# ZEROS, QUALITY AND SPACE:
# TRADE THEORY AND TRADE EVIDENCE

Richard Baldwin
Graduate Institute, Geneva, CEPR, and NBER

James Harrigan
University of Virginia and NBER

March 2009

**Abstract**

Product-level data on bilateral U.S. exports exhibit two strong patterns. First, most potential export flows are not present, and the incidence of these “export zeros” is strongly correlated with distance and importing country size. Second, export unit values are positively related to distance. We show that the leading multi-good general equilibrium trade models are inconsistent with at least some of these facts. We also offer direct statistical evidence of the importance of trade costs in explaining zeros, using the long-term decline in the relative cost of air shipment to identify a difference-in-differences estimator. To match these facts, we propose a new version of the heterogeneous-firms trade model pioneered by Melitz (2003). In our model, high quality firms are the most competitive, with heterogeneous quality increasing with firms’ heterogeneous cost.

Baldwin: Graduate Institute, Geneva, 11a Ave de la Paix, Geneva, Switzerland, rbaldwin@cepr.org. Harrigan: Department of Economics, University of Virginia, P.O. Box 400182, Charlottesville, VA 22904, james.harrigan@virginia.edu. We thank seminar audiences at Columbia, Dartmouth, Georgetown, Penn State, Virginia, Wisconsin, Pompeu Fabra, EIIT-Purdue, ERWIT, FRB-Philadelphia, LSE, and NBER.

# 1. INTRODUCTION

The gravity equation relates bilateral trade volumes to distance and country size. Countless gravity equations have been estimated, usually with “good” results, and trade theorists have proposed various theoretical explanations for gravity’s success. However, the many potential explanations for the success of the gravity equation make it a problematic tool for discriminating among trade models[1].

As a matter of arithmetic, the value of trade depends on the number of goods traded, the amount of each good that is shipped, and the prices they are sold for. Most studies of trade volumes have not distinguished among these three factors. In this paper we show that focusing on how the number of traded goods and their prices differ as a function of trade costs and market size turns out to be very informative about the ability of trade theory to match trade data.

We establish some new facts about product-level U.S. trade. First, most potential export flows are not present, and the incidence of these “export zeros” is strongly correlated with distance and importing country size. Second, export unit values are positively related to distance and negatively related to market size.  We show that every well-known multi-good general equilibrium trade model is inconsistent with at least some of these facts. We also offer direct statistical evidence of the importance of trade costs in explaining export zeros, using the long-term decline in the cost of air shipment to identify a difference-in-differences estimator.

We conclude the paper with a new version of the heterogeneous-firms trade model pioneered by Melitz (2003). Our model maintains the core structure of Melitz, namely heterogeneity in firms’ productivity with fixed market entry costs. In our model, however, firms’ competitiveness depends upon their quality-adjusted price so higher quality goods are more costly, more profitable and better able to penetrate distant markets. Our model’s predictions are borne out by the facts established in our data analysis.

### *Plan of paper*

In section 2 we generate testable predictions concerning the spatial pattern of trade flows and prices. The predictions come from three multi-good general equilibrium models that are representative of a wide swath of mainstream trade theory – one based purely on comparative advantage (Eaton and

[1] An important exception to this principle is Feenstra, Markusen, and Rose (2001), who show and test how different trade models imply different variations on the gravity model. Our paper is similar in approach, though different in focus.

Kortum 2002), one based purely on monopolistic competition (a multi-country Helpman-Krugman (1985) model with trade costs), and one based on monopolistic competition with heterogeneous firms and fixed market-entry costs (a multi-country version of the Melitz (2003) model). These models predict very different spatial patterns of zeros, i.e. the impact of country size and bilateral distance on the likelihood of two nations trading a particular product. They also generate divergent predictions on how observed trade prices should vary with bilateral distance and country size.

Section 3 confronts these theoretical predictions with highly disaggregated U.S. data on bilateral trade flows and unit values. On the quantity side, we focus on the pattern of zeros in product-level, bilateral trade data since this data contains information that is both rich and relatively unexploited[2]. Another advantage of focusing on zeros (the extensive margin) rather than volumes of positive flows (the intensive margin), is that it allows us to avoid issues such as the indeterminacy of trade flows at the product level in comparative advantage theory and the lack of data on firms' cost functions. On the price side, we focus on bilateral, product-specific f.o.b. unit values. When it comes to empirically confronting the theoretical implications of changes in trade costs, we exploit the fact that air shipping costs have fallen much faster than the surface shipping costs in recent decades. This opens the door to a difference-in-difference strategy since our data includes product-level information on air-versus-surface shipping modes.

All three mainstream models fail to explain the broad outlines of the data along at least one dimension. The best performance is turned in by the heterogeneous-firms trade (HFT) model based on Melitz (2003). However, this model fails to account for the spatial pattern of trade prices, in particular the fact that average unit values clearly increase with distance while the HFT model predicts that they should decrease with distance. Section 4 therefore presents a new general equilibrium model in which firms compete on the basis of heterogeneous quality as well as unit costs, with high quality being associated with high prices. Since a nation's high-quality/high-price goods are the most competitive, they more easily overcome distance-related trade costs so the average price of goods in distant markets tends to be higher.

---

[2] We are not the first to exploit zeros. Haveman and Hummels (2004) is similar in sprit to our paper, although they focuses on import zeros. Feenstra and Rose (2000) and Besedes and Prusa (2006a, 2006b) have looked at time-series variation in product level zeros to test trade models.

## 2. ZEROS AND PRICES IN THEORY

This section derives testable hypotheses concerning the spatial pattern of zeros and trade prices in models that represent a broad swath of trade theory. In the three models selected, trade is driven by: 1) comparative advantage, 2) monopolistic competition, and 3) monopolistic competition with heterogeneous firms.

The models we study share some assumptions and notation. There are *C* countries and a continuum of goods. Preferences are given by the indirect CES function,

$$U = \frac{E}{P}, \quad P \equiv \left(\int_{i\in\Theta} p_i^{1-\sigma} di\right)^{\frac{1}{1-\sigma}}, \quad \sigma > 1. \tag{1}$$

where *E* is expenditure, $p_i$ is the price of variety *i*, and Θ is a set of available varieties. Transport costs are assumed to be of the iceberg form, with $\tau_{od} \geq 1$ representing the amount of a good which must be shipped from nation-*o* to nation-*d* for one unit to arrive (*o* stands for "origin", and *d* stands for "destination"). All the models assume just one factor of production, labor, which is in fixed supply and paid a wage *w*.

### 2.1. What is a product?

In the theory-models we discuss throughout the paper, the definition of a product is perfectly clear. From the standpoint of consumers, products enter the utility function (1) with an elasticity of substitution $\sigma$. Firms produce distinct products and then decide where to sell them.

In Sections 3 and 4 below, we work with annual data on the least aggregated trade data that is publicly available, the U.S. ten-digit level of the Harmonized System (HS 10). We will refer to the HS10 categories as "codes", recognizing that each HS10 code may contain products that are made by different firms and/or are regarded by consumers as imperfect substitutes. Some examples of HS10 codes exported by the United States in 2005 include

| | |
|---|---|
| 6110110020 | women's or girls' wool sweaters |
| 8703230075 | new motor vehicles, engine between 1500 - 3000cc, more than 6 cylinders |
| 8712002600 | bicycles with wheels greater than 63.25 cm diameter |
| 8803200010 | undercarriages & parts for use in civil aircraft |
| 9013200000 | lasers, other than laser diodes |

Plainly, there is ample scope for distinct products being sold in these and most other HS10 codes. Bernard, Jensen, and Schott (2009) report that more than a quarter million different firms exported from the United States in 2000 in just over 8,500 HS10 codes, or more than 30 firms per code on average[3]. As a consequence, we are careful in translating firm- and/or variety-level predictions into predictions for HS10 codes.

## 2.2. Comparative advantage: Eaton-Kortum

Economists have been thinking about the effects of trade costs on trade in homogeneous goods since Ricardo, but we had to wait for Eaton and Kortum (2002) to get a clear, rigorous, and flexible account of how distance affects bilateral trade in a competitive general equilibrium trade model. Appendix 1 presents and solves a slightly simplified Eaton-Kortum model (EK for short) explicitly. Here we provide intuition for the EK model's predictions on the spatial pattern of zeros and prices.

Countries in the EK model compete head-to-head in every market on the basis of c.i.f. prices, with the low-price supplier capturing the whole market[4]. This "winner takes all" form of competition means that the importing country buys each good from only one source. As usual in Ricardian models, the competitiveness of a country's goods in a particular market depends upon the exporting country's technology, wage and bilateral trade costs – all relative to those of its competitors. A key novelty of the EK model is the way it describes each nation's technology. The EK model does not explicitly specify each nation's vector of unit-labor input coefficients (the *a*'s in Ricardian notation). Rather it views the national vectors of *a*'s as the result of a stochastic technology-generation process – much like the one used later by Melitz (2003). Denoting the producing nation as nation-*o* ('*o*' for origin), and the unit labor coefficient for a typical good-*j* as $a_o(j)$, each $a_o(j)$ is an independent draw from the cumulative distribution function (cdf)[5]

$$F_o[a] = 1 - e^{-T_o a^{\theta}}, \quad a, T_0 \geq 0, \quad \theta > 1, \qquad o = 1, ..., N \qquad (2)$$

where $T_o > 0$ is the nation-specific parameter that reflects the nation's absolute advantage, and *N* is the number of nations.

---

[3]. The exact calculation is (265,644 exporting firms)/(8,572 HS10 codes) = 31.0 exporting firms per HS10 code. Data on number of exporting firms is from Bernard, Jensen, and Schott (2009), Table14.4

[4] c.i.f. and f.o.b. stand for "cost, insurance, and freight" and "free on board", respectively, i.e. the price with and without transport costs. Without domestic sales taxes, c.i.f. and f.o.b. correspond to the consumer and producer prices respectively.

[5] EK work with $z=1/a$, so their cdf is $\exp(-T/z^{\theta})$.

Equation (2) permits calculation of the probability that a particular nation has a comparative advantage in a particular market in a typical good. Since the $a_o(j)$'s for all nations are random variables, determining comparative advantage becomes a problem in applied statistics. Perfect competition implies that nation-*o* will offer good-*j* in destination nation-*d* at a price of $p_{od}(j) = \tau_{od} w_o a_o(j)$ where $w_o$ is nation-*o*'s wage. As the appendix shows, this implies that the distribution of prices in market-*d* in equilibrium is

$$G_d[p] = 1 - \exp\left[-\Delta_d p^{\theta}\right], \qquad \Delta_d \equiv \sum_{c=1}^{N} T_{cd}, \qquad T_{cd} \equiv \frac{T_c}{(w_c \tau_{cd})^{\theta}} \tag{3}$$

Given (3) and (2), the probability that origin nation-*o* has comparative advantage in destination nation-*d* for any product is[6]

$$\pi_{od} = \frac{T_{od}}{\Delta_d} \tag{4}$$

This probability (which is the probability of observing positive trade between nations *o* and *d* in a given good) is the key to characterizing the spatial pattern of zeros in the EK model It reflects the relative competitiveness of nation-*o*'s goods in market-*d*. Namely, $T_{od}$ is inversely related to *o*'s average unit-labor cost for goods delivered to market-*d*, so $\pi_{od}$ is something like the ratio of *o*'s average unit-labor cost to that of all its competitors in market-*d*.[7]

The EK model does not yield closed-form solutions for equilibrium wages, so a closed form solution for $\pi_{od}$ is unavailable. We can, however, link the $T_{od}$'s to observable variables by employing the market clearing conditions for all nations (see appendix for details). In particular, wages must adjust to the point where every nation can sell all its output and this implies

$$\pi_{od} = Y_o \left(\frac{P_d}{\tau_{od}}\right)^{\theta} \left(\frac{1}{Y_d P_d^{\theta} + \Sigma_{c \neq d} Y_c (P_c \ / \tau_{oc})^{\theta}}\right) \tag{5}$$

[6] Technology draws are independent across goods, so this is valid for all goods. See the appendix for details.
[7] Nation-*o*'s unit-labour cost, averaged over all goods, for goods delivered to *d* is $\tau_{od} w_o / T^{1/\theta}$; this equals $1/(T_{od})^{\theta}$.

where the $Y$'s are nations' total output (GDP) and the $P$'s are nations' price indices from (1) for the continuum of goods $\Theta = [0,1]$. While this is not a closed form solution, the export probability is expressed in terms of endogenous variables for which we have data or proxies.

### 2.2.1. **Spatial pattern of zeros and trade prices in the Eaton-Kortum model**

Equation (5) gives the sensible prediction that the probability of *o* successfully competing in market-*d* is decreasing in bilateral transport costs. The incidence of export zeros (that is, products exported to at least one but not all potential markets) should be increasing in distance if distance is correlated with trade costs, and import zeros (products imported from at least one potential source but not all) should predominate since each importer buys each good from just one supplier.

For tractability, the EK model assumes that iceberg trade costs are the same for all goods that travel from *o* to *d*. Harrigan (2006) shows that allowing for heterogeneity in trade costs across goods in a simplified version of EK introduces a further role for relative trade costs to influence comparative advantage. For our purposes here, the main interest of Harrigan (2006) is the result that a fall in variable trade costs for a subset of goods leads to an increase in the probability that they will be successfully exported.

The role of market size in determining the probability of exporting can also be studied with (5). The bigger is market-*d*, as measured by its GDP $Y_d$, the *smaller* is the probability that *o* successfully sells in *d*. There are two elements explaining this counter-intuitive result. Large countries must sell a lot so they need, on average, low unit-labor-costs (as measured by $w_o^{\theta}/T_o$). This means that large nations are often their own low-cost supplier. The second is that there are no fixed market-entry (i.e. beachhead) costs, so that an exporter will supply all markets where it has the lowest c.i.f. price regardless of how tiny those markets might be. Expression (5) also predicts that nation-*d* imports more goods from larger exporters, with size measured by $Y_o$.

The EK model makes extremely simple predictions for the spatial distribution of import prices. The distribution of prices inside nation-*d* is given by (3) and each exporting nation has a constant probability of being the supplier of any given good. Consequently, the c.i.f. price of nation-*o*'s exports to nation-*d* is just a random sample from (3), which means (3) also describes the distribution of import prices for every exporting nation. The average c.i.f. price of goods imported from every partner should be identical and related to nation-*d* price index by (see appendix for details)

$$p_{od}^{e} = P_d\left(\frac{\Gamma[(1-\sigma+\theta)/\theta]}{\Gamma[(1+\theta)/\theta]}\right) \tag{6}$$

where Γ[.] is the Gamma function. Since trade costs are fully passed on under perfection competition, the average bilateral export (f.o.b.) price, $p_{od}^{e}/\tau_{od}$, should be increasing in the destination nation's price index and declining in bilateral distance.

### 2.2.2. Extensions and modifications of the Eaton-Kortum model

The EK model is a multi-country Ricardian model with trade costs. In all Ricardian models, the locus of competition is within each destination nation. This means that exporters must meet the competitive demands in each nation if they are to export successfully. Given this basic structure, the prediction of equal average import prices from all source nations is quite robust. Putting it differently, highly competitive nations export a wider range of goods than less competitive nations but the average import price of their goods does not vary with exporter's competitiveness, size or distance from the importing market. Staying in the Ricardian-Walrasian framework limits the range of modifications and extensions, so most extensions and modifications of the EK model lead to quite similar spatial predictions for zeros and prices.

One important extension of EK is Bernard, Eaton, Jensen and Kortum (2003). This model introduces imperfect competition into the EK framework with the low-cost firm in each market engaging in limit pricing. Limit pricing ties the market price to the marginal cost of the second-best firm, rather than the first-best as in EK. However with randomly generated technology, the outcome for the spatial pattern of zeros and prices is qualitatively unaltered.

Eaton, Kortum and Kramarz (2008) modify the EK framework model further, and the resulting model is completely out of the Walrasian framework. The paper introduces monopolistic competition (thus deviating from perfect competition) and fixed market-entry, i.e. beachhead costs (thus deviating from constant returns). Eaton, Kortum and Kramarz (2008) is thus best thought of as an HFT model, which we consider below.

### 2.2.3. **Summary of empirical implications of the Eaton-Kortum model**

To recap what the EK model predicts about zeros and prices across space:

Export zeros The probability that exporter-*o* sends a good to destination-*d* is decreasing in the distance between *o* and *d*, and also decreasing in the size of *d*. A fall in trade costs reduces the incidence of zeros.

Export prices Considering products sold by *o* in multiple destinations *d*, the average f.o.b price is decreasing in the distance between *o* and *d*, and unrelated to the size of *d*.

In terms of HS10 codes, the export-zero prediction is that the probability that no firm exports in a given code from *o* to *d* is decreasing in the distance between *o* and *d* and in the size of *d*. The export price prediction is that, within a given code, higher-cost products are less likely to be shipped longer distances. As a consequence of this composition effect, the average export price within a code will be decreasing in distance.

## 2.3. Monopolistic competition

Monopolistic competition (MC) models constitute another major strand in trade theory. The particular MC model that we focus on has *C* countries, iceberg trade costs, and a single factor of production *L*. Goods are produced under conditions of increasing returns and Dixit-Stiglitz monopolistic competition. Firms are homogenous in that they all face the same unit-labor requirement, *a*. The model is very standard, so we will move quickly (see Appendix for details).

Dixit-Stiglitz competition implies that 'mill pricing' is optimal, i.e. firms charge the same f.o.b. export price regardless of destination, passing the iceberg trade cost fully on to consumers. With mill pricing and CES demand, the value of bilateral exports for each good is

$$v_{od} = \phi_{od}\left(\frac{w_o a}{1-1/\sigma}\right)^{1-\sigma} B_d\,; \qquad \phi_{od} \equiv \tau_{od}{}^{1-\sigma} \in [0,1], \quad B_d \equiv \frac{w_d L_d}{P_d^{1-\sigma}}. \tag{7}$$

where $v_{od}$ is the value of bilateral exports for a typical good, $\phi_{od}$ reflects the 'freeness' of bilateral trade ($\phi$ ranges from zero when $\tau$ is prohibitive to unity under costless trade, i.e. $\tau = 1$), $B_d$ is the per-firm demand-shifter in market-*d*, and $P_d$ is as in (1), with $\Theta$ being the set of goods sold in *d*.

