products and destinations amount to 58.9% of total export value.
in (R1), we choose four moments: The (95, 05), (90, 10), (75, 25), and (60, 40) percentile ratios. The estimate of trade costs increases slightly, to 0.43, as shown in column (R3).\(^70\) This suggests that although the product-destination pairs we estimate on are not a random sample, the selection bias resulting from truncation is not very large.

Fourth, we investigate whether the choice of units affects the results. The high share of products that are measured in kilos might bias the results if weight per-unit is varying across both destinations and firms. For example, if high productivity firms are able to reduce unit weight in remote markets, while low productivity firms are not, then dispersion will decrease. We address this issue by selecting the subsample of products that are measured in units, not kilos. This truncates the data set to 40 products and six markets. Again, the results do not change much, as shown in column (R4) in the table.

Fifth, we re-estimate the model on the 2003 cross-section instead of the 2004 cross-section. The results in column (R5) show that the grand mean of trade costs is identical to the baseline result.

Sixth, we estimate the model on a data set of Portuguese exporters. The data have the same structure as the Norwegian one.\(^71\) The results in column (R6) show that the mean of per-unit trade costs for Portugal is 0.34, very close to the Norwegian estimates (for \(\sigma = 6\)).

Finally, we also check the sensitivity of the results to heterogeneity in the elasticity of substitution \(\sigma\) and the Pareto coefficient \(\gamma\). First, we take estimates of the \(\sigma\) from Broda and Weinstein (2006), and take the unweighted average of their HS 10-digit estimates for every 4-digit product.\(^72\) Second, we allow for product-specific \(\gamma\) values, so that the theoretical percentile ratios become \(D(\vartheta_2, \vartheta_1; \beta_k^k, \gamma_k, \sigma_k)\) and the coefficient vector to be estimated becomes \(\Psi = (\beta_k^k, \gamma_k)\), in total \(2K + N - 1\) coefficients. The results are reported in

\(^70\)Our estimation algorithm spent 15 hours minimizing the objective function in this case. Therefore, we do not report standard errors in column (R2), as bootstrapping becomes prohibitively costly.

\(^71\)A detailed description of the dataset of Portuguese exporters can be found in Martins and Opreomolla (2009). The average correlation between unit value and export quantity is \(-.36\) (the unweighted average over product-destination pairs, using only the pairs that we estimate on) and 97.5 percent of the correlations are negative.

\(^72\)We average up to the 4-digit level because i) only the first six digits are internationally comparable and (ii) not all products are jointly present in the Norwegian and U.S. data.
column (R7).\textsuperscript{73} Again, per-unit costs are large and significant, although the point estimate falls somewhat compared to the baseline case.

### 3.6.2 Other Robustness Checks

We have shown that the concavity of the export distribution is systematically related to market characteristics and that per-unit trade costs are a reasonable explanation for this fact. However, we would like the model to fit other aspects of the data as well, in dimensions that are not easily explained in competing models. One such feature is f.o.b. export prices. Our model predicts that f.o.b. prices are increasing in per-unit trade costs (see theory section).\textsuperscript{74} The reason is that the perceived elasticity of demand is lower when per-unit costs are high, leading firms to charge a higher markup.\textsuperscript{75} In Table 3 we provide evidence that this is indeed the case in the data. We regress firm-product-destination level unit values on a firm-product fixed effect, distance, GDP, and GDP per capita. Standard errors are clustered on HS8 products. The distance coefficient is identified purely from the variation within a firm-product pair across destinations. The coefficient is positive and significant, using both Norwegian and Portuguese firm-level data, suggesting that a given exporter charges a higher price for the same HS8 good in more remote markets. This result is difficult to reconcile with existing heterogeneous firms trade models, as noted by Manova and Zhang (2009). In standard models with CES demand, e.g. Melitz (2003), firms charge the same f.o.b. price in all locations. In standard models with linear demand, e.g. Melitz and Ottaviano (2008), firms charge lower markups in remote markets. In standard quality-sorting models, e.g. Baldwin and Harrigan (2007), firms are assumed to sell the same quality worldwide.

Eaton, Kortum, and Kramarz (2008) argue that sales and entry shocks are needed in order to explain the entry and sales patterns of French exporters. Our model, on the other

\textsuperscript{73}We do not report standard errors in this case, because bootstrapping is prohibitively time-consuming.

\textsuperscript{74}A model with endogenous quality choice and per-unit costs will also generate a positive correlation between f.o.b. prices and per-unit trade costs.

\textsuperscript{75}Note that, as in Berman et al. (2009), our model is consistent with incomplete exchange rate pass-through. The elasticity of the f.o.b. price to a real depreciation is less than one as long as per-unit trade costs are finite. Our model predicts that this elasticity (and therefore the degree of exchange rate pass-through) is increasing in $t/\tau$. 37
<table>
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<th></th>
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<th>Portugal</th>
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<td>.087 a</td>
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<tr>
<td><strong>(log) GDP</strong></td>
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<tr>
<td></td>
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<td>(.004)</td>
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<tr>
<td><strong>(log) GDP per capita</strong></td>
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<td># of Firms</td>
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<td>15,684</td>
</tr>
<tr>
<td># of Destinations</td>
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</tr>
</tbody>
</table>

Notes: Dependent variable: f.o.b. unit value by firm, HS8 product and destination. Standard errors (in parentheses) are clustered by HS8 product.

\( a \ p<0.01, \ b \ p<0.05, \ c \ p<0.1 \)

hand, has only variability along the productivity dimension. Although additional error components would certainly increase the fit of the model, we decided to choose a somewhat simpler setup in this paper.\(^76\) First, the defining feature of the data we have attempted to explain is the varying dispersion in exports across destinations. A model with entry and sales shocks but without per-unit costs cannot explain this,\(^77\) unless one assumes that the variances and/or covariances of the shocks are correlated with distance. Second, our econometric model is expressed in closed-form, even though analytical expressions for many key relationships do not exist. This helps to keep the run-time of the estimation algorithm down to an acceptable level.

\(^76\)In an earlier paper (Irarrazabal, Moxnes, and Opromolla 2009) we estimated demand and fixed cost shocks in a model with heterogeneous firms, exports, and multinational production.

