

THE QUARTERLY JOURNAL OF ECONOMICS

Vol. 129

May 2014

Issue 2

INTERNATIONAL PRICES AND ENDOGENOUS QUALITY*

ROBERT C. FEENSTRA AND JOHN ROMALIS

The unit values of internationally traded goods are heavily influenced by quality. We model this in an extended monopolistic competition framework where, in addition to choosing price, firms simultaneously choose quality subject to nonhomothetic demand. We estimate quality and quality-adjusted price indexes for 185 countries over 1984–2011. Our estimates are less sensitive to assumptions about the extensive margin of firms than are purely “demand-side” estimates. We find that quality-adjusted prices vary much less across countries than do unit values and, surprisingly, the quality-adjusted terms of trade are negatively related to countries’ level of income. *JEL* Codes: F12, F14.

I. INTRODUCTION

The quality of internationally traded products has become an important area of study. Product quality is a key feature of how countries specialize in production (Schott 2004), the direction of trade between countries (Hallak 2006), and even how countries grow (Hummels and Klenow 2005). Trade prices and countries’ terms of trade have also long played a central role in international trade theory and international macroeconomics. Researchers studying these variables are often limited to statistics for individual nations, sometimes made available as short series in international databases such as the World Bank’s World Development Indicators. This article develops and implements a new methodology exploiting a pervasive supply-driven

*The authors thank George Dan, Dan Liu, Phil Luck, John Lennox, Anson Soderbery, and Greg Wright for excellent research assistance, as well as Juan Carlos Hallak, Pablo Fajgelbaum, Robert Inklaar, Marcel Timmer, and numerous seminar participants for helpful comments. Financial support from the National Science Foundation Grants no. 0648766 and 1061880, from the Sloan Foundation, and from the Australian National University is gratefully acknowledged.

© The Author(s) 2014. Published by Oxford University Press, on behalf of President and Fellows of Harvard College. All rights reserved. For Permissions, please email: journals.permissions@oup.com

The Quarterly Journal of Economics (2014), 477–527. doi:10.1093/qje/qju001.
Advance Access publication on February 5, 2014.

feature of trade data to decompose widely available unit values of internationally traded goods into quality and quality-adjusted price components. Results for individual products for almost all countries from 1984 to 2011 are aggregated to industry-level indexes of import and export quality, import and export prices, and terms of trade.

We are not the first to attempt to disentangle quality from trade unit values; other recent authors to do so include Schott (2004, 2008), Hallak (2006), Hallak and Schott (2011), Khandelwal (2010), and Martin and Méjean (2012).¹ These studies rely on the demand side to identify quality together with a simple supply side to control for the extensive margin. In the words of Khandelwal (2010, p. 1451): “The procedure utilizes both unit value and quantity information to infer quality and has a straightforward intuition: conditional on price, imports with higher market shares are assigned higher quality.” Likewise, Hallak and Schott (2011) rely on trade balances to identify quality, with higher net exports—conditional on price—implying higher quality.

To this demand-side intuition we add a supply side, in two respects. First, our model of endogenous quality choice by firms, described in Section II, gives rise to a “Washington apples” effect (Alchian and Allen 1964; Hummels and Skiba 2004): goods of higher quality are shipped longer distances. We find that this positive relationship between quality and distance, or between exporter free on board (f.o.b.) price and distance, is an immediate implication of the first-order condition of firms for optimal quality choice. It allows us to use the exporter f.o.b. price to help identify quality.

We embed this quality decision into a Melitz (2003) model with heterogeneous firms, described in Section III. Included in the model is the zero-cutoff-profit condition that determines the marginal exporter. That condition is a second supply-side relation that will help us identify quality, and it works in the opposite direction as the demand-side intuition. As foreign demand rises, less efficient exporters enter, and they produce lower quality. It follows that quality and bilateral trade are *negatively* related from this supply-side relation. Combined with the positive

1. Another line of literature empirically distinguishes between productivity and quality versions of the Melitz (2003) model: see Mandel (2010), Baldwin and Ito (2011), Crozet, Head, and Mayer (2012), and Johnson (2012).

relationship between trade and quality from the demand side, we obtain a much sharper solution for quality than is found in previous literature. That solution depends on cost, insurance, and freight (c.i.f.) and f.o.b. prices (measured by unit values) and the parameters of our model: the elasticity of substitution, a Pareto productivity parameter, and also a parameter governing nonhomothetic demand, which we allow as in recent literature.²

A key feature of our solution for quality is that it does *not* depend on the mass of firms (or product variety), in contrast to solutions that use only the demand side to identify quality. This key advantage comes with a limitation, however. We still need to specify a proxy for the mass of firms in the equation used to estimate our model parameters. In practice we have found that the model parameters and our quality estimates are not very sensitive to that proxy. But our quality estimates are quite sensitive to the fixed cost of exporting, which is crucial to the supply side of the model. To offset this sensitivity, we allow for a rather general specification of the fixed cost of exporting, which can depend on firm productivity and the size of the importing market, in addition to bilateral “gravity” variables, such as language differences between the exporting and importing countries. As discussed in Section III, this general structure of fixed costs is important to our results.