### 2.3.1. **Spatial pattern of zeros and prices in the monopolistic competition model**

The spatial patterns are exceedingly simple in the MC model. Consumers buy some of every good with a finite price, so there should be no zeros in the trade matrix – if a good is exported to one country it is exported to all. In particular, neither the size of the destination market nor the distance between the origin and destination markets has any bearing on the probability of observing a zero.

The MC model also has sharp predictions for the spatial pattern of trade prices. Mill pricing is optimal, so the f.o.b. export price for all destinations should be identical. Since trade costs are passed fully on to consumers, the c.i.f. import prices should increase with bilateral distance but there should be no connection between market size and pricing (f.o.b. or c.i.f). There should also be no connection between the f.o.b. price and the distance between the origin and destination markets.

### 2.3.2. **Extensions and modifications of the monopolistic competition model**

The extremely simple and stark predictions of the MC model depend upon standard simplifying assumptions. Some of these have been relaxed in the literature, so we consider the predictions that are robust across well-known variants of the MC model.

The core elements of the MC model are imperfect competition, increasing returns and homogenous firms. Since imperfect competition can take many forms, many variants of the standard MC model are possible. The general formula for optimal pricing under monopolistic competition sets consumer price to $\frac{a\tau_{od}}{1-\varepsilon_d^{-1}}$, where $\varepsilon_d$ is the perceived elasticity of demand in market-*d*. Different frameworks link $\varepsilon_d$ to various parameters. Under Dixit-Stiglitz monopolistic competition, $\varepsilon_d$ equals $\sigma$. Under the Ottaviano, Tabuchi and Thisse (2002) monopolistic competition framework firms face linear demand, so $\varepsilon_d$ rises as firms move up the demand curve. This means that the markup falls as greater trade cost drive consumption down. In other words, producers absorb some of the trade costs, so the f.o.b. export prices should be lower for more distant markets. Linear demand also implies that there is a choke-price for consumers and thus trade partners that have sufficiently high bilateral trade costs will export nothing to each other. A corollary is that a fall in trade costs will reduced the incidence of zeros. Finally, if demand curves are sufficiently convex, higher bilateral trade costs raise the markup and this implies that f.o.b. prices can rise with distance. Because this degree of convexity implies a counterfactual more-than-full pass-through of cost shocks (e.g., more than 100% exchange rate pass-through) such demand structures are not typically viewed as part of the standard MC model. With the

Ottaviano, Tabuchi and Thisse (2002) framework, the predicted pattern of zeros is very stark. Nation-*o*'s export matrix has either no zero with respect to nation-*d*, or all zeros. Moreover, since market size does not affect the demand curve intercept in Ottaviano, Tabuchi and Thisse (2002), there should be no relationship between the number of zeros and destination-market size.

### 2.3.3. **Summary of empirical implications of monopolistic competition model**

To recap the prediction for zeros and prices across space, considering both the baseline MC model with CES preferences and no beachhead costs as well as the version based on Ottaviano, Tabuchi and Thisse (2002) monopolistic competition:

<u>Export zeros</u> The baseline model predicts zero zeros: if an exporter-*o* sends a good to any destination-*d* it will send the good to all destinations. With linear demand, the probability of a zero is increasing in the distance between *o* and *d*, but unrelated to the size of *d*. A fall in trade costs will reduce the probability of zeros with linear demand.

<u>Export prices</u> Considering a single product sold by *o* in multiple destinations, the baseline model predicts no variation in f.o.b export prices. With linear demand, the f.o.b price is decreasing in the distance between *o* and *d*, and unrelated to the size of *d*.

In terms of HS10 codes, the export zero prediction with linear demand is that the probability that no firm exports in code *i* from *o* to *d* is decreasing in the distance between *o* and *d*. Unlike in the EK model, the export price prediction with linear demand has nothing to do with a composition effect. Rather, the prediction is driven by the reduction in markups with distance.

## 2.4. A multi-nation asymmetric heterogeneous-firms trade model

One of the beauties of the original Melitz (2003) heterogeneous-firms trade (HFT) model is that it provides a clean and convincing story about why some products are not exported at all. But since Melitz (2003) works with symmetric countries, it can not address the spatial pattern of export zeros or export prices. Here we present a multi-country HFT model with asymmetric countries and arbitrary trade costs to generate testable hypotheses concerning zeros and prices.

The HFT model we work with embraces all of the features of the baseline monopolistic competition model and adds in two new elements – fixed market-entry (beachhead) costs and heterogeneous productivity (i.e. marginal cost) at the firm level. Firm-level heterogeneity is introduced

– as in the Eaton-Kortum model – via a stochastic technology-generation process. When a firm pays its set-up cost, e.g. the innovation cost of developing a new variety, it simultaneously draws a unit labor coefficient from the Pareto distribution,[8]

$$G[a]=\left(\frac{a}{a_0}\right)^{\kappa}; \qquad \kappa>1, \qquad 0\le a\le a_0 \tag{8}$$

where $\kappa$ is the shape parameter and $a_0$ is the maximum $a$ possible; as a regularity condition, $\kappa > \sigma - 1$. After seeing its *a*, the firm decides how many markets to enter. The assumed Dixit-Stiglitz competition means that: (i) a firm's optimal price is proportional to its marginal cost, (ii) its operating profit is proportional to its revenue, and (iii) its revenue is inversely proportional to its relative price. Thus a firm that draws a relatively high marginal cost earns little if it does produce. If this amount is insufficient to cover the beachhead cost *F* in any market, the firm never produces. Firms that draw lower marginal costs may find it profitable to enter some markets (especially their local market where the absence of trade costs provides them with a relative cost advantage). More generally, each export market has a threshold marginal cost for every origin nation, i.e. a maximum marginal cost that yields operating profit sufficient to cover the beachhead cost. Using (7), which shows the revenue a nation-*o* firm would earn if it sold in market-*d*, and the constant operating profit share (i.e. $1/\sigma$), the cut-off conditions that define the bilateral maximum-marginal-cost thresholds $a_{od}$ are[9]

$$\phi_{od}B_d w_o a_{od}^{1-\sigma} = f; \qquad f\equiv \sigma F(1-1/\sigma)^{1-\sigma}$$

so

$$w_o a_{od} = \frac{1}{\tau_{od}}\left(\frac{B_d}{f}\right)^{\frac{1}{\sigma-1}} \tag{9}$$

for each destination nation. The HFT model also involves a free entry condition (see appendix), but this does not come into play in characterizing the spatial pattern of zeros and prices.

---

[8]The HFT model is easily solved with an exponential cdf as in the EK model, but (8) is more traditional and can be justified by reference to data on the U.S. firm size distribution (Axtell, 2001). Note that Melitz works with firm-level efficiency 1/*a*.
[9] Here we have chosen units (without loss of generality) such that $a_0=1$. We also assume the regularity condition $\kappa > \sigma$-1, and that beachhead costs are the same everywhere for notational simplicity.

In Melitz' original model with symmetric countries, the additional assumption of the Pareto distribution for marginal cost makes it possible to obtain analytical solutions for all the endogenous variables, including wages and per-firm demands (Baldwin (2005)). With asymmetric countries solution is more difficult. The approach taken by Helpman, Melitz, and Yeaple (2004) is to assume the existence of a costlessly traded constant returns numeraire sector[10]. If all countries produce the numeraire good in equilibrium (which parameter restrictions can guarantee), then wages are equalized across countries and the per-firm demand levels $B_d$ are independent of market size (see appendix). This has the counterfactual implication that, controlling for distance, a given exporting firm has the same level of sales in every market. The economics behind this result is that larger markets attract greater numbers of entrants, which reduces demand levels facing every firm below what they would be in the absence of entry. In equilibrium, entry exactly offsets country size differences, so that demand levels for a given firm are the same regardless of which market they sell in.

An alternate solution-procedure dispenses with the assumption of a costlessly traded good and analyzes Melitz' original model with the single change of allowing for differences in country size. As we show in the appendix, it is not possible to solve this model analytically, but numerical simulation is straightforward. We show that larger countries have larger per-firm demands, and as a result any given firm sells more to larger countries than to smaller ones (controlling for trade costs). The mechanism is that larger countries have endogenously higher wages, which leads to less entry than there would be if wages were equalized. A way to see the contrast between the two solutions is to note that incipient entry raises the demand for labor in the larger country, but that this has different effects depending on the behavior of wages. When wages are fixed by the numeraire sector, all the adjustment takes place through entry. Without the numeraire sector, part of the adjustment comes through higher nominal wages in the larger country, which dampens entry and consequently leaves per-firm demand higher in the larger country.

[10] This solution approach has also been taken by Demidova (2008) and Falvey, Greenaway, and Yu (2006) in their analyses of a two-country asymmetric HFT model.

### 2.4.1. Asymmetric HFT's spatial pattern of zeros and prices

The spatial pattern of zeros comes from the cut-off conditions. The probability that a firm producing variety-*j* with marginal costs $w_o a_o(j)$ will export to nation-*d* is the probability that its marginal cost is less than the threshold defined in (9), namely

$$\Pr\left[ w_o a_o\left(j\right) < \frac{1}{\tau_{od}}\left(\frac{B_d}{f^{\beta}}\right)^{\frac{1}{\kappa}} \right] = \frac{B_d}{\tau_{od}^{\kappa} f^{\beta}} \tag{10}$$

where we used (8) to evaluate the likelihood. In our empirics, we only have data on products that are actually exported to at least one market so it is useful to derive the expression for the conditional probability, i.e. the probability that a firm exports to market *d* given that it exports to at least one market. This conditional probability of exports from *o* to *d* by a typical firm is

$$\frac{\tau_{od}^{-\kappa} B_d}{\min_{i \neq o} \tau_{oi}^{-\kappa} B_i} \tag{11}$$

Since we work with data for a single exporting nation, the denominator here will be a constant for all products. Thus the probability that an exporting firm exports to a given market is predicted to decline as the distance to that market increases, and increase as the market size rises. A fall in variable trade costs increases the marginal cost cutoff for profitable exporting, and hence reduces the probability of export zeros.

The spatial pattern of prices in the asymmetric HFT model is also simple to derive. We consider both the export (f.o.b.) price for a particular good exported to several markets, and the average export (f.o.b.) price for all varieties exported by a particular nation. Because the model relies on Dixit-Stiglitz monopolistic competition, mill pricing is optimal for every firm, so the f.o.b. export price of each good exported should be identical for all destinations. In particular, the export price for any given good should be unrelated to bilateral distance and unrelated to the size of the exporting and importing nations. However, the range of goods exported does depend on bilateral distance and size, so the average bilateral f.o.b. export price will differ systematically. The cut-off conditions (9) imply that the weighted average of the f.o.b. prices of all varieties exported from nation-*o* to nation-*d*, $\overline{p}_{od}$ , is

$$\overline{p}_{od} = \int_0^{a_{od}} \left( \frac{\tau_{od} w_o a}{1-1/\sigma} \right)^{1-\sigma} dG\left(a_{od} \mid a \le a_{oo}\right)$$

Using (8) to evaluate the integral and eliminating the cutoff $a_{od}$ using (9), this becomes

$$\overline{p}_{od} = \frac{\delta_o}{\tau_{od}^{\kappa}} \left( \frac{B_d}{f} \right)^{\frac{1+\kappa-\sigma}{\sigma-1}} \tag{12}$$

where $\delta_o$ is a function of parameters and country *o* variables only. Equation (12) implies that the relative average export price to any two markets *c* and *d* from a single origin *o* depends only on relative distance from *o* and relative market size:

$$\frac{\overline{p}_{od}}{\overline{p}_{oc}} = \left( \frac{\tau_{oc}}{\tau_{od}} \right)^{\kappa} \left( \frac{B_d}{B_c} \right)^{\frac{\kappa+\sigma-1}{\sigma-1}}$$

The logic of (12) is that since the cut-off marginal cost, $a_{od}$, falls with bilateral distance and increases with market size, the average export price of nation-*o* varieties to nation-*d* should be decreasing in distance and increasing in the size of the export market. The intuition is that the cheapest goods are the most competitive in this model, so they travel the furthest.

### 2.4.2. Extensions and modifications of the asymmetric HFT model

The asymmetric HFT model, like the monopolistic competition model, has imperfect competition and increasing returns as core elements. As noted above, there are many different forms of imperfect competition and scale economies. The other core elements of the HFT model are beachhead costs or choke-prices (these explain why not all varieties are sold in all markets) and heterogeneous marginal costs (these explain why some nation-*o* firms can sell in a market but others cannot). This suggests three dimensions along which HFT models can vary: market structure, source of scale economies, and source of heterogeneity.

For example, Eaton, Kortum, and Kramarz (2008) present a model that incorporates beachhead and iceberg costs in a setting that nests the Ricardian framework of Eaton-Kortum (2002) and Bernard et al (2003) with the monopolistic competition approach of Melitz (2003). They do not include set-up costs since firms' are endowed with a technology draw. Another difference is that they work with a technology-generating function from the exponential family. Demidova (2008) and Falvey, Greenaway and Yu (2006) allow for technological asymmetry among nations but embrace Dixit-Stiglitz competition with icebergs, beachhead and set-up costs. Yeaple (2005) assumes the source of the heterogeneous marginal costs stems from workers who are endowed with heterogeneous productivity; he works with Dixit-Stiglitz monopolistic competition with icebergs and beachhead costs. As these models all involve Dixit-Stiglitz monopolistic competition, icebergs and beachhead costs, their spatial predictions for zeros and price are qualitatively in line with the model laid out above.

Melitz and Ottaviano (2008) work with the Ottaviano, Tabuchi, and Thisse (2002) monopolistic competition framework with linear demands. The implied choke-price substitutes for beachhead costs in shutting off the trade of high-cost varieties. The Melitz-Ottaviano prediction for the spatial pattern of zeros matches that of the asymmetric HFT model with respect to bilateral distance, but not with respect to market size. As our appendix illustrates, the cut-off marginal cost in Melitz-Ottaviano is tied to the y-axis intercept of the linear residual demand curve facing a typical firm. More intense competition lowers this intercept (this is how pure profits are eliminated in the model) and thus the cut-off ($a_{od}$ in our notation) falls with the degree of competition. Since large nations always have more intense competition from local varieties, Melitz-Ottaviano predicts that large countries should have lower cut-offs, controlling for the nation's remoteness. In other words, Melitz-Ottaviano predicts a *positive* relationship between the size of the partner nation and the number of zeros in an exporter's matrix of bilateral, product-level exports. As far as the spatial pattern of prices is concerned, Melitz-Ottaviano predict that export prices should decline with the market's distance and with market size, a result which follows from the result that the cutoffs are declining in distance and market size.

### 2.4.3. **Summary of empirical implications of asymmetric HFT model**

To recap, considering both the baseline HFT model with CES preferences and the Melitz-Ottaviano (2005) model with linear demand:

<u>Export zeros</u> The probability of an export zero is increasing in bilateral distance. The effect of market size on the probability of an export zero is negative in the baseline model, and positive in the Melitz-Ottaviano variant. A decline in trade costs reduces the incidence of zeros.

<u>Export prices</u> Considering a single product sold by *o* in multiple destinations, the average f.o.b price is decreasing in the distance between *o* and *d* since only the cheapest (i.e. most competitive) varieties are sold in distant markets. The effect of market size

on average f.o.b. price is positive in the baseline model, and negative in the Melitz-Ottaviano variant.

In terms of HS10 codes, the export-zero prediction refers to the probability that no variety is exported in code *i* from *o* to *d*. The export-price prediction is driven by a composition effect within HS10 codes, as was the export-price prediction in the EK model.

## 3. ZEROS AND PRICES IN TRADE DATA

The models described in the previous section all make predictions about detailed trade data in a many country world. These predictions are collected for easy reference in the first five rows of Table 1. To evaluate these predictions, we use the most detailed possible data on imports and exports – the trade data collected by the U.S. Customs Service and made available on CD-ROM. For both U.S. imports and U.S. exports, the Census reports data for all trading partners classified by the 10-digit Harmonized System (HS). For each country-HS10 record, Census reports value, quantity, and shipping mode. In addition, the import data include shipping costs and tariff charges. Our data analysis also includes information on distance and various macro variables, which come from the Penn-World Tables.

The Census data are censored from below, which means that very small trade flows are not reported. For imports, the cut-off is $250, so the smallest value of trade reported is $251. For exports, the cut-off is 10 times higher, at $2500. This relatively high censoring level for exports is a potential problem, since there might be many economically meaningful export relationships which are inappropriately coded as nonexistent. One hint that this problem is not too prevalent comes from the import data, where only 0.8% of the non-zero trade flows are between $250 and $2500.

### 3.1. How many zeros?

We define a zero as a trade flow which could have occurred but did not. For exports, a zero occurs when the U.S. exports an HS10 code to at least one country but not all. The interpretation of an export zero is simple, since they are defined only for goods actually produced. For imports, a zero is an HS10 code which is imported from at least one country but not all. The interpretation of an import zero is not as simple; they may be defined in cases when the country in question does not even produce the good (the U.S. has zero imports of bananas from Canada, for example).

The incidence of zeros in U.S. trade in 2005 is reported in Table 2. The United States imported in nearly 17,000 different HS10 categories from 228 countries, for a total of over 3.8 million potential trade flows. Over 90% of these potential trade flows are zeros. The median number of supplier countries was 12, with a quarter of goods being supplied by at least 23 countries. Only 5% of codes have a unique supplier. In principle this pattern of imports is consistent with a homogeneous goods model, since if we define a good narrowly enough it will have just one supplier ("red wine from France"). However, the large number of suppliers for the majority of narrowly defined codes seems instead to be suggestive of product differentiation[11]. This well-known phenomenon is part of what motivated the development of monopolistic competition trade models.

