Trade and Prices with Heterogeneous Firms*

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First Draft: November 2007
This Draft: October 2008

Abstract

This paper estimates a heterogeneous firms trade model using disaggregate data on export values and prices. Prices contain information about differences in product quality across firms and countries that helps identify key mechanisms in the model. Examining within-country variation in export prices across destination markets, I find that prices behave in a manner inconsistent with the benchmark model that ignores product quality differences across firms. In doing so, I demonstrate that export prices in most sectors are consistent with a model in which high productivity firms choose to produce high quality goods and charge high prices. Using model estimates, I also quantify the role of endogenous non-tradability in accounting for variation in prices and trade flows, and construct an index of cross-country quality and variety within sectors.

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*I am grateful to Pierre-Olivier Gourinchas for many productive discussions regarding this work. I also thank Chang-Tai Hsieh, Chad Jones, Guillermo Noguera, Maurice Obstfeld, Jonathan Rose, and participants in seminars at Boston University, Dartmouth, Federal Reserve Board, Georgetown, Harvard, LSE, Maryland, MIT, Northwestern, Pompeu Fabra (CREI), Rochester, UC Berkeley, World Bank DERG, and the 2008 SED Meetings. My thanks as well to Marc Melitz for providing data on trade costs.

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1 Introduction

A substantial volume of empirical research has documented that exporting firms are systematically different than non-exporters. They are larger, more productive, more skill and capital intensive, and pay higher wages than non-exporters. Further, there is a strong hierarchy among firms and destination markets, with larger, more capable firms exporting to difficult foreign markets. To make sense of these facts, researchers have turned to models in which heterogeneous firms self-select into export markets. These models put structure on how the number and average characteristics (size, productivity, etc.) of exporting firms vary across destination markets. As such, they generate rich predictions for the joint behavior of participation in bilateral trade, aggregate trade flows, and aggregate export prices.

This paper estimates one such model of trade with heterogeneous firms using sector-level data on participation, trade, and unit value prices. The empirical work is organized around two central themes. First, prices contain valuable information regarding product quality. Integrating this information into the estimation yields insight into the underlying nature of firm heterogeneity that is obscured when one looks at exports or participation alone. That is, in benchmark models – such as Melitz (2003) – differences in physical productivity and product quality across firms are observationally equivalent in terms of how they influence participation and trade flows. In contrast, productivity and quality heterogeneity do have distinct implications for prices (quoted per physical unit). Prices, therefore, can be used to identify sources of firm heterogeneity and distinguish between competing formulations of the model. Second, though selection into exporting generates predictions for both bilateral trade and prices, little is known about the quantitative importance of selection in shaping these variables. Estimation of participation, trade, and price relations for a wide variety of countries and sectors helps fill this gap.

To organize the empirics, I augment the heterogeneous firms model developed by Helpman, Melitz and Rubinstein (2008) to allow firms to choose the quality of the good they produce, subject to costs of upgrading quality. In the model, higher productivity firms optimally choose to produce higher quality goods. As a result, productivity has countervailing

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2Prior work on trade has focused on matching micro-data for selected countries, not bilateral trade patterns. See the previous footnote for references. Prior work on prices has focused on cross-country differences in prices, ignoring within-country differences that selection generates. See, for example, Schott (2004) and Hummels and Klenow (2005).
effects on prices. On the one hand, higher productivity directly lowers prices by driving down the marginal cost of production. On the other hand, higher productivity induces the firm to upgrade quality, which raises marginal costs and prices. Whether high productivity firms charge absolutely higher or lower prices than low productivity firms depends on the strength of incentives to upgrade quality.

In addition to choosing quality, firms decide whether to export. To enter foreign markets, firms incur destination-specific fixed costs and therefore self-select into exporting and non-exporting groups according to whether they surpass a destination-specific productivity threshold for exporting. Variation in this threshold across destinations then generates variation in the number of exporting firms, aggregate exports, and the average price of exports. Moreover, because the average productivity of exporting firms varies across markets as a function of the productivity threshold, within-country variation in observed aggregate export prices across destinations reveals how firm-level prices vary with productivity. Correspondingly, export price variation also reveals how strongly quality covaries with firm level productivity.

I bring together sector-level data on prices, export participation, and trade volumes to estimate the three main components of the model. Following Helpman, Melitz and Rubinstein (2008), I use binary, sector-level data on participation in trading relationships to estimate relative export productivity thresholds for each country against alternative destination markets. I then proceed to jointly estimate equations that relate bilateral export volumes and export prices to the estimated thresholds. The price equation, based on the aggregation of firm-level prices, relates observed export prices to home country characteristics and partner specific export thresholds. As in Helpman, Melitz and Rubinstein, the trade equation is a gravity-style specification derived from the demand structure that accounts for both variation in the set of firms engaged in trade across partners and endogenous selection into bilateral trade relationships.

Confronting the model with the data, I find that export prices behave in a manner inconsistent with the benchmark, homogeneous quality formulation of the model. The benchmark model makes the counterfactual prediction that the price at which a country exports should be decreasing in the productivity threshold for exporting to the destination market. In the data, export prices are increasing in the productivity threshold for the majority of sectors. That is, export prices are higher on average to difficult export destinations.

While inconsistent with the benchmark model, the data are consistent with my quality-augmented model. In my model, high productivity firms charge higher unit prices when
the incentive to upgrade quality is strong enough to overcome the direct effect of higher productivity on unit prices. Because these high productivity firms are the only firms able to profitably serve difficult markets, export prices will be increasing in the export productivity threshold. Thus, the flexibility introduced by within-country variation in product quality across firms helps make sense of the data. That said, while export prices are increasing in the productivity threshold in most sectors, I also find that prices in a subset of related sectors behave in a manner more consistent with the benchmark model. These sectors include apparel, footwear, and electronic appliances. According to my model, these sectors should be ones in which large firms charge low unit prices either because the benefits of quality upgrading are small or the cost of upgrading quality is steep.

Having established the relationship between productivity thresholds and prices, I proceed to study the quantitative importance of threshold variation in explaining both prices and trade patterns. In practice, productivity thresholds play a relatively small quantitative role in understanding price variation, both within and across exporters. Rather, variation in exporter-specific factors, common to all destination markets that a given exporter serves, explain a large portion (about one-half) of the overall variation in prices. Furthermore, the estimated exporter-specific component of prices is highly correlated with source country income. To a first approximation, the export price schedule for a rich country is shifted upward relative to the price schedule of a poor country. As such, this suggests large variation in average product quality across countries within sectors.

In contrast to prices, productivity cutoffs account for a large portion (approximately 40%) of the overall variation in exports. This suggests that variation in the number and characteristics of exporting firms plays a large quantitative role in explaining aggregate export patterns. To shed further light on the determinants of trade patterns, I use the estimated exporter-specific component of prices to recover a quality/variety composite from the exporter-specific component of the trade equation. This composite provides evidence that quality/variety heterogeneity across countries can explain much of the variation in aggregate export volumes within sectors across countries.

1.1 Related Literature

Most previous empirical work using heterogeneous firms models has studied export participation decisions, industry dynamics, and trade flows. Within this large and growing literature, this paper draws most heavily on the insights and estimation framework of Helpman, Melitz,
and Rubinstein (2008). In a departure from their paper, I endogenize product quality and extend their methodology to use information on prices in estimating the model. Further, whereas Helpman, Melitz and Rubinstein focus on aggregate trade patterns, I shift emphasis toward studying disaggregated sectoral flows that more closely match the industrial structure assumed in the model.

More recently, a number of papers have directed attention toward studying prices using heterogeneous firms models. Most closely related to this paper, Baldwin and Harrigan (2007) explore how information contained in the incidence of export zeros and export prices in U.S. bilateral data helps distinguish between alternative models of international trade, including Helpman-Krugman, Eaton-Kortum, and Melitz style trade models. They provide evidence that trade costs are an important determinant of differences in trade participation across industries and argue that all three existing models are inconsistent with the data. They suggest that a quality-augmented Melitz model might be able to rationalize these results.

Also related to this paper, several recent papers have used firm-level data to study the links between firm productivity, product quality, and export behavior. Crozet, Head, and Mayer (2007), Hallak and Sivadasan (2008), Iacovone and Javorcik (2008), and Kugler and Verhoogen (2008) all provide micro-based evidence that supports the emphasis on quality differences that this paper appeals to in order to understand multi-country, sector-level aggregates. I discuss this line of work in greater detail below.

2 Trade with Heterogeneous Firms and Endogenous Quality

In this section I introduce a multi-country model of trade in a continuum of differentiated products. The model follows Melitz (2003) and Helpman, Melitz, and Rubinstein (2008) closely in conceptualizing the firm-level decision to export, but deviates from it by introducing endogenous product quality and focusing attention on the price implications of the

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3 In addition to the papers in the text, Atkeson and Burstein (forthcoming), Ghironi and Melitz (2005), and Bergin, Glick, and Taylor (2006) also study prices, but characterize aggregate price behavior using calibrated heterogeneous firms models.

4 For example, Baldwin and Harrigan report that both U.S. export prices and the number of zero-export observations at the HS 10-digit level are increasing in distance to foreign markets, controlling for aggregate GDP and the GDP per capita of the destination market.
I exposit the main results on prices and exports relevant to estimation of the model in the main text, relegating discussion of details concerning entry, model closure, and equilibrium definition to Appendix A. Taking the number of firms and wages as given, the model in the main text completely describes the economy. Further, I focus on a one-sector version of the model to reduce notational clutter. In the empirical work, I straightforwardly extend the framework to multiple sectors.

2.1 Consumption

To begin, assume that there is a representative consumer in each country with constant elasticity of substitution (CES) preferences over consumption of differentiated varieties of manufactures given by:

\[ C_i = \left( \int_{\omega \in \Omega_i} [\lambda(\omega) c_i(\omega)]^{(\sigma - 1)/\sigma} d\omega \right)^{\sigma/(\sigma - 1)}, \]

where \( \omega \) indexes an individual variety among the set \( \Omega_i \) of varieties available in country \( i \), \( c_i(\omega) \) is the quantity consumed measured in physical units, \( \lambda(\omega) \) is the quality of variety \( \omega \) measured in utility per physical unit, and \( \sigma > 1 \) is the elasticity of substitution between varieties. Product quality here is a demand shifter; higher quality goods yield higher consumption utility per unit consumed.

Preferences are assumed to be identical across countries. With a price \( p_i(\omega) \) for variety \( \omega \) in country \( i \), the consumer will allocate consumption according to:

\[ c_i(\omega) = [\lambda(\omega)]^{\sigma - 1} \left( \frac{p_i(\omega)}{P_i} \right)^{-\sigma} C_i, \]

where \( P_i = \left( \int_{\omega \in \Omega_i} [p_i(\omega)/\lambda(\omega)]^{1-\sigma} d\omega \right)^{1/(1-\sigma)} \) is the CES aggregate price level of consumption. The consumer inelastically supplies \( L_i \) units of labor to firms, receives wage \( w_i \), and exhausts his budget constraint: \( P_i C_i = w_i L_i \).

Kugler and Verhoogen (2008) and Hallak and Sivadasan (2008) also develop Melitz-style models with endogenous quality. My approach is similar in spirit to Hallak and Sivadasan in that I assume that firms incur fixed costs that are a function of quality. The fixed cost approach is appealing since it is the basis for a prominent line of the industrial organization literature. In practice, however, my approach yields estimating equations that are equivalent to those that would arise from the Kugler and Verhoogen “quality-complementarity” framework.

Implicitly, this means that individuals in different countries have identical perceptions of and tastes for quality. Relaxing this assumption is a natural direction for future work.
2.2 Production

Each variety of the differentiated good is produced by an individual monopolistically competitive firm. Firms are heterogeneous with respect to idiosyncratic physical productivity $z(\omega)$, which is measured relative to aggregate productivity $Z_i$ in firm’s home country. The number of firms in each country is $N_i$.