In Section IV, we estimate these parameters from a gravity-like equation implied by our model, using detailed bilateral trade data at the four-digit SITC digit level (nearly 800 products a year) for 185 countries during 1984–2011. Our median estimate of the elasticity of substitution is higher than that in Broda and Weinstein (2006), which we attribute to several features: our expanded sample over many countries, the fact that quality is included, and by using a specification that is more robust to measurement error. Our median estimate of the Pareto parameter is quite close to the estimated Fréchet parameter in Eaton and Kortum (2002), who also consider trade between many countries.

Given the parameter estimates, product quality is readily constructed in Section V. On the export side we find that much of the variation in unit values is explained by quality, so quality-adjusted prices vary much less than the raw unit values or than the quality-adjusted estimates of Hallak and Schott (2011) and

2. Our specification of nonhomothetic tastes is similar to that in Hallak (2006), but working with the expenditure rather than utility function.

Khandelwal (2010). We also find that our estimates are less sensitive to assumptions about the extensive margin than the “demand-side” estimates of these authors (because we solve for the extensive margin in our model).

On the import side we find that quality-adjusted import prices tend to be lower for poor countries. It follows that countries’ quality-adjusted terms of trade are negatively related to their level of income. This surprising result is due in part to the lower unit value of imports for poor countries, but it also relies on the supply side of our model: countries with lower imports (because they are poor or just small) buy from more efficient foreign firms who can overcome the fixed costs of exporting, and these firms sell higher quality. Offsetting that effect is the reduced preference for quality in low-income countries. Balancing these opposing effects, import quality is only weakly related to country income. Because import unit values are more strongly related to income, it follows that the quality-adjusted import prices are lower for poor countries. This result lends support to the proposition of Fajgelbaum, Grossman, and Helpman (2011a) that poorer countries are net importers of higher-quality goods (because they are not produced locally): we find that import quality is less related to income than is export quality, so that poorer countries do appear to be net importers of higher quality goods.

We provide indexes of quality and quality-adjusted prices for the four-digit SITC and one-digit Broad Economic Categories (distinguishing food and beverages, other consumer goods, capital, fuels, intermediate inputs, and transport equipment), that should be useful to researchers interested in the time-series or cross-country properties of these indexes and that will be incorporated into the next generation of the Penn World Tables (PWT; see Feenstra, Inklaar, and Timmer 2013).³ In addition to their use in the PWT, the quality and price indexes produced by our study will find wide application in international trade and macroeconomics. For example, trade prices are important for the study of trade and wages (Lawrence and Slaughter 1993). Capital goods prices are used in “development accounting” (Hsieh and Klenow 2010). Intermediate goods prices are used to study the effects of trade on growth (Estevadeordal and Taylor 2013). Terms of trade

3. The quality and quality-adjusted price indexes for all countries and years, for both exports and imports at either the SITC four-digit or BEC one-digit level, are available at http://cid.econ.ucdavis.edu/Html/Quality_Data_Page.html.

indexes are used to study the arguments for fixed versus flexible exchange rates (Broda 2001) and the world income distribution (Acemoglu and Ventura 2002). Finally, an extensive database of international tariffs collected for this article will be useful for empirical international trade research.

II. OPTIMAL QUALITY CHOICE

II.A. Consumer Problem

Consumers in country k have available a continuum i of differentiated varieties of a product in a sector. These products can come from different source countries. Denote the price and quality of good i in country k by p_i^k and z_i^k , respectively. Demand in country k arises from the expenditure function:

$$(1a) \quad E^k = U^k \left[\int_i \left(p_i^k / z_i^{\alpha^k} \right)^{(1-\sigma)} di \right]^{\frac{1}{1-\sigma}},$$

with

$$(1b) \quad \alpha^k = h(U^k) = 1 + \lambda \ln U^k, \text{ for } U^k > 0.$$

Quality z_i^k is raised to the power $\alpha^k > 0$, which we denote by $z_i^{\alpha^k} \equiv (z_i^k)^{\alpha^k}$ for brevity. Thus, quality acts as a shift parameter in the expenditure function. Hallak (2006) introduced a similar exponent on quality, but in the context of the *direct* utility function (as also used by Demir 2012). In that case it is not possible to make the exponents α^k depend on utility or per capita income; by working with the expenditure function we are able to do just that. Because $\alpha^k = h(U^k)$ depends on utility, this expenditure function has nonhomothetic demand for quality, as in Fajgelbaum, Grossman, and Helpman (2011a,b).⁴