Zeros are almost as common in the export data as in the import data. Table 2 shows that in 2005 the U.S. exported 8,880 HS10 codes to 230 different destinations, for a total of more than 2 million potential trade flows. Of these, 82% are zeros. Unlike the import zeros these have an unambiguous interpretation, since a zero is defined only if a good is exported to at least one country, which necessarily means the good is produced in the U.S. The median number of export markets is 35, with a quarter of codes exported to at least 59 markets. Only 1% of codes are sent to a unique partner.

Many of the 230 places that the U.S. trades with are tiny to the point of insignificance (Andorra, Falkland Islands, Nauru, Pitcairn, Vatican City, and the like). Restricting attention to the 100 large countries for which we have at least some macroeconomic data reduces the incidence of zeros somewhat (86% for imports, 70% for exports), but does not fundamentally change the message that zeros predominate.

From the standpoint of theory, the predominance of HS10 code zeros almost certainly understates the number of zeros at the level of firms and/or products. This is because, as noted in Section 2.1.1, each HS10 code contains products from an average of 31 different firms, and each firm-product in a given code might be exported to a proper subset of the countries with positive purchases in that code.

The predominance of export zeros is at odds with the "zero zeros" prediction of the baseline monopolistic competition model with CES preferences discussed in Section 2, so even without formal statistical analysis we can conclude that this model is a non-starter.

[11] The largest number of trading partners for any product is 125, for product 6204.52.2020, "Women's trousers and breeches, of cotton, not knitted or crocheted". This is not a homogeneous goods category.

## 3.2. Export zeros across space

The gravity equation offers a flexible and ubiquitous statistical explanation for the aggregate volume of trade between countries. The basic logic of the gravity equation is simplicity itself: bilateral trade volumes depend positively on country size and negatively on distance. Here we adopt the gravity approach to explain not the *volume* of trade but rather its *incidence*. This descriptive statistical exercise is intended to help us understand the pattern of export zeros summarized in Table 2.

We emphasize that the purpose of our statistical exercises in this and the following section is to document robust reduced form relationships in the data. Any structural model of trade should be consistent with these correlations. We contrast our approach with the well-known recent paper by Helpman, Melitz, and Rubinstein (2008). In their paper, Helpman *et al* structurally estimate the distance elasticity of trade in the context of a particular theoretical model. They also focus only on country-level zeros, that is, pairs of countries that have no trade in *any* product. As Table 2 and Figure 1 illustrate, product level zeros are a first-order feature of the data for U.S. trade, while the U.S. has positive trade in *some* products with virtually every country in the world.

We focus on U.S. export zeros because of their unambiguous interpretation as products which the U.S. produces and ships to at least one, but not all, countries. Extending the gravity logic suggests that exports should be more likely the larger the production of the good, the larger the export market, and the shorter the distance the good would have to travel. We have no information on production volumes by good, so we focus on within-product variation across export partners. As indicated in Table 2, the dimensions of the data in 2005 are 8,880 HS10 codes and 100 countries.

Figure 1 offers a first look at the data. The vertical axis shows market size (measured as log real GDP of the importing country) and the horizontal axis shows distance from the United States (measured as log kilometers between Chicago and the capital city of the importer). Each point is represented by a circle, where the size of the circle is proportional to the number of HS10 codes exported from the U.S. to the importer. Canada and Mexico are identified, with other country names left out in the interest of legibility.

A number of patterns are visible in Figure 1. First, controlling for distance, size is associated with more codes being exported (to see this, pick a point on the log distance axis such as 8 or 9 and observe that the circles generally get bigger from bottom to top). Second, the small, distant exporters clustered in the lower right hand corner of the plot have very small circles, meaning that few codes are exported to these markets. Overall, Figure 1 suggests a gravity relationship: the number of codes exported increases with market size and decreases with distance.

We next turn to statistical analysis of the probability that a code is exported to a particular market. The statistical model we estimate is

$$\Pr\left(z_{ic}=1\right)=F\left(\alpha_i+\beta_1 d_c+\beta_2\log Y_c+\beta_3\log\frac{Y_c}{L_c}\right)$$

where

$z_{ic}$ = 1 if positive exports of HS10 code $i$ from the U.S. to country $c$.

$\alpha_i$ = intercept for HS10 code $i$.

$d_c$ = distance from U.S. to country $c$.

$Y_c$ = real GDP of country $c$.

$L_c$ = labor force in country $c$.

and $F$ is a probability distribution function. There is no particular reason to expect the relationship to be linear, so we allow the relationship between zeros and distance to be a step function and also include GDP per worker (aggregate productivity) as a control. The distance step function is specified by looking for natural dividing points in the raw distance data, and the countries in each category are listed in Table 3. As is well known, fixed effects logit and probit estimators are not consistent when the number of effects is large. As a consequence, we estimate two other statistical models, the linear probability and random effects logit models, with results reported in Table 4.

Before turning to the results, a few comments about estimation are in order. Our sample is a panel of HS10 codes and countries, with thousands of codes and 100 countries. In the linear probability model of this section, and in the linear statistical models of later sections, it is important to correctly model the error process, which we model as having a generic two-way error components structure,

$$\varepsilon_{ic}=\mu_i+\delta_c+u_{ic},\qquad i=1,\ldots,N_c,\qquad c=1,\ldots,C$$

In all of the linear statistical models, we will remove the code effects $\mu_i$ by the within transformation (that is, with HS10 code fixed effects). To allow for estimation of the effects of country characteristics (distance, market size, etc) we assume that the country effects $\delta_c$ are random and orthogonal to the observed country characteristics. Finally, we allow the idiosyncratic effects $u_{ic}$ to have arbitrary heteroskedasticity. Our estimator can thus be summarized as a two-way error components model (with fixed code and random country effects), with heteroskedasticity of unknown form in the idiosyncratic component. We note in passing that cluster sample methods are not relevant here because we do not have a cluster sample structure: each code is potentially sold to all countries, whereas a cluster sample would have disjoint subsets of codes sold to each country[12].

The first two columns of Table 4 report the results of the linear probability model. The coefficients have the simple interpretation as marginal effects on the probability of a code being exported to a particular country, conditional on being exported to at least one country. The excluded distance category of 0 kilometers includes Mexico and Canada. For nearby countries distance has no statistically significant effect on zeros, an effect which jumps to about 0.33 for distances greater than 4000km. Country size also has a very large effect, with a 10% increase in real GDP of the importing country lowering the probability of a zero by 8 percentage points. The importer's aggregate productivity also has a large effect, with a 10% increase raising the probability of trade by more than 5 percentage points. Except for the aggregate productivity effect the sign of the estimated effects is not surprising, but it is useful to see how large the magnitudes are[13]. The results are very similar for the sample restricted to HS codes that belong to SITC 6 (manufactured goods), 7 (machinery and transport equipment), and 8 (miscellaneous manufactures).

The final two columns of Table 4 report marginal effects from the random effects logit. There are two strong technical assumptions behind these computations which give reasons to be skeptical of the results: first, the assumption that the random product effects are orthogonal to country characteristics is a strong one which can be rejected statistically, and second, the covariance matrix estimator assumes that errors for each export market are independent across goods (that is, we use a one-way error components estimator rather than the two-way estimator, which is feasible only for linear models). In any event, the marginal effects from the logit are broadly consistent with the coefficients of the linear probability model, which suggests that the functional form assumption of the

[12] Wooldridge (2006) has a clear discussion of the differences between panel data and cluster samples, and persuasively argues for an amendment to the traditional error components approach to allow for arbitrary heteroskedastcity (which is what we do). Hansen (2007) shows that the standard (and *Stata* default) computation of the robust covariance matrix is appropriate for panel data with moderately large "*T*" dimensions as in our application.

[13] The large effect of aggregate productivity may be related to the mechanism recently studied by Choi, Hummels and Xiang (2006).

former model doesn't do too much violence to the data[14]. As with the linear probability model, splitting the sample does not change much.

While in many respects not surprising, *the results of Table 4 are not consistent with most of the models summarized in Table 1*. Only the heterogeneous firm model with CES preferences is consistent with the positive market size and negative distance effects identified in the data.

## 3.3. Export unit values across space

We now turn to a descriptive analysis of export unit values. The statistical model is very similar to the previous section, with within-HS10 code variation in unit values regressed on distance, market size, and aggregate productivity of the importing country:

$$p_{ic} = \alpha_i + \beta_1 d_c + \beta_2 \log Y_c + \beta_3 \log \frac{Y_c}{L_c} + \varepsilon_{ic}$$

where $p_{ic}$ is the log of the f.o.b. average unit value of code *i* shipped to country *c*. The code fixed effect controls both for the average unit value of products (industrial diamonds vs. peanuts) and differences in units (kilos vs. bushels) across codes. Because this analysis uses only non-zero export observations, the sample size is much smaller than in the previous section, and the panel is highly unbalanced because the incidence of zeros varies widely across products.

The most common definition of units in the U.S. export data unit is a simple count, with the second most common being weight in kilograms (some records report two unit definitions, in which case the second unit is almost always kilos). Other units include bushels, barrels, square meters, grams, and the like. While the code fixed effects sweep out differences in units across products, there may still be a difficulty in comparing the effects of distance and market size on unit values not in common units. To address this concern, we run the regression above on the subset of data for which kilograms are the unit, so that unit value is simply the value/weight ratio.

Product level unit values are notoriously noisy indicators of prices, particularly for very small trade flows. To make sure that our results are not overly influenced by noisy and economically unimportant observations we trim the estimation sample in two ways. The first trim is to discard all export flows of less than $10,000, which eliminates the smallest 7% of observations. Our second trim is

[14] A common informal check of the adequacy of the linear probability model is to see how many fitted values for the probabilities lie outside the unit interval. In our case the share is 0.18.

to look only at flows where the data reports a count (as in, “number of cars” or “dozens of pairs of socks”), and to discard all observations with a count of one. Since there are almost no products where both a count and kilos are reported, we do not analyze this subset of data.

Table 5 reports the results of our export unit value regressions. A striking message is that *distance has a very large positive effect on unit values*. For manufactured goods, compared to the excluded Canada/Mexico category, small distances (less than 4000km) increase unit values by 4-10 log points, while larger distances increase unit values by 60-80 log points, which is a factor of about 2. For goods where units are reported in kilos, so that unit value is also value/weight, the effect of small distance is somewhat larger at 18 log points, while the effect of larger distances is about the same as for manufactured goods. For the subset of goods where units are a count, and the count is greater than 1, results are broadly similar.

Table 5 also shows that market size has an important and statistically significant negative effect on export unit values of manufactured goods, with an elasticity of -0.09 when small values are excluded. This elasticity implies a large effect of market size across the sample: a doubling of country size lowers the average unit value by 9 percent. This effect is also apparent when nonmanufactured goods are pooled with manufactured goods. For goods measured in kilos the effect is -0.02 when small values are excluded. The effect of aggregate productivity is fragile: there is a small positive effect when the sample is restricted to products measured in kilos, and a small negative effect for manufactured goods, with the effect for the sample as a whole indistinguishable from zero.

The Table 5 results are consistent with the findings of Hummels and Skiba (2004). In particular, equation (12) in Hummels and Skiba is quite similar to the specification estimated in Table 5. The biggest difference is that we include market size as an explanatory variable for log unit values while Hummels and Skiba do not.

Figure 2 illustrates the price-distance relationship that is described statistically in Table 5. To construct this figure, we first subtracted HS10 means from all log export unit values[15]. The distribution of the de-meaned unit values is then plotted, with the histogram of unit values for goods sent to Mexico and Canada rendered as green solid bars, and the corresponding histogram for goods sent 4000-7800km

[15] That is, we regressed all log export unit values on a full set of HS10 fixed effects. The residuals from this regression are plotted in Figure 2, by distance category.

rendered as red open bars[16]. This distance category was chosen for comparison with Canada/Mexico because it contains the largest value of trade of the distance categories we examine, but figures for other distance categories are very similar, as would be expected from the Table 5 results. Figure 2 shows a clear right shift in the distribution for goods sent across an ocean: even without controlling for composition, market size, etc, distance is systematically associated with higher export unit values.

The strong positive relationship between export unit values and distance seen in Table 5 and Figure 2 is inconsistent with *all* of the models presented in Section 2. The baseline monopolistic competition model predict a zero relationship, while the other models predict a negative relationship between export unit values and distance, the exact opposite of what shows up so strongly in the data. Only the Melitz-Ottaviano model is consistent with the negative market size effect on prices.

We emphasize that the effect of distance on unit values found here can not be given a clear structural interpretation. Most obviously, since we know from the results of Table 4 that distance has a strong influence on the probability of zeros, the effect estimated here conflates a selection effect (which markets are exported to) and a treatment effect (conditional on positive exports, what is the effect of distance on unit value).

## 3.4. Variable trade costs and zeros

Table 4 shows conclusively that zeros are increasing in distance. If variable trade costs are increasing in distance, then this result is consistent with all of the models except the baseline monopolistic competition model, which is a bit of a straw man in light of Table 2. Nonetheless, the evidence of Table 3 is only indirect, since it does not include direct measures of trade costs. In this section we use more direct evidence on falling variable trade costs to confirm their importance in explaining zeros.

Shipping costs are probably the largest component of variable trade costs (other components include the cost of insurance and the interest cost of goods in transit). While most observers take it for granted that shipping costs have fallen dramatically since World War II, hard data is surprisingly difficult to come by and the trends are ambiguous when the data is analyzed (Hummels, 1999). However, there is no doubt that the relative cost of air shipment has declined precipitously. Hummels (1999) shows the decline in air shipment costs to 1993, though Hummels' data (as he notes) is not a

[16] The figure is quite vivid when rendered in color, somewhat less so in black and white.

price index. Since 1990, the U.S. Bureau of Labor Statistics has been collecting price indices on the transport costs borne by U.S. imports. Figure 3 uses this data to illustrate that between 1990 and 2005, the relative price of air to ocean liner shipping for U.S. imports fell by nearly 40%, continuing the trend documented by Hummels (1999). As illustrated in the figure, this drop in the relative price of air shipment is partly due to the increasing nominal cost of ocean liner shipping and partly due to a drop in the nominal price of air shipment. Micco and Serebrisky (2006) show that the drop in air shipment rates is partly due to economic policy: the United States implemented a series of "Open Skies Agreements" between 1990 and 2003 which reduced nominal air transport costs by 9%. There is no comparable data on the price of shipping by train and truck, modes used exclusively on imports from Canada and Mexico. The BLS also reports a price index for air freight on exports, but does not report a price index for ocean liner shipping on exports. Not surprisingly, there is no trend in the relative price of air shipping for imports and exports. In what follows we assume that the trend illustrated in Figure 3 holds for exports as well.

The fall in the relative price of air shipment since 1990 implies that products shipped by air saw a fall in their variable trade costs compared to products shipped by ocean liner. This has direct implications for the incidence of export zeros: export zeros should have disappeared more often for air shipped than for surface shipped goods. We test this implication with a simple but powerful differences-in-differences empirical strategy.

The data used in this section is 6-digit HS U.S. exports for 1990 and 2005. We use HS6 rather than the more disaggregated HS10 data of the previous sections because HS10 definitions change frequently, making an accurate match of products over 15 years impossible.[17]

Consider export zeros in 1990. By 2005, some of these zeros have disappeared for various reasons. Conditional on a good being exported, firms choose the optimal shipment mode, and those who choose to ship by air benefit from the falling cost of air shipment. If the theory prediction is correct, then new export flows in 2005 will be more likely when they are shipped by air. Define

$x_{ict}$ = exports of HS6 code $i$ to country $c$ in year $t$.

$a_{ict}$ = 1 if exports shipped by air, 0 otherwise

[17] Even using HS6 data we had to discard about 20% of exports by value because of matching problems, mainly having to do with differences in units over time

$y_{ic}$ = 1 if ($x_{ic1990}$ = 0 and $x_{ic2005}$ > 0), 0 otherwise

The variable $y_{ic}$ is an indicator of a new trade flow starting sometime between 1990 and 2005: there were no exports in 1990 and positive exports in 2005. Note that $y_{ic}$ = 0 for three distinct reasons:

| | |
|---|---|
| ($x_{ic1990}$ > 0 and $x_{ic2005}$ > 0) | export in both years |
| ($x_{ic1990}$ = 0 and $x_{ic2005}$ = 0) | export in neither year |
| ($x_{ic1990}$ > 0 and $x_{ic2005}$ = 0) | export in 1990 but not in 2005 |

An empirical model to explain $y_{ic}$ is

$$\Pr\left(y_{ic}=1\right)=F\left(\alpha_i+\alpha_c+\beta a_{ic2005}\right)$$

where $F$ is the normal or logistic cdf, and the $\alpha$'s are country and HS6 code fixed effects. That is, the probability of a new export depends on country and code effects and the shipment mode in 2005. Note that since $a_{ic2005}$ is undefined if $x_{ic2005}$ = 0, the statistical model includes observations only on active trade flows in 2005, and compares the characteristics of new flows ($y_{ic}$ = 1) versus old flows ($y_{ic}$ = 0). Under the null $\beta$ > 0: the new flows are more likely to be sent by air.

Table 6 summarizes the data. There were nearly 200,000 non-zero HS6 export flows in 2005, of which more than 40% were zeros in 1990. Of these "new" trade flows, 39% were shipped by air, compared to 34% shipped by air among "old" flows. Thus there is a 5 percentage point difference in the likelihood of air shipment for new flows.

Given all the other changes in the global economy since 1990, Table 6 is certainly not definitive evidence of the importance of falling variable trade costs in explaining disappearing export zeros. Table 7 reports estimates of the dichotomous probability model above. For technical reasons it is not possible to estimate two-way logit or probit fixed effects models with HS6 code indicators, so the first three rows of the Table report results with country effects only. The final row of the Table is the most interesting, since it includes country and code fixed effects. The effect of air shipment is precisely estimated: exports shipped by air in 2005 are 2.5 percentage points more likely to be new. This is a substantial effect compared to the overall share of new exports in 2005 (42 percent), so that the air shipment dummy accounts for almost 6 percent of new trade flows in 2005.