Each firm chooses both the price and quality of the good they produce. The firm produces physical output using labor with constant returns to scale, and I assume that the marginal cost of production depends on the quality of the good produced. For a firm in country $i$, marginal cost is given by $MC_i(z(\omega), \lambda(\omega))$. In choosing quality, the firm pays $f_i(\lambda)$ to produce goods with quality level $\lambda$, with $f_i'(\lambda) > 0$. Further, for analytical tractability, I assume that the firm chooses quality based on the revenue generated via sales in its home market only.

As is standard with CES preferences, each firm sets price as a constant markup over marginal cost: $p_i(\omega) = \frac{\sigma}{\sigma - 1} MC_i(z(\omega), \lambda(\omega))$. The firm producing variety $\omega$ chooses $\lambda(\omega)$ to solve:

$$
\max_{\{\lambda(\omega)\}} p_i(\omega)c_i(\omega) - MC_i(z(\omega), \lambda(\omega))c_i(\omega) - f_i(\lambda(\omega)) \\
\text{s.t. } c_i(\omega) = [\lambda(\omega)]^{\sigma-1} \left( \frac{p_i(\omega)}{P_i} \right)^{-\sigma} C_i \\
\text{and } p_i(\omega) = \frac{\sigma}{\sigma - 1} MC_i(z(\omega), \lambda(\omega)),
$$

(1)

taking $P_i, C_i$ as given. Since any two firms with identical idiosyncratic productivity will choose identical quality levels, quality choice reduces heterogeneity to a single dimension.

Each firm can thus be characterized by the pair $\{z, \lambda(z)\}$, where $\lambda(z)$ is the quality of the

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7 The subscript $i$ allows the fixed cost to be country specific, though this plays a minor role in the analysis.

8 This assumption ensures that quality is a smooth function of productivity and simplifies aggregation. If firms choose quality based on the sum of home and foreign revenue, then selection into exporting implies that revenue is discontinuous in $z$. With fixed costs of choosing quality, the optimal quality schedule inherits this discontinuity. While this extension complicates the analysis, it does not change the basic prediction of the model regarding the dependence of quality on productivity. Moreover, one can motivate this assumption directly by noting that firms typically earn most of their revenue from their domestic market. In the empirical work, I show that my basic results regarding prices are robust to relaxation of this assumption.

9 One could construct an alternative model with heterogeneity in two dimensions that yields essentially similar empirical predictions to this quality-choice model. If firms draw $\{z(\omega), \lambda(\omega)\}$ from a joint distribution, then the covariance between $z(\omega)$ and $\lambda(\omega)$ governs the behavior of aggregate prices with respect to thresholds for exporting. To rationalize the data, this covariance must be positive. The quality choice model provides a non-stochastic, microeconomic interpretation regarding the origins of this covariance.
product produced by firm with productivity level $z$.

To evaluate this problem, I make parametric assumptions regarding the form of the marginal cost function and the fixed cost of quality upgrading. I assume that a firm with productivity $z$ in country $i$ produces with marginal cost $MC_i(z, \lambda(z)) = \frac{w_i(z)^\beta}{Z_i z}$, where $\beta$ is the elasticity of marginal cost with respect to quality. As for the fixed cost, I assume that $f_i(\lambda(z)) = \frac{w_i(z)^\phi}{Z_i f_i}$, where $\phi$ is the elasticity of fixed costs with respect to quality. I impose the parameter restriction $0 < (1 - \beta)(\sigma - 1) < \phi$. This restriction combines three elements. First, fixed costs are increasing in quality ($\phi > 0$). Second, quality-adjusted prices are falling in quality ($\beta < 1$). Third, the elasticity of substitution ($\sigma$) is not so large that it creates benefits of upgrading quality that overwhelm the cost of quality upgrading: $(1 - \beta)(\sigma - 1) < \phi$. Together these ensure that an optimal quality level exists and is positive.

A firm with productivity level $z$ chooses product quality to solve:

$$\max_{\lambda} \quad p_i(z, \lambda)c_i(z, \lambda) - \left[ \frac{w_i(z)^\beta}{Z_i z} c_i(z) - \frac{w_i(z)^\phi}{Z_i f_i} \right]$$

s.t. $c_i(z, \lambda) = [\lambda]^{\sigma - 1} \left( \frac{p_i(z, \lambda)}{P_i} \right)^{-\sigma} C_i$

and $p(z, \lambda) = \left( \frac{\sigma}{\sigma - 1} \right) \frac{w_i(z)^\beta}{Z_i z}$.

The optimal choice of quality for a firm with productivity $z$ can be written as:

$$\lambda_i^*(z) = \lambda_i z^\alpha,$$

where $\lambda_i \equiv \left[ \frac{1 - \beta}{\phi f_i} \left( \frac{\sigma}{\sigma - 1} \frac{w_i(z)^\sigma}{Z_i} \right)^{-\sigma} P_i^{\alpha C_i} \right]^{1/(\phi - (1 - \beta)(\sigma - 1))}$ and $\alpha = \frac{\sigma - 1}{\phi - (1 - \beta)(\sigma - 1)}$. Optimal quality thus has a country-specific component and a firm-specific component that depends on idiosyncratic productivity. Quality is increasing in productivity since $\phi - (1 - \beta)(\sigma - 1) > 0$ implies $\alpha > 0$. This has a natural intuition. Starting from the same level of quality, upgrading quality carries the same cost all firms. But increasing quality carries a larger benefit to high productivity firms because they are able to charge lower quality-adjusted prices and therefore spread the cost of quality upgrading over a larger scale.

A number of results about the distribution of firm sizes and the schedule of prices follow.
from this quality choice result. To start, I use the quality schedule in (3) to write prices as:

\[ p_i(z) = \left( \frac{\sigma}{\sigma - 1} \frac{w_i}{Z_i} \right) \left( \frac{\lambda_i^\beta}{z^{1-\alpha\beta}} \right). \] (4)

Then, defining the quality-adjusted price of a good as \( \tilde{p}_i(z) = \frac{p_i(z)}{\lambda_i(z)} \), quality-adjusted prices are given by:

\[ \tilde{p}_i(z) = \left( \frac{\sigma}{\sigma - 1} \frac{w_i}{Z_i} \right) \left( \frac{\lambda_i^{\beta-1}}{z^{1-\alpha\beta+\alpha}} \right). \] (5)

High productivity firms charge lower quality adjusted prices than low productivity firms because \( 1 + \alpha - \alpha\beta > 0 \) under the parameter restrictions discussed above.

The first result regarding the firm size distribution is almost immediate. Since domestic firm revenue is a power function of quality-adjusted prices \( \tilde{p}_i(z) \), then firm sizes are Pareto if \( \tilde{p}_i(z) \), and hence \( z \), is Pareto. As in Helpman, Melitz, and Rubinstein (2008), I will therefore assume that firms draw \( z \) from a truncated Pareto distribution. The CDF of this distribution is given by:

\[ G(z) = \frac{z^{-k} - z_L^{-k}}{z_H^{-k} - z_L^{-k}}, \] (6)

with support \( z \in [z_L, z_H] \) and shape parameter \( k > 0 \).10

The second set of results about the schedule of prices are important for understanding how export prices behave. The model implies that high productivity firms choose to produce high quality goods and have low quality adjusted prices. On the other hand, whether larger firms have higher or lower unit prices is indeterminate. Rather, the slope of the schedule of absolute prices with respect to productivity is governed by the strength of the quality upgrading channel. In terms of the model, the key point is that the unit price of firm \( z \)’s good is increasing in \( z \) only if \( \alpha\beta > 1 \) and decreasing otherwise.11 This inequality will hold when both quality is strongly increasing in productivity and marginal cost is sufficiently responsive to quality. In contrast to this flexible formulation, models that assume quality is homogeneous across firms (normalized to \( \lambda(z) = 1 \forall z \)) imply a price schedule of the form: \( p_i(z) = \left( \frac{\sigma}{\sigma - 1} \frac{w_i}{Z_i} \right) \). And so more productive firms always charge lower prices in these restricted models.12

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10Note that this distribution is not country-specific. In the estimation framework below, variation in \( z_H \) across countries is observationally equivalent to variation in aggregate productivity. So restricting \( z_H \) in this manner does not result in loss of generality. Further, the lower bound \( z_L \) plays no role in the analysis.

11This inequality can equivalently be written in terms of fundamental parameters as: \( \phi < (\sigma - 1) \).

12Melitz (2003), Ghironi and Melitz (2005) and Helpman, Melitz and Rubinstein (2008) all work with pric-
2.3 Selection into Exporting and Export Prices

Firms face both a fixed cost to enter each specific export market and a variable iceberg trade cost to serve that market. A firm from country $i$ selling to country $j$ pays fixed cost $f_{xij}$ and must ship $\tau_{ij} > 1$ units of the good for one unit to arrive in $j$. Firm revenue from exporting to country $j$ is:

$$R_{xij}(z) = \left( \frac{\tilde{p}_i(z)\tau_{ij}}{P_j} \right)^{1-\sigma} E_j$$  \hspace{1cm} (7)

where $P_j$ is the price index in country $j$, $E_j$ is expenditure in $j$, and $\tilde{p}_i(z)$ is the quality-adjusted price (exclusive of trade costs).

Firms elect to export if they earn positive profits. With optimal pricing, export revenue net of marginal production costs is: $\frac{1}{\sigma}R_{xij}(z)$. Then, a firm chooses to export if:

$$\frac{1}{\sigma}R_{xij}(z) \geq f_{xij}.$$  \hspace{1cm} (8)

For each market, there exists a marginal firm with threshold productivity $z_{xij}$ such that (8) holds with equality. The quality adjusted price of the marginal firm is:

$$\tilde{p}_c(z_{xij}) = \frac{P_j}{\tau_{ij}} \left( \frac{E_j}{\sigma f_{xij}} \right)^{1/(\sigma-1)}.$$  \hspace{1cm} (9)

Note that revenue and selection into exporting depend on a firm having a low quality-adjusted price. Conditional on fixed costs, foreign markets that are either larger (higher $E_j$), less competitive (higher $P_j$), or have lower variable trade costs ($\tau_{ij}$) generate higher revenue for any given firm that enters and therefore allow firms with higher quality adjusted prices to profitably enter. Evaluating the quality adjusted price using results above, I can solve for the threshold productivity for exporting directly:

$$z_{xij} = \left[ \frac{\sigma}{\sigma - 1} \frac{w_i \lambda_i^{\beta - 1} P_j}{Z_i \tau_{ij}} \left( \frac{\sigma f_{xij}}{E_j} \right)^{1/(\sigma-1)} \right]^{1/(1-\alpha \beta + \alpha)}.$$  \hspace{1cm} (10)

Melitz (2003, p.1699) also suggests an alternative formulation of the model in which firms are costlessly endowed with heterogeneous quality and have identical marginal costs of production. In that model, unit prices would be identical across all firms.

$^{13}$Defining $q_{ij}(z)$ as the quantity of goods shipped, then $c_{ij}(z) = \frac{q_{ij}(z)}{\tau_{ij}}$. If the factory gate price for produced output is $p_i(z)$ then the consumer price of one unit of consumption of that good in the foreign country is $p_{ij}(z) = \frac{p_i(z)}{\tau_{ij}}$.