The assumptions of the constant elasticity of substitution (CES) functional form in equation (1a) and the parameterization of the exponents $h(U^k)$ in (1b) are both made for convenience. The key assumption is that *price is divided by quality in the expenditure function*, enabling us to reformulate consumer decisions in terms of *quality-adjusted* prices and quantities. Differentiating

4. Other recent literature including Choi, Hummels, and Xiang (2009), Bекkers, Francois, and Manchin (2012), and Simonovska (2013) analyze models of international trade and quality where nonhomothetic demand plays a central role.

this expenditure function to compute demand q_i^k :

$$q_i^k = \frac{\partial E^k}{\partial p_i^k} = \frac{\partial E^k}{\partial P_i^k} \frac{1}{z_i^{\alpha^k}},$$

where we define the *quality-adjusted prices* $P_i^k \equiv p_i^k/z_i^{\alpha^k}$, which are the natural arguments of the expenditure function in equation (1a). Likewise defining *quality-adjusted demand* $Q_i^k \equiv z_i^{\alpha^k} q_i^k$, we can rearrange terms to obtain $Q_i^k = \partial E^k / \partial P_i^k$. It follows that working with the quality-adjusted magnitudes still gives quantity as the derivative of the expenditure function with respect to price.

The expenditure function in equation (1) is valid provided that it is increasing in utility and nondecreasing in price.⁵ Using the assumed functional forms, we derive:

$$\frac{\partial E^k}{\partial U^k} = \frac{E^k}{U^k} + \int_i Q_i^k \frac{dP_i^k}{dU^k} di = \frac{E^k}{U^k} \left[1 - \lambda \int_i \left(\frac{P_i^k Q_i^k}{E^k} \right) \ln z_i^k di \right],$$

since $dP_i^k/dU^k = -P_i^k \ln z_i^k h'(U^k) = -\lambda P_i^k \ln z_i^k / U^k$, using $P_i^k \equiv p_i^k/z_i^{\alpha^k}$ and equation (1b). The final integral is interpreted as the average of log quality across products. Thus, the expenditure function in equation (1) is increasing in utility provided that λ is sufficiently small, which is readily confirmed in our estimates.

II.B. Firms' Problem

The production side of the model is an extension of Melitz (2003) to allow for endogenous quality choice by firms. The detailed assumptions are as follows:

ASSUMPTION 1. Firms may produce multiple products, one for each potential market.

ASSUMPTION 2. Firm j producing in country i simultaneously chooses the quality z_{ij}^k and f.o.b. price p_{ij}^{*k} for each market k .

We are thinking of quality characteristics as being modified easily and tailored to each market: the specification of a Volkswagen Golf sold in various countries is a realistic example.⁶

5. The idea of allowing the parameters of the expenditure function to depend on utility is borrowed from Deaton and Muellbauer (1980, pp. 154–58), who define an expenditure function as a utility-weighted combination of any two functions that are nondecreasing in price, which is valid provided that the resulting function is increasing in utility.

6. To justify our assumption that quality characteristics are changed just as often as prices are, we can look to the example of the “voluntary” export restraint on Japanese auto exports to the United States in the early 1980s. As documented

This assumption allows for a convenient solution for quality and was used by Rodriguez (1979) and other early literature studying the impact of import quotas on product quality.⁷ Much of the recent literature on product quality in trade also adopts Assumption 2 when quality is treated as endogenous: see Mandel (2010), Khandelwal (2010), Antoniades (2012), Demir (2012), and Johnson (2012, Appendix), for example.⁸

ASSUMPTION 3. To produce each unit of a good with quality z_{ij}^k , the firm with productivity φ_{ij} must use a composite input (“labor”) l_{ij}^k according to the Cobb-Douglas production function:

$$(2) \quad z_{ij}^k = (l_{ij}^k \varphi_{ij})^\theta,$$

where $0 < \theta < 1$ reflects diminishing returns to quality.

The Cobb-Douglas functional form in equation (2) is used for convenience, similar to Verhoogen (2008). In later work, Kugler and Verhoogen (2012) used a CES functional form. We discuss later and in Online Appendix A how Assumption 3 can be generalized while retaining the convenient log-linear results that we derive. This generalization would be challenging to implement for data reasons, however, so we rely on the Cobb-Douglas formulation in equation (2).

ASSUMPTION 4. Productivity is Pareto distributed with distribution function $G_i(\varphi) = 1 - (\varphi/\varphi_i)^{-\gamma}$, where the location parameter $\varphi_i \leq \varphi$ is the lower bound to the productivities of firms in country i .

By varying this lower bound, we can achieve differences in average productivity across countries, but for analytical convenience we assume that the dispersion parameter γ is identical across countries.⁹

ASSUMPTION 5. There are both specific trade costs T_i^k and ad valorem trade costs between countries i and k .

by Feenstra (1988), the characteristics of the Japanese exports where changed on the same annual basis as their prices.