\(^77\)Abstracting from possible effects of truncation of the distribution on dispersion.
4 Conclusions

In this paper we have first explored theoretically the implications of introducing more flexible trade costs in an otherwise standard Melitz (2003) heterogeneous firm model of international trade. An important theoretical finding is that per-unit frictions are more harmful than equal yield ad valorem frictions. Since a non-negligible share of existing trade barriers are per-unit, standard welfare assessments of trade liberalization may be understated. A corollary and policy implication of our work is that, if governments are determined to raise revenue through import duties, they should impose ad valorem duties rather than per-unit duties, and even more so, in markets characterized by extensive heterogeneity. The mechanism behind the result is that per unit trade frictions generate distortions in relative prices (and consumption) both across and within markets. Ad valorem frictions generate price distortions only across markets. It is thus the marriage of per-unit costs and price heterogeneity that drives the theoretical results in this paper.

We tie the stylized model to a rich firm-level data set of exports, by product and destination. By using the identifying assumption from theory that higher-order moments from the export quantity distribution (for a given product-destination pair) are systematically related to (per-unit) trade costs, we are able to back out a structural estimate of trade costs. Our empirical results indicate that per-unit costs are not just a theoretical possibility: they are pervasive in the data, and the grand mean of trade costs, expressed relative to the consumer price, is between 35% and 45%. We therefore conclude that pure iceberg is rejected, and that empirical work, especially at this level of disaggregation, must account for both the tip of the iceberg, as well as the part of trade costs that are largely hidden under the surface: per-unit costs.

References


**A Appendix.**

**A.1 Elasticity of Quantity Sold to Trade Costs (Proposition 1)**

In this subsection we summarize (and extend) the conditions outlined in Proposition 1 and Figure 1.
Derivatives with respect to \( z \). The relevant derivatives are
\[
\frac{\partial |\varepsilon_{t_{in}}^{k}|}{\partial z} = \frac{\tau_{in}^{k}}{\sigma t_{in}^{k}} \varepsilon^{2}_{t_{in}} > 0 ; \quad \frac{\partial^{2} |\varepsilon_{t_{in}}^{k}|}{\partial z^{2}} = -2 \frac{\tau_{in}^{k}}{\sigma t_{in}^{k} \varepsilon_{t_{in}}^{k}} \varepsilon^{2}_{t_{in}} < 0
\]
\[
\frac{\partial |\varepsilon_{t_{in}}^{k+1}|}{\partial z} = -\frac{\tau_{in}^{k}}{\sigma t_{in}^{k}} \varepsilon^{2}_{t_{in}} - 1 < 0 ; \quad \frac{\partial^{2} |\varepsilon_{t_{in}}^{k+1}|}{\partial z^{2}} = -2 \left( \frac{\tau_{in}^{k}}{\sigma t_{in}^{k} - \sigma} \right)^{2} \varepsilon^{3}_{t_{in}} > 0,
\]
showing that \( |\varepsilon_{t_{in}}^{k}| \) is increasing and concave in \( z \) while \( |\varepsilon_{t_{in}}^{k+1}| \) is decreasing and convex in \( z \). The signs of the derivatives rely upon \( \sigma > 1, z \geq 1, \tau_{in}^{k} > 0 \) and \( t_{in}^{k+1} \geq 0 \).

Derivatives with respect to \( t_{in}^{k} / (\tau_{in}^{k} - 1) \). The relevant derivatives are
\[
\frac{\partial |\varepsilon_{t_{in}}^{k}|}{\partial t_{in}^{k} / (\tau_{in}^{k} - 1)} = \frac{(\tau_{in}^{k})^{2}}{\sigma z (t_{in}^{k})^{2}} \varepsilon^{2}_{t_{in}} > 0 \quad \text{and}
\]
\[
\frac{\partial |\varepsilon_{t_{in}}^{k+1}|}{\partial t_{in}^{k} / (\tau_{in}^{k} - 1)} = -\frac{(1 + z t_{in}^{k})}{\sigma t_{in}^{k}} \varepsilon^{2}_{t_{in}} - 1 < 0,
\]
showing that \( |\varepsilon_{t_{in}}^{k}| \) is increasing in \( t_{in}^{k} / (\tau_{in}^{k} - 1) \) while \( |\varepsilon_{t_{in}}^{k+1}| \) is decreasing in \( t_{in}^{k} / (\tau_{in}^{k} - 1) \). The signs of the derivatives rely upon \( \sigma > 1, z \geq 1, t_{in}^{k} \geq 0 \).

The statement that \( z > (\tau_{in}^{k} - 1) / t_{in}^{k} \Rightarrow |\varepsilon_{t_{in}}^{k}| > |\varepsilon_{t_{in}}^{k+1}| \) and the upper bounds for \( |\varepsilon_{t_{in}}^{k}| \) and \( |\varepsilon_{t_{in}}^{k+1}| \) can be easily derived from the expressions for \( |\varepsilon_{t_{in}}^{k}| \) and \( |\varepsilon_{t_{in}}^{k+1}| \).

A.2 Simulating the Model

In this subsection we show how to simulate the model numerically. For simplicity we restrict the number of products to one and suppress the product index. The numerical approximation of the equilibrium consists of the following steps.

1. Choose a starting value of the price index \( P_{n}^{0} \).

2. Solve the equilibrium cutoffs and global profits simultaneously, conditional on \( P_{n}^{0} \). The cutoffs and global profits are
\[
\bar{z}_{in} = f\left(P_{n}, \pi\right) \quad \forall i, j
\]
\[
\pi = g\left(\bar{z}_{11}, ..., \bar{z}_{1N}, \bar{z}_{21}, ..., \bar{z}_{N1}\right),
\]
where only the endogenous arguments in functions \( f \) and \( g \) are explicitly shown. The expression for \( \pi \) is shown further below. The system consists of \( N^{2} + 1 \) equations and \( N^{2} + 1 \) unknowns and can be solved by choosing a candidate \( \pi \), solving \( \bar{z}_{in} \) using \( f \), inserting the solution back into \( g \), etc., until the system converges.

3. Given the solutions \( \bar{z}_{in}^{0} \), a new candidate price index \( P_{n}^{1} = h(\bar{z}_{11}, \bar{z}_{22}, ..., \bar{z}_{NN}) \) is calculated.