$^{14}$Only low quality-adjusted price firms are able sell enough to recoup the fixed costs $f_{xij}$ of entering the foreign market.
The productivity threshold is increasing in country $i$’s country-specific productivity-adjusted wage $\frac{w_i}{Z_i}$ and decreasing in country-specific quality $\lambda_i$.\footnote{These results are both sensible. Since higher productivity adjusted wages raise marginal costs and prices all else equal, this raises the minimum idiosyncratic productivity level at which a firm could profitably export. On the other hand, higher country-specific quality lowers the quality-adjusted price all else equal and relaxes the productivity threshold for exporting since it raises demand for all country $i$ firms.}

In the export price data, we observe aggregate unit values rather than prices for individual firms. Thus, I construct aggregate unit values in the model to match the data. Aggregate exports from country $i$ to country $j$ are given by:

$$EX_{ij} = \int_{z_{xij}}^{z_H} R_{xij}(z) N_i dG(z)$$

$$= N_i \tilde{V}_{ij} \left( \frac{\sigma}{\sigma - 1} \frac{w_i \lambda_i^{-1}}{Z_i} \right)^{1-\sigma} \tau_{ij}^{1-\sigma} P_j^\sigma E_j,$$

where $\tilde{V}_{ij} = \int_{z_{xij}}^{z_H} z^{(1-\alpha\beta+\alpha)(\sigma-1)} dG(z)$ is a country-pair specific term that quantifies the influence of the endogenous threshold on export volumes. Similarly I solve for the quantity of goods shipped from $i$ to $j$ as:

$$Q_{ij} = \int_{z_{xij}}^{z_H} q_{xij}(z) N_i dG(z)$$

$$= N_i \tilde{V}_{ij} \left( \frac{\sigma}{\sigma - 1} \frac{w_i \lambda_i^{-1}}{Z_i} \right)^{-\sigma} \tau_{ij}^{1-\sigma} P_j^\sigma E_j,$$

where $q_{ij}(z)$ is the quantity of goods shipped and $\tilde{V}_{ij} = \int_{z_{xij}}^{z_H} z^{\sigma(1-\alpha\beta+\alpha)-\sigma} dG(z)$ quantifies the effect of endogenous thresholds on the quantity of exports.

The unit value export price for trade between $i$ and $j$ is $\bar{p}_{ij} = \frac{EX_{ij}}{Q_{ij}}$. To solve for this price, I evaluate $\tilde{V}_{ij}$ and $\bar{V}_{ij}$ using the Pareto distribution (6) and obtain:

$$\tilde{V}_{ij} = k \left( \frac{z_{xij}^{-\delta_1} - z_H^{-\delta_1}}{z_L^{-k} - z_H^{-k}} \right),$$

$$\bar{V}_{ij} = k \left( \frac{z_{xij}^{-\delta_2} - z_H^{-\delta_2}}{z_L^{-k} - z_H^{-k}} \right),$$

where $\delta_1 = k - (\sigma - 1)(1 - \alpha\beta + \alpha)$ and $\delta_2 = k - \sigma(1 - \alpha\beta + \alpha) + \alpha$. Implicitly, I have imposed the technical restrictions that $\delta_1 > 0$ and $\delta_2 > 0$ to ensure $\tilde{V}_{ij}$ and $\bar{V}_{ij}$ are finite.
Using these results, I solve for unit value prices:

\[
\tilde{p}_{xcd} = p_i(z_H)V_{ij}
\]

with

\[
V_{ij} \equiv \frac{\tilde{V}_{ij}}{\bar{V}_{ij}} \equiv \left[ \frac{\delta_2}{\delta_1} \left( \frac{z_{xij}}{z_H} \right)^{-\delta_1} - 1 \right].
\]

The average export price for country \(i\) exporting to \(j\) is proportional to the absolute price of the most productive firm \(p_i(z_H)\), where the proportional scaling factor \(V_{ij}\) depends on the productivity of the marginal exporter to market \(j\) with productivity \(z_{xij}\) relative to the most productive firm.

Whether the average price is higher or lower than \(p_i(z_H)\) depends on the values of \(\delta_1\) versus \(\delta_2\). Specifically, the sign of the slope of prices with respect to the productivity cutoff depends on the sign of \(\delta_2 - \delta_1\). Notice that \(\delta_2 - \delta_1 = \alpha \beta - 1\), and recall that firm-level prices are decreasing in productivity if and only if \(\alpha \beta < 1\). Naturally, the export price schedule inherits the behavior of firm-level prices. When \(\alpha \beta < 1\), every firm charges prices that are equal to or higher than the most productive firm and the average price is scaled up relative to this firm \((V_{ij} > 1)\). Of course, the opposite holds when \(\alpha \beta > 1\) and \(V_{ij} < 1\).

As with the firm-level price schedule, the flexibility built into (13) contrasts with the standard homogeneous quality formulation of the model. With homogeneous quality, one can derive a formula analogous to (13) in which the values of \(\{\delta_1, \delta_2\}\) are replaced with \(\delta_{M1} = k + 1 - \sigma\) and \(\delta_{M2} = k - \sigma\). With this formulation, \(\delta_{M2} - \delta_{M1} = -1\) and prices are unambiguously decreasing in the export threshold. Thus, evidence that prices are decreasing in the export threshold does not allow me to discriminate between the endogenous quality model versus the homogeneous quality formulation of the model. However, if I find that prices are increasing in the export threshold, I can both reject the homogeneous quality assumption as well as the hypothesis that \(\alpha \beta < 1\) in the endogenous quality model.

### 2.4 Trade Volumes and Export Participation

As emphasized by Helpman, Melitz and Rubinstein (2008), the framework outlined above yields predictions for export participation and export values. First, the model predicts that aggregate bilateral exports depend directly on the bilateral threshold. Second, the model
predicts when two countries will engage in bilateral trade. Using this aspect of the model, Helpman, Melitz and Rubinstein outline a method via which binary data on participation in trade can be used to infer information about relative export thresholds. This section briefly exposits these features of the model.

Export thresholds influence aggregate exports by determining the number and identity of exporting firms. To clarify this point, I rewrite the bilateral export equation (11) using the definition of \( \bar{V}_{ij} \) to isolate variation in the number of exporting firms from variation in exports per firm:

\[
EX_{ij} = \frac{N_i}{N_{xij}} \left[ 1 - G(z_{xij}) \right] \int_{z_{xij}}^{zH} \left( \frac{\bar{p}_i(z)\tau_{ij}}{P_j} \right)^{1-\sigma} E_j \, dG(z | z > z_{xij})
\]

This reformulation highlights that the number of exporting firms – denoted \( N_{xij} \) – is decreasing in the productivity threshold. Thus, holding exports per firm constant, increasing the export threshold depresses aggregate exports. Aggregate exports do not fall one for one with the number of firms exporting, however, because as the threshold rises the smallest exporters are the first to fall out of the foreign market. Thus, exports per remaining firm actually rises.

Putting the two margins together, aggregate exports across markets are always decreasing in the threshold. Evaluating the expression for exports yields:

\[
EX_{ij} = N_i \left[ (\bar{p}_i(z_H))^{1-\sigma} \right] \left( \frac{1}{\delta_1} \left( \frac{z_{xij}}{z_H} \right)^{-\delta_1} - 1 \right).
\]  

(14)

Exports are decreasing in the threshold because \( \delta_1 > 0 \). Note also that aggregate exports are proportional to the exports of the most productive firm: \( EX_{ij}(z_H) = (\bar{p}_i(z_H))^{1-\sigma} \tau_{ij}^{1-\sigma} P_j^{1-\sigma} E_j \). If all firms were as productive as the most productive firm, then all firms would export and aggregate exports would be \( N_i \) times \( EX_{ij}(z_H) \). But not all firms export and not all firms are equally productive. The term including \( \frac{z_{xij}}{z_H} \) scales down aggregate exports to account for these two facts.

Obviously, export thresholds are not directly observable in aggregate data. Helpman, Melitz and Rubinstein also introduce a procedure to infer these cutoffs from data on bilateral

16Unlike traditional variety-based trade models, this framework makes sense of the fact the vast majority of country pairs in fact do not trade with one another either in any given sector, or even in the aggregate.
export participation. Since firm productivity is drawn from a truncated distribution, quality-adjusted prices for each exporter are bounded below by the quality-adjusted price of the highest productivity firm. No firm from country \( i \) finds it profitable to export to destination \( j \) unless the most productive firm finds it profitable to serve that destination. Referring back to \((8)\), the most productive firm serves destination \( j \) if \( \frac{1}{\sigma} R_{xij}(z_H) \geq f_{xij} \). Define \( \chi_{ij} \) to measure of the profitability of the most productive firm in \( i \) serving market \( j \):

\[
\chi_{ij} = \frac{\frac{1}{\sigma} R_{xij}(z_H)}{f_{xij}}.
\]

(15)

Then country \( i \) exports to \( j \) only if \( \chi_{ij} \geq 1 \). Based on this result, define a binary variable \( T_{ij} = 1(\chi_{ij} > 1) \) that takes the value one if \( i \) exports to \( j \) and zero otherwise. Observation of this binary variable then reveals information about \( \chi_{ij} \). This turns out to be useful.

The key insight is that the relative productivity cutoff \( \frac{z_{xij}}{z_H} \) is a monotonically decreasing function of \( \chi_{ij} \). To see this, note that \( \frac{1}{\sigma} R_{xij}(z_{xij}) = f_{xij} \). Using this fact, it is straightforward to show that:

\[
\frac{z_{xij}}{z_H} = \chi_{ij}^{-1/[(\sigma - 1)(1 - \alpha \beta + \alpha)]}.
\]

(16)

Thus, the relative productivity cutoff for a firm in country \( i \) to earn profits selling in \( j \) is falling in the profitability of the most productive firm of serving market \( j \). Since the binary participation data contain information on \( \chi_{ij} \), they also reveal relative export thresholds across destinations that determine the behavior of prices and exports.

### 3 Empirical Procedure

In this section, I translate the framework outlined above into a set of conditional expectations for participation, exports, and export prices and discuss details about how I use these to estimate the model.

#### 3.1 The Participation Equation

Drawing on the previous section, we observe a binary variable \( T_{ij} = 1(\chi_{ij} > 1) \) that takes the value one when the most productive firm in country \( i \) finds it profitable to serve market \( j \). To use this information, I take logs of \( (15) \) and substitute for revenue using \( (7) \):

\[
\log(\chi_{ij}) = \log(1/\sigma) + (1 - \sigma) \log(\bar{p}_i(z_H)) + (1 - \sigma) \log(\tau_{ij}) + \log(P_j^\sigma E_j) - \log(f_{xij})
\]
Following Helpman, Melitz and Rubinstein (2008), I parameterize the bilateral fixed and variable trade costs as follows:

\[(1 - \sigma) \log (\tau_{ij}) = \rho D_{1ij} + \epsilon_{1ij} \]

\[- \log (f_{xij}) = \vartheta_i + \vartheta_j + \gamma D_{2ij} + \epsilon_{2ij},\]

where \(D_{1ij}\) and \(D_{2ij}\) are multidimensional, possibly overlapping sets of observable proxies for bilateral fixed and variable trade costs (e.g., distance, common language, etc.), \(\epsilon_{1ij}\) reflects random unobserved variation in variable trade costs, \(\epsilon_{2ij}\) reflects random unobserved variation in fixed trade costs, and \(\vartheta_i, \vartheta_j\) are exporter and importer fixed effects. Substituting this parameterization back into the expression for \(\log(\chi_{ij})\) yields a reduced form:

\[\log(\chi_{ij}) = \xi_0 + \xi_i + \xi_j + \rho D_{1ij} + \gamma D_{2ij} + \eta_{ij},\]

where \(\eta_{ij} = \epsilon_{1ij} + \epsilon_{2ij}\) is the composite of unobserved fixed and variable costs of trade, \(\xi_0 = \log(1/\sigma)\) is a constant, \(\xi_i = (1 - \sigma) \log(\tilde{p}_i(\tilde{z}_H)) + \vartheta_i\) is an exporter fixed effect, and \(\beta_j = \log(P_j^{\gamma - 1} E_j) + \vartheta_j\) is an importer fixed effect.\(^{17}\)