7. For example, Krishna (1987) and Das and Donnenfeld (1987).

8. Gervias (2010) has quality chosen for the lifetime of a product, so he does not use Assumption 2.

9. In this respect we are making the same assumption as in Eaton and Kortum (2002), who allowed for different location parameters of the Fréchet distribution across countries, but with the same dispersion parameter.

One plus the ad valorem trade costs are denoted by τ_i^k , which includes 1 plus the ad valorem tariff, denoted by tar_i^k . The ad valorem trade costs are applied to the value *inclusive* of the specific trade costs.¹⁰ The tariff-inclusive c.i.f. price therefore is $p_{ij}^k \equiv \tau_i^k(p_{ij}^{*k} + T_i^k)$, and the net-of-tariff c.i.f. price is p_{ij}^k/tar_i^k .¹¹

ASSUMPTION 6. Firms must pay fixed costs of $f_i^k(\varphi_{ij})$ to export, which depends on their productivity φ_{ij} .

We include a detailed discussion of the specification of fixed costs in Section III.

We now solve for the optimal f.o.b. price p_{ij}^{*k} and quality z_{ij}^k that a firm simultaneously chooses for each destination market, conditional on exporting (in Section III we turn to the export decision). We denote the price of the composite input l_{ij}^k by the wage w_i . The marginal cost of producing a good of quality z_{ij}^k is then solved from equation (2) as

$$(3) \quad c_{ij}(z_{ij}^k, w_i) = w_i l_{ij}^k = w_i (z_{ij}^k)^{1/\theta} / \varphi_{ij}.$$

From the iceberg costs, τ_i^k units of the good are exported for 1 unit to arrive, so total exports are $y_{ij}^k = \tau_i^k q_{ij}^k$. When evaluating profits from exporting to country k , we need to divide by 1 plus the ad valorem tariff tar_i^k , obtaining:

$$\begin{aligned} \max_{p_{ij}^{*k}, z_{ij}^k} [p_{ij}^{*k} - c_{ij}(z_{ij}^k, w_i)] \frac{\tau_i^k q_{ij}^k}{tar_i^k} &= \max_{p_{ij}^{*k}, z_{ij}^k} \left[\frac{p_{ij}^{*k}}{z_{ij}^{\alpha^k}} - \frac{c_{ij}(z_{ij}^k, w_i)}{z_{ij}^{\alpha^k}} \right] \frac{\tau_i^k Q_{ij}^k}{tar_i^k} \\ &= \max_{P_{ij}^k, z_{ij}^k} \left\{ P_{ij}^k - \tau_i^k \frac{[c_{ij}(z_{ij}^k, w_i) + T_i^k]}{z_{ij}^{\alpha^k}} \right\} \frac{Q_{ij}^k}{tar_i^k}. \end{aligned}$$

(4)

The first equality in equation (4) converts from observed to quality-adjusted consumption, whereas the second line converts to quality-adjusted, tariff-inclusive c.i.f. prices $P_{ij}^k \equiv \tau_i^k(p_{ij}^{*k} + T_i^k)/z_{ij}^{\alpha^k}$, while changing the choice variables from p_{ij}^{*k}, z_{ij}^k to P_{ij}^k, z_{ij}^k . This change in variables relies on Assumption 2

10. Most countries apply tariffs to the transport-inclusive (c.i.f.) price of a product. The exceptions are Afghanistan, Australia, Botswana, Canada, Democratic Republic of the Congo, Lesotho, Namibia, New Zealand, Puerto Rico, South Africa, Swaziland, and the United States. See the Customs Info Database at <http://export.customsinfo.com/> and http://export.gov/logistics/eg_main_018142.asp. If we instead assumed that ad valorem trade costs only applied to the f.o.b. price, then we would replace T_i^k with T_i^k/τ_i^k in our formulas.

11. In our estimation we further model the costs as depending on distance and the quantity shipped, with the full specification in Online Appendix E.

that prices and characteristics are chosen simultaneously, but equation (4) does not rely on the functional forms in equation (1).

It is immediate that to maximize profits in equation (4), firms must choose z_{ij}^k to minimize $[c_{ij}(z_{ij}^k, w_i) + T_i^k]/z_{ik}^{\alpha^k}$. In the case where $\alpha^k = 1$, this problem is interpreted as *minimizing the average variable cost per unit of quality, inclusive of specific trade costs*, which is obtained where marginal cost equals average cost as found by Rodriguez (1979). More generally, with $\alpha^k > 0$ the solution to this problem is:

$$(5) \quad \frac{\partial c_{ij}(z_{ij}^k, w_i)}{\partial z_{ij}^k} = \alpha^k \frac{[c_{ij}(z_{ij}^k, w_i) + T_i^k]}{z_{ij}^k},$$

so there is a wedge of α^k between the marginal and average costs of producing quality. The second-order condition for this minimization problem is satisfied if and only if $\partial^2 c_{ij}/\partial(z_{ij}^k)^2 > 0$, so there must be increasing marginal costs of improving quality. In that case, either an increase in the valuation of quality α^k or an increase in the specific transport costs to the destination market T_i^k will raise quality z_{ij}^k . This occurs in particular with an increase in T_i^k due to greater distance, which is related to the well-known “Washington apples” effect.¹²