4. Iterate over 2 and 3. When \( |P_{n}^{r} - P_{n}^{r-1}| \) is sufficiently small, the equilibrium \( \{P_{n}, \bar{z}_{in}, \pi\} \) is found.

Since the price index does not have a closed-form solution, we approximate it with Monte Carlo methods. Specifically, we take \( 1e + 5 \) random draws \( z^{*} \) from the Pareto density \( g(z) \). An integral of the form
\[
P = \int_{z}^{\infty} p(z)^{1-\sigma} g(z) \, dz
\]

Superscripts denote the round of iteration.
Here we derive the expressions for Welfare Effects of Changes in A.3

\( P \approx \text{mean} \left( p(z)^{1-\sigma} \mid z^r > Z \right) \times \frac{\text{#obs} > Z}{1e + 5}. \)

**A.2.1 Global Profits**

Following Chaney (2008), we assume that each worker owns \( w_n \) shares of a global fund. The fund collects global profits \( \Pi \) from all firms and redistributes them in units of the *numéraire* good to its shareholders. Dividend per share in the economy is defined as \( \pi = \frac{\Pi}{\sum w_i L_i} \), and total labor income is \( Y_n = w_n L_n (1 + \pi) \). Profits for country \( i \) firms selling to market \( n \) are

\[
\pi_{in} = \frac{S_{in}}{\sigma} - n_{in} f_{in},
\]

where \( S_{in} \) denotes total sales from \( i \) to \( n \), \( n_{in} \) is the number of entrants, and \( f_{in} \) is the entry cost. Global profits are then

\[
\Pi = \sum_i \sum_n \left( \frac{S_{in}}{\sigma} - n_{in} f_{in} \right) = \sum_n \mu_k Y_n / \sigma - \sum_i \sum_n n_{in} f_{in}.
\]

Note that \( \sum_i S_{in} \) is simply \( \mu_k Y_n \). Dividend per share is then:

\[
\pi = \frac{\Pi}{\sum_i w_i L_i} = \frac{(1/\sigma) \sum_n \mu_k Y_n - \sum_i \sum_n n_{in} f_{in}}{\sum_i w_i L_i} = \frac{(\mu_k / \sigma)(1 + \pi) \sum_n w_n L_n - \sum_i \sum_n n_{in} f_{in}}{\sum_i w_i L_i}.
\]

Solving for \( \pi \) yields

\[
\pi = \frac{\mu_k / \sigma - \sum_i \sum_n n_{in} f_{in}}{\sum_i w_i L_i}.
\]

Note that since \( n_{in} = w_i L_i \int_{\tilde{z}_{in}} dF_1(z) = w_i L_i \tilde{z}_{in} \), \( \pi \) is only a function of the endogenous variables \( \tilde{z}_{in} \). That is why we expressed \( \pi = g(\tilde{z}_{11}, \ldots, \tilde{z}_{1N}, \tilde{z}_{21}, \ldots, \tilde{z}_{NN}) \) in the section above.

**A.3 Welfare Effects of Changes in \( \tau \) and \( t \)**

Here we derive the expressions for \( G_B / G_A \) and \( \tau(t) \) stated in the main text. Define \( A \) as the equilibrium with a \( t \) barrier on imports from \( m \) to \( n \) and \( B \) as the equilibrium with a welfare-neutral \( \tau \) barrier on imports from \( m \) to \( n \). All other trade flows are assumed to be frictionless. The price indices in (A) and (B) are:

\[
P_{An}^{1-\sigma} = \left( \frac{\sigma}{\sigma - 1} \right)^{1-\sigma} \left[ \sum_{i \neq m} w_i L_i \int_{\tilde{z}_{Ami}}^{\infty} \frac{1}{w_i / z} \int_{\tilde{z}_{Ami}}^{\infty} w_m(1/z + t)^{1-\sigma} dF(z) \right],
\]

and

\[
P_{Bn}^{1-\sigma} = \left( \frac{\sigma}{\sigma - 1} \right)^{1-\sigma} \left[ \sum_{i \neq m} w_i L_i \int_{\tilde{z}_{Bmi}}^{\infty} \frac{1}{w_i / z} \int_{\tilde{z}_{Bmi}}^{\infty} w_m(1/z + t)^{1-\sigma} dF(z) \right],
\]

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where $\bar{z}_{A_{m}}$ and $\bar{z}_{B_{m}}$ are the entry hurdles in the two cases. Let $P_{A_{n}} = P_{B_{n}}$. Then

$$\left( \frac{\sigma}{\sigma - 1} \right)^{1-\sigma} \int_{\bar{z}_{A_{m}}}^{\infty} [w_{m} (1/z + t)]^{1-\sigma} dF (z) = \left( \frac{\tau \sigma}{\sigma - 1} \right)^{1-\sigma} \int_{\bar{z}_{B_{m}}}^{\infty} (w_{m}/z)^{1-\sigma} dF (z).$$

Here we used the fact that $\bar{z}_{A_{m}} = \bar{z}_{B_{m}}$, $\forall i \neq m$, since these cutoffs are determined by the same price level. Rearranging, the welfare-neutral iceberg barrier $\bar{\tau}$ is

$$\bar{\tau}^{1-\sigma} = \frac{\int_{\bar{z}_{A_{m}}}^{\infty} (1/z + t)^{1-\sigma} dF (z)}{\int_{\bar{z}_{B_{m}}}^{\infty} z^{\sigma-1} dF (z)}. \quad (8)$$