Then substituting these expressions back, rewrite the expression for \(T_{ij}\) as:

\[T_{ij} = 1(\log(\chi_{ij}) > 0) \]

\[= 1(\eta_{ij} > -[\xi_0 + \xi_i + \xi_j + \rho D_{1ij} + \gamma D_{2ij}]).\]

With this in hand, the expectation of \(T_{ij}\) conditional on observables is:

\[E[T_{ij}|\xi_i, \xi_j, D_{1ij}, D_{2ij}] = \text{Pr}\{\eta_{ij} > -[\xi_0 + \xi_i + \xi_j + \rho D_{1ij} + \gamma D_{2ij}]\}\]

To operationalize this, I assume that the errors \(\epsilon_{1ij}\) and \(\epsilon_{2ij}\) are jointly distributed, mean zero normal random variables. Then \(\eta_{ij}\) is distributed \(N(0, \sigma^2_\eta)\), where \(\sigma^2_\eta\) is the variance of the composite error. Then it follows that:

\[E[T_{ij}|\xi_i, \xi_j, D_{1ij}, D_{2ij}] = \Phi(\xi_0^* + \xi_i^* + \xi_j^* + \rho^* D_{1ij} + \gamma^* D_{2ij})\]

\[= \Phi(X_{ij}^* \theta^*),\]

\(^{17}\)I define these parameters in a manner that is easy to interpret. One could equivalently re-define the parameters so that elements of \(\tilde{p}_i(\tilde{z}_H)\) that do not vary across countries in the model (e.g., markups and \(z_H^{1 - \alpha_1} - \alpha_1\gamma\)) are contained in the constant term. There are a number of constants in this equation that are not separately identified.
where \( x^* \) indicates that that \( x \) has been divided by \( \sigma_\eta \) so that \( \eta_{ij}^* \) has unit variance, and 
\[ X_{ij}\theta^* \equiv \xi_0^* + \xi_i^* + \xi_j^* + \rho^* D_{1ij} + \gamma^* D_{2ij} \]
for notational convenience.

### 3.2 The Trade Equation

As discussed above, the model implies a gravity-style equation for bilateral export volumes. To illustrate this, I take logs of (14):

\[
\log(EX_{ij}) = \log(N_i) + (1 - \sigma) \log(\hat{p}_i(z_H)) + (1 - \sigma) \log(\tau_{ij}) + \log(P_{\sigma-1j}E_j) + \log(k/\delta_1) \log \left( \left( \frac{z_{xij}}{z_H} \right)^{-\delta_1} - 1 \right).
\]

Then using the same parameterization of variable trade costs and redefining terms:

\[
\log(EX_{ij}) = \psi_0 + \psi_i + \psi_j + \rho D_{1ij} + \log \left( \left( \frac{z_{xij}}{z_H} \right)^{-\delta_1} - 1 \right) + \epsilon_{1ij},
\]

where \( \psi_0 = \log(k/\delta_1) \) is a constant, \( \psi_i = \log(N_i) + (1 - \sigma) \log(\hat{p}_i(z_H)) \) is an exporter fixed effect, and \( \psi_j = \log(P_{\sigma-1j}E_j) \) is an importer fixed effect. The expected value of exports conditional on observables and observing trade between the pair \( ij \) is: 
\[ E[EX_{ij} | \cdot, T_{ij} = 1], \]
where the dot notation stands for conditioning on observables \( \{\psi_i, \psi_j, D_{1ij}, X_{ij}\} \).

To evaluate \( E[\epsilon_{ij} | \cdot, T_{ij} = 1] \), note that \( \epsilon_{1ij} \) and \( \eta_{ij} \) are bivariate normal by assumption in the previous section. Therefore, the standard Heckman-style correction is appropriate:

\[ E[\epsilon_{1ij} | \cdot, T_{ij} = 1] = E[\epsilon_{1ij} | \cdot, \eta_{ij}^* > -X_{ij}\theta^*] = \psi \frac{\phi(X_{ij}\theta^*)}{\Phi(X_{ij}\theta^*)}, \]

where \( \psi \) is a selection parameter to be estimated and \( \frac{\phi(X_{ij}\theta^*)}{\Phi(X_{ij}\theta^*)} \) is the inverse Mills ratio.

Evaluating the conditional expectation of the term involving the productivity threshold \( \frac{z_{xij}}{z_H} \) requires linking the threshold to observables. To do so, I rewrite the threshold using equation (16) and the parameterization of \( \chi_{ij} \) introduced in specifying the participation equation:

\[
\frac{z_{xij}}{z_H} = \chi_{ij}^{-1/[(\sigma-1)(1-\alpha\beta+\alpha)]} = [\exp \left( (X_{ij}\theta^* + \eta_{ij}^*) \right)]^{-\sigma_\eta/[(\sigma-1)(1-\alpha\beta+\alpha)]}
\]

16
Then insert this in the productivity threshold term to get:

\[
\log \left( \left( \frac{z_{xij}}{z_H} \right)^{-\delta_1} - 1 \right) = \log \left( \exp(\bar{\delta}_1(X_{ij}^\theta* + \eta_{ij}^*) - 1) \right),
\]

where \( \bar{\delta}_1 = \frac{\sigma_{\eta_{ij}}}{\sigma(1-1)} \). Using this substitution, I then use the assumption that \( \eta^* \) is normally distributed to construct the conditional expectation of the cutoff term as follows:

\[
E \left[ \log \left( \left( \frac{z_{xij}}{z_H} \right)^{-\delta_1} - 1 \right) \mid \cdot, X_{ij}, T_{ij} = 1 \right] \\
= \int_{-X_{ij}^\theta*}^\infty \log \left( \exp(\bar{\delta}_1(X_{ij}^\theta* + \eta_{ij}^*) - 1) \right) d\Phi_T(\eta_{ij}^*) \\
\equiv F(X_{ij}^\theta*, \bar{\delta}_1),
\]

where \( \Phi_T(\eta_{ij}^*) = \frac{\phi(\eta_{ij}^*)}{1-\Phi(-X_{ij}^\theta*)} \) is the truncated distribution for \( \eta_{ij}^* \).

With these inputs, the conditional expectation from which I generate moments for estimation is:

\[
E[EX_{ij} \mid \cdot, T_{ij} = 1] = \psi_0 + \psi_i + \psi_j + \rho D_{1ij} + F(X_{ij}^\theta*, \bar{\delta}_1) + \nu \frac{\phi(X_{ij}^\theta*)}{\Phi(X_{ij}^\theta*)}.
\]

The expected value of exports depends on importer and exporter fixed effects, bilateral trade costs, the level of the bilateral productivity threshold via \( F(X_{ij}^\theta*, \bar{\delta}_1) \), and a term correcting for sample selection.

3.3 The Price Equation

To estimate the price equation, I use techniques developed in previous sections. To introduce a stochastic component to prices, I assume (realistically) that prices are measured with multiplicative measurement error. Then I take logs of the export price equation (13) to obtain:

\[
\log(\bar{p}_{xij}) = \log(\delta_2/\delta_1) + \log(p_i(z_H)) + \log \left( \frac{z_{xij}}{z_H} \right)^{-\delta_2} - 1 \right) + \nu_{ij},
\]

where \( \nu_{ij} \) is mean-zero measurement error. Then, I substitute for the thresholds as in the previous section and construct \( E[\log(\bar{p}_{xij}) \mid \cdot, T_{ij} = 1] \). In doing so, I deal with the function
of the thresholds as in the previous section by substituting for the thresholds and then evaluating the conditional expectation using the truncated normal distribution $\Phi^T(\eta^*_ij)$. I denote this conditional expectation by $H(X_{ij}\theta^*; \bar{\delta}_1, \bar{\delta}_2)$, with $\bar{\delta}_1$ is defined as in the previous section and $\bar{\delta}_2 = \frac{\sigma \delta_2}{(\sigma-1)(1-\alpha \beta + \alpha)}$.

Further, note that $\log(p_i(z_H))$ is a constant for each exporting country and therefore can be absorbed by a exporter fixed effect. The conditional expectation of the price equation is then:

$$E[\log(\bar{p}_{xij})|; T_{ij} = 1] = \mu_0 + \mu_i + H(X_{ij}\theta^*; \bar{\delta}_1, \bar{\delta}_2),$$

(19)

where $\mu_0 = \log(\delta_2/\delta_1)$ is a constant and $\mu_i = \log(p_i(z_H))$ is an exporter fixed effect.

### 3.4 Estimation Details

In principle, it is possible to estimate all three components of the model simultaneously. In practice, this is computationally burdensome due to the high dimensionality of the parameter space. Therefore, I follow a two-step GMM procedure. In the first step, I use binary participation data to estimate the export participation equation (17) within each sector. With these estimates in hand, I generate values for the Probit index that are then used to construct the functions $F(X_{ij}\theta^*; \bar{\delta}_1)$, $H(X_{ij}\theta^*; \bar{\delta}_1, \bar{\delta}_2)$, and the inverse Mills ratio in expressions (18) and (19). For convenience, I rewrite the conditional expectations here as estimating equations:

$$\log(\bar{p}_{xij}) = \mu_0 + \mu_i + H(X_{ij}\hat{\theta}^*; \bar{\delta}_1, \bar{\delta}_2) + e_{1ij}$$

(20)

$$\log(EX_{ij}) = \psi_0 + \psi_i + \psi_j + \rho D_{1ij} + F(X_{ij}\hat{\theta}^*; \bar{\delta}_1) + \frac{\phi(X_{ij}\hat{\theta}^*)}{\Phi(X_{ij}\hat{\theta}^*)} + e_{2ij},$$

(21)

where I have substituted the first stage estimator of $\theta^*$ for the true value and have defined:

$$e_{1ij} \equiv \log(\bar{p}_{xij}) - E[\log(\bar{p}_{xij})|; T_{ij} = 1]$$

$$e_{2ij} \equiv \log(EX_{ij}) - E[EX_{ij}|; T_{ij} = 1].$$

I estimate these two equations jointly using sectoral trade and prices by stacking moment conditions and imposing the cross equation restriction that the value of $\bar{\delta}_1$ is identical across

---

18In unreported results, I have compared the results from the two-step procedure implemented in the main text to alternative estimates for selected sectors obtained by simultaneously estimating the three equations. The results are indistinguishable. This implies that the pattern of export participation contains all available information regarding the values of the productivity thresholds.
the two equations. I focus on a small set of straightforward moments to estimate these equations, all built on the orthogonality between the errors and the regressors. As implemented, the problem is exactly identified and hence moments are equally weighted. In light of the fact that I use a two-stage estimation procedure, I construct standard errors for the second stage estimates using the two-step GMM procedure laid out in Newey and McFadden (1994).

In specifying the trade equation above, there are two non-linear functions of the Probit index: \( F(X_{ij}\theta^*, \delta_1) \) and the inverse Mills ratio. To ensure that identification of parameters in that equation does not rest on functional form alone, I require a variable that influences the probability of observing exports but does not directly affect the level of exports. On theoretical grounds, measures of fixed trade costs satisfy the necessary exclusion restriction. In the absence of direct measures of fixed costs, I use lagged participation in bilateral trade as an excluded variable. While there is much churning in trading relationships, participation in bilateral trade with a given partner in the past is a strong predictor of whether two countries trade today. A number of a priori theoretical arguments can explain this result and suggest lagged participation is well suited as a proxy for current fixed costs. To the extent that some of the fixed export cost is sunk at the firm level, payment of this cost in the past makes it more likely firms will find it profitable in the present to export to a given country. At the aggregate level, initiating trade may entail establishment of sector-wide contacts and relationships, information sharing mechanisms, and distribution networks that persist through time and whose cost does not vary with the actual volume of goods traded. With this motivation, I construct a measure of how frequently two countries have traded in the past to use in estimating the participation equation.