We conclude from this section that higher variable trade costs increase the incidence of export zeros.

# 4. TRADE WITH HETEROGENEOUS QUALITY

The empirical evidence presented above has a clear message: the Melitz (2003) model extended to multiple asymmetric countries does a good job of explaining export zeros, but can not explain spatial variation in prices. By contrast, the predictions of the Eaton-Kortum, monopolistic competition, and Melitz-Ottaviano models are inconsistent with both zeros and spatial price variation. In this section we build a model that has the virtues of the asymmetric HFT model when it comes to zeros, but also can account for the spatial facts on prices. Since firms compete on the basis of quality as well as price in the model, we refer to it as the quality heterogeneous-firms model, or QHFT for short.

## 4.1. Quality and trade: antecedents and recent work

The idea that exporting firms compete on quality as well as price has a long history in international trade economics. In examining the linkages between quality and national trade patterns, we follow a number of important recent papers, including primarily empirical papers by Schott (2004), Hummels and Klenow (2005), and Hallak (2006). Schott's (2004) importance lies in the finding of a strong positive relationship between exporter GDP per capita and the average unit value of HS10 codes sold to the United States (in contrast, our results reported in Table 5 look at the opposite flow and find no robust relationship between U.S. export unit values and the GDP per capita of the importer). Hummels and Klenow (2005) sketch the empirical implications of a number of homogenous-firms trade theories that take quality as national attributes. As such, the Melitz-like selection effect of distance-related trade costs is not in operation; bilateral export patterns are marked by an all-varieties-or-none pattern. A key empirical finding of Hummels and Klenow (2005) is an empirical association between exporter GDP per capita and export unit value. While Schott (2004) and Hummels and Klenow (2005) find a relationship between exporter GDP per capita and quality, Hallak (2006) looks at the demand side, and finds that the demand for quality is related to importer GDP per capita.

In an important recent paper, Hallak and Schott (2008) take a more nuanced approach to estimating exporter product quality, both across countries and over time, by developing a method to disentangle price and quality variation in unit value data. Among their findings is a confirmation that the level of quality is correlated with the level of development, but the relationship is somewhat weaker in growth rates. Khandelwal (2007) also separates price and quality, and finds that this decomposition enables provocative insights into the nature of U.S. manufacturer's exposure to competition from imports. Khandelwal also confirms the association between exporter level of development and export quality.

There are a number of different approaches to modeling the demand for quality. The most common is to model preferences for what might be called box-size-quality: the utility of consuming two boxes of variety-*j* with quality 1 is identical to consuming one box of variety-*j* with quality 2, just as if it were a bigger box of the same good[18]. In the standard CES monopolistic competition setting this means consumers make their decisions on quality-adjusted price rather than the observed price (i.e. they care about the observed price adjusted for box-size). An older theoretical literature, exemplified by Murphy and Shleifer (1997) and Grossman and Helpman (1991) worked with vertical quality models where several firms compete on price and quality to win a single market. A separate approach is found in the Industrial Organization "buy only one" models of quality demand used in the trade literature by Verhoogen (2008), Khandelwal (2007), and Sutton (2007).

Models of the supply of quality by firms differ in their details, but invariably deliver a mapping between an exogenous parameter (Sutton (2008) calls it "capability", Khandelwal (2007) calls it "ability", Verhoogen (2006) calls it "productivity", etc) and the possibly endogenous supply of quality, a characteristic valued by consumers[19]. Market equilibrium in these models is usually some variant of Nash equilibrium (including monopolistic competition).

The value added of our QHFT model developed below lies in three main dimensions. First, we work out a general equilibrium trade model with trade costs and many nations where quality is a basis of comparative advantage and quality is linked to fundamentals in each nation. As part of this, we show that adding in quality as part of a firm's competitiveness is quite simple since the QHFT is best thought of as a conceptual amendment to the standard HFT models. Second, the model allows for firm heterogeneity in productivity and quality in line with empirical evidence. Third, we develop specific, testable hypotheses and, referring back to Section 3 above, show that the QHFT model is more consistent with the data than the models discussed in Section 2 above.

[18] Hummels and Klenow (2005), Hallak (2006), Hallak and Schott (2008) and Kugler and Verhoogen (2008), among many others, use variations on this approach.
[19] An exception is Helble and Okubo (2006), whose model assumes that quality has no affect on demand, but that high quality products face lower beachhead costs.

**More recent work**. Since the first draft of our paper was widely disseminated in March 2007, a number of “quality heterogeneous-firms trade” models have been developed or are in development. Several of these use the box-size-quality preferences over quality and monopolistic competition (Johnson 2008, Kugler and Verhoogen 2008), while others work in the buy-only-one-unit preferences or the linear preferences taken from the tradition of partial equilibrium models of Industrial Organisation theory (Sutton 2007, Auer and Chaney 2007). The only paper that works out the full general equilibrium with trade costs is Antoniades (2008, in progress), who incorporates quality competition into the Melitz-Ottaviano model. Others assume away trade costs, which are essential to our empirically testable predictions (Kugler and Verhoogen 2008, Sutton 2007).

## 4.2. Quality, heterogeneous firms, and trade: the QHFT model

Most of the assumptions and notation of our QHFT model are in keeping with the HFT model introduced above, with two main changes. On the demand side consumers now care about quality, and on the supply side firms produce varieties of different quality. More precisely, consumers regard some varieties as superior to others. This superiority could be regarded purely as a matter of taste, but we will interpret superiority as a matter of “quality.” The utility function is

$$U = \left(\int_{i\in\Theta} (c_i q_i)^{1-1/\sigma} di\right)^{1/(1-1/\sigma)}; \qquad \sigma > 1 \tag{13}$$

where $c$ and $q$ are the units consumed and quality of a typical variety and $\Theta$ is the set of consumed varieties. The corresponding expenditure function for nation-$d$ is

$$p_d(j)c_d(j) = \left(\frac{p_d(j)}{q(j)}\right)^{1-\sigma} B_d; \qquad P_d \equiv \left(\int_{j\in\Theta}\left(\frac{p_d(j)}{q(j)}\right)^{1-\sigma} dj\right)^{1/(1-\sigma)} \tag{14}$$

where $p(j)/q(j)$ has the interpretation of a quality-adjusted price of good-$j$, $P$ is the CES index of quality-adjusted prices, and $\Theta$ the set of consumed varieties; $B_d$ is defined as above. The standard CES preferences are a special case of (13) with $q(j)$=1, for all $j$.

As in the standard HFT model, manufacturing firms draw their $a$ from a random distribution after paying a fixed innovation cost of $F_I$ units of labor (see appendix for details). In the QHFT model, however, high costs are not all bad news, for higher quality is assumed to be come with higher marginal cost. In particular

$$q(j) = \left(a(j)\right)^{1+\theta}, \qquad \theta > -1 \tag{15}$$

where 1 + $\theta$ is the 'quality elasticity', namely the extent to which higher marginal costs are related to higher quality (setting θ = -1 reduces this to the standard HFT model).

A similar positive (and often log-linear) relationship between quality and marginal cost is common to many of the papers discussed above, including Khandelwal (2007), Verhoogen (2008), Johnson (2008), and Antoniades (2008). Some of these papers derive this relationship as the solution of the firm's optimal quality choice problem, but the reduced forms plainly depend only upon a firm's randomly assigned productivity. The point is that all firms face identical parameters (factor costs, etc) except for their firm-specific productivity draw. Obviously then the optimal, firm-specific quality choice will vary only with firm-specific productivity. This fact led us to skip the optimization step and move directly to the relationship given by (15) in the interests of simplicity. The most important contribution of Kugler and Verhoogen (2008) is to provide direct empirical support for the relationship between quality and cost. Using a remarkable dataset from Colombia which records information on the cost of firms' inputs, Kugler and Verhoogen (2008) show that higher cost inputs are systematically associated with higher quality outputs, as we assume in (15).

At the time it chooses prices, the typical firm takes its quality and marginal cost as given, so the standard Dixit-Stiglitz results apply. Mill-pricing with a constant mark-up, σ/(σ-1), is optimal for all firms in all markets and this means that operating profit is a constant fraction, $1/\sigma$, of firm revenue market by market. Using (15) in (14), operating profit for a typical nation-*o* firm selling in nation-*d* is

$$\left(\frac{w_o a(j)}{1-1/\sigma}\right)^{\theta(1-\sigma)} \frac{B_d}{\sigma} \tag{16}$$

The only difference between this and the corresponding expression for profits without quality differences is the $\theta$ in the exponent. Plainly, the properties of this model crucially depend on how elastic quality is with respect to marginal cost. For $\theta \in [-1, 0)$, quality increases slowly with cost and the optimal quality-adjusted consumer price, namely $\phi_{od}\left(w_o a\right)^{-\theta}$, increases with cost. In this case, a firm's revenue and operating profit fall with its marginal cost. For $\theta > 0$, by contrast, quality increases quickly enough with cost so that the quality-adjusted price falls as *a* rises, so higher *a*'s are associated with higher operating profit. Henceforth we focus on the $\theta > 0$ case because, as the empirics above suggested, it is the case that is most consistent with the data.

With (16), the cut-off condition for selling to typical market-*d* is $\phi_{od}\left(w_o a_{od}\right)^{\theta(1-\sigma)} B_d = f$, which can be rewritten as

$$w_o a_{od} = \left[\frac{\phi_{od} B_d}{f}\right]^{\frac{1}{\theta(\sigma-1)}} \tag{17}$$

Assuming $\theta > 0$, this tells us that only firms with sufficiently high-price/high-quality goods find it worthwhile to sell to distant markets. This is the *opposite* of Melitz (2003) and all other HFT models. In standard HFT models, competition depends only on price, so it is the lowest priced goods that make it to the most distant markets. In the QHFT model, competition depends on quality-adjusted prices and with $\theta > 0$, the most competitive varieties are high-price/high-quality. This means that distance selects for high-priced varieties rather than low-priced variety as in the HFT model. Plant-level evidence for this mechanism is found by Brooks (2006), Verhoogen (2008) and Kugler and Verhoogen (2008).

Since the QHFT model can be reduced to the HFT model with quality adjusted prices, the general equilibrium solution for the QHFT model is isomorphic to that of the HFT model (see appendix for details). More elaborate and nuanced models of quality choice, such as in Johnson (2008) and Sutton (2007), are not amenable to general equilibrium analysis, so we do not pursue such extensions here.

### 4.3. Quality HFT's spatial pattern of zeros and prices

The spatial pattern of zeros in the QHFT model conforms to those of the HFT model, as a comparison of the cut-off conditions of the two models, (9) and (17), reveals. The key, new implication has to do with the relationship between prices and distance. Since a high price indicates high competitiveness (quality-adjusted price falls as the price rises), the marginal cost thresholds are increasing in distance, rather than decreasing as in the HFT model. Given that mill pricing is optimal, this means that both landed (c.i.f.) and shipping (f.o.b.) prices increases with the distance between trade partners. (See the appendix for the exact relationship.)

Thus, average f.o.b. prices are increasing in distance. This is consistent with the evidence presented in Section 3. Finally, we note that the logic of the model is that average f.o.b. *quality-*

*adjusted* prices are decreasing in distance, but since the data report only average unit values this is not a testable implication. Equation (17) also implies that the relationship between average f.o.b. prices and market size is decreasing, the opposite of the relationship given by (12) in the baseline asymmetric HFT model. The reason for the different prediction is that as export market size increases lower quality firms will find it profitable to enter, which lowers average f.o.b. price in larger markets.

We summarize the quality HFT model's predictions as

<u>Export zeros</u> The probability of an export zero is increasing in bilateral distance, and decreasing in market size.

<u>Export prices</u> Considering a single product sold by *o* in multiple destinations, the f.o.b price is increasing in the distance between *o* and *d*. The effect of market size on average f.o.b. price is negative in the baseline model.

These predictions are noted in the last line of Table 2. Once again, the QHFT model is the only one that we considered which matches the findings of the data analysis in Section 3.

# 5. CONCLUDING REMARKS

This paper has shown that existing models of bilateral trade all fail to explain key features of the product-level data. In particular, the influential models of Eaton and Kortum (2002), Melitz (2003) and Helpman and Krugman (1985) all fail to match at least some of the following facts, which we document using product-level U.S. trade data:

- Most products are exported to only a few destinations.
- The incidence of these “export zeros” is positively related to distance and negatively related to market size.
- The average unit value of exports is positively related to distance.

We also show that falling air shipment costs are related to the disappearance of export zeros.

We finish the paper by proposing a modification to Melitz’ (2003) model which fits all of the facts just summarized. In this new general equilibrium model, the QHFT model, firms’ competitiveness is based on their quality-adjusted price rather than simply on price as in the HFT model, so that high-priced/high-quality firms are the most competitive.  Our model incorporates a simple reduced form mapping between marginal cost and quality which is consistent with the micro evidence by Verhoogen (2008), Kugler and Verhoogen (2008) and Brooks (2006).

## References

Antoniades, Alexis, 2008, "Heterogeneous Firms, Quality, and Trade", incomplete draft, http://www.columbia.edu/~aa2182/research.htm

Axtell, Robert L., 2001, "Zipf Distribution of U.S. Firm Sizes", *Science* 293(5536): 1818 - 1820 (September 7).

Baldwin, Richard, 2005, "Heterogeneous firms and trade: testable and untestable properties of the Melitz model", NBER Working Paper 11471 (June).

Bernard, Andrew B., Jonathan Eaton, J. Bradford Jensen, and Samuel Kortum, 2003, "Plants and Productivity in International Trade", *American Economic Review* 93(4): 1268-1290 (September).

Bernard, Andrew B., J. Bradford Jensen, and Peter K. Schott, 2009, "Importers, Exporters, and Multinationals: A Portrait of Firms in the U.S. that Trade Goods," Chapter 14 in Timothy Dunne, J. Bradford Jensen, and Mark J. Roberts, Editors, *Producer Dynamics: New Evidence from Micro Data*, Studies in Income and Wealth Volume 68, Chicago: University of Chicago Press for the NBER. Also appeared as NBER Working Paper 11404 (June 2005).

Besedeš , Tibor, and Thomas J. Prusa (2006a), "Ins, outs, and the duration of trade" *Canadian Journal of Economics* 39(1): 266–295.

Besedeš , Tibor, and Thomas J. Prusa (2006b), "Product differentiation and duration of US import trade" *Journal of International Economics* 70(2): 339-358.

Brooks, Eileen, 2006, "Why don't firms export more? Product quality and Colombian plants", *Journal of Development Economics* 80(1): 160-178 (June).

Choi, Yo Chul, David Hummels, and Chong Xiang, 2006, "Explaining Import Variety and Quality: The Role of the Income Distribution", NBER Working Paper 12531 (September).

Demidova, Svetlana, (2008), Productivity Improvements and Falling Trade Costs: Boon or Bane? *International Economic Review* 49(4): 1437-1462.

Eaton, Jonathan and Samuel Kortum, 2002, "Technology, Geography, and Trade", *Econometrica* 70(5): 1741-1779 (September).

Eaton, Jonathan, Samuel Kortum and Francis Kramarz (2008). "An Anatomy of International Trade: Evidence from French Firms," NBER Working Paper 14610 (December).

Falvey, Rod, David Greenaway, and Zhihong Yu, 2006,. "Extending the Melitz Model to Asymmetric Countries," University of Nottingham GEP Research Paper 2006/07.

Feenstra, Robert C., James R. Markusen, and Andrew K. Rose, 2001, "Using the gravity equation to differentiate among alternative theories of trade" *Canadian Journal of Economics* 34 (2): 430-447 (May).

Feenstra, Robert C.; and Andrew K. Rose, 2000, "Putting Things in Order: Trade Dynamics and Product Cycles", *Review of Economics and Statistics* 82(3): 369-382.

Grossman, Gene, and Elhanan Helpman, 1991, *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press.

Hallak, Juan Carlos, 2006, “Product Quality and the Direction of Trade”, *Journal of International Economic*s 68(1): 238-265.

Hallak, Juan Carlos, and Peter Schott, 2008, “Estimating Cross-Country Differences in Product Quality”, NBER Working Paper 13807 (February).

Hansen, Christian B., 2007, “Asymptotic properties of a robust variance matrix estimator for panel data when *T* is large”, *Journal of Econometrics* 141: 597-620.

Harrigan, James, 2003, “Specialization and the Volume of Trade: Do the Data Obey the Laws?” in *Handbook of International Trade*, edited by James Harrigan and Kwan Choi, London: Basil Blackwell.

Harrigan, James, 2006, “Airplanes and comparative advantage”, revision of NBER Working Paper 11688.

Haveman, Jon and David Hummels, 2004, “Alternative hypotheses and the volume of trade: the gravity equation and the extent of specialization”, *Canadian Journal of Economics* 37 (1): 199-218 (February).

Helble, Mathias, and Toshihiro Okubo, 2006, “Heterogeneous quality and trade costs,” HEI mimeo, Geneva.

Helpman, Elhanan and Paul Krugman, 1985, *Market Structure and Foreign Trade*, Cambridge, MA: MIT Press.

Helpman, Elhanan, Marc Melitz, and Stephen Yeaple, 2004, “Export Versus FDI with Heterogeneous Firms”, *American Economic Review* 94(1): 300-316.

Helpman, Elhanan, Marc Melitz, and Yona Rubinstein (2008), “Estimating Trade Flows: Trading Partners and Trading Volumes”, *Quarterly Journal of Economics* 123:2, 441-487.

Hummels, David, 1999, “Have International Transportation Costs Declined?”, http://www.mgmt.purdue.edu/faculty/hummelsd/

Hummels, David, and Peter Klenow, 2005, “The Variety and Quality of a Nation’s Exports”, *American Economic Review* 95(3): 704-723 (June).