Let us calculate government revenue in the two cases,

$$G_{A} = w_{m} L_{m} \int_{\bar{z}_{A_{m}}}^{\infty} x_{A}(z) t w_{m} dF (z)$$

$$= \left( \frac{\sigma}{\sigma - 1} \right)^{-\sigma} w_{m}^{2-\sigma} L_{m} t \mu_{n} \int_{\bar{z}_{A_{m}}}^{\infty} (1/z + t)^{-\sigma} dF (z)$$

and

$$G_{B} = w_{m} L_{m} \int_{\bar{z}_{B_{m}}}^{\infty} x_{B}(z) (\bar{\tau} - 1) p^{s} (z) dF (z)$$

$$= \left( \frac{\sigma}{\sigma - 1} \right)^{1-\sigma} w_{m}^{2-\sigma} L_{m} (\bar{\tau} - 1) \frac{\tau^{-\sigma}}{\tau} \mu_{n} \int_{\bar{z}_{B_{m}}}^{\infty} (1/z + t)^{-\sigma} dF (z),$$

where $p^{s} (z)$ denotes the frictionless price$^{79}\text{ and using } x_{s} = p_{s}^{\sigma-1} \mu Y, s = A, B$. Note that the demand shifter is the same in both equilibria because the price index is identical. Relative tariff revenue is then

$$G_{B} \quad G_{A} = \frac{\sigma}{\sigma - 1} \frac{\bar{\tau} - 1}{\bar{\tau}} \int_{\bar{z}_{B_{m}}}^{\infty} z^{\sigma-1} dF (z) \quad \int_{\bar{z}_{A_{m}}}^{\infty} (1/z + t)^{-\sigma} dF (z).$$

We can proceed further by using the expression for productivity cutoffs and the Pareto assumption. The relationship between the cutoffs is

$$\bar{z}_{B_{m}} = \frac{\tau}{\bar{z}_{A_{m}} + t} \quad \text{or} \quad \frac{\bar{z}_{B_{m}}}{\bar{z}_{A_{m}}} = \frac{\tau}{1 + \bar{z}_{A_{m}} t} \quad \text{or} \quad \frac{\bar{z}_{B_{m}}}{\bar{z}_{A_{m}}} = \frac{\tau}{1 + \bar{z}_{A_{m}} t} \quad (9)$$

Since the support of the Pareto is $[1, +\infty]$, the cutoff is well defined when $\bar{\tau} / (\bar{z}_{A_{m}} + t) > 1$. Inserting $dF (z) = \gamma z^{-\gamma-1} dz$ and using the substitution, $z_{A} = z/\bar{z}_{A_{m}}$ and $z_{B} = z/\bar{z}_{B_{m}}$, we can re-express equation (8) as

$$\bar{\tau}^{1-\sigma} = \left( \frac{\bar{z}_{A_{m}}}{\bar{z}_{B_{m}}} \right)^{\sigma-\gamma-1} \int_{1}^{\infty} (1/z_{A} + \bar{z}_{A_{m}} t)^{1-\sigma} dF (z_{A}) \int_{1}^{\infty} z_{B}^{\sigma-1} dF (z_{B}) \quad \text{or} \quad \frac{\bar{z}_{B_{m}}}{\bar{z}_{A_{m}}}$$

$^{79}$I.e. the government resells the iceberg on the global market and receives the frictionless price $p (z) per unit.
Eliminating $\tilde{z}_{Bmn}$ using (9) then yields

$$\hat{\tau}^\gamma = (1 + \tilde{z}_{Amn}t)^{\gamma - \sigma + 1} \frac{\int_1^\infty \tilde{z}_B^{\gamma - 1} dF(\tilde{z}_B)}{\int_1^\infty (1/\tilde{z}_A + \tilde{z}_{Amn}t)^{1-\sigma} dF(\tilde{z}_A)}.$$ 

This is the expression for welfare-neutral iceberg costs used in the main text.

Finally, we can re-express the revenue ratio in the same fashion,

$$\frac{G_B}{G_A} = \sigma \frac{\hat{\tau} - 1}{\sigma - 1} \tilde{z}_{Amn} t (1 + \tilde{z}_{Amn}t)^{\sigma - \gamma - 1} \frac{\int_1^\infty \tilde{z}^{\sigma - 1} dF(\tilde{z})}{\int_1^\infty (1/\tilde{z} + \tilde{z}_{Amn}t)^{-\sigma} dF(\tilde{z})}.$$ 

This is the expression for relative revenue used in the main text.

### A.4 Extension: Quality heterogeneity

In this section, we extend our model to account for quality heterogeneity across firms. We show that the welfare result from Subsection 2.6 still applies. We also discuss the conditions under which the exports volume distribution retains the properties derived in Subsection 2.7.1. In order to deal with quality heterogeneity, we consider an extended CES utility function of the following type,

$$U = \left( \int_{\omega \in \Omega} [x(\omega) q(\omega)]^{(\sigma - 1)/\sigma} d\omega \right)^{\sigma/(\sigma - 1)},$$

where $q(\omega)$ is the quality of variety $\omega$ and $\Omega$ is the set of available varieties. Quantity demanded is given by

$$x_{in}(\omega) = q_{in}(\omega)^{\sigma - 1} p_{in}(\omega)^{-\sigma} P_n^{\sigma - 1} \mu Y_n,$$

and the CES price index is

$$P_n^{1-\sigma} = \sum_{i} \int_{\omega \in \Omega_{in}} [p_{in}(\omega)/q_{in}(\omega)]^{1-\sigma} d\omega.$$

### A.4.1 Quality and Welfare

With this framework, it is relatively straightforward to replicate the analysis shown in Subsection A.2. Define $p(\omega)$ as the frictionless price for firm $\omega$. The price indices in cases (A) and (B) are:

$$P_{An}^{1-\sigma} = \sum_{i \neq m} w_i L_i \int_{\Omega_{An}} \left( \frac{p(\omega)}{q(\omega)} \right)^{1-\sigma} d\omega + w_m L_m \int_{\Omega_{Amn}} \left( \frac{p(\omega) + t}{q(\omega)} \right)^{1-\sigma} d\omega,$$

and

$$P_{Bn}^{1-\sigma} = \sum_{i \neq m} w_i L_i \int_{\Omega_{Bn}} \left( \frac{p(\omega)}{q(\omega)} \right)^{1-\sigma} d\omega + w_m L_m \tau^{1-\sigma} \int_{\Omega_{Bmn}} \left( \frac{p(\omega)}{q(\omega)} \right)^{1-\sigma} d\omega,$$
where \( \tilde{t} = \frac{tw_m}{(\sigma - 1)} \) and \( \Omega_{Ain} \) and \( \Omega_{Bin} \) are the sets of firms selling from \( i \) to \( n \) in the \( (A) \) and the \( (B) \) equilibrium.\(^{80}\) Let \( P_{An} = P_{Bn} \). Then the welfare-neutral iceberg barrier \( \tilde{\tau} \) is\(^{81}\)

\[
\tilde{\tau}^{1-\sigma} = \frac{\int_{\Omega_{Amn}} \left( \frac{p(\omega)}{q(\omega)} \right)^{1-\sigma} d\omega}{\int_{\Omega_{Bmn}} \left( \frac{p(\omega)}{q(\omega)} \right)^{1-\sigma} d\omega} \quad (10)
\]