The price equation also includes a function of the Probit index. In contrast to the trade equation, however, the theory implies that both fixed and variable trade costs are excludable from the price equation. Therefore, identification of the trade equation does not rest upon

\[ \text{The only modestly non-standard conditions worth mentioning are: } E[e_{1ij}(X_{ij}\theta^*)] = 0 \text{ and } E[e_{2ij}(X_{ij}\theta^*)] = 0. \] These are non-standard only in the sense that they are constructed such that the composite \( X_{ij}\theta^* \) is orthogonal to the error rather than the individual elements of \( X_{ij} \). One could also use these individual elements, though in practice the composite contains much more useful identifying variation.

\[ \text{Helpman, Melitz, and Rubinstein (2008) use data on general firm entry costs and common religion as excluded variables. Manova (2006) uses a dummy variable coding whether a country is an island. In the sector-level data I use, neither of these variables is robustly correlated with with the probability of trading.} \]

\[ \text{Roberts and Tybout (1997), for example, find that prior export experience increases the probability of exporting in the present by approximately 60 percentage points for individual firms in Colombia.}\]

\[ \text{In addition, importer specific characteristics also generate variation in the Probit index, but do no directly influence prices.} \]
the lagged participation exclusion restriction and is robust to failure of this assumption. Of course, one could estimate the price equation in isolation. The “slope” of the prices with respect to the export thresholds – corresponding to $\bar{\delta}_2 - \bar{\delta}_1$ – is well identified by this equation. However, the functional form of the price equation makes it difficult to pin down the level of the coefficients $\{\bar{\delta}_1, \bar{\delta}_2\}$ when estimating that equation alone. As a result, the trade equation is helpful to pin down $\bar{\delta}_1$ and therefore the level of the the parameters. Because the lagged participation exclusion restriction is necessary to identify the trade equation, failure of that restriction would influence the level of the estimates for $\{\bar{\delta}_1, \bar{\delta}_2\}$, but has almost no effect on the difference $\bar{\delta}_2 - \bar{\delta}_1$. Since most of the empirical work below is focused on interpreting this difference, this fact is reassuring. Further, in the empirical work, I relax the functional form of the price equation and estimate this equation in isolation to illustrate the robustness of the underlying price-threshold correlations.

### 3.5 Interpreting the Estimates

Before moving on to the actual estimation, I pause to discuss how to interpret the estimated parameters and combine them to draw inferences about the underlying structure of export selection and trade patterns.

First, $\{\bar{\delta}_1, \bar{\delta}_2\}$ govern the correlation of export prices and export thresholds. Recalling previous results, the price schedule slopes downward with respect to the productivity threshold only if $\alpha \beta < 1$. The difference $\bar{\delta}_2 - \bar{\delta}_1$ reveals whether this condition holds:

$$\bar{\delta}_2 - \bar{\delta}_1 = \frac{\sigma_{\eta}}{(\sigma - 1)(1 - \alpha \beta + \alpha)} (\delta_2 - \delta_1)$$

$$= \frac{\sigma_{\eta}}{(\sigma - 1)(1 - \alpha \beta + \alpha)} (\alpha \beta - 1).$$

The sign of this difference is a direct indication as to whether the price schedule is increasing or decreasing in the productivity threshold. If $\bar{\delta}_2 - \bar{\delta}_1 > 0$, then export prices are increasing in the threshold. Furthermore, this difference directly reveals whether $\alpha \beta > 1$, since $(1 - \alpha \beta + \alpha) > 0$ in the model.\textsuperscript{23} As a result, this difference will serve as a focal point in the discussion of the empirical results.

Exploiting the structure of the model, I obtain additional results regarding the relative importance of cross-country quality and variety versus price differences in explaining trade

\textsuperscript{23}Recall that $(1 - \alpha \beta + \alpha) > 0$ due to parameter restrictions necessary to ensure the existence of an interior maximum in the firm’s quality choice problem.
patterns. First, note that by the definition of the parameters, \( \exp(\mu_0 + \mu_i) = \frac{\delta_i}{\delta_1} p_i(z_H) \). Defining \( M_i = \exp(\mu_0 + \mu_i) \), the ratio \( \frac{M_i}{M_j} = \frac{p_i(z_H)}{p_j(z_H)} \) then allows me to recover the relative prices of the most productive exporting firm across countries. Similarly, note that by definition:

\[
\exp(\psi_0 + \psi_i) = \frac{kN_i}{\delta_1} (\bar{p}_i(z_H))^{1-\sigma} = \frac{k}{\delta_1} [N_i(\lambda_i(z_H))^{\sigma-1}] (p_i(z_H))^{1-\sigma}
\]

Then, define \( \Psi_i = \exp(\psi_0 + \psi_i) \) and it follows that:

\[
\frac{\Psi_i}{\Psi_j} = \left( \frac{N_i(\lambda_i(z_H))^{\sigma-1}}{N_j(\lambda_j(z_H))^{\sigma-1}} \right) \left( \frac{M_i}{M_j} \right)^{1-\sigma}.
\]

(23)

Thus, with an assumption about the value of \( \sigma \), I can back out \( \frac{N_i(\lambda_i(z_H))^{\sigma-1}}{N_j(\lambda_j(z_H))^{\sigma-1}} \), where \( N_i(\lambda_i(z_H))^{\sigma-1} \) is a composite index of product variety and quality for each country. Decomposing the exporter fixed effect in this manner sheds light on the role of quality and variety in explaining differences in aggregate exports across countries\(^{24}\).

4 Estimation Results

This section implements the estimation framework outlined in previous sections. I begin with a discussion of the data, and then proceed to the results.

4.1 Data

I take values and quantities for world trade from the NBER-UN data set compiled by Robert Feenstra and Robert Lipsey and available the NBER and the Center for International Data at UC Davis. Because data for the United States in the Feenstra-Lipsey data is less reliable and comprehensive than U.S.-sourced data, I also use U.S. data compiled by Robert Feen-

\(^{24}\)In economic terms, higher country-specific quality \( (\lambda_i) \) and total variety \( (N_i) \) shift the aggregate export demand schedule for country \( i \) outward relative to other countries. In contrast, differences in prices across countries move exporters along their respective aggregate export demand curves. Decomposing the fixed effect in this manner then allows us to quantify the extent to which differences in aggregate exports are associated with differences in the location of aggregate demand curves across countries versus differences in the countries location along their respective demand curves, holding factors like aggregate destination size, bilateral trade costs, and export productivity thresholds constant.
straa, John Romalis, and Peter Schott. While these data are available at the 4-digit level of disaggregation, I aggregate reported exports and quantities into 3-digit sectors. Furthermore, I discard non-manufacturing trade on the grounds that monopolistic competition models ought to be best suited to understanding trade in differentiated manufactures. After dropping several sectors due to missing data, I am left with data on 141 3-digit sectors spanning SITC categories 5-8. From these data on values and quantities, I construct bilateral unit values within each sector. Details regarding data preparation are discussed in Appendix B.

In addition to these trade data, I use standard proxies for bilateral trade costs as in Helpman, Melitz, and Rubinstein (2008). The data include a measure of distance between capital cities, as well as dummies for whether two countries share a border, whether one partner is landlocked, and whether one partner is an island. Further, the data contain measures of cultural and historical ties that may facilitate or impede trade, including a measure of the commonality of religious affiliation, and dummy variables for past colonial relationship, common legal origin, and common language. As mentioned above, I also construct an additional variable based on previous trading experience to use in estimating the participation equation. In the year 2000 base estimation, I construct a variable for each pair equal to the fraction of years between 1985-1995 in which the two countries engaged in trade. In analyzing prices and thresholds, I also employ data on real GDP per capita and population across countries from the Penn World Tables (Version 6.2).

The final estimation sample includes the 125 countries listed in Table I for which I have data on trade, prices, and trade costs in the year 2000. The exact composition and size of the estimation sample varies from sector to sector depending on which countries engage in trade in a given sector.

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26 Work in progress extends the estimation to the 4-digit level and the HS 6-digit level using alternative data from the CEPII. These unreported results indicate that the results reported below are not sensitive to the level of aggregation.

27 For reference, the 1-digit category headings are as follows: 5-“Chemicals and related products”; 6-“Manufactured goods, classified chiefly by material”; 7-“Machinery and transport equipment”; 8-“Miscellaneous manufactured articles”.

28 See Appendix B for details.
4.2 Estimating the Participation Equation

In Table 2, I present representative results from the first stage Probit estimation for eight sectors. I naturally omit estimates for the large number of exporter and importer fixed effects from the table. Suffice it to say that the vast majority of these coefficients are significantly different from zero and that they account for a large share of the overall variation in the data. The remaining variables in the Probit specification are proxies for fixed and variable costs of trade — $D_{1ij}$ and $D_{2ij}$ in the nomenclature of (17). In practice, I allow all trade cost proxies, with the exception of lagged participation in trade, to appear in both $D_{1ij}$ and $D_{2ij}$. As a result, the estimated coefficients on these variables in the participation equation measure the net effect of these variables operating via both fixed and variable costs on the probability of bilateral trade.

The probability of trade between two countries is strongly and robustly decreasing in the distance between them. To the extent that distance is correlated with bilateral fixed and/or variable trade costs, the negative coefficient is consistent with theory since higher costs of serving foreign markets make it less likely that the most productive firm will find it profitable to export to that market. The probability of trade also tends to increase if the countries share a common border, common language, or common legal system. Interpreted via the theory, these coefficients are also sensible. A common border is likely to be associated with lower variable and/or fixed costs. Further, sharing a common language or legal system could plausibly lower fixed costs of establishing a trading relationship. The consequences of being an island, being landlocked, or of sharing common colonial history and religion are more mixed. It is not surprising that some estimates are unstable across sectors, since the country composition of the estimation sample varies substantially across sectors simply because many countries participate only in a subset of sectors. The probability of engaging in trade today is also positively related to the average propensity of the two countries to have traded in the past. As discussed above, the strong and robust nature of this relationship is an important fact that provides identification in estimating the trade equation.

Before proceeding to the second step of the estimation, I pause to assess the plausibility of the estimates. From a mechanical perspective, the predicted probability of trade between

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29 For example, sharing a common language or legal system could lower the costs of making contacts and establishing a distribution network in foreign markets. The link between common language and common legal system on variable trade costs is less obvious.

30The median number of exporters in a sector is 75, and 90% of the sectors have 60 or more exporters. The maximum is 99 and the minimum is 33. The number of importers per sector is somewhat larger. The median number is importers is 105, and 90% of the sectors have more than 95 importers.
two countries can be high when either the exporter fixed effect is large, the importer fixed effect is large, or bilateral trade costs (measured via proxies) are low. Conditional on participation in trade in a given sector, the exporter fixed effect is high when a country exports to many destinations and the importer fixed effect is high when a country imports from many destinations. On the import side, the aggregate market size of the importer is likely to be a strong determinant of demand in any given sector. High demand in turn leads a large number of countries to serve the market and raises the predicted probability of any given source country serving the market. To check whether the estimates are consistent with this mechanism, I construct a trade-weighted average of the predicted Probit index \((X_{ij} \hat{\beta})\) for each importing country \(j\) in four random sectors. In Figure I plot the resulting aggregate index against aggregate real GDP of the importer. The predicted Probit index is clearly increasing in the aggregate size of the destination market in all four sectors. Since the predicted probability of trade is increasing in the Probit index, large destination markets will have a higher probability of importing on average from any given partner. In turn, the predicted productivity thresholds for serving those large markets will be lower on average.

As an alternative credibility check, I rank U.S. export destinations according to the ease of foreign market access on average. Similar to the previous calculation, I construct an aggregate index for each destination market that equals the trade-weighted average of the predicted Probit index across all sectors. I then rank destinations according to the probability of observing trade, with low numbered rankings indicating a high probability of trade and hence a low threshold for exporting to that market. Table 3 contains the resulting ranking. The results are mostly consistent with intuition and the model. Mexico is ranked as the easiest market for U.S. firms to enter, and the United Kingdom and other European markets dominate the top portion of the list. The bottom of the list is populated by predominantly low income countries and small markets. Overall, the level of the threshold across markets appears to convey sensible information about how hard it may be for U.S. firms to penetrate foreign markets.