Making use of the Cobb-Douglas production function for quality in equation (2) and the cost function in equation (3), the second-order condition for an interior solution is satisfied when $0 < \alpha^k \theta < 1$, as we shall assume holds. Then the first-order condition (5) is readily solved for quality as:

$$(6) \quad \ln z_{ij}^k = \theta [\ln T_i^k - \ln(w_i/\varphi_{ij}) + \ln(\alpha^k \theta / (1 - \alpha^k \theta))].$$

Conveniently, the Cobb-Douglas production function and specific trade costs give us a log-linear form for the optimal quality choice. Since we are allowing $\alpha^k = h(U^k)$ to depend on the utility of the destination market, it follows that richer countries (with higher utility) may import higher quality, as found empirically by Hallak (2006). In addition, quality in equation (6) is rising in the

12. The Washington apples effect from Alchian and Allen (1964) states that the relative price of a higher quality product will fall as a specific transport cost is increased. That effect does not occur in our model because, as noted in equation (7), the nominal prices charged by firms of differing productivity and quality to a given destination market are identical. But an increase in the specific transport cost still lead all firms to increase their quality.

productivity of the exporting firm, confirming the finding of Schott (2004) that richer (more productive) countries export higher quality goods.¹³ Substituting equation (6) into the cost function (3), we obtain $c_{ij}(z_{ij}^k, w_i) = [\alpha^k \theta / (1 - \alpha^k \theta)] T_i^k$. Thus, the marginal costs of production are proportional to the specific trade costs, which we use later.

Applying the CES expenditure function in equation (1a) and solving equation (4) for the optimal choice of the f.o.b. price yields the familiar markup,

$$(p_{ij}^{*k} + T_i^k) = [c_{ij}(z_{ij}^k, w_i) + T_i^k] \left(\frac{\sigma}{\sigma - 1} \right).$$

This equation shows that firms not only mark up over marginal costs c_{ij} in the usual manner, they also mark up over specific trade costs. Then using the relation $c_{ij}(z_{ij}^k, w_i) = [\alpha^k \theta / (1 - \alpha^k \theta)] T_i^k$ from before, we solve for the f.o.b. and tariff-inclusive c.i.f. prices as:

$$(7a) \quad p_{ij}^{*k} = T_i^k \left[\left(\frac{1}{1 - \alpha^k \theta} \right) \left(\frac{\sigma}{\sigma - 1} \right) - 1 \right] \equiv \overline{p}_i^{*k},$$

$$(7b) \quad p_{ij}^k = \tau_i^k T_i^k \left[\left(\frac{1}{1 - \alpha^k \theta} \right) \left(\frac{\sigma}{\sigma - 1} \right) \right] \equiv \overline{p}_i^k.$$

Thus, both the f.o.b. and c.i.f. prices vary across destination markets k in proportion to the specific transport costs to each market, but are independent of the productivity of the firm j , as indicated by the notation \overline{p}_i^{*k} and \overline{p}_i^k . This result is obtained because more efficient firms sell higher quality goods, leading to constant prices in each destination market, and is a razor-edge case between having the largest firms charge low prices (due to high productivity) or high prices (due to high quality). Although this razor-edge case simplifies our analytical results, it is not essential to our analysis because we ultimately rely on industry rather than firm-level prices.

We can generalize the cost function in Assumption 2 to take the form $z_{ij}^k = (\varphi_{ij} l_{ij}^k + \psi_{ij})^\theta$, where ψ_{ij} can be interpreted as either

13. We could write $T_i^k = w_i d_i^k$, where d_i^k is in units of the aggregate factor and depends on distance. In that case, wages w_i (which also depend on productivity) cancel out from equation (6).

plant capability or the factor requirement of another input, as explained in Online Appendix A. In that case, we no longer find that the prices of firms are constant in a particular destination market, but can be rising or falling in firm productivity. Much of our theoretical analysis goes through in that case, and in particular the log-linear solution for quality as in equation (6), except that in place of the specific transport cost T_i^k appearing in equation (6)—which is tightly related to the f.o.b. price from equation (7a)—we instead have the f.o.b. price plus specific transport cost, $p_{ij}^{*k} + T_i^k$, appearing in equation (6). In practice it would be difficult to measure this hybrid variable lying in between the f.o.b. and c.i.f. prices (since the latter also include ad valorem trade costs),¹⁴ so for this reason we do not use the more general cost function.