Let us calculate government revenue in the two cases,

\[
G_A = w_m L_m \int_{\Omega_{Amn}} x_A(\omega) t w_m d\omega
\]

\[
= w_m L_m \int_{\Omega_{Amn}} q(\omega)^{\sigma-1} \left[ p(\omega) + \tilde{t} \right]^{-\sigma} Dt w_m d\omega
\]

and

\[
G_B = w_m L_m \int_{\Omega_{Bmn}} x_B(\omega) (\tilde{\tau} - 1) p(\omega) d\omega
\]

\[
= w_m L_m \int_{\Omega_{Bmn}} q(\omega)^{\sigma-1} (\tilde{\tau} - 1) p(\omega)^{1-\sigma} D d\omega
\]

where \( D = \mu P_n^{-\gamma} Y_n \) and \( x_n \) denotes quantity under \( n = A, B \).\(^{82}\) Note that the demand shifter \( D \) is the same in both equilibria because the price index is identical. Relative tariff revenue is then

\[
\frac{G_B}{G_A} = \frac{\sigma}{\sigma - 1} \frac{\tilde{\tau} - 1}{\tilde{t}} \frac{1}{\int_{\Omega_{Amn}} q(\omega)^{\sigma-1} \left[ p(\omega) + \tilde{t} \right]^{-\sigma} d\omega}.
\]

It remains to determine the sets of firms \( \Omega_{Amn} \) and \( \Omega_{Bmn} \) that choose to enter in the two cases. From here on, we make the simplifying assumption that \( \Omega_{Amn} = \Omega_{Bmn} \), i.e. that the set of firms from \( m \) entering market \( n \) is identical in the two cases. First, this enables us to evaluate the \( G_B/G_A \) ratio without imposing any particular assumptions about the relationship between efficiency and quality. Second, we have already solved the \( G_B/G_A \) ratio allowing for extensive margin effects in the case with no quality heterogeneity. We therefore consider this an acceptable trade-off.

### A.5 Dispersion and Trade Costs (Proposition 2)

In this subsection we prove Proposition 2. The first part of the subsection is about the relationship between dispersion in the exports volume distribution and per-unit costs. The second part is about the relationship between dispersion in the exports volume distribution and iceberg costs.

**Proof that** \( D_{\theta_2, \theta_1} \) **is decreasing in** \( t_h^k \), **when** \( t_h^k > 0 \). Recall from (6) that the percentile ratio is

\[
D_{\theta_2, \theta_1} = \frac{(1 - \theta_1)^{1/\gamma} + B_n^k \gamma}{(1 - \theta_2)^{1/\gamma} + B_n^k}.
\]

\(^{80}\)Recall that \( t \) is defined as the unit labor requirement of a trade friction, so \( \tilde{t} \) is the price of the friction, including the markup \( \sigma/((\sigma - 1)) \).

\(^{81}\)As in the baseline case, here we used the fact that \( \Omega_{Ain} = \Omega_{Bin}, \forall i \neq m \), since these sets are determined by the same price level.

\(^{82}\)In the expression for \( G_B \), we used substituted the labor requirement \( 1/\gamma \) with \( \frac{p(\omega)}{w_\sigma} \).
where $B_n^k = \frac{z_{n,k}^k}{\tau_{n,k}}$. Consider the impact on $D_{\vartheta_2, \vartheta_1}$ of a small change in $t_{n,k}^k$.

$$\hat{D}_{\vartheta_2, \vartheta_1} = \sigma D_{\vartheta_2, \vartheta_1}^{-1/\gamma} (1 - \vartheta_2)^{1/\gamma} - (1 - \vartheta_1)^{1/\gamma} \left[ (1 - \vartheta_2)^{1/\gamma} + B_n^k \right]^{1/\gamma} \hat{B}_n^k.$$ 

Note that the fraction is negative since $0 < \vartheta_1 < \vartheta_2 < 1$. It remains to evaluate the sign of $\hat{B}_n^k$.

The percentage change in the cutoff is

$$\frac{z^k_n}{\tau_{n,k}} = \frac{t_{n,k}^k}{\tau_{n,k}} \hat{B}_n^k - \hat{P}_n^k \left( 1 + \frac{t_{n,k}^k}{\tau_{n,k}} \right).$$

Inserting the previous expression back into $\hat{B}_n^k$ yields

$$\hat{B}_n^k = \left( 1 + \frac{t_{n,k}^k}{\tau_{n,k}} \right) \left( \hat{P}_n^k - \hat{B}_n^k \right).$$

Since $\hat{t}_{n,k}^k > \hat{P}_n^k$ (see proof below), $\hat{B}_n^k > 0$ and $\hat{D}_{\vartheta_2, \vartheta_1} < 0$. Therefore, dispersion, measured by the $D_{\vartheta_2, \vartheta_1}$ percentile ratio, is declining in per-unit trade costs. 