31 In terms of economic fundamentals, comparative advantage based on technology or endowments is likely to be an important determinant of how many destinations a given exporter serves. Bernard, Redding, Schott (2007) study the theoretical properties of the Melitz model in an environment in which comparative advantage influences the sectoral composition of production and exports. To my knowledge, the empirical validity of this prediction has not been explored empirically at the sectoral level for a wide range of countries. This is a natural extension of the empirical work presented here.

32 Ranking countries on a sector-by-sector basis provides an alternative to this aggregate ranking and yields generally similar results. Moreover, it does not suffer from the problem that aggregate country ranks are distorted by the fact that the U.S. exports to a different set of countries in each sector and exports in only a small number of categories to some countries. The aggregate rankings may therefore be misleading when
A further interesting fact about average propensities to trade is that the predicted probability of exporting is generally higher for large and wealthy exporters. To document this, I construct an aggregate trade-weighted predicted Probit index for each exporter in the same four sectors as above and plot the result against real GDP per capita of the exporter in Figure 2. The figures clearly indicate that poorer countries tend to have lower indices and hence predicted probabilities of exporting on average. As a result, they will also have higher export thresholds on average. Though the data do not permit me to identify the origin of this statistical relationship, the theoretical model suggests that lower income countries might face higher thresholds due to higher fixed and/or variable costs of accessing foreign markets. Alternatively, lower average product quality in low income countries could also explain this result. For the present paper, the important consequence of this result is that differences in average export thresholds across countries could result in price differences across countries. I return to this point below.

4.3 Estimating the Trade and Price Equations

With the first stage estimates in hand, I turn to discussing estimates from the trade and participation equations. Motivated by the theoretical development above, I focus on documenting three facts. First, in the typical sector, prices are increasing in the export productivity threshold of serving foreign markets. This amounts to a rejection of the price predictions of the benchmark Melitz model in which prices are uniformly decreasing in the export productivity threshold. The results are consistent with the endogenous quality version of the model outlined in Section 2. Furthermore, the pattern of slope estimates across sectors provides supportive evidence that differences in incentives for quality upgrading across sectors can explain differences in estimated slopes. Second, variation in productivity thresholds plays only a small role in explaining variation in prices either within exporters across destinations or across countries on average. Instead, exporter-specific factors (common to all destination markets for a given exporter) explain a sizable portion of the overall variation. Third, variation in export thresholds appears to play a large role in accounting for the volume of trade at the sector level.

they are based on a small subset of goods. As such, the literal ranking should be interpreted carefully as it provides a possibly distorted picture of typical rankings within specific sectors and may fail to rank countries with which the U.S. does not trade extensively (e.g., Iran) inappropriately.
4.3.1 Slope of the Price Schedule

The relationship between export prices and productivity thresholds is controlled by $\bar{\delta}_2 - \bar{\delta}_1$. As discussed above, export prices are increasing in the productivity threshold when $\bar{\delta}_2 - \bar{\delta}_1 > 0$ and decreasing otherwise. Tables 4 and 5 contain estimates and standard errors for $\bar{\delta}_1$, $\bar{\delta}_2$ and the difference $\bar{\delta}_2 - \bar{\delta}_1$.33

The point estimates of $\bar{\delta}_2 - \bar{\delta}_1$ indicate that the price schedule is positively sloped in 87 sectors, and significantly positive (at the 10% level) in 68 sectors. The remaining sectors have a negative slope, and this slope is significantly negative in 30 sectors. Thus, positive price slopes are in general more prevalent in the data, and only a fifth of the sectors can be said with any certainty to have a negative slope.

These results strongly contradict the basic prediction of the Melitz model that export prices for a given exporter should be decreasing in the productivity threshold across destination markets. In contrast, the quality-choice augmented model provides an explanation for the prevalence of positive slopes. Interpreted via that model, the data suggest that quality is typically strongly increasing in productivity. That is, quality is both on average positively associated with the physical productivity of the firm and that incentives to upgrade quality for high productivity firms are typically strong enough to lead them to charge higher absolute prices.

To study the pattern of estimates across sectors, I plot $\bar{\delta}_2 - \bar{\delta}_1$ by sector in Figure 3. In the figure, solid points indicate that the point estimate for the slope in that sector is significantly positive or negative at the 10% level or better in a test against the one-sided alternative. Several features of the figure are worth noting. First, if the benchmark Melitz model provided accurate price predictions, then all the point estimates should lie below zero on the graph. Obviously, that is not the case. Most of the significant estimates are positive and even most insignificant estimates are either positive or close to zero. Second, the estimates tend to cluster in two main groups, indicated in the graph by the vertical line superimposed at SITC category 756. To the left of this partition, the point estimates are nearly all greater than zero. To the right, they are predominantly less than zero. Moreover, nearly all the significant negative estimates are clustered in specific groups of sectors. The significant negative estimates are centered almost exclusively in categories 751-778 and 831-881. The

33Careful inspection of the table indicates that estimates of the level of these parameters separately are somewhat less precise than estimates of the difference between the two parameters. This is because estimates of $\bar{\delta}_1$ and $\bar{\delta}_2$ are very highly correlated. In most sectors, they move together nearly one-for-one. As a result, the slope of the price equation is tightly identified even when the absolute levels of the separate parameters are not.
first grouping (751-778) includes electronics and appliances, such as typewriters, television receivers, car radios, and household laundry equipment. The second grouping (831-881) is predominantly apparel and footwear, with several additional categories for other electronics including cameras and gas/liquid/electricity meters. In contrast, in SITC category 5 – comprised entirely of manufactured chemicals – 17 of 23 point estimates are significant and positive. In SITC category 6 – comprised of a variety of primarily industrial-use manufactures classified by material (including iron and steel, rubber, paper, etc.) – 32 of 49 point estimates are significant and positive.\footnote{Counting positive point estimates without regard to statistical significance, 19 of 23 point estimates are positive in category 5, and 37 of 49 in category 6.}

The fact that positive and negative point estimates are tightly clustered into clearly identifiable product groups suggests that the pattern of sectoral heterogeneity is informative about the mechanism at work in both the data and model. In the quality choice model, we should observe negative point estimates if incentives to upgrade quality are weak. Weak incentives can result either because upgrading quality has minimal demand-side benefits, or because technological opportunities to upgrade quality are limited. In the model, benefits of upgrading quality are weak when consumers are unresponsive to changes in quality adjusted prices ($\sigma$ is small). Limited technological opportunities for upgrading can be thought of as a situation in which the cost of upgrading quality increases sharply in the level of quality ($\phi$ is large). Both these scenarios lead to relatively low equilibrium quality dispersion within a sector and allow the direct marginal cost benefits of high productivity to dominate the behavior of prices. If the quality upgrading channel is to explain the data, then electronics and apparel and footwear should have relative low quality dispersion relative to chemical manufacturing, for example.\footnote{In fact, Khandelwal (2008) argues that apparel/footwear and electronics are sectors characterized by relatively small degree of vertical quality differentiation across countries, whereas quality differences in chemicals are large. To the extent that international quality dispersion proxies for the technological and/or demand-related features of different sectors that carry over to producers within countries, then this evidence suggests that quality upgrading may account for a large portion of the sectoral heterogeneity in point estimates. Work in progress examines these results in greater detail.}

**Existing Evidence on Firm Level Prices** While this paper uses aggregate data to make inferences about the relationship between quality and productivity, quality upgrading also produces detectable patterns in firm-level data.\footnote{It is perhaps more accurate to refer to this data as “plant-level” data, since it is typically collected for plants and not firms per se.} There are at least two pieces of microeconomic evidence that would provide evidence in favor of the quality hypothesis. First,
the endogenous quality model with strong quality upgrading \((\alpha \beta > 1)\) implies that exporting firms should charge higher prices on average than non-exporting firms. In contrast, both the standard model and the endogenous quality model with weak quality upgrading \((\alpha \beta < 1)\) would predict that exporting firms charge lower prices on average. Second, the model also predicts that firm level prices in strong quality upgrading sectors should be increasing in firm size (revenue). As a corollary, since Eaton, Kortum, and Kramarz (2007) report that larger firms serve more foreign markets than smaller firms, the endogenous quality model with \(\alpha \beta > 1\) also predicts that prices should be increasing in the number of foreign markets that a firm serves.

Recently a number of papers have examined prices in census-style data and shed light of the relationship between productivity, size, and unit prices at the firm level. Hallak and Sivadasan (2008) incorporate endogenous quality choices into a Melitz style model of trade with two dimensional firm heterogeneity and minimum quality requirements for exporting. Using data from the Indian Annual Survey of Industries for 1997-1998 that includes price data, Hallak and Sivadasan (2008) find both that exporters within industries charge higher prices than non-exporters on average and that firm-level unit prices are increasing in firm size.\textsuperscript{37} Kugler and Verhoogen (2008) present a model in which firm productivity and input quality are complements. They show that this implies a positive association between both input and output prices and firm size, and document these relationships in Columbian data. Using data from Mexico, Iacovone and Javorcik (2008) find that exporters tend to charge higher prices in the domestic market than non-exporting firms and that increases in unit values, indicative of quality upgrading, predict future entry into export markets. Crozet, Head, and Mayer (2007) use data on French wine exporters and rankings of product quality to demonstrate that the average quality of products exported to a given market is increasing in the difficulty of accessing the foreign market. Finally, Aw, Batra and Roberts (2001) use data on Taiwanese electronics manufacturers and show that export unit values are typically lower than unit values for goods sold on the domestic market. This data is consistent the estimates I obtain for the electronics sector in my data, and points to the potential importance of cross-industry heterogeneity in understanding how quality is related export participation.\textsuperscript{38} These consistent results from a variety of datasets provide strong evidence

\textsuperscript{37}These results are based on within industry variation. This means that fixed characteristics common to all firms in an industry that affect average prices, export behavior, and/or size of firms in one industry versus another are not driving these results.

\textsuperscript{38}Further, they provide evidence that this result is not due to price discrimination by individual firms across the two markets, but rather seems to be due to variation in the composition for firms across home
that the quality-augmented Melitz model could provide an explanation for firm level price facts.

Evidence for the United States on the relationship between plant level prices and plant size and/or export status is limited. Even the few studies that do exist do not address the questions raised in this paper directly because they focus exclusively on homogeneous quality industries. Nonetheless, they do provide a useful benchmark in the sense that the model in this paper predicts that prices should be decreasing in firm size and physical productivity in these homogeneous quality industries. And indeed, the data seem to confirm this prediction. Roberts and Supina (1996, 2000) find that for a selection of homogeneous industries prices are typically decreasing in firm size, with small producers charging prices up to 20% higher than the mean within sectors and large producers charging prices around 10% lower than the mean. Looking at similar industries, Foster, Haltiwanger and Syverson (2008) also report that plant-level prices are typically falling in measured plant level physical productivity. These results are comforting to the extent that they indicate that the relationship between prices and plant size in homogeneous quality industries conforms to theory. This strengthens the case that the price behavior I uncover using aggregate export prices is inconsistent with the behavior of prices in homogeneous quality industries.