Combining equations (6) and (7a) reveals that log quality is a fraction of the log f.o.b. price:

$$(8) \quad \ln z_{ij}^k = \theta \left[\ln(\kappa_1^k \overline{p_i^{*k}}) - \ln(w_i/\varphi_{ij}) \right], \text{ with } \kappa_1^k \equiv \left[\frac{\alpha^k \theta (\sigma - 1)}{1 + \alpha^k \theta (\sigma - 1)} \right].$$

Thus, to isolate quality from the f.o.b. price we need to know the key parameter θ from the production function for quality, which we estimate in Section IV, and productivity-adjusted input prices, to which we now turn.

III. SOLVING FOR WAGES AND QUALITY-ADJUSTED PRICES

It would be a formidable challenge to assemble the data on wages, other input prices, and firms' productivities needed to directly measure quality in equation (8) across many goods and countries. In our trade data, we will not have such firm-level information. Accordingly, we rely instead on the zero-cutoff-profit condition of Melitz (2003) to solve for the productivity-adjusted wage of the marginal exporter to each destination market and thereby obtain quality and quality-adjusted prices.

We let $\hat{\varphi}_i^k$ denote the cutoff productivity for a firm in country i that can just cover the fixed costs of exporting to country k .

14. Irarrazabal, Moxnes, and Opmolla (2011) provide a method for estimating specific trade costs that relies on firm-level data, which we do not have for our broad sample of goods and countries.

Using this productivity in equation (8), $\hat{P}_i^k \equiv \overline{p}_i^k / [z_i^k(\hat{\varphi}_i^k)]^{\alpha^k}$ denotes the quality-adjusted price for the marginal exporter:

$$(9) \quad \hat{P}_i^k = \overline{p}_i^k \left[(w_i / \hat{\varphi}_i^k) / \kappa_1^k \overline{p}_i^{*k} \right]^{\alpha^k \theta}$$

We let \hat{Q}_i^k denote the quantity of exports for this marginal firm so that $\hat{X}_i^k \equiv \hat{P}_i^k \hat{Q}_i^k$ is tariff-inclusive export revenue for the firm. From the CES markups, profits earned by the firm are then $(\hat{X}_i^k / \text{tar}_i^k \sigma)$, which must cover fixed costs in the zero-cutoff-profit (ZCP) condition:

$$(10) \quad \frac{\hat{X}_i^k}{\text{tar}_i^k \sigma} = f_i^k(\hat{\varphi}_i^k).$$

The term 1 plus the ad valorem tariff tar_i^k appears in the denominator on the left because tariffs must be deducted from revenue before computing profits. Equivalently, we can move the term tar_i^k to the right, where it will multiply fixed costs $f_i^k(\hat{\varphi}_i^k)$, which from Assumption 6 are assumed to depend on the cutoff productivity for reasons that we now explain.

The ZCP condition potentially imposes a tight connection between the quality-adjusted prices of two countries i and j selling to the same destination market k . Dividing equation (10) for these two countries and using the CES demand system,

$$(10') \quad \frac{\hat{X}_i^k}{\hat{X}_j^k} = \left(\frac{\hat{P}_i^k}{\hat{P}_j^k} \right)^{-(\sigma-1)} = \frac{\text{tar}_i^k f_i^k}{\text{tar}_j^k f_j^k}.$$

Thus, if market k has the same import tariffs on countries i and j , and if their fixed costs of exporting are the same, $f_i^k = f_j^k = f^k$, then the export revenue and quality-adjusted prices of the marginal firms from both source countries are equal. With a Pareto distribution for productivity, this equality will also apply to the average quality-adjusted prices from both source countries to market k .¹⁵ In that case, the entire difference in observed unit-values between exporters would be attributed to quality.

15. As shown in Online Appendix B, with a Pareto distribution for firm productivities the average quality-adjusted price to a market is proportional to the quality-adjusted price of the marginal exporter from each country.

To avoid this automatic outcome, we adopt a more flexible specification for fixed costs. For the firm with productivity $\hat{\varphi}_i^k$, the fixed cost of exporting from country i to k is assumed to be:

$$(11) \quad f_i^k(\hat{\varphi}_i^k) = \left(\frac{w_i}{\hat{\varphi}_i^k} \right) \left(\frac{Y^k}{p^k} \right)^{\beta_0} e^{\beta' F_i^k}, \beta_0 > 0.$$

There are three features of these fixed costs that deserve attention. First, we have written wages on the right of equation (11) as adjusted for productivity of the ZCP exporter. That is, we are assuming that an exporting firm's productivity applies equally well to variable and fixed costs, as also assumed by Bilbiie, Ghironi, and Melitz (2012)—although in their case, productivity is equal across firms. This specification implies that more productive (marginal) exporters have lower fixed costs and therefore lower quality-adjusted prices from equation (10'), implying higher quality.