**Proof that $\hat{t}_{n,k}^k > \hat{P}_n^k$.** The price index in country $n$ is defined as

$$P_n^k = \frac{\sigma}{1 - \sigma} \left[ \sum_i w_i L_i w_i^{-\sigma} \int_{z_i}^{\tau_{n,k}} \left( \frac{\tau_{n,k}}{z_i} + t_{n,k}^k \right)^{1-\sigma} dF_1 (z) \right]^{1/(1-\sigma)},$$

where $F_1 (z)$ is the Pareto CDF with support $z \in [1, +\infty)$ and $f_1 (z)$ is the corresponding PDF. Consider a percentage change in the price index due to a marginal change in $t_{n,k}^k$,

$$\hat{P}_n^k = \frac{1}{1 - \sigma} \sum_i w_i L_i w_i^{-\sigma} \int_{z_i}^{\tau_{n,k}} \left( \frac{\tau_{n,k}}{z_i} + t_{n,k}^k \right)^{1-\sigma} dF_1 (z)$$

$$= \sum_i w_i L_i w_i^{-\sigma} \int_{z_i}^{\tau_{n,k}} \left( \frac{\tau_{n,k}}{z_i} + t_{n,k}^k \right)^{1-\sigma} dF_1 (z) \left[ \frac{\hat{t}_{n,k}^k}{(1 - \sigma)} \right]$$

$$= \sum_i \lambda_{n,i}^k \frac{\hat{t}_{n,k}^k}{(1 - \sigma)},$$

where

$$t_{n,k}^k = \int_{z_i}^{\tau_{n,k}} \left( \frac{\tau_{n,k}}{z_i} + t_{n,k}^k \right)^{1-\sigma} dF_1 (z),$$

and $\lambda_{n,i}^k$ is the share of country $n$’s total expenditure that is devoted to goods from country $i$ (the import share),

$$\lambda_{n,i}^k = \frac{w_i L_i w_i^{-\sigma} \int_{z_i}^{\tau_{n,k}} \left( \frac{\tau_{n,k}}{z_i} + t_{n,k}^k \right)^{1-\sigma} dF_1 (z)}{\sum_j w_j L_j w_j^{-\sigma} \int_{z_j}^{\tau_{n,k}} \left( \frac{\tau_{n,k}}{z_j} + t_{n,k}^k \right)^{1-\sigma} dF_1 (z)}.$$
Applying Leibnitz’s Rule, the percentage change in \( I_{in}^k \) is
\[
\hat{I}_{in}^k = (1 - \sigma) \frac{\partial}{\partial t} \chi_{in}^{k} - \frac{z_{in}^{k}}{t_{in}^{k}} \frac{\partial}{\partial t} z_{in}^{k},
\]
where
\[
\chi_{in}^{k} = \frac{\int z_{in}^{k}}{\int z_{in}^{k}} \frac{t_{in}^{k}}{z_{in}^{k} + t_{in}^{k}} - \frac{\partial}{\partial t} \chi_{in}^{k},
\]
and
\[
\hat{\chi}_{in}^{k} = \frac{\int z_{in}^{k}}{\int z_{in}^{k}} \frac{t_{in}^{k}}{z_{in}^{k} + t_{in}^{k}} - \frac{\partial}{\partial t} \hat{\chi}_{in}^{k}. \]
Note that \( \chi_{in}^{k} \) is always less than one.

Consider a change in per-unit costs (\( dt_{in}^{k} \)) from a particular country (ex. Norway) to country \( n \). Denote with \( \lambda_{n}^{k}, t_{n}^{k}, \chi_{n}^{k}, \bar{z}_{n}^{k} \) the values of the corresponding variables when associated with the source country under consideration. Disregard any possible second-order effects so that \( d\bar{z}_{in}^{k} = 0 \) whenever the source country is not Norway. Then
\[
\hat{p}_{n}^{k} = \lambda_{n}^{k} \frac{\hat{I}_{n}^{k}}{1 - \sigma} = \lambda_{n}^{k} \left( \chi_{n}^{k} + \frac{\bar{z}_{n}^{k}}{\sigma - 1} \right).
\]
The first term in the expression above captures the intensive margin effect on the price index, while the second term captures the extensive margin effect. Using (11) and solving for \( \hat{p}_{n}^{k} \) yields
\[
\hat{p}_{n}^{k} = \frac{\lambda_{n}^{k} \frac{\hat{I}_{n}^{k}}{1 - \sigma} + \chi_{n}^{k} \frac{\bar{z}_{n}^{k}}{\sigma - 1} \hat{z}_{n}^{k}}{1 + \lambda_{n}^{k} \frac{\bar{z}_{n}^{k}}{\sigma - 1} \hat{z}_{n}^{k} + \hat{z}_{n}^{k} \left( 1 + \frac{\bar{z}_{n}^{k} \hat{I}_{n}^{k}}{\sigma - 1} \right)}.
\]
Since \( \lambda_{n}^{k}, \lambda_{n}^{k} < 1 \), the fraction is less than one and therefore \( \hat{p}_{n}^{k} < \hat{i}_{n}^{k} \).

**Proof that \( D_{\phi_{2},\phi_{1}} \) is increasing in \( \tau_{n}^{k} \), when \( t_{n}^{k} > 0 \).** Consider the impact on \( D_{\phi_{2},\phi_{1}} \) of a small change in \( \tau_{n}^{k} \). The expression for \( \hat{D}_{\phi_{2},\phi_{1}} \) remains the same as above, but \( \hat{B}_{n}^{k} \) now becomes
\[
\hat{B}_{n}^{k} = \frac{z_{n}^{k}}{\tau_{n}^{k}} - \frac{\tau_{n}^{k} - 1}{\tau_{n}^{k}} \frac{z_{n}^{k}}{\tau_{n}^{k}},
\]
and the percentage change in cutoff becomes
\[
\frac{\hat{z}_{n}^{k}}{\tau_{n}^{k}} = \frac{\tau_{n}^{k} - 1}{\tau_{n}^{k}} \frac{z_{n}^{k}}{\tau_{n}^{k}} - \frac{\tau_{n}^{k} - 1}{\tau_{n}^{k}} \frac{\hat{z}_{n}^{k}}{\tau_{n}^{k}} \left( 1 + \frac{\tau_{n}^{k} \hat{I}_{n}^{k}}{\tau_{n}^{k}} \right).
\]
Inserting this back into \( \hat{B}_{n}^{k} \) yields
\[
\hat{B}_{n}^{k} = -\hat{p}_{n}^{k} \left( 1 + \frac{\tau_{n}^{k} \hat{I}_{n}^{k}}{\tau_{n}^{k}} \right),
\]
Note that \( \hat{B}_{n}^{k} < 0 \) since \( \hat{p}_{n}^{k} > 0 \). Therefore \( \hat{D}_{\phi_{2},\phi_{1}} > 0 \) and dispersion rises with iceberg costs.