Hummels, David, and Alexandre Skiba, 2004, “Shipping the Good Apples Out? An Empirical Confirmation of the Alchian-Allen Conjecture”, *Journal of Political Economy* 112(6): 1384-1402.

Johnson, Robert C., 2008, “Trade and Prices with Heterogeneous Firms”, http://emlab.berkeley.edu/econ/grad/students/johnson_r.shtml.

Khandelwal, Amit, 2007, “The Long and Short (of) Quality Ladders”, http://www0.gsb.columbia.edu/faculty/akhandelwal/research.html.

Kugler, Maurice, and Eric Verhoogen, 2008, “Product Quality at the Plant Level: Plant Size, Exports, Output Prices and Input Prices in Colombia”, http://www.columbia.edu/~ev2124/

Melitz, Marc, 2003, “The impact of trade on intraindustry reallocations and aggregate industry productivity”, *Econometrica* 71(6): 1695-1725 (November).

Marc J. Melitz and Gianmarco I. P. Ottaviano, 2008, Market Size, Trade, and Productivity, *Review of Economic Studies* 75, 295–316.

Micco, Alejandro and Tomas Serebrisky, 2006, “Competition regimes and air transport costs: The effects of open skies agreements”, *Journal of International Economics* 70(1): 25-51 (September).

Murphy, Kevin, and Andrei Shleifer, 1997, “Quality and Trade”, *Journal of Developmental Economics* 53: 1-15.

Ottaviano G., T. Tabuchi, and J. Thisse, 2002, “Agglomeration and Trade Revisited” *International Economic Review* 43(2): 409-436 (May).

Schott, Peter K., 2004, “Across-product versus within-product specialization in international trade”, *Quarterly Journal of Economics* 119(2)*:*647-678 (May).

Sutton, John, 2007, “Quality, trade, and the moving window: the globalisation process”, *The Economic Journal* 117 (November): F469-F498.

Verhoogen, Eric, 2008, “Trade, quality upgrading, and wage inequality in the Mexican manufacturing sector”, *Quarterly Journal of Economics* 123 (2): May.

Wooldridge, Jeffrey W., 2006, “Cluster sample methods in applied econometrics: an extended analysis”, http://www.msu.edu/~ec/faculty/wooldridge/current%20research.htm.

Yeaple, Stephen Ross, 2005, “A simple model of firm heterogeneity, international trade, and wages.” *Journal of International Economics* 65(1): 1-20.

Table 1 - Summary of model predictions

| | Pr(export zero) | | f.o.b. export price | |
|---|---|---|---|---|
| | distance | importer size | distance | importer size |
| Eaton-Kortum | + | + | - | 0 |
| Monopolistic competition, CES | n/a | n/a | 0 | 0 |
| Monopolistic competition, linear demand | + | 0 | - | 0 |
| Heterogeneous firms, CES | + | - | - | + |
| Heterogeneous firms, linear demand | + | + | - | - |
| Heterogeneous firms, quality competition | + | - | + | - |

**Notes to Table 1** The first five rows of the table summarize the theoretical comparative static predictions discussed in Section 2, with the last row giving the predictions of the model that we develop in Section 4. The six models under discussion are listed in the first column. Each entry reports the effect of an increase in distance or importer size on the probability of an export zero or f.o.b. export price. An export zero is defined to occur when a country exports a good to one country but not all.

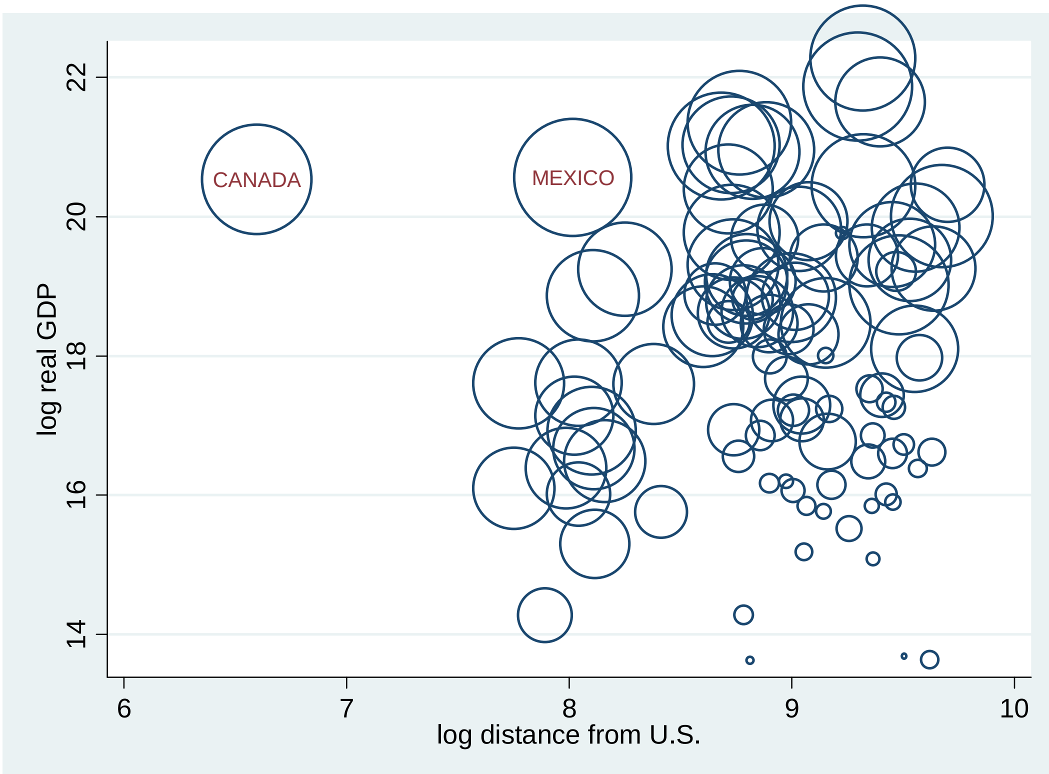
Table 2 - Incidence of zeros in U.S. trade, 2005

| | Imports | Exports |
|---|---|---|
| *all countries* | | |
| Trading partners | 228 | 230 |
| HS10 products | 16,843 | 8,880 |
| partners × products | 3,840,204 | 2,042,400 |
| percent zeros | 92.6 | 82.2 |
| *100 largest countries* | | |
| HS10 products | 16,843 | 8,880 |
| partners × products | 1,684,300 | 888,000 |
| percent zeros | 85.5 | 70.0 |

# Table 3 - Countries classified by distance from United States

| country | km | country | km |
|---|---|---|---|
| Canada | 0 | Mexico | 0 |
| 1-4000km | | | |
| Jamaica | 2326 | Costa.Rica | 3300 |
| DominicanRep | 2376 | Venezuela | 3317 |
| Belize | 2670 | Panama | 3341 |
| Honduras | 2936 | Barbados | 3345 |
| El.Salvador | 3049 | TrinidadTobago | 3501 |
| Guatemala | 3110 | Colombia | 3829 |
| Nicaragua | 3115 | | |
| 4000-7800km | | | |
| Ecuador | 4357 | Gambia | 6535 |
| Iceland | 4518 | Switzerland | 6607 |
| Ireland | 5448 | Sweden | 6641 |
| Peru | 5671 | Guinea.Bissau | 6730 |
| Portugal | 5742 | Brazil | 6799 |
| United.Kingdom | 5904 | Algeria | 6800 |
| Spain | 6096 | Finland | 6938 |
| Morocco | 6109 | Guinea | 7050 |
| France | 6169 | Austria | 7130 |
| Netherlands | 6198 | Poland | 7183 |
| Belgium-Lux | 6221 | Italy | 7222 |
| Bolivia | 6235 | Mali | 7328 |
| Norway | 6238 | Hungary | 7344 |
| Senegal | 6379 | Tunisia | 7347 |
| Germany | 6406 | Paraguay | 7421 |
| Denmark | 6518 | | |
| 7800-14000km | | | |
| Burkina.Faso | 7908 | Japan | 10910 |
| Bulgaria | 7920 | China | 11154 |
| Romania | 7985 | Korea | 11174 |
| Chile | 8079 | Pakistan | 11389 |
| Niger | 8146 | Yemen | 11450 |
| Cote.D'Ivour | 8175 | Ethiopia | 11530 |
| Greece | 8261 | Rwanda | 11629 |
| Argentina | 8402 | Burundi | 11670 |
| Uruguay | 8488 | Uganda | 11679 |
| Ghana | 8488 | India | 12051 |
| Togo | 8572 | Kenya | 12152 |
| Benin | 8669 | Nepal | 12396 |
| Turkey | 8733 | Zambia | 12400 |
| Nigeria | 8737 | South.Africa | 12723 |
| Chad | 9351 | Tanzania | 12759 |
| Egypt | 9358 | Malawi | 12781 |
| Syria | 9445 | Zimbabwe | 12835 |
| Israel | 9452 | Bangladesh | 12943 |
| Jordan | 9540 | Hong.Kong | 13129 |
| Cameroon | 9622 | Mozambique | 13428 |
| Gabon | 9686 | Comoros | 13442 |
| Iran | 10190 | Philippines | 13793 |
| Congo | 10515 | | |
| over 14000km | | | |
| New.Zealand | 14098 | Mauritius | 15224 |
| Thailand | 14169 | Malaysia | 15350 |
| Madagascar | 14291 | Australia | 15958 |
| Sri.Lanka | 14402 | Indonesia | 16371 |
| Seychelles | 15095 | | |

Figure 1 - Positive trade flows, distance, and market size




**Notes to Figure 1**: Each circle in the plot represents a U.S. export market, and the size of the circle is proportional to the number of HS10 products exported by the U.S. to that destination in 2005. Distance is measured as kilometers between Chicago and the capital city of each country.

Table 4 - Statistical determinants of non-zero U.S. exports, 2005

| | linear probability model | | random effects probit model | |
|---|---|---|---|---|
| | coefficient | *t*-statistic | marginal eff. | *t*-statistic |
| *full sample* | | | | |
| 1 < km ≤ 4000 | -0.079 | *-0.83* | 0.040 | *9.74* |
| 4000 < km ≤ 7800 | -0.335 | *-3.82* | -0.238 | *-67.6* |
| 7800 < km ≤ 14000 | -0.341 | *-3.88* | -0.273 | *-65.4* |
| 14000 < km | -0.316 | *-3.33* | -0.160 | *-63.5* |
| landlocked | -0.017 | *-0.55* | -0.036 | *-21.4* |
| log real GDP | 0.080 | *10.0* | 0.101 | *90.9* |
| log real GDP/worker | 0.054 | *3.78* | 0.087 | *80.9* |
| *manufactured goods only* | | | | |
| 1 < km ≤ 4000 | -0.021 | *-0.22* | 0.072 | *11.3* |
| 4000 < km ≤ 7800 | -0.295 | *-3.35* | -0.268 | *-56.3* |
| 7800 < km ≤ 14000 | -0.311 | *-3.53* | -0.311 | *-55.1* |
| 14000 < km | -0.287 | *-3.00* | -0.196 | *-55.1* |
| landlocked | -0.018 | *-0.55* | -0.041 | *-17.6* |
| log real GDP | 0.086 | *10.2* | 0.121 | *87.9* |
| log real GDP/worker | 0.062 | *4.02* | 0.103 | *75.8* |

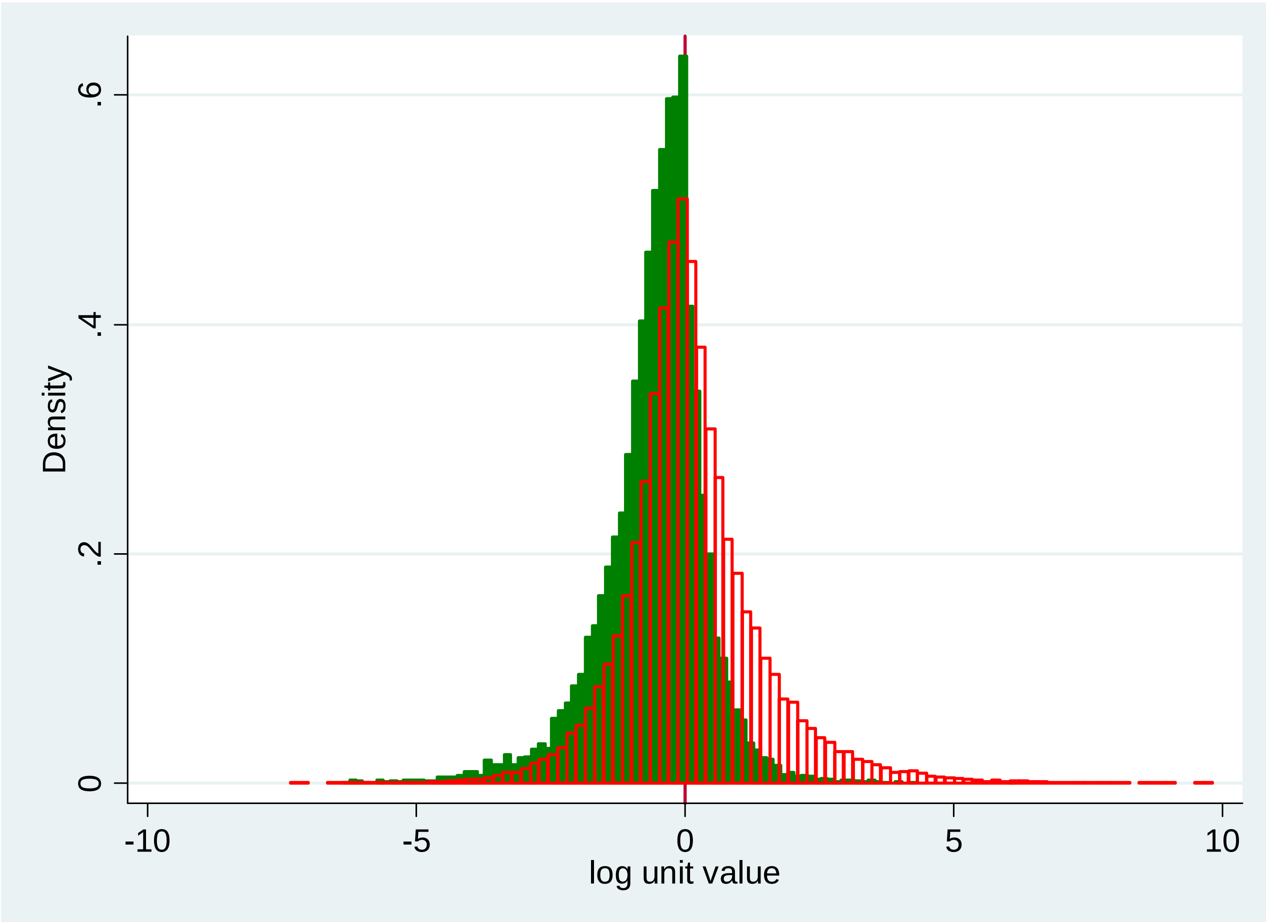
**Notes to Table 4**: Dependent variable is indicator for non-zero exports of HS10 products. Independent variables are characteristics of U.S. export destinations. Estimator for linear probability model is two way error components, with HS10 product fixed effects and random country effects. Robust *t*-statistics in *italics*. Estimator for random effects probit is maximum likelihood, with product random effects. Panel dimensions are 8,800 products and 100 countries for full sample, 5,834 products and 100 countries for manufactured goods only sample.