The second important feature of the fixed costs in equation (11) is that we allow them to depend on real expenditure (Y^k/p^k) in the destination market k .¹⁶ This specification follows from the hypothesis of Arkolakis (2010) that small markets have lower fixed costs because it is easier to reach all customers. By adopting this specification, we prevent very small markets from automatically having the highest import quality because only the most efficient firms can export there. We rely on estimates from Arkolakis and others for the parameter β_0 .

The final term appearing in equation (11) is the exponential of a vector of bilateral variables F_i^k that influence fixed costs, times their coefficients β . In principle these could be any variables that determine the fixed cost of exporting to a market. We rely on several measures of language similarity between any two countries to measure these, as discussed in Online Appendix C.

Having specified the fixed costs of exporting, the next step is to use equations (10)–(11) to solve for productivity-adjusted wages, and substitute that solution into equation (9) to obtain quality-adjusted prices. To illustrate this solution, we assume for the moment that firms are homogeneous in their productivities, so that $\hat{\varphi}_i^k$ does not depend on k and denotes the

16. For p^k we use an import unit-value for that good in country k , not adjusted for quality.

productivity of every firm in country i . This assumption is just an expositional device, and in fact, the solution for quality-adjusted prices is nearly the same once we allow for heterogeneous firms with a Pareto distribution for productivities.¹⁷ We indicate in the text precisely how the solution changes when we allow for heterogeneous firms and provide the derivations in that more complex case in Appendix B.

With the assumption of firm homogeneity, the total exports from country i to k are $X_i^k = \hat{X}_i^k N_i$, where N_i denotes the number of firms in country i . Combining this equation with equations (9)–(11), we readily obtain the quality-adjusted price,

$$(12) \quad \hat{P}_i^k = \left(\frac{\bar{p}_i^k}{\left(\kappa_1^k \bar{p}_i^{*k} \right)^{\alpha^k \theta}} \right) \left(\frac{X_i^k}{\sigma \text{tar}_i^k N_i} \left(\frac{Y^k}{p^k} \right)^{-\beta_0} e^{-\beta' F_i^k} \right)^{\alpha^k \theta}.$$

This solution for the quality-adjusted price comes from the supply side of the model, that is, from the ZCP condition. Notice that given the number of firms, exports X_i^k are *positively* related to the quality-adjusted price, in contrast to the demand-side intuition discussed in Section I. That positive relation occurs because when comparing exports from two countries to the same destination market, higher exports per firm are associated with higher fixed costs of exporting, from equation (10), and therefore with higher productivity-adjusted wages in equation (11). Hence, quality is lower in equation (8) and the quality-adjusted price is higher.

A very similar supply-side relation and intuition continues to hold when we allow for heterogeneous firms. In that case, we assume that productivity is Pareto distributed according to Assumption 4. With heterogeneous firms, we first integrate the quality-adjusted prices over all firms exporting to country k with productivity greater than $\hat{\varphi}_i^k$. Letting M_i denote the mass of firms in country i , only $M_i[1 - G(\hat{\varphi}_i^k)]$ actually export to country k . Then using the ZCP condition, we show in Online Appendix B that the

17. As shown by Demidova and Krishna (2007) and Melitz and Redding (2013), with homogeneous firms and fixed costs of exporting, either all firms find it profitable to export or no firms export. Only in a razor-edge case will the ZCP condition apply so that firms are indifferent between exporting or not. Because we rely on the ZCP condition in our discussion of the homogeneous firms case, we view this discussion as an expositional device only, and we show in Online Appendix B that a very similar solution is obtained with heterogeneous firms.

average quality-adjusted price \overline{P}_i^k for exports from country i to k is:

$$(13) \quad \overline{P}_i^k = \left(\overline{p}_i^k / (\kappa_1^k \overline{p}_i^{*k})^{\alpha^k \theta} \right) \left(\frac{X_i^k / \kappa_2^k \text{tar}_i^k (Y^k)^{-\beta_0}}{M_i(\varphi_i/w_i)^\gamma (p^k)} e^{-\beta^k F_i^k} \right)^{\frac{\alpha^k \theta}{(1+\gamma)}} (\kappa_2^k)^{\frac{1}{1-\sigma}}$$

with

$$\kappa_2^k \equiv \frac{\gamma}{[\gamma - \alpha^k \theta (\sigma - 1)]} > 1.$$

Comparing equations (12) and (13), we see that there are three differences: (i) σ in equation (12) is replaced by $\kappa_2^k \equiv \sigma\gamma/[\gamma - \alpha^k \theta (\sigma - 1)]$, which includes additional terms that arise from integrating with the Pareto distribution; (ii) N_i in equation (12) is replaced by $M_i(\varphi_i/w_i)^\gamma$ in equation (13), which includes a term reflecting the lower bound of productivity relative to country wages;¹⁸ (iii) the final exponent $\alpha^k \theta$ in equation (12) is replaced by $\alpha^k \theta / (1 + \gamma)$ in (13), which includes the Pareto parameter γ . This third change arises because only a subset of firms $M_i[1 - G(\hat{\varphi}_i^k)]$ actually export from country i to k , and because this set of firms is endogenous, it introduces an additional *extensive* margin of substitution in trade between them that is governed by the Pareto parameter γ .