Robustness of Slope Estimates

Before proceeding, I perform some additional analysis to confirm that the estimates of the price equation slope are not artifacts of assumptions I have made in the estimation process, specifically regarding functional form and the exclusion restriction used to estimate the trade equation along with the price equation. To do so, I run a sequence of linear regressions within each sector to sign the correlation of prices with the productivity thresholds. As in the general model, special attention must be paid to both the fact that the thresholds are unobserved and prices are observed only if trade takes place. To be clear, I specify the conditional expectation of log export prices as:

\[
E[\log(\bar{p}_{ij})|\cdot, T_{ij} = 1] = \mu_i + \varsigma E[\log\left(\frac{z_{xij}}{z_{H}}\right)|\cdot, T_{ij} = 1],
\]

(24)

where the dot notation indicates conditioning on observables \{X_{ij}, \mu_i\}. Then I substitute for \(\frac{z_{xij}}{z_{H}}\), construct the appropriate conditional expectation as in the general model, and estimate the resulting equation to sign the partial correlation coefficient \(\varsigma\). I start by signing \(\varsigma\) in the full data set, and then repeat the exercise using only U.S. export prices in the 118 sectors and foreign markets.
that the U.S. exports to 20 or more partners. The results are tabulated in Table 6 along with the tabulation of slope estimates from the non-linear specification discussed above. The results confirm the incidence of positive and negative slopes documented previously. In the full data set, 64% of the price equation slopes are positive (with 49% significant and positive) and the remaining slopes are negative (with 23% significant and negative). For the U.S. data, even a greater share of point estimates are positive (74%), though less are statistically significant. The reduced statistical significance is likely due to the much smaller sample sizes in the U.S. data. Moreover, only 2% of the estimates correlations for the U.S. are negative and significant.

To see these raw correlations in the data, I turn to export data for the U.K. In Figure 4, I plot log export prices in four sectors for the U.K. against the rank of the destination market in the U.K.’s export hierarchy in that sector (with 1 indicating the easiest foreign market to enter). As is evident, three of the four sectors here have positive and one has a negative slope. To the naked eye, it also appears that there is a substantial amount of price variation within these sectors not explained by productivity thresholds. I return to this issue in the next section.

4.3.2 Accounting for Prices and Trade

Given that prices and trade volumes vary across countries, an important question is whether differences in productivity thresholds explain this variation or whether other factors are at work. I thus turn to a discussion of accounting. In general, the model accounts for a substantial amount of the overall variation in prices and trade volumes. Figure 5 plots the fraction of the variance in log exports and log prices within each sector that is accounted for by the model. In most sectors, the model captures upwards of 80% of the overall variance of trade. As for prices, on average the model is able to account for almost half of the overall variance in prices, though the fit of the model varies from sector to sector.

The model also does quite well in accounting for the stylized fact documented by Schott (2004) that the price at which the U.S. imports from different source countries within sectors is strongly correlated with GDP per capita of the importing country. To replicate Schott’s

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39 As in estimation of the general model, I include a U.S. importer dummy in addition to exporter fixed effects when using the full data set to account for differences in units between the U.S. and rest of the world.

40 For export prices, this figure and the related calculations exclude the United States. Because the U.S. data has different units, this introduces artificial volatility into raw prices due to level differences between the U.S. and rest of the world. These are picked up in U.S. exporter and importer fixed effects in the estimation. Including the U.S. in these variance calculations would therefore overstate the ability of the model to match price variation.
results, I regress the log U.S. import price in each sector on the GDP per capita of the exporter. To compare this to the model, I perform an identical regression with predicted prices in place of actual prices. The resulting coefficients for the 102 3-digit sectors in which the U.S. imports from 20 or more partners are plotted against one another in Figure 6. In general, these coefficients match up very closely indicating that the model is able to replicate the strong relationship between log income and export prices that Schott documents.

The natural question to ask is whether the ability of the model to match the price facts derives from variation in the productivity thresholds or country-specific factors. The answer is that country-specific factors play the dominant role in explaining overall price variation. To illustrate this fact, I decompose the variance of predicted prices in the model by calculating the variances and covariance of the exporter fixed effect and the threshold term. Figure 7 plots the results as a share of the total variance of predicted prices. As the figure indicates, the ratio of the variance in the exporter fixed effect to total variance in predicted prices is near or even exceeds one in many sectors. On the other hand, the ratio of the variance of the cutoff term to total variance is low in most sectors. Moreover, the role for cutoffs in explaining overall variation in prices is diminished by the fact that the threshold term covaries negatively with the exporter fixed effect. This negative covariance arises due to the fact that poor (rich) countries have high (low) export thresholds on average, a fact I documented in Section 4.2 as well as low (high) exporter fixed effects. That is, poor countries both have low average export prices and high export thresholds. When the price schedule slopes up in the threshold, this means that there will be a negative covariance between the exporter fixed effect and the threshold term. In contrast, in sectors where the price schedule slopes down, there will be a positive covariance and a somewhat larger overall role for threshold variation in explaining prices.

Returning to Schott’s stylized facts, this discussion naturally leads to the conclusion that differences in country-specific unit costs, rather than differences in productivity thresholds across countries, explain the strong correlation between prices and source-country income in U.S. import prices. To illustrate this, Figure 8 plots observed prices, predicted prices, the estimated exporter price fixed effect, and the predicted value of the threshold term in the price equation against exporter GDP per capita for SITC 583 (Polymerization Products) in which prices are increasing in the export productivity threshold for exporting. Figure 9 does the same for SITC 842 (Men’s Outerwear) in which prices are decreasing in the thresholds.

\[41\] The fact that the variance of the cutoff term is near zero in some sectors is obviously a reflection of the fact that the estimated slope of the price equation is near zero in those sectors.
In both figures, the fact that prices are increasing in exporter GDP per capita is evident in the upper left hand graph. The upper right graph replaces actual prices with predicted prices to illustrate that the model does a good job matching this fact. Comparing this graph to the lower left hand graph of exporter fixed effects, we see that predicted prices predominantly reflect variation in the average exporter-specific level of prices.

To illustrate the role of productivity thresholds in determining prices, I plot the threshold term in the price formula against income of the source country in the lower right hand graph. Two important points stand out here. First, variation in the threshold term is quite small overall and is thus unable to explain a large portion of the variation in import prices. Second, variation in the threshold term works is different directions in the two sectors. For Polymerization Products, the threshold term is negatively correlated with source country income and thus actually works in the wrong direction for understanding prices. This is because rich countries have low bilateral export thresholds relative to poor countries in this sector. Combined with the fact that the price schedule is upward sloping in this sector, lower thresholds for rich countries translate into lower prices as a result. Because the price schedule is positively sloped in most sectors, this pattern is quite common. However, as the bottom right panel for Men’s Outerwear shows, there are cases in which the threshold component of prices contributes positively to explaining price differences between rich and poor countries. In this sector, the price schedule is downward sloping in productivity. Therefore, low productivity thresholds for wealthy countries generate higher prices. In both cases, however, the contribution of the threshold term of the price equation is quite small relative to the role of exporter-specific costs in understanding the pattern of U.S. import prices.

In contrast to these results for prices, variation in bilateral productivity thresholds explains a substantial portion of variation in exports. To quantify the role of productivity thresholds, I decompose the variance of of predicted trade in the model into variances and covariances of the components associated with bilateral thresholds and a composite of all other components. Figure 10 contains the results. On average, the productivity threshold term can account for around half of the total variation in predicted trade. Given that the model accounts for around 80% of the total variance in trade, then thresholds account may account for as much as 40% of the total variation in exports. This suggests a very large role for endogenous non-tradability in explaining trade volumes.

To illustrate the good fit of the model along this dimension, I purge log exports of the estimated exporter and importer fixed effects and the direct effect of trade costs and plot the resulting residual exports against the expected value of the Probit index $E[X_{ij}|\hat{\theta}^*, T_{ij} = 1]$
for two sectors (SITC categories 781 and 659). I then superimpose on this plot the predicted value of the threshold term in the export equation along with a composite of the threshold term and the selection term. As is evident in Figure 11, the data is tightly clustered and clearly positively related to $E[X_{ij}\hat{\theta}^*, T_{ij} = 1]$. To the extent that poor countries tend to have lower productivity thresholds on average, then this strong positive relationship would suggest that one reason they export lower volumes than rich countries is that a smaller fraction of firms in these countries export. Also, the values of trade predicted by the model match up quite closely with the data. Variation in the threshold term does most of the work in matching the overall pattern of the data. However, in the lower tail, the selection effect plays a larger role. The selection effect is actually negative in these two sectors, and is generally negative in most sectors. This selection effect plays only a small role in accounting for trade volumes overall.

4.3.3 Cross-Country Quality and Variety

One advantage to using price data in studying trade patterns is that it provides a means to identify separately the role of prices and latent quality and/or variety in generating observed export quantities. Following the procedure outlined in Section 3.5, I combine the estimated price of the most productive firm in each sector with the estimated exporter fixed effect in the trade equation to calculate a country-specific variety/quality index. In doing so, I take estimates of the elasticity of demand for U.S. SITC 3-Digit imports from Broda and Weinstein (2006). Further, I normalize the quality-variety composite of the United Kingdom to one in each sector and report measures of the country-specific index as proportional deviations from this numeraire country.\(^{42}\)

In line with intuition, the imputed quality-variety composite covaries strongly with exporter income per capita. For reference, Figure 12 plots the quality-variety composite versus exporter income for four sectors. In all four cases, the relationship is positive and statistically statistically. This result holds more generally as well. Figure 13 plots slopes estimates from regressions of the quality-variety composite on income per capita in each sector. To summarize the figure, 69% of the 141 sectors have a statistically significant positive slope at the 10% level or higher. Only 4% of the sectors have a statistically significant negative slope.\(^{43}\) Thus, combining price and export value information strongly suggests that rich countries produce

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\(^{42}\)Because the U.S. exporter fixed effect is polluted by differences in units, the U.S. is excluded from these calculations.

\(^{43}\)Tabulating slopes without regard to significance, 84% of the point estimates are positive.
higher quality goods and/or produce a larger variety of goods within sectors. Furthermore, the positive point estimates are distributed evenly across sectors, meaning that wealthier countries appear to enjoy superior quality/variety across the board in manufacturing.

The fact that latent quality-variety is strongly correlated with income per capita across the board in manufacturing is a result of a robust fact in the data. Rich countries both export a lot, and do so at relatively high unit values. To illustrate this, Figure 14 plots the exporter fixed effects from the export and price equations against exporter income in one sector. Both are strongly increasing in income. To reconcile these facts in the context of standard trade models requires that rich countries produce high quality and/or a large variety of goods. A main challenge for future work is to decompose composite quality/variety into independent quality and variety sub-components.

5 Concluding Remarks

This paper establishes that ignoring product quality differences across firms produces counterfactual predictions for export prices. By contrast, a model in which high productivity firms choose to produce high quality goods and charge high unit prices is consistent with the most common pattern of export prices. As a side benefit, the estimates also shed light on the relationship between productivity, quality choices, and prices at the plant level.

These results have implications for future research. First, research aimed at careful examination of firm level prices and exports in census-style data should yield high returns, especially where that data contains information on bilateral trade for individual firms. Firm level data would permit the researcher to accommodate richer interaction between productivity and quality heterogeneity, as well as and demand-side influences, in determining prices and export selection than I am able to allow using aggregate data. Second, productivity thresholds appear to play a limited role in explaining cross-country variation in prices. Rather, exporter-specific factors explain around half of the total variation in prices. Therefore, research should aim at identifying the sources of this vertical differentiation across countries. Third, productivity thresholds appear to play a large role in explaining exports. As such, research into the sources of variation in export thresholds across destinations and across source countries could substantially improve our understanding of trade patterns.
Appendix A

This appendix sketches the general equilibrium solution to the endogenous quality model presented in Section 1. Most of the model has been described previously in the main text. The main component of the model yet to be specified is the procedure via which firms decide to enter and produce. Similar to Ghironi and Melitz (2005), I assume that firms are ex-ante identical and pay a fixed cost $f_{E_i}$ units of labor for the right to draw idiosyncratic productivity $z$ from a distribution $G(z)$. Because this cost is sunk, all firms produce post. To close the model, I will assume that trade is balanced in the aggregate for each country.