Table 5 - Statistical determinants of U.S. export unit values, 2005

| | *unrestricted sample* | | | *value ≥ $10,000* | | | *number ≥ 2* | |
|---|---|---|---|---|---|---|---|---|
| | *all* | *manuf.* | *kilos* | *all* | *manuf.* | *kilos* | *all* | *manuf.* |
| 1 < km ≤ 4000 | 0.078 | 0.095 | 0.175 | 0.064 | 0.038 | 0.189 | 0.253 | 0.266 |
| | *1.36* | *1.17* | *2.74* | *1.27* | *0.53* | *3.57* | *2.35* | *2.36* |
| 4000 < km ≤ 7800 | 0.724 | 0.814 | 0.729 | 0.647 | 0.727 | 0.628 | 0.840 | 0.853 |
| | *17.2* | *13.1* | *15.4* | *18.5* | *14.1* | *16.9* | *9.39* | *9.02* |
| 7800 < km ≤ 14000 | 0.670 | 0.793 | 0.656 | 0.600 | 0.707 | 0.557 | 0.816 | 0.830 |
| | *13.7* | *11.3* | *12.3* | *14.7* | *11.9* | *13.3* | *8.61* | *8.29* |
| 14000 < km | 0.616 | 0.741 | 0.628 | 0.524 | 0.623 | 0.534 | 0.743 | 0.759 |
| | *10.6* | *8.93* | *9.94* | *10.4* | *8.45* | *10.3* | *6.63* | *6.49* |
| landlocked | 0.049 | 0.021 | 0.180 | 0.065 | 0.046 | 0.164 | -0.109 | -0.109 |
| | *0.73* | *0.25* | *2.48* | *0.95* | *0.49* | *2.41* | *-1.23* | *-1.23* |
| log real GDP | -0.091 | -0.103 | -0.049 | -0.073 | -0.092 | -0.022 | -0.085 | -0.086 |
| | *-10.8* | *-8.89* | *-5.41* | *-9.17* | *-8.16* | *-2.61* | *-6.18* | *-6.19* |
| log real GDP/ worker | -0.020 | -0.058 | 0.080 | -0.009 | -0.054 | 0.101 | -0.092 | -0.091 |
| | *-1.14* | *-2.45* | *4.14* | *-0.56* | *-2.31* | *5.85* | *-3.39* | *-3.37* |
| num. products | 8,880 | 4,908 | 4,626 | 7,831 | 4,886 | 4,582 | 2,370 | 2,322 |
| number of obs | 218,025 | 150,077 | 112,537 | 181,020 | 123,547 | 92,085 | 80,519 | 79.892 |

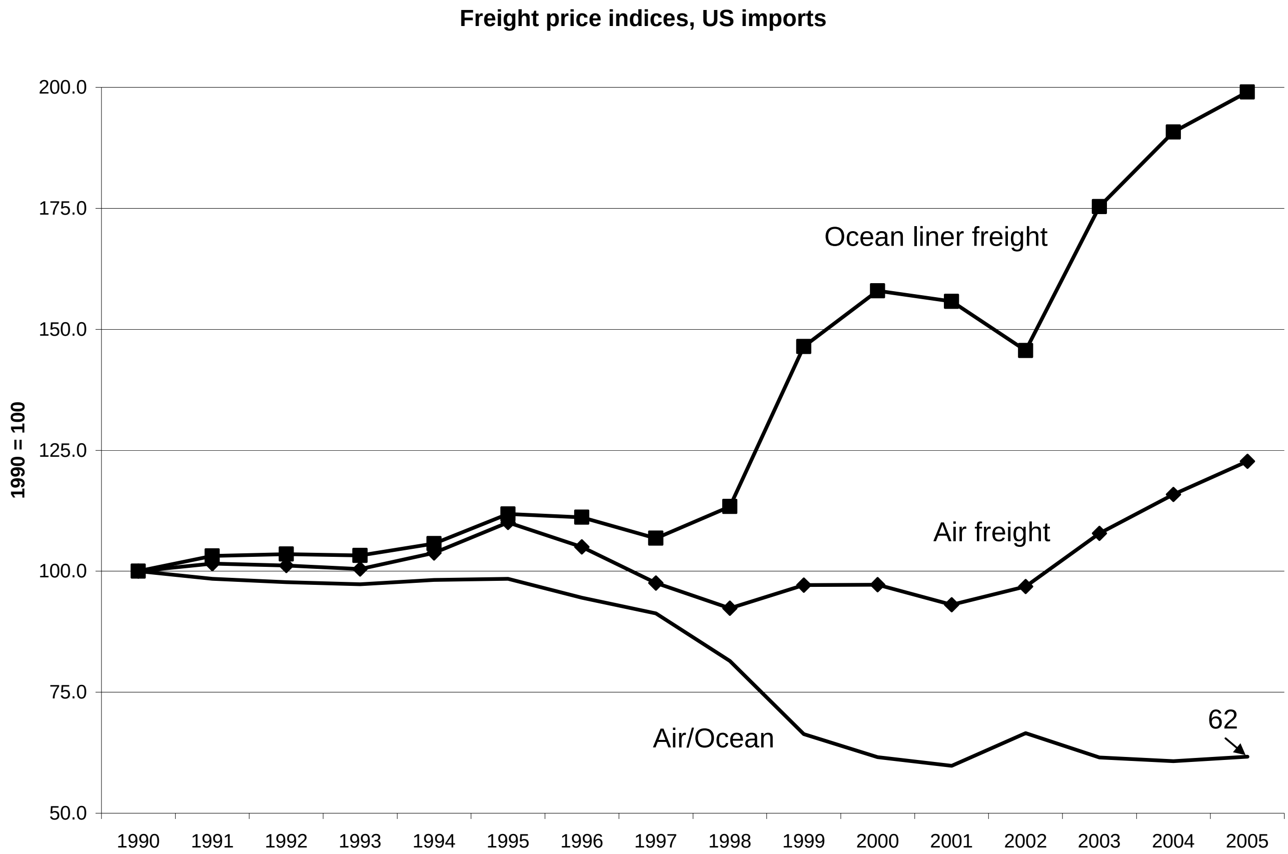
**Notes to Table 5**: Dependent variable is log unit value of exports by HS10 product and export destination. Independent variables are characteristics of export destinations. Estimator is two way error components, with HS10 product fixed effects and random country effects. Robust *t*-statistics in *italics*. See text for discussion of different subsamples.

Figure 2- Distributions of unit values by distance




**Notes to Figure 2**: Data are log U.S. export unit values by HS10 and export destination, relative to HS10 means. The green/solid histogram shows the distribution of log unit values to Canada and Mexico, and the red/unfilled histogram shows the distribution to countries between 4000km and 7800km from the U.S.

Figure 3




Source: Bureau of labor Statistics, authors' calculations.

Table 6 - Air shipment and export zeros, 1990 to 2005

| | number (%) | % air shipped 2005 |
|---|---|---|
| exports > 0 in 2005, of which | 197,959 (100) | 36 |
| old: exports > 0 in 1990 | 114,185 (58) | 34 |
| new: exports = 0 in 1990 | 83,774 (42) | 39 |

**Notes to Table 6**: Data is count of non-zero HS6 export flows in 2005, subdivided into "old" and "new" export flows, where "old" is defined as a non-zero flow in 1990 and "new" is a zero flow in 1990

Table 7 - Probability models for air shipment and export zeros, 1990 to 2005

| | coefficient on air indicator | marginal effect |
|---|---|---|
| all models include country fixed effects | | |
| Probit | 0.0262 | 0.01 |
| | *3.73* | |
| Logit | 0.0447 | 0.01 |
| | *3.79* | |
| Linear | 0.00798 | 0.008 |
| | *3.79* | |
| Linear, product fixed effects | 0.0246 | 0.025 |
| | *10.74* | |

**Notes to Table 7**: Dependent variable is indicator for new trade flow in 2005, independent variable is indicator for air shipment in 1995. Robust *t*-statistics are in *italics*. Sample size is 197,959 for the linear probability models, and 186,635 for the probit and logit models (the difference arises because the logit and probit models drop the 46 countries for which there is no variation across goods in the dependent variable).

*NOT FOR PUBLICATION*

# APPENDIX FOR "ZEROS, QUALITY AND SPACE: TRADE THEORY AND TRADE EVIDENCE"

Richard Baldwin and James Harrigan,

original version June 2007; this version, March 2009.

This appendix provides a more complete treatment of the models discussed in the paper.

## 1.1. Comparative advantage: Eaton-Kortum

The slightly simplified version of the Eaton-Kortum (EK) model that we work with has *C* nations each of which is endowed with a single factor of production (labor) used to produce a continuum of goods under conditions of perfect competition and constant returns. The transport costs between a typical origin nation (nation-*o*) and a typical destination nation (nation-*d*) are assumed to be of the iceberg type $\tau_{od} \geq 1$ where $\tau_{od}$ is the amount of the good that must be shipped from *o* to sell one unit in *d*. The double-subscript notation follows the standard 'from-to' convention, so $\tau_{oo} = 1$ for all nations (intra-nation trade costs are zero). Consumer preferences are identical across nations and defined over the continuum of goods. They are described by a CES utility function, and expenditure on any typical variety-*j* by a typical destination nation (nation-*d*) is

$$p_d(j)c_d(j) = \left(p_d(j)\right)^{1-\sigma} B_d; \qquad B_d \equiv \frac{E_d}{P_d^{1-\sigma}}, \quad P_d \equiv \left( \int_{j\in\Theta} \left(p_d(j)\right)^{1-\sigma} dj \right)^{\frac{1}{1-\sigma}} \tag{A1}$$

where $c_d(j)$ and $p_d(j)$ are nation-*d*'s consumption and consumer price of good-*j*, $P_d$ is the ideal CES price index, $E_d$ is total expenditure (GDP in equilibrium), and $\sigma$ is the elasticity of substitution among varieties. Without loss of generality, we order product indices such that the set of available goods $\Theta$ equals the unit interval.

Each nation's manufacturing technology – its' vector of unit labor input coefficients – comes from a stochastic technology-generation process much like the one used later by Melitz (2003). In the EK model, this exogenous process is costless and realizations are drawn before the analysis opens.

Denoting nation-$o$'s unit labor coefficient for good-$j$ as $a_o(j)$, the model assumes that each $a_o(j)$ is an independent draw from the nation-specific cumulative distribution function (cdf)[1]

$$F_o[a] = 1 - e^{-T_o a^\theta}, \quad a \geq 0 \tag{A2}$$

where $T_o > 0$ is a technology parameter that differs across countries. The expectation of $a_o(j)$ is $T^{-1/\theta}\Gamma\left[1+\frac{1}{\theta}\right]$, where Γ is the gamma function, so $T_o$ can be thought of as nation-$o$'s average absolute advantage parameter, i.e. its technology level. Importantly, the draws are independent across goods and nations.

Although all nations can make all goods, perfect competition means only the lowest cost supplier actually sells in destination $d$. The price that each nation-$o$ could offer for good-$j$ in destination nation-$d$ is:

$$p_{od}(j) = \tau_{od} w_o a_o(j) \tag{A3}$$

where $w_o$ and $a_o(j)$ are nation-$o$'s wage and unit labor coefficient in good-$j$, respectively. Perfect competition implies that the equilibrium price for good-$j$ in nation-$d$ satisfies:

$$p_d(j) = \min_{o=1\ldots C} \tau_{od} w_o a_o(j) \tag{A4}$$

***Finding comparative advantage***

The next step is to find the probability that a particular nation is the lowest cost supplier in a particular good in a particular market. This task involves a series of probability calculations that use two implications of (A2) and (A3). First, the cdf of $p_{cd}(j)$ is $G_{cd}[p] = 1 - \exp(-p^\theta T_{cd})$ where $T_{cd} \equiv T_c(w_c\tau_{cd})^{-\theta}$.[2] Thus the probability that $p_{cd}(j) > k$ equals $\exp(-k^\theta T_{cd})$. Second, $p_{od}(j)$ is lower than the offer price of all other nations with probability 1 minus the probability that all other prices are higher. Since all draws of the $a$'s are independent across nations, the probability that all other prices are

[1] EK work with firm productivity as the random variable rather than the standard Ricardian labour input coefficient, namely $z = 1/a$, so their cdf is $\exp(-T/z^\theta)$.

[2] Dropping subscripts where clarity permits, $\Pr(p \leq k) = \Pr(aw\tau \leq k) = \Pr\left(a \leq \frac{k}{w\tau}\right) = 1 - \exp\left(-T\left(\frac{k}{w\tau}\right)^\theta\right)$, where $k$ is an arbitrary price level. Noting that this holds for all $k$ and the supports of $p$ and $a$ are identical, we get the result in the text.

higher is $\prod_{c\neq o}\exp\left(-p_{cd}{}^{\theta}T_{cd}\right)$, which simplifies to $\exp\left(-p_{od}^{\theta}\left(\sum_{c\neq o}T_{cd}\right)\right)$. Since $p_{od}(j)$ is just one of many offer-prices that nation-*o* may have drawn, we must integrate over all possible $p_{od}(j)$, weighting each by its probability. Thus the probability of nation-*o* having a comparative advantage in good-*j* in market *d* is $\int_0^{\infty}\exp\left(-p_{od}^{\theta}\left(\sum_{c\neq o}T_{cd}\right)\right)dG_{od}[p]$ where $G_{od}[p]=1-\exp(-p^{\theta}T_{od})$. Solving the integral,

$$\pi_{od}=\frac{T_{od}}{\Delta_d};\qquad\qquad \Delta_d\equiv\sum_{c=1}^{C}T_{cd}\qquad\qquad\text{(A5)}$$

Here $\pi_{od}$ is the probability that nation-*o* exports any given good-*j* to nation-*d*. Since the technology draws are independent across goods, $\pi_{od}$ applies to each good in the continuum of goods $j\in[0,1]$. Notice that $\Delta_d$ is akin to the inverse of the remoteness variable in standard gravity equations, i.e. it is an inverse index of the distance between nation-*d* and its trade partners, assuming that trade costs rise with distance.

Given the complexity of the model, it is remarkable that the expression for 'stochastic comparative advantage', $\pi_{od}$, is so simple and intuitive. Thinking of the $T_{id}$'s as the expected competitiveness of nation-*i*'s goods in nation-*d*'s market, the probability that nation-*o* is the most competitive in any given good is just the ratio of nation-*o*'s expected competitiveness to that of the sum of all nations. Notice that the probability $\pi_{od}$ falls as the bilateral trade costs rises but rises with nation-*o*'s average absolute advantage parameter, $T_o$. As we shall see, expression (A5) is the key to characterizing the spatial pattern of zeros in the EK model.

### *Finding the equilibrium prices*

To characterize the predictions for the spatial pattern of prices, we draw on two further implications of (A2) and (A3). First, with all draws independent across nations, the probability that we have $p_{cd}(j) > k$ for all origin-nations equals $\prod_{c=1}^{C}\exp\left(-k^{\theta}T_{cd}\right)$, which simplifies to $\exp\left(-k^{\theta}\Delta_d\right)$. Second, the probability of at least one nation having a $p_{cd}(j) < k$ is 1 minus the probability that $p_{cd}(j) > k$ for all nations, or $1-\exp\left(-k^{\theta}\Delta_d\right)$.[3]

Since we do not know each nation's actual *a*'s, we cannot determine the price for any given good. Rather we find the distribution of the prices nation-*d* pays for a typical good. Due to competition, the price paid – i.e. the equilibrium price – is the lowest offer price as described by (A4). By definition, the cdf that describes the equilibrium price gives the probability that the equilibrium price is less than or equal to any particular level. To find the distribution that describes this 'lowest price', we use $F_{cd}[p]=1-\exp(-p^{\theta}T_{cd})$ and the independence of prices across goods and suppliers. Specifically, the probability that all $p_{od}(j)$'s are greater than an arbitrary level $p_d$ is $\exp\left(-p_d{}^{\theta}\Delta_d\right)$, so the probability that at least one $p_{od}(j)$ is below $p_d$ is $1-\exp\left(-p_d{}^{\theta}\Delta_d\right)$. This holds for all possible $p_d$ and for any good-*j* so the nation-specific distribution that describes the equilibrium price for any good is

$$G_d[p]=1-\exp\left(-p^{\theta}\Delta_d\right) \tag{A6}$$

Because each good's *a* is identically and independently distributed, $G_d[p]$ describes the price distribution for any nation-*d*, $d=1,\ldots,C$ for any good $j \in [0,1]$.

Using (A1), (A6) and switching the variable of integration, it is easy to find the equilibrium CES price index for nation-*d*, namely $P_d{}^{1-\sigma}$ which is defined as $\int_{i\in\theta}\left(p_d(i)\right)^{1-\sigma} di$. As noted, we cannot determine the equilibrium price of any given good-*j*, but we know its cdf to be (A6). Moreover, with a continuum of varieties (which implies an infinite number of draws from $G_d[p]$), we know that the distribution of equilibrium prices across all varieties is identical to the underlying distribution $G_d[p]$ for any given variety. This means that $P_d{}^{1-\sigma} = \int_0^{\infty} p^{1-\sigma} dG_d[p]$. Solving the integral,

$$P_d = \Delta_d^{-1/\theta}\left(\Gamma\left[\frac{1-\sigma+\theta}{\theta}\right]\right)^{1/(1-\sigma)} \tag{A7}$$

---

[3] $\Pr\left(p_{cd} > k\right) = 1-\left(1-\exp\left(\frac{-T_c k^{\theta}}{w_c \tau_{cd}}\right)\right) = \exp\left(\frac{-T_c k^{\theta}}{w_c \tau_{cd}}\right)$. Since the draws are independent, the joint probability that they are all higher is $\prod_{c=1}^{C}\exp\left(\frac{-T_c k^{\theta}}{w_c \tau_{cd}}\right)$. Simplification yields the result in the text.

where the term in large parenthesis is the gamma function. This requires that the regularity condition 1 - $\sigma$+ $\theta$ > 1 holds.

The final task is to determine the distribution of prices for the goods that nation-*o* exports to nation-*d*. Since the probability of nation-*o* exporting any particular good to nation-*d* is $\pi_{od}$ for all goods, the goods that nation-*o* actually exports to *d* is a random sample of all the goods that *d* buys. Thus, $G_d[p]$ also describes the cross-good distribution of the prices for the exports from every origin nation to nation-*d*. This elegant and somewhat surprising result follows from the fact that it is competition inside nation-*d* that determines prices, not the characteristics of any particular exporting nation. Successful exporting countries sell a large number of goods but do not on average charge lower prices. As we shall see, this result is the key to characterizing the spatial price implications in the EK model.

### *Linking export probability to observables*

It is impossible to analytically solve the EK model for general trade costs. The reason is that all nations' wages enter the system non-linearly, so we cannot use market clearing conditions to determine what wage a nation must have in order to sell all its output. More specifically, every $T_{cd}$ contains the inverse of the wage of nation-*c*. This, together with the form of $\pi_{od}$ means that each $\pi_{od}$ is of order *C* in each wage. While solutions exist for $C \leq 5$, in practice the solution even for a pair of quadratic equations is typically too complicated to be useful. One can, however, easily find the wages in the case of autarky and free trade, as EK show. Without explicit solutions for the *w*'s, we cannot find a closed form solution for $\pi_{od}$ and thus we cannot solve the precise pattern of zeros predicted by the model. Although this is a major drawback for a theoretical investigation, it poses no problems for our empirical work. We use data from a single exporting nation for a single year so all identification comes from the spatial variation in the data which occurs regardless of the level of wages.

We can link the $T_{od}$'s and thus the $\pi_{od}$'s to observable variables that allow estimation of the impact of distance and destination market-size on the probability of observing a zero. To this end, we specify the market-clearing condition for each origin nation. The share of nation-*d*'s total expenditure on manufactures from nation-*o* is $\pi_{od}$ times $E_d$, where $E_d$ is *d*'s total expenditure on manufactures. Rearranging yields a version of EK's expression 10, namely

$$V_{od} = \pi_{od} E_d \qquad \text{(A8)}$$

where $V_{od}$ is the value of all exports from nation-$o$ to nation-$d$, and $E_d$ is nation-$d$'s expenditure.[4] Nation-$o$'s market clearing condition is the summation of (A8) over all destination nations. Using (A5), the total sales of nation-$o$ to all markets (including its own) equals the value of its total output, $Y_o$ i.e. GDP, when[5]

$$Y_o = \frac{T_o}{w_o^{\theta}} \left( \sum_{d=1}^{N} \tau_{od}^{-\theta} \Delta_d^{-\theta} E_d \right) \qquad \text{(A9)}$$

Solving (A9) for $T_o/w_o^{\theta}$, using the definitions in (A5), and substituting out the Δ's using (A7), noting that the gamma functions cancel, we get

$$\pi_{od} = \frac{Y_o \tau_{od}^{-\theta} P_d^{\theta}}{\tau_{od}^{-\theta} E_d P_d^{\theta} + \sum_{c \neq d} \tau_{cd}^{-\theta} E_c P_c^{\theta}} \qquad \text{(A10)}$$

This explains equation (5) in the main text, taking expenditure $E$ and income $Y$ as equal in each nation.