**Proof that \( D_{\phi_{2},\phi_{1}} \) is independent of \( \tau_{n}^{k} \), when \( t_{n}^{k} = 0 \).** Consider the impact on \( D_{\phi_{2},\phi_{1}} \) of a small change in \( \tau_{n}^{k} \) when \( t_{n}^{k} = 0 \). The percentile ratio then collapses to
\[
D_{\phi_{2},\phi_{1}} = \left( \frac{1 - \phi_{1}}{1 - \phi_{2}} \right)^{\gamma},
\]
clearly showing that dispersion is independent of variable trade costs in the Chaney (2008) model.
A.5.1 Quality and the Export Distribution

In this subsection, we explore how the exports volume distribution responds to an increase in per-unit trade costs in the presence of quality heterogeneity. In particular, we analyze the conditions under which the distribution becomes less dispersed as per-unit trade costs increase. This is equivalent to determining the circumstances under which firms charging low prices also sell higher quantities. The optimal quantity sold is $x_{in} = P_n^{-\sigma} \mu Y_n q^{\sigma-1} p_{in}^{-\sigma}$. Using the expression for quality, we get $x_{in} = P_n^{-\sigma} \mu Y_n z^{-\eta(\sigma-1)} p_{in}^{-\sigma}$, or equivalently,

$$x_{in} = P_n^{-\sigma} \mu Y_n \left( \frac{\sigma}{\sigma - 1} w_1 t_{in} \right)^{-\eta(\sigma-1)} \frac{p_{in}^{-\sigma + \eta(\sigma-1)}}{p_{in}} ,$$

using the fact that $p_{in}(z) = \frac{\sigma}{\sigma - 1} w_1 t_{in} \iff z = \frac{\sigma}{\sigma - 1} w_1 t_{in} p_{in}(z)^{-1}$ under $t_{in} = 0$. As a consequence, low price firms sell more when $\eta < \sigma / (\sigma - 1)$.

Higher per-unit costs will now reduce dispersion since the low price firms (in the top of the distribution) will be hit harder by per-unit costs than the high price firms (in the bottom of the distribution). The fundamental identifying assumption in the econometric model is therefore consistent with quality heterogeneity, as long as the (positive) relationship between unit costs and quality is not too convex. In our particular data set, we know that for an overwhelming majority of product-destination pairs, the correlation between quantity and price is negative. This suggests that $\eta$ is less than $\sigma / (\sigma - 1)$ (but not necessarily zero). As a comparison, Johnson (2009) finds that $\eta > 1$ in most of the SITC 4-Digit sectors in his data. Since $\sigma / (\sigma - 1) > 1$, our results are fully compatible with his.

A.6 Extension: Departures from CES

In this subsection we consider two departures from standard CES preferences: marketing costs à la Arkolakis (2008) and linear demand with horizontal product differentiation à la Ottaviano, Tabuchi, and Thisse (2002).

A.6.1 Marketing Costs

We consider an extension of our model that includes marketing costs à la Arkolakis (2008). The problem of the firm is now the following:

$$\max_{h_{in}(z), p_{in}(z)} x_{in}(z) \left[ p_{in}(z) - w_i \left( \frac{\tau_{in}}{z} + t_{in} \right) \right] - w_n^{\sigma} w_i^{1-\sigma} \frac{L_n^\alpha}{\psi^{1-\beta}} \left[ 1 - h_{in}(z) \right]^{1-\beta} ,$$

s.t. $h_{in}(z) \in [0,1].$

where demand is

$$x_{in}(z) = \left[ \frac{p_{in}(z)}{P_n} \right]^{-\sigma} y_n h_{in}(z) L_n ,$$

$y_n$ is per-capita spending in country $n$, $L_n$ is population of country $n$, and $h_{in}(z)$ is the fraction of country $n$ consumers reached by the firm. The remaining parameters and the functional form adopted to describe marketing costs are discussed extensively in Arkolakis (2008). The optimal price charged by an exporter to country $n$ is the same as in our framework and equal to (1). The elasticity of the total volume of goods exported to country $n$ to trade costs ($\varepsilon_{t_{in}}$ and $\varepsilon_{\tau_{in}-1}$) is equal to the sum of (i) the elasticity of the per-consumer volume to trade costs and (ii) the elasticity of the fraction of consumers reached to trade costs ($\varepsilon_{h_{in}(z),t_{in}}$ and $\varepsilon_{h_{in}(z),\tau_{in}-1}$). The elasticity of the

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85: This condition is necessary and sufficient when $t_{in} = 0$ but only necessary when $t_{in} > 0$.  
86: Returning to a previous example, this would be the case if, for example, IKEA were selling fewer beds than Crate and Barrel.
per-consumer volume to trade costs in this modified model is equal to the elasticity of total volume to trade costs in our baseline model. Overall,

\[
\varepsilon_{t_{in}} = -\sigma \left( \frac{t_{in}}{2t_{in} + 1} \right)^{-1} + \varepsilon_{h_{in}(z),t_{in}},
\]

\[
\varepsilon_{\tau_{in}-1} = -\sigma \left( \frac{t_{in} - 1}{\tau_{in} + 1} \right)^{-1} + \varepsilon_{h_{in}(z),\tau_{in}-1}.
\]

We can now draw two conclusions. The first conclusion is that in a standard Arkolakis (2008) model (that is when \(t_{in} = 0\)) the dispersion of the export volume distribution is increasing in ad valorem trade costs. To see this note that: (i) the elasticity of per-consumer volume to ad-valorem trade costs reduces to \(\varepsilon_{h_{in}(z)}\) and therefore does not depend on the productivity of the firm; (ii) the elasticity of the fraction of consumers reached to ad-valorem trade costs is negative and its absolute value is lower for more productive firms.\(^{87}\) Therefore, a higher \(\tau\) reduces the volume sold per consumer for all firms in the same proportion, but the fraction of consumers reached (the customer base) decreases less the higher is the productivity of the firm. The overall volume sold by more productive firms increases relative to that sold by less productive firms.