Much of the model solution, has been detailed in the main text, including the solution to the consumer’s problem, the firm’s optimal pricing and quality choice decision, and firm decisions about whether to export. I restate those results here in bullet point form.

- The consumer in country $i$ allocates consumption across available varieties according to:
  \[ c_{ij}(z) = \left[ \lambda_j(z) \right]^{\sigma-1} \left( \frac{\tau_ip_j(z)}{P_i} \right)^{-\sigma} C_i, \tag{25} \]
  where $c_{ij}(z)$ indicates consumption by a consumer in country $i$ of a variety with idiosyncratic productivity $z$ produced in country $j$ and $C_i$ is aggregate consumption as defined in the text. Further, I assume $\tau_{ii} = 1$. Exhaustion of the budget constraint for the consumer implies that $P_iC_i = w_iL_i$.

- The firm chooses prices and quality as described in the main text, leading to optimal prices and quality choices that are a function of the firm’s idiosyncratic productivity:
  \[ p_i(z) = \left( \frac{\sigma}{\sigma - 1} \right) w_i \lambda_i(z)^{\beta} \]
  \[ \lambda_i(z) = \lambda_i z^\alpha, \tag{27} \]
  with $\lambda_i$ defined as in the main text.

- The zero profit condition for the marginal exporting firm to each market pins down $z_{xij}$ for $j \neq i$ as:
  \[ z_{xij} = \left[ \frac{\sigma}{\sigma - 1} \frac{w_i \lambda_i^{\beta-1} P_j}{Z_i \tau_{ij}} \left( \frac{\sigma f_{xij}}{E_j} \right)^{1/(\sigma-1)} \right]^{1/(1-\alpha \beta + \alpha)}, \tag{28} \]
with \( E_i = P_i C_i \). Combined with the fact that \( z \) has distribution \( G(z) \) in each country, then these productivity thresholds pin down the number of firms exporting to each market as: \( N_{xij} = N_i (1 - G(z_{xij})) \).

With these preliminaries, it remains to clearly define \( \{P_i\} \) and solve for the collection of endogenous variables \( \{w_i, N_i\} \) necessary to evaluate the expressions above. To do so, I follow Melitz (2003) and Ghironi and Melitz (2005) in defining convenient productivity aggregates that allow me to write the equilibrium conditions in terms of the behavior of representative domestic firms and representative exporters. Thus, I define the productivity of a representative firm located in country \( i \) producing for the home market as \( \tilde{z} \) and a representative exporter from \( i \) to \( j \) as \( \tilde{z}_{xij} \) where:

\[
\tilde{z} = \left[ \int_{z_L}^{z_H} z^{(1 - \alpha \beta + \alpha)(\sigma - 1)} dG(z) \right]^{1/(1 - \alpha \beta + \alpha)(\sigma - 1)}
\]

\[
\tilde{z}_{xij} = \left[ \int_{z_{xij}}^{z_H} z^{(1 - \alpha \beta + \alpha)(\sigma - 1)} dG(z) \right]^{1/(1 - \alpha \beta + \alpha)(\sigma - 1)}
\]

These expressions are similar to those in Ghironi and Melitz (2005). The only difference is the addition here of the term \((1 - \alpha \beta + \alpha)\) multiplying \((\sigma - 1)\). With these definitions in hand, it is straightforward to define the aggregate price level in each country in terms of the quality-adjusted price charged by the representative domestic firm and representative exporters from each destination that serves the domestic market:

\[
P_i = \left[ N_i \tilde{p}_i(\tilde{z})^{1 - \sigma} + \sum_{j \neq i} N_{xji} [\tau_{ji} \tilde{p}_j(\tilde{z}_{xji})]^{1 - \sigma} \right]^{1/(1 - \sigma)}.
\]

(29)

Ultimately, the aggregate price level is a function of \( \{w_i, N_i\} \) just as all the other objects defined above. If there are \( I \) countries in total, then the combination of \( I \) free entry conditions and \((I - 1)\) balanced trade conditions define the number of firms in each country and relative wages across countries up to the definition of a numeraire (say \( w_1 = 1 \)).

Free entry requires that the expected value of profits conditional on entry is equal to the fixed cost of entry. To write the free entry condition, I define the profits of the representative
domestic firm and representative exporters for each destination market as:

\[
\pi_i (\tilde{z}) = \frac{1}{\sigma} \left( \frac{\hat{p}_i (\tilde{z})}{P_i} \right)^{1-\sigma} (w_i L_i) - \frac{w_i \lambda_i (\tilde{z})}{Z_i} f
\]

\[
\pi_i (\tilde{z}_{xij}) = \frac{1}{\sigma} \left( \frac{\hat{p}_i (\tilde{z}_{xij}) \tau_{ij}}{P_j} \right)^{1-\sigma} (w_j L_j) - f_{xij},
\]

where I have used the fact that \( E_i = w_i L_i \) and the profits of the representative home firm are expressed net of the cost of upgrading quality. Then, since there are ex-post \( N_i \) domestic firms and \( N_{xij} \) exporters to each destination market, the free entry condition can be written as:

\[
N_i \pi_i (\tilde{z}) + N_{xij} \pi_i (\tilde{z}_{xij}) = N_i (w_i f_{E_i}). \tag{30}
\]

Finally, I write aggregate exports from country \( i \) to \( j \) using the definition of the representative exporter’s productivity:

\[
EX_{ij} = N_{xij} \left( \frac{\hat{p}_i (\tilde{z}_{xij}) \tau_{ij}}{P_j} \right)^{1-\sigma} (w_j L_j),
\]

where I again appeal to the fact that \( E_i = w_i L_i \) to express exports explicitly in terms of wages. Then the balanced trade conditions take the form:

\[
\sum_{j \neq i} EX_{ij} = \sum_{j \neq i} EX_{ji}. \tag{31}
\]

Using the appropriate definitions, we can reduce the system down to the following collection of endogenous variables \( \{c_{ij}(z), p_i(z), \lambda_i(z), z_{xij}, P_i, w_i, N_i\} \) for each country. Equations (25)-(29) for \( I \) countries plus (I-1) balanced trade conditions as in (31) then define a monopolistically competitive equilibrium for the world economy.

**Appendix B**

This appendix describes procedures I use for dealing with several problems that arise in working with the quantity data and provides details on the trade cost measures used in estimating the model. In unreported work, I have experimented with alternative procedures dealing with the problems in the quantity data and found the estimation results to be robust to the exact procedure used.
There are several complications that arise due to differences in the way quantity units are recorded across countries and sectors. Due to the manner in which the Feenstra-Lipsey data were assembled, units are not always homogeneous within sectors or for individual countries. When there are multiple units within a sector, I discard prices associated with the minority unit. In practice, this results in a small, quasi-random loss of data. In the vast majority of sectors, this results in a loss of somewhere between 1-5% of price observations. Some sectors lose no data, and the maximum loss is around 25% in the Feenstra-Lipsey data. In the U.S. data, the problem is somewhat larger because the U.S. simply has a larger number units categories. Usually the problem manifests itself as observing two different prices for exports to each destination in a sector. In this event, I drop the minority set of units. In addition, sometimes quantities and units are simply missing either for part or all of a country’s trade with a specific partner. When quantities are missing for a majority of trade for a given exporter to a specific destination, I treat that category as if I observe no quantity and hence no price. Whereas quantities/prices are available for nearly all U.S. trade, quantity data is somewhat patchier in the Feenstra-Lipsey data. Missing data appear to be due principally to quasi-random reporting gaps and do not follow obvious systematic patterns. Nearly all countries in the sample have prices for upwards of 80-90% of the value of exports. A further complication arises because U.S.-sourced trade data is reported in entirely different quantity units than the Feenstra-Lipsey data. This has two implications. First, the U.S. fixed effect in the price equation picks up both variation in average prices in the U.S. relative to the rest of the world as well as differences in units. As a result, all the analysis in the body of the paper that uses the estimated fixed effects omits the U.S.. Second, I include a U.S. importer fixed effect as well in the price regression to purge the effects of units differences from prices associated with exports to the U.S.

Finally, the price data contain a small but influential number of outlying prices. These appear to be due to measurement error in the data, and therefore I remove these observations. Specifically, I remove observations that differ from the median price in a sector by more than a factor of five. Purging observations that differ by more than a factor of ten yields similar results.

Turning to measurement of trade costs, I take most of these measures directly from Helpman, Melitz, and Rubinstein (2008). Marc Melitz graciously provided me with most of the data used in their paper. The only exceptions were categorical variables classifying islands and landlocked countries. I constructed these using the CIA World Fact Book. A few of the variable definitions deserve some extra comments. The common religion variable
is a continuous variable equal to: \( \% \text{Protestants in country } i \cdot \% \text{Protestants in country } j + \% \text{Catholics in country } i \cdot \% \text{Catholics in country } j + \% \text{Muslims in country } i \cdot \% \text{Muslims in country } j \). The common legal system variable takes on a value of one if the importing and exporting country share the same legal origin, and the colonial ties variable takes the value one if either country was once a colony of the other. In addition to these trade cost variables used in the main text, I have experimented with policy-type variables, including free trade areas, WTO membership, and currency unions and obtained roughly identical results to those reported.
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Notes: Exporter and Importer fixed effects included in all regressions. Standard Errors in Parentheses. * p<.10, ** p<.05, *** p<.01
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Notes: Destinations are ranked by trade-weighted average Probit Index for all sectors. Low numbers indicate high probability of trade and low threshold productivity cutoff. See main text for details.
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Notes: See main text for details.
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Notes: Bold indicates that estimated price equation slope is significantly positive or negative in one-sided test at 10% level or higher. See main text for details.
Table 6: Tabulation of Price Equation Slopes

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<td>negative &amp; significant</td>
<td>21%</td>
<td>23%</td>
<td>2%</td>
</tr>
<tr>
<td>Total sectors:</td>
<td>141</td>
<td>141</td>
<td>118</td>
</tr>
</tbody>
</table>

Notes: Column 1 reports tabulation for full non-linear estimation. Columns 2 and 3 report tabulation for linear regressions in full data and US export prices alone. “Significant” indicates that estimated slope is significantly positive or negative in one-sided test at 10% level or higher. See main text for details.
Figure 1: Trade Weighted Average of Predicted Probit Index by Importing Country vs. Real GDP of the Importer

Figure 2: Trade Weighted Average of Predicted Probit Index by Exporting Country vs. Real GDP Per Capita of the Exporter
Figure 3: Estimated Slope of the Prices Schedule ($\bar{\delta}_2 - \bar{\delta}_1$), by SITC 3-Digit Sector

Figure 4: Log Export Price for United Kingdom vs. Ranking of Destination Market by Productivity Threshold
Figure 5: Fraction of Total Variance in Log Prices and Log Exports Explained by Model, by SITC 3-Digit Sector

Figure 6: Coefficients from Within-Sector Regressions of Actual and Predicted U.S. Import Prices on Exporter GDP Per Capita
Figure 7: Decomposition of Predicted Prices into Variances and Covariance of Exporter Fixed Effect and Threshold Term

Figure 8: Log Prices, Predicted Prices, and Estimated Components of Prices for U.S. Imports of Polyethylene vs. Log GDP Per Capita of Exporter
Figure 9: Log Prices, Predicted Prices, and Estimated Components of Prices for U.S. Imports of Men’s Coats vs. Log GDP Per Capita of Exporter

Figure 10: Decomposition of Predicted Trade into Variances and Covariance of Non-Threshold and Threshold Terms
Figure 11: Log Exports Purged of Fixed Effects and Trade Costs with Predicted Threshold and Selection Terms

Figure 12: Estimated Index of Quality and Variety vs. Exporter Real GDP Per Capita
Figure 13: Correlation between Estimated Index of Quality and Variety and Exporter Real GDP Per Capita, by Sector

Figure 14: Estimated Exporter Specific Component of Exports and Prices for Representative Sector
References