## 1.2. Monopolistic competition

Our version of the monopolistic competition model has $C$ countries and a single primary factor $L$ that is used in the production of differentiated goods (manufactures) whose trade is subject to iceberg trade costs. Preferences are CES, so expenditure on manufactured good-$j$ in typical nation-$d$ is given by (A1).

Manufactured goods are produced under conditions of increasing returns and Dixit-Stiglitz monopolistic competition. Unlike the EK model, all firms in all countries face the same unit labor requirement, $a$. According to well-known properties of Dixit-Stiglitz monopolistic competition, nation-$o$ firms charge consumer (i.e. c.i.f.) prices in nation-$d$ equal to $p_{od} = \frac{\sigma}{\sigma - 1} w_o a \tau_{od}$. Consequently, the shipping (f.o.b.) price for any good is the same for every bilateral trade flow. The CES price index for typical nation-$d$ involves the integral over all prices

$$P_d^{1-\sigma} = \sum_{c=1}^{C} \phi_{cd} n_c w_c^{1-\sigma}, \qquad \phi_{od} \equiv \tau_{od}^{1-\sigma} \in [0,1]$$

[4] Note that this is the expected expenditure of nation-$d$ on nation-$o$ goods, but since $o$ exports an infinite number of goods to $d$, the realisation will be identical to the expectation by the law of large numbers.

[5] This is related to EK's unnumbered expression between their expressions 10 and 11.

where we have, without loss of generality, chosen units such that $a = 1\text{-}1/\sigma$. The parameter $\phi_{od}$ reflects the 'freeness' of bilateral trade ($\phi$ ranges from zero when $\tau$ is prohibitive to unity under costless trade, i.e. $\tau = 1$). $n_c$ is the number of goods produced in $c$.

### 1.2.1. Free entry conditions

With Dixit-Stiglitz competition, a typical nation-$o$ firm's operating profit from selling in market-$d$ is[6]

$$\phi_{od} w_o^{1-\sigma} \frac{B_d}{\sigma} \qquad \text{(A11)}$$

Summing across all $C$ markets, total operating profit of a typical firm in nation-$o$ is $\frac{w_o^{1-\sigma}}{\sigma}\sum_{c=1}^{C}\phi_{oc}B_c$.

Developing a new variety involves a fixed set-up cost, namely an amount of labor $F_I$ ($I$ for innovation).[7] In equilibrium, free entry ensures that the benefit and cost of developing a new variety match, so the free-entry condition for nation-$o$ is

$$w_o^{1-\sigma}\sum_{c=1}^{C}\phi_{oc}B_c = w_o \sigma F_I \qquad \text{(A12)}$$

for all $o = 1,\ldots,C$. The equilibrating variables here are the per-firm demand shifters $B_d$ and the wage.

### 1.2.2. Employment condition and National budget constraint

In equilibrium, all labor must be employed. The amount of labor used per variety is $ax + F_I$, where $x$ is production of a typical good. Using the demand function, iceberg trade costs and equilibrium prices, the total production of a typical variety produced in $o$ is $\sum_{c=1}^{C}(\tau_{oc}w_o)^{-\sigma}B_c$. Solving the integral and using the expression for $P$, the full employment condition for typical nation-$o$ is:

$$n_o\left(\sum_{c=1}^{C}(\tau_{oc}w_o)^{-\sigma}B_c + F_I\right) = L_o \qquad \text{(A13)}$$

[6] Operating profit is proportional to firm revenue since the first order condition $p(1-1/\sigma)=a$ implies $(p-a)c$, equals $pc/\sigma$.
[7] To relate this model to the previous one and the next, it is as if a firm must pay $F_I$ to take a draw from the technology-generating distribution, but the distribution is degenerate, always yielding $a=1-1/\sigma$.

The final equilibrium expression requires that expenditure equals income. Since free entry eliminates pure profits, all income comes from labor income, and so equals $w_o L_o$. The national budget constraint is thus:

$$E_o = w_o L_o \qquad \text{(A14)}$$

### 1.2.3. **Equilibrium**

There are three endogenous variable here for each nation, *w*, *n* and *E* and three equilibrium conditions, the free entry, employment and national budget constraint conditions. As usual, the three equilibrium conditions – the free entry, employment and national budget constraint conditions – are not independent since we derived the demand equations imposing individual budget constraints. This redundancy allows us to drop one equilibrium condition and choose the labor of one nation as the numeraire.

Unfortunately, it is impossible to solve the model analytically for the same reason the EK model could not be solved – the wages enter the model in a highly non-linear manner. Specifically, we can use (A14) to eliminate the *E*'s and our expression for the price index to get the free entry condition in terms of the *n*'s and *w*'s only. Then we can use mill pricing to express the free-entry condition as $x_o = w_o^{-\sigma} F_I \sigma$, where $x_o$ is the output of a typical firm in nation-*o*, so that the employment condition becomes $n_o = L_o / \{F_I (w_o^{-\sigma}(\sigma - 1) + 1)\}$. This gives us two equations per nation in the *n*'s and *w*'s. However, the *w*'s enter these equations with non-integer powers and this renders analytic solutions impossible.

As before, this lack of tractability is not a problem for our empirics since we work with a single exporter and a single year of data. The key is that given the CES demand structure, the choke-point price is infinity so every importing nation will buy some of every variety produced by every nation. Moreover, given Dixit-Stiglitz monopolistic competition, mill pricing is optimal so the export (i.e. f.o.b.) price should be the same for every destination regardless of transportation costs.

### 1.2.4. **Aside: MC with an 'outside' sector**

A standard theoretical artifice yields analytic solutions pinning down the wage in all nations. The trick is to introduce a Walrasian sector whose output is costlessly traded. Assuming nations are similar enough in size for all nations to produce some of this 'outside' good, free trade equalizes wages globally. Choosing the outside good as numeraire and choosing its units such that its prices equals the wage, free trade equalizes all wages to unity worldwide. Under this artifice, the free entry condition for nation-*o* is

$$\sum_{c=1}^{C} \phi_{oc} B_c = \sigma F_I \qquad \text{(A15)}$$

The equilibrating variables here are the per-firm demand shifters $B_d$. The $C$ free-entry conditions are linear in the $B_d$'s and so easily solved.[8] In matrix notation

$$\mathbf{B} = \mathbf{\Phi}^{-1} \sigma F_I \qquad \text{(A16)}$$

where $\mathbf{\Phi}$ is an $C \times C$ matrix of bilateral trade freeness parameters (e.g., the first row of $\mathbf{\Phi}$ is $\phi_{11},\ldots,\phi_{1C}$), and $\mathbf{B}$ is the $C \times 1$ vector of $B_d$'s. This shows that the equilibrium $B$'s depend upon bilateral trade freeness in a complex manner; all the $\phi$'s affect every $B$. The complexity can be eliminated by making strong assumptions on trade freeness, e.g. imposing $\phi_{od}=\phi$ for all trade partners, but we retain arbitrary $\phi_{od}$'s. Importantly, the equilibrium $B$'s are completely unrelated to market size; they depend only upon the parameters of bilateral trade freeness. The deep economic logic of this has to do with the Home Market Effect; big markets have many firms since firms enter until the per-firm demand is unrelated to market size.[9]

We can characterize the equilibrium without decomposing the $\mathbf{B}$ into their components ($E$'s and $n$'s) but doing so is awkward because the $B$'s do not map cleanly into real world variables. The natural equilibrating variable – the mass of firms in each nation, $n_c$ – can be extracted from the $B$'s. Using the definition of the CES price index, Dixit-Stiglitz mark-up pricing and nation-wise symmetry of varieties, $P_d^{1-\sigma} = \sum_{c=1}^{C} n_c \phi_{cd}$. Using this, along with the definition of $B_d$ in (A1), we write the $C$ definitions of the $B$'s (with a slight abuse of matrix notation) as $\mathbf{\Phi}'\mathbf{n} = \mathbf{E}/\mathbf{B}$, where $\mathbf{n}$ is the $C \times 1$ vector of $n_c$'s and $\mathbf{E}/\mathbf{B}$ is defined as $(E_1/B_1, \ldots, E_C/B_C)$. Solving the linear system

[8] This solution strategy follows Behrens, Lamorgese, Ottaviano and Tabuchi (2004).

[9] In the terminology of Chamberlinian competition, the extent of competition rises until the residual demand curve facing each firm (i.e. $p^{-\sigma}B$) shifts in to the point where each firm is indifferent to entry. Since entry costs are identical in all markets, the residual demand-curve must be in the same position in every market.

$$\mathbf{n} = \mathbf{\Phi}'^{-1}\left[\frac{E_1}{B_1},\ldots,\frac{E_C}{B_C}\right] \qquad \text{(A17)}$$

Each $n_o$ directly involves all the $\phi$'s, all the $E$'s, and all the $B$'s (each of which involves all the $\phi$'s). Solutions for special cases are readily available, but plainly the equilibrium $n$'s are difficult to characterize for general size and trade cost asymmetries. The complexity of (A17) is the heart of the difficulties the profession has in specifying the Home Market Effect in multi-country models (see Behrens, Lamorgese, Ottaviano and Tabuchi 2004).

Notice that under this artifice, an increase in a nation's $L$ is fully offset by a rise in its $n$, so it $B$ remains unaffected. This can happen since labor can be drawn from the outside sector at a constant wage rate. In the baseline model without the outside good, the rise in $L$ results partly in a rise in $n$ and partly in a rise in $w$. Or, to put it differently, the Home Market Effect is much stronger in the model with the outside good since a rising wage does not dampen the profits of local firms.

### 1.3. A multi-nation asymmetric HFT model

Our HFT model embraces all of the demand, market-structure and trade cost features of the MC model above but adds in two new elements – beachhead costs (i.e. fixed market-entry costs) and hetero-generous marginal costs at the firm level. Firm-level heterogeneity is introduced – as in the EK model – via a stochastic technology-generation process. When a firm pays its standard Dixit-Stiglitz cost of developing the 'blueprint' for a new variety, $F_I$, it simultaneously draws a unit labor coefficient '$a$' associated with the blueprint from the Pareto cdf[10]

$$G[a] = \left(\frac{a}{a_0}\right)^{\kappa}, \qquad 0 \le a \le a_0 \qquad \text{(A18)}$$

After seeing its $a$, the firm decides how many markets to enter. Due to the assumed Dixit-Stiglitz market structure, the firm's optimal price is proportional to its marginal cost, its operating profit is proportional to its revenue, and its revenue in a particular market is inversely proportional to its relative price in the market under consideration.

[10] The EK and HFT models work well with a broad family of distributions, but the analytics are more transparent with an explicit distribution, e.g. either the Pareto or exponential distributions; the Pareto is traditional in HFT models. This formulation of the randomness differs trivially from Melitz, who, like EK, works firm-level efficiency (i.e. $1/a$).

### 1.3.1. **Cut-off conditions**

Thus, the cut-off conditions that define the maximum-marginal-cost thresholds for market-entry are

$$\phi_{od} B_d w_o^{1-\sigma} a_{od}{}^{1-\sigma} = w_o f; \qquad f \equiv \sigma F (1-1/\sigma)^{1-\sigma} \tag{A19}$$

for all $o$, $d$ = 1,…,$N$, where $F$ is the beachhead cost (identical all firms in all nations for notational simplicity). Here $B_d$ is defined as in (A1), and the endogenous $a_{od}$'s are the cut-off levels of marginal costs for selling from nation-$o$ to nation-$d$.

### 1.3.2. **The free entry conditions**

From the cut-off conditions, we know that not all blueprints will be produced. Thus the mass of blueprints in typical nation $o$ – what we call $m_o$ – exceeds the mass of produced varieties – what we call $n_o$ in line with standard MC model notation. Usual Dixit-Stiglitz results imply that the mass of blueprints rises to the point where potential entrants are just indifferent to sinking the development costs $w_oF_I$ and taking a draw from the technology-generating distribution (A18).

A potential entrant in $o$ knows the various $a$'s that may be drawn will result in different levels of operating profit. Before paying $w_oF_I$ to take a draw from (A18), the firm forms an expectation over all possible draws using its knowledge of the thresholds defined by (A19). The expected value of drawing a random $a$ is $\sum_{d=1}^{C} \int_0^{a_{od}} (\phi_{od} B_d w_o^{1-\sigma} a^{1-\sigma} - w_o f) dG[a] / \left(\sigma\left(1-1/\sigma\right)^{1-\sigma}\right)$. Here each term in the sum reflects the expected operating profit from selling to a particular market (net of the beachhead cost) taking account of the fact that the firm only finds it profitable to sell to the market if it draws a marginal cost below the market-specific threshold marginal cost, $a_{od}$. Potential entrants are indifferent to taking a draw when this expectation just equals the set-up cost, $w_oF_I$, so the free-entry conditions hold when $\sum_{d=1}^{C} \int_0^{a_{od}} (\phi_{od} B_d w_o^{1-\sigma} a^{1-\sigma} - w_o f) dG[a] = w_o F_I \sigma (1-1/\sigma)^{1-\sigma}$ for each nation $o$. Solving the integrals (assuming the regularity condition 1 - $\sigma + \kappa > 0$ so the integrals converge), the free-entry condition for nation-$o$ is

$$\sum_{d=1}^{C} \left(\frac{\phi_{od} B_d w_o^{1-\sigma} a_{od}^{1-\sigma}}{1-1/\beta} - w_o f\right) a_{od}^{\kappa} = w_o f_I; \qquad f_I \equiv F_I \sigma (1-1/\sigma)^{1-\sigma}, \quad \beta \equiv \frac{\kappa}{\sigma - 1} > 1$$

We use the cut-off conditions to write the free entry condition more simply as

$$f\sum_{d=1}^{N} a_{od}^{k} = (\beta - 1)\, f_I \tag{A20}$$

Here we have, without loss of generality, chosen units such that $a_0$ is unity.

### 1.3.3. Employment condition and National budget constraint

The labor demand arising from the sale of produced varieties in market-*d* is

$\int_0^{a_{od}} \left[ \left( \frac{w_o}{1-1/\sigma} \right)^{-\sigma} a^{1-\sigma} B_d + F \right] m_o dG[a]$. Solving the integral yields

$a_{od}^{\kappa} m_o \left[ \left( \frac{1-1/\sigma}{1-1/\beta} \frac{1}{w_o} \right) \left( \frac{w_o a_{od}}{1-1/\sigma} \right)^{1-\sigma} B_d + F \right]$. Using the cut-off condition, this simplifies to

$m_o F \left( \frac{\sigma\beta - 1}{\beta - 1} \right) a_{od}^{\kappa}$. Summing over the labor demand from sales to all markets, adding in the labor demand from developing new blueprints and setting this equal to the labor supply in nation *o*, the full employment condition is

$$m_o F \left( \frac{\sigma\beta - 1}{\beta - 1} \right) \sum_{d=1}^{C} a_{od}^{\kappa} + m_o F_I = L_o$$

Using the free entry condition this simplifies even further to

$$m_o = \frac{L_o}{\sigma\beta F_I}, \qquad o = 1, \ldots C \tag{A21}$$

Finally, the national budget constraint is just $E_o = w_o L_o$ since there are no pure profits in equilibrium (the pure profits earned by active firms just pays for the pure losses incurred by firms that abandon their blueprints and never produce).

### 1.3.4. Equilibrium

There are $C^2$ threshold $a_{od}$'s, and *C* *m*'s, *E*'s and *w*'s; these are determined by the $C^2$ cut-off conditions, *C* free entry conditions, employment conditions and national budget constraints. We can eliminate the *E*'s with the national budget constraints and lack of pure profit, and the *m*'s with (A21). This leaves $C^2$ cut-off thresholds and the *C* *w*'s to be determined from the $C^2$ cut-off conditions and the *C* free entry conditions. Since the *w*'s enter the cut-off and free-entry conditions with different non-integer powers, there is no analytic solution to the system. Numerical solutions, however, are readily available.

Simulation results (available upon request) demonstrate that the *B*'s for big nations (i.e. nations with high *L*'s) are larger than the *B*'s for small nations. Thus a nation's real GDP can be used as a proxy for its *B*.

### 1.3.5. Aside: Asymmetric HFT with an 'outside' sector

In earlier drafts of this paper, we worked with an outside sector. The result, as in the MC-with-outside-sector model considered above, was that the *B*'s are completely unrelated to market size. This implies that the threshold marginal costs are independent of market size and thus the number of export zeros should be independent of market size. Since this is clearly counterfactual (see Table 4), we decided to eliminate the theoretical artifice of an outside sector despite the fact that this modeling choice implies a lack of analytic solutions.

### 1.3.6. HFT's spatial pattern of zeros and prices

The spatial pattern of zeros comes from the cut-off thresholds. For a typical nation's export matrix, there should be more zeros with more distant partners. More formally, consider the firm that produces variety-*j* with marginal costs *a*(*j*). The probability of this firm exporting to nation-*d* is the probability that its marginal cost is less than the threshold defined in (A19), namely

$$\Pr\left\{a(j) < \frac{B_d^{1/(\sigma-1)}}{\tau_{od} w_o^{\sigma} f^{1/(\sigma-1)}}\right\} = \frac{B_d^{\beta}}{\tau_{od}^{\kappa} w_o^{\sigma\kappa} f^{\beta} a_0^{\kappa}} \qquad \text{(A22)}$$

where we used the Pareto distribution to evaluate the probability. In our empirics, we only have data on products that are actually exported to at least one market so it is useful to derive the expression for the conditional probability, i.e. the probability that a firm exports to market *j* given that it exports to at least one market. This conditional probability of exports from *o* to *d* by typical firm *j* is

$$\frac{\tau_{od}^{-\kappa} B_d^{\beta}}{\min_{c\neq o} \tau_{oc}^{-\kappa} B_c^{\beta}} \qquad \text{(A23)}$$

The wage drops out since we work with data for a single exporting nation. Again, for a typical exporting nation-*o*, the denominator is the same for all destination markets. As discussed in the previous subsection, market size in *d* will be positively related to GDP in *d*. Equation (A23) thus illustrates that the probability of a good being exported from nation-*o* depends positively on the destination nation's GDP and negatively on trade costs between *o* and *d*.