The second conclusion regards the effects of per-unit trade costs. It turns out that

\[
\frac{\partial \varepsilon_{h_{in}(z),t_{in}}}{\partial z} > 0 \quad \text{iff} \quad h_{in}(z) < \frac{\sigma - 1}{\beta} \equiv \tilde{h},
\]

so that, within the set of firms that reach a fraction of consumers lower than \(\tilde{h}\), the most efficient ones (those with a higher initial customer base) adjust proportionally less the “new consumer margin” than the less efficient firms. Therefore, in this extended model, while more efficient firms are still the ones that decrease the most the volume of goods sold to each customer, they are also the ones that reduce less, in percentage terms, their customer base in the event of a rise in per-unit trade costs. The overall effect on the total volume of exports depends on how strong the “marketing effect” is compared to the “per-unit trade costs” effect.

A.6.2 Endogenous Markups

The CES assumption in the main text ensures that markups (over production plus transportation costs) are constant. A model with non-CES preferences will typically generate endogenous markups, which may have an effect on the dispersion of exports. In this section we explore this case, and discuss whether departures from CES alone (with no per-unit costs) can generate the observed correlation between dispersion in exports and trade costs. Specifically, we examine the model of Melitz and Ottaviano (2008), who incorporate endogenous markups using the linear demand system with horizontal product differentiation developed by Ottaviano, Tabuchi, and Thisse (2002). The assumed linear demand system implies that higher prices are associated with higher demand elasticities and therefore lower markups. Specifically, the price charged by an exporter with cost \(c\) from country \(h\) selling in market \(n\) is\(^{88}\)

\[
p_{lh}(c) = \frac{1}{2} (c_{D} + \tau_{h}c)
\]

where \(c_{D}\) is the domestic cost cutoff (see Appendix A.3 in Melitz and Ottaviano, 2008). Absolute markups are \(p_{lh}(c) - \tau c = \frac{1}{2} (c_{D} - \tau_{h}c)\), so that more efficient firms, facing lower demand elasticities, are charging higher markups. An increase in trade costs \(\tau_{h}\) will in this case lead to more dispersion in prices. To see this, let \(c_{1} < c_{2}\), so that \(p_{lh}(c_{1}) < p_{lh}(c_{2})\). Then \(E_{\tau_{inh}}p_{lh} = c\tau / (c_{D} + \tau_{h}c)\), so

\(^{87}\)Proof available upon request.

\(^{88}\)In this subsection we use, for simplicity, Melitz and Ottaviano (2008) notation.
that prices will increase more, in percentage terms, among the low-efficiency (high cost) firms when \( \tau^{th} \) increases. As a consequence, \( p^{th}(c_2)/p^{th}(c_1) \) rises. The intuition behind this result is that, as \( \tau \) goes up, markups are reduced the most among high efficiency firms, since they are already charging high markups and face lower demand elasticities.

Naturally, when price dispersion increases, export (volume) dispersion increases as well. Using the expression for optimal exports in Melitz and Ottaviano (2008) we find that relative exports are

\[
\frac{q^{th}(c_1)}{q^{th}(c_2)} = \frac{c^{D}_{h} - \tau^{th}c_1}{c^{D}_{h} - \tau^{th}c_2}
\]

If \( c_1 < c_2 \), then this ratio increases, i.e. the more efficient firm increases its market share as trade costs rise.

All in all, this shows that introducing a standard model of endogenous markups (with only iceberg costs) will not generate the observed correlation between dispersion in exports and trade costs. However, the structural point estimate of trade costs would surely be affected, introducing endogenous markups. Specifically, since dispersion is increasing with trade costs in Melitz-Ottaviano, an extension of their model with per-unit costs would require higher per-unit costs (compared to what we estimate) in order to match the dispersion in the data. Therefore, we can interpret our estimate as a lower bound of trade costs if endogenous markups are believed to be important.

### A.7 The prevalence of non-ad valorem duties (NAVs)

A significant share of duties are non-ad valorem (NAVs). According to the WTO World Tariff Profiles (2006), “NAVs are applied by 68 out of the 151 countries shown in this publication including several LDCs...” Table 4 reports, for a set of countries, the share of Harmonized System six-digit subheadings (both for agricultural and non-agricultural products) subject to non-ad valorem duties. The share of products subject to NAVs is usually higher in the case of agricultural products but is also important for non-agricultural products. For example, in the United States, the 3.4% of non-agricultural products that are subject to NAVs account for 18.9% of imports. Still according to the WTO World Tariff Profiles (2006) “One of the peculiarities of NAVs resides in the fact that even if they are applied to a limited number of tariff lines, the products concerned are often classified as sensitive, either because governments collect significant tariff revenues, e.g. cigarettes and alcoholic drinks, or for protecting domestic products against lower priced imports. These highlight the importance of analysing NAVs.”
Table 4: Non-ad Valorem Tariffs and Tariff Quotas

<table>
<thead>
<tr>
<th></th>
<th>NAV (in %)</th>
<th>Tariff quotas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MFN Applied</td>
<td>Imports</td>
</tr>
<tr>
<td>United States</td>
<td>AG 39.9</td>
<td>33.9</td>
</tr>
<tr>
<td></td>
<td>N AG 3.4</td>
<td>18.9</td>
</tr>
<tr>
<td>European Communities</td>
<td>AG 31.0</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td>N AG 0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>AG 25.6</td>
<td>58.6</td>
</tr>
<tr>
<td></td>
<td>N AG 10.1</td>
<td>6.1</td>
</tr>
<tr>
<td>China</td>
<td>AG 0.3</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>N AG 0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Switzerland</td>
<td>AG 73.0</td>
<td>80.3</td>
</tr>
<tr>
<td></td>
<td>N AG 81.3</td>
<td>62.7</td>
</tr>
<tr>
<td>Japan</td>
<td>AG 13.8</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>N AG 2.1</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Note: NAV (in %) corresponds to the share of HS six-digit subheadings subject to non-ad valorem duties under the non-discrimination principle of most-favored nation (MFN). When only part of the HS six-digit subheading is subject to non-ad valorem duties, the percentage share of these tariff lines is used. Tariff quotas (in %) corresponds to the percentage of HS six-digit subheadings in the schedule of agricultural concession covered by tariff quotas. Partial coverage is taken into account on a pro rata basis. Only duties and imports recorded under HS Chapters 01-97 are taken into account. AG stands for "agricultural" while N AG for "non-agricultural" products. Source: WTO World Tariff Profiles 2006.