The spatial pattern of prices in the HFT model is also simple to derive. We consider both the export (f.o.b.) price for a particular good exported to several markets, and the average export (f.o.b.) price for all varieties exported by a particular nation. As the HFT model relies on Dixit-Stiglitz monopolistic competition, mill pricing is optimal for every firm, so the f.o.b. export price each good exported should be identical for all destinations. For example, export prices should be unrelated to bilateral distance and unrelated to the destination-nation's size. When it comes to the average export price – i.e. the weighted average of the f.o.b. prices of all varieties exported from nation-*o* to nation-*d* – the cut-off conditions imply $\bar{p}_{od} = \int_0^{a_{od}} \left( \frac{\tau_{od} w_o a}{1-1/\sigma} \right)^{1-\sigma} dG\left(a_{od} \mid a \le a_{oo}\right)$, where $\bar{p}_{od}$ is the average f.o.b. price. Solving the integral,

$$\bar{p}_{od} = \delta_o \tau_{od}^{-\kappa} \left( \frac{B_d}{f} \right)^{\frac{1+\kappa-\sigma}{\sigma-1}} \qquad \text{(A24)}$$

where $\delta_o$ is a function of parameters and country *o* variables only. Since the maximum marginal cost falls $a_{od}$ with bilateral distance, the average export price of nation-*o* varieties in nation-*d* should be lower for more distant trade partners.

### 1.3.7. **The Melitz-Ottaviano model**

Melitz and Ottaviano (2008) work with the Ottaviano, Tabuchi and Thisse (2002) monopolistic competition framework and assume *C* nations, a single factor of production, *L*, and iceberg trade costs. They do not allow for beachhead costs. Adopting the standard outside-good artifice to pin down wages, they assume that there are two types of goods: a costlessly traded Walrasian good that equalizes wages internationally, and differentiated goods produced under conditions of monopolistic competition and increasing returns. Nations can be asymmetric in terms of size (i.e. their *L* endowment) and location (i.e. the bilateral iceberg trade costs faced by their firms).

The Ottaviano *et al* framework assumes quasi-linear preferences and this generates a linear demand system where income effects have been eliminated. As usual in the monopolistic competition tradition, there are many firms each producing a single differentiated variety. Since the firms are small, they ignore the impact of their sales on industry-wide variables. Practically, this means that the producer of each differentiated variety acts as a monopolist on a linear residual demand curve. Indirectly, however, firms face competition since the demand curve's intercept declines as the number of competing varieties rises. Specifically, the residual demand curve in market-*d* facing a typical firm is:[11]

$$c_d(i) = \frac{L_d}{\gamma}\left(B_d - p_d(i)\right); \qquad B_d \equiv \frac{\alpha\gamma + P_d}{n_d^c + \gamma}; \quad P_d \equiv \int_{\Theta_d} p_d(j)dj \qquad \text{(A25)}$$

where $L_d$ is the number of consumers in *d* (and thus nation's labor supply since each person has one unit of labor), $B_d$ is the endogenous *y*-axis intercept (the per-firm demand shifter as in the HFT model), and $n_d^c$ is the mass of varieties consumed in *d* (since not all varieties are traded, we need a separate notation for the number of varieties produced and consumed). Finally, $P_d$ is the price index and $\Theta_d$ is the set of varieties sold in market-*d*. Inspection of (A25) reveals two channels thorough which a typical firm faces indirect competition: 1) a *ceteris paribus* increase in the number of varieties consumed, $n^c$, lowers the intercept *B*, and 2) a decrease in the price index *P* lowers the intercept.

The linear demand system makes this model extremely simple to work with. Atomistic firms take $B_d$ as given and act as monopolists on their linear residual demand curve. A monopolist facing a linear demand curve sets its price halfway between marginal cost and the intercept. Thus optimal prices are linked to heterogeneous marginal costs via

$$p_{od}[a] = \frac{B_d + a\,\tau_{od}}{2} \qquad \text{(A26)}$$

Here $p_{od}$ is the consumer (i.e. c.i.f.) price and $\tau_{oo} = 1$ for all nations *o*. The operating profit earned by a firm that sells to market-*d* is then

$$\pi_{od}[a] = \frac{L_d}{4\gamma}\left(B_d - a\tau_{od}\right)^2 \qquad \text{(A27)}$$

[11] The utility function for the representative consumer is $U = c_0 + \alpha\int_{\Theta} c(j)dj - \frac{\gamma}{2}\int_{\Theta} c(j)^2 dj - \frac{\eta}{2}\left(\int_{\Theta} c(j)dj\right)^2$ where $c_0$ is consumption of the numeraire and $c_j$ is consumption of variety *j*. We assume that each economy is large enough so that some numeraire is made and consumed in both nations regardless of trade barriers. To reduce notational clutter, we normalise $\eta = 1$ by choice of units (and thus without loss of generality).

### *Cut-off and free-entry conditions*

It is immediately obvious from (A25) that firms with marginal costs above the demand curve intercept $B_d$ find it optimal to sell nothing to market-$d$. This fact defines the $C^2$ cut-off conditions

$$a_{od} = \frac{B_d}{\tau_{od}}, \qquad \forall o, d = 1, ..., C \tag{A28}$$

Note that (A28) implies that export cut-offs into market $d$ are just a fraction of the domestic survival cut-off, $a_{od} = \frac{a_{dd}}{\tau_{od}}$. The expected operating profit in all markets to be earned from a random draw from $G[a]$ is $\frac{1}{4\gamma}\sum_{d=1}^{C} L_d \int_0^{a_{od}} \left(B_d - a\tau_{od}\right)^2 dG[a]$. The free entry condition is that this expected profit equals the entry cost $F_I$. Using (A28) to eliminate $B_d$, assuming the Pareto distribution (A18) for $G[a]$ and solving the integrals, and finally substituting $a_{od} = \frac{a_{dd}}{\tau_{od}}$, the free-entry condition is

$$\sum_{d=1}^{C} L_d \phi_{od} a_{dd}^{2+\kappa} = f_I, \qquad \phi_{od} \equiv \tau_{od}^{-\kappa}, \qquad f_I \equiv F_I 2\gamma(2+\kappa)(1+\kappa) \tag{A29}$$

for all $o = 1,\ldots C$. This is a system of $C$ equations in the $C$ domestic survival cutoffs $a_{dd}$. The $\phi$'s reflect the 'freeness' of bilateral trade, i.e. $\phi_{od} = 0$ corresponds to infinite trade costs ($\tau_{od} = \infty$) and $\phi_{od} = 1$ corresponds to free trade ($\tau_{od} = 1$). The system can be written in matrix notation as $\mathbf{L\Phi\tilde{A}} = f_I \boldsymbol{\iota}$, where $\mathbf{L} = diag\left[L_1, \ldots, L_C\right]$ is a $C \times C$ matrix with country sizes along the diagonal and zeros elsewhere, $\mathbf{\Phi}$ is a $C \times C$ symmetric positive definite[12] matrix with typical element $\phi_{od}$, $\mathbf{\tilde{A}} \equiv \left[a_{11}^{2+k}, ..., a_{CC}^{2+k}\right]^T$ is a $C \times 1$ vector of transformed domestic survival cutoffs, and $\boldsymbol{\iota}$ is a $C \times 1$ vector of ones. The solution for the $a_{dd}^{2+\kappa}$ terms is $\mathbf{\tilde{A}} = \mathbf{\Phi}^{-1}\mathbf{L}^{-1} f_I$. Denoting the $d$-th diagonal element of $\mathbf{\Phi}^{-1}$ as $\tilde{\phi}_d$, the equilibrium cut-offs are

$$a_{od} = \frac{1}{\tau_{od}}\left(\frac{\tilde{\phi}_d}{L_d}\right)^{\frac{1}{2+k}}, \qquad \forall o, d = 1, ..., C \tag{A30}$$

[12] Symmetry follows by $\tau_{od} = \tau_{do}$. A sufficient condition for non-singularity is that trade costs depend on distance, and that no two countries occupy the same point. Positive definiteness follows because the diagonal elements are 1 and the off-diagonal elements are between 0 and 1.

Using this and the optimal pricing rule in (A26) with the cutoff condition (A28), the equilibrium cif import prices are

$$p_{od}[a] = \frac{1}{2}\left(\left(\frac{\tilde{\phi}_d}{L_d}\right)^{\frac{1}{2+k}} + a\tau_{od}\right)$$

Weighted average f.o.b. export prices are computed by dividing $p_{od}[a]$ by bilateral trade costs, and integrating over the density of *a* conditional on exporting from *o* to *d*:

$$\overline{p}_{od} = \int_0^{a_{od}} \frac{p_{od}[a]}{\tau_{od}} dG\left(a \mid a \le a_{od}\right) = \frac{1+2\kappa}{(2+2\kappa)\tau}\left(\frac{\tilde{\phi}_d}{L_d}\right)^{\frac{1}{2+\kappa}} \qquad \text{(A31)}$$

***MO's spatial pattern of zeros and prices***

Inspection of (A30) and (A31) yield the predictions for zeros and prices. Expression (A30) shows that the threshold marginal cost falls with bilateral trade costs and with the size of the destination market[13]. Using these facts with the distribution of *a*'s, we see that zeros are more likely with partners that are distant and large. The counter-intuitive (and counter-factual) prediction for market size on zeros is an implication of the Home Market Effect; large markets have many local firms which implies more severe competition for foreign firms (i.e. a lower $P_d$ and thus lower $B_d$). Given this intuition for the cutoffs, expression (A31)is not surprising: average f.o.b. export prices are falling with bilateral distance and will be lower for partners with big markets.

## 1.4. The Quality HFT model

Here we lay out all the assumptions and solve the quality-based heterogeneous-firms trade model that was introduced in the text.

As usual, we assume a world with *C* nations and a single factor of production *L*. The goods produced consist of a continuum of goods that we refer to as manufactures. All goods are traded; labor is internationally immobile and inelastically supplied. CES preferences are as usual with one major difference, which is that consumers value "quality". The utility function is

[13] The bilateral thresholds for exporting to *d* also depend in a complex way on the full distribution of world transport costs through the term $\tilde{\phi}_d$ . In a world where all countries are equidistant, $\tilde{\phi}_d$ will not vary across countries.

$$U = \left(\int_{i\in\Theta} (c_i q_i)^{1-1/\sigma} di\right)^{1/(1-1/\sigma)}; \qquad \sigma > 1 \qquad \text{(A32)}$$

where $c$ and $q$ are the consumption and quality of a typical variety and Θ is the set of consumed varieties. The corresponding expenditure function for nation-*d* is

$$p_d(j)c_d(j) = \left(\frac{p_d(j)}{q(j)}\right)^{1-\sigma} B_d; \qquad B_d \equiv \frac{E_d}{P_d^{1-\sigma}}, \quad P_d \equiv \left(\int_{j\in\Theta} \left(\frac{p_d(j)}{q(j)}\right)^{1-\sigma} dj\right)^{\frac{1}{1-\sigma}} \qquad \text{(A33)}$$

where $\frac{p_d(j)}{q(j)}$ is the quality-adjusted price of good-*j*, *E* is expenditure, and *P* the CES index of quality-adjusted prices.

Manufacturing firms have constant marginal production costs and three types of fixed costs. The first fixed cost, $F_I$, is the standard Dixit-Stiglitz cost of developing a new variety. The second and third fixed costs are beachhead costs that reflect the one-time expense of introducing a new variety into a market. Its cost *F* units of *L* to introduce a variety into any market and potential manufacturing firms pay $F_I$ to take a draw from the random distribution of unit labor coefficients, the *a's*. By assumption, quality is linked to marginal cost (the *a*'s) by

$$q(j) = (a(j))^{1+\theta}, \qquad \theta > -1 \qquad \text{(A34)}$$

where $1+\theta$ is the elasticity of quality with respect to *a*. We could easily generalize the model by allowing a positive correlation between costs and quality, but doing so would raise the level of complexity without providing any compensating insight. The assumed distribution of the *a*'s is

$$G[a] = 1 - \left(\frac{a_0}{a}\right)^{\kappa}, \quad a_0 \le a \qquad \text{(A35)}$$

(This *G* is distinct from the one in the baseline HFT model.) Notice that it is necessary to flip the usual Pareto distribution for *a*'s to ensure that there are fewer high quality (i.e. high *a*) firms than low quality firms. Without loss of generality, we choose units of manufactures such that $a_0 = 1$.

At the time it chooses prices, the typical firm takes its quality and marginal cost as given, so it faces a demand that can be written as $\left(p(j)/q(j)\right)^{-\sigma} B_d$ where *q(j)* is its quality. Since *p* enters this in the standard way, the standard Dixit-Stiglitz results therefore obtain; mill-pricing with a constant markup, $\sigma/(\sigma\text{-}1)$, is optimal for all firms in all markets and operating profit is a constant fraction, $1/\sigma$, of firm revenue market by market. Using these facts, operating profit for a typical nation-*o* firm selling in nation-*d* is

$$\left(\frac{a^{-\theta}w_o}{1-1/\sigma}\right)^{1-\sigma}\frac{B_d}{\sigma} \tag{A36}$$

The only substantial difference between this and the corresponding expression for profits without quality differences is the $\theta$ in the exponent.

Plainly, the properties of this model depend crucially on how elastic quality is with respect to the unit input coefficient. For $\theta \in [-1,0)$, quality increases slowly with cost and the optimal quality-adjusted consumer price increases with cost. In this case, a firm's revenue and operating profit fall with its marginal cost. For $\theta > 0$, by contrast, quality increases quickly enough with marginal cost to ensure that the quality-adjusted price falls as *a* rises. The means that higher *a*'s are associated with higher operating profit. Henceforth we focus on the $\theta > 0$ case.

### 1.4.1. **Cut-off conditions**

The cut-off condition for selling to typical market-d is

$$\phi_{od} w_o^{1-\sigma} a_{od}{}^{\theta(\sigma-1)} B_d = w_o f \; ; \qquad f \equiv F\sigma(1-1/\sigma)^{1-\sigma} \tag{A37}$$

(This *f* is distinct from the *f* in the HFT model.) With $\theta > 0$, this tells us that only firms with sufficiently high-price/high-quality goods find it worthwhile to sell in a given market. Moreover, controlling for the per-firm demand, the threshold quality rises for more distant markets (since $\phi$ falls with distance). Notice that the $a_{od}(j)$'s here are minimum cost thresholds rather than maximums as in the standard HFT model.

### 1.4.2. **Free-entry conditions**

Turning to the free-entry conditions, a potential entrant pays $F_I$ to develop a new variety with a randomly assigned *a* and associated quality $a^{1+\theta}$. After observing its *a*, the potential entrant decides which markets to enter. In equilibrium, free entry drives expected pure profits to zero. The free entry condition for typical nation-*o* is

$$\sum_{d=1}^{N}\int_{a_{od}}^{\infty}(\phi_{od}w_o^{1-\sigma}a^{\theta(\sigma-1)}B_d - w_o f)dG[a] = w_o f_I\ ; \qquad f_I \equiv F_I\sigma(1-1/\sigma)^{1-\sigma}$$

Assuming the regularity condition $\theta(\sigma\text{-}1)\text{-}k < 0$, this solves to[14]

$$\sum_{d=1}^{N}\left(\frac{\phi_{od}w_o^{1-\sigma}B_d a_{od}{}^{\theta(\sigma-1)}}{1-1/\beta} - w_o f\right)a_{od}^{-\kappa} = w_o f_I\ ; \qquad f_I \equiv F_I\sigma(1-1/\sigma)^{1-\sigma}\ , \quad \beta \equiv \frac{k/\theta}{\sigma-1} > 1$$

Using the cut-off conditions as in the HFT model, the free entry condition is

$$f\sum_{d=1}^{N}a_{od}^{-\kappa} = (\beta-1)f_I \qquad \text{(A38)}$$

Inspection of the $N(N\text{-}1)$ equilibrium conditions defined by (A38) reveals that the QHFT model is isomorphic to the HFT model apart from the definition of the constants, powers and the fact that the $a_{od}$'s are minimums rather than maximums. Thus our analysis of the HFT model applies here directly and so need not be repeated.

One point that bares some study is the spatial implications for average prices. As in the HFT model, distance acts as selection device on varieties, but the highest priced variety are the most competitive, the basket of varieties sold in distant markets (controlling for $B_d$ of course) will have a higher average price than the basket for a near-by market. The impact of distance and market size on zeros, however, will be identical to that of the HFT model.

## Appendix Reference


Behrens, Kristian, Andrea Lamorgese, Gianmarco Ottaviano, and Takatoshi Tabuchi, 2004, "Testing the Home Market Effect in a Multi-Country World: The Theory," CEPR Discussion Papers 4468.


[14] The typical integral is $\int_{a_{od}}^{\infty}(\phi_{od}w_o^{1-\sigma}B_d a^{\theta(\sigma-1)} - w_o f)a_0^{-\kappa}\kappa a^{-\kappa-1}a_0^{\kappa}da$ . As long as $\theta(\sigma\text{-}1)\text{-}k<0$, this solves to $\left(\frac{\kappa\phi_{od}w_o^{1-\sigma}B_d a_{od}^{\theta(\sigma-1)}}{\kappa-\theta(\sigma-1)} - w_o f\right)a_{od}^{-\kappa}$ . Using the definition of β yields (A38).