With heterogeneous firms, we see once again in equation (13) that an increase in exports to a market, given the mass of firms, raises the relative quality-adjusted price. That occurs because an increase in relative exports means that less efficient firms are exporting to that market, and therefore average quality falls. Again, that relationship sounds contrary to the demand-side intuition discussed in Section I: given nominal prices, higher sales to a market should mean higher quality. In fact, that intuition continues to hold in our model, and we use it in conjunction with equation (13) to solve for the quality-adjusted prices.

III.A. Quality-Adjusted Export Prices

We return to the expositional assumption that firms are homogeneous. Then in the ZCP condition (10), the firm-level sales \hat{X}_i^k are obtained from total exports as $\hat{X}_i^k = X_i^k / N_i$, which

18. With country wages following the lower bound of productivity in equilibrium, this extra term should not be too important. We control for it by including the labor force in our empirical specification; see equation (21).

in turn equals CES demand from the expenditure function in equation (1):

$$(14) \quad \hat{X}_i^k = \frac{X_i^k}{N_i} = \left(\frac{\hat{P}_i^k}{P^k} \right)^{-(\sigma-1)} Y^k,$$

where P^k is the price index corresponding to the CES expenditure function in equation (1). Consider dividing equation (14) for two countries i and j selling to the same market k , to solve for the relative quality-adjusted export prices,

$$(15) \quad \frac{\hat{P}_i^k}{\hat{P}_j^k} = \left(\frac{X_i^k/N_i}{X_j^k/N_j} \right)^{\frac{-1}{\sigma-1}}.$$

Given an empirical specification of the number of products available from each country, and the elasticity of substitution, we could use equation (15) to determine the relative quality-adjusted export prices to each market. This equation embodies the demand-side intuition that goods with higher market shares are assigned higher quality and hence lower quality-adjusted price, as used by Khandelwal (2010) and Hallak and Schott (2011).

Our framework with zero profits for the marginal exporter allows for a tighter solution for the quality-adjusted export prices, however. We can substitute the demand-side equation (14) into the supply-side equation (12) to eliminate exports X_i^k , in which case the number of products N_i cancels out and we readily solve for the ratio:

$$(16) \quad \frac{\hat{P}_i^k}{\hat{P}_j^k} = \left(\frac{\bar{p}_i^k / \left(\text{tar}_i^k \bar{p}_i^{*k} e^{\beta' F_i^k} \right)^{\alpha^k \theta}}{\bar{p}_j^k / \left(\text{tar}_j^k \bar{p}_j^{*k} e^{\beta' F_j^k} \right)^{\alpha^k \theta}} \right)^{\frac{1}{1+\alpha^k \theta (\sigma-1)}}.$$

Comparing equation (15) with equation (16), it is apparent that we obtain a different solution for quality-adjusted export prices when the supply side of the model is also used: in equation (16), the quality-adjusted prices are tightly pinned down by the c.i.f. and f.o.b. prices that appear on the right, as well as by tariffs and the fixed cost terms. Remarkably, the relative number of products N_i/N_j does not enter equation (16), which occurs because

the ZCP condition is solving for the *per firm* exports \hat{X}_i^k/\hat{X}_j^k , which also appears in the demand equation (14), and so these supply and demand conditions together are eliminating the unobserved number of firms. Eliminating this variable is the key simplification that we obtain by using the supply side of our model.¹⁹

When we allow for heterogeneous firms with a Pareto distribution for productivities, the solution for quality-adjusted export prices is the same as in equation (16). As shown in Online Appendix B, the demand equation (14) can be reexpressed in a form that is close to a gravity equation:

$$\frac{X_i^k}{M_i(\varphi_i/w_i)^\gamma} = \left(\frac{\overline{P}_i^k}{\overline{P}^k}\right)^{-(\sigma-1)(1+\gamma)} (Y^k)^{(1+\gamma)} \left(\sigma\kappa_2^k \text{tar}_i^k \left(\frac{Y^k}{P^k}\right)^{\beta_0} e^{\beta F_i^k}\right)^{-\gamma}, \quad (17)$$

where \overline{P}_i^k is the average quality-adjusted price. Higher exports on the left of this expression imply a lower quality-adjusted price on the right, *ceteris paribus*, so this equation has the demand-side intuition. Exports are divided by the mass of potential exporters M_i on the left, analogous to dividing by N_i in equation (14), even though only a fraction of firms $M_i[1 - G(\hat{\varphi}_i^k)]$ actually export from i to k . That extensive margin of substitution is reflected in the exponent $-(\sigma - 1)(1 + \gamma)$ which appears on the relative price in equation (17): we refer to this term as the “elasticity of trade,” and comparing equation (14) with equation (17), we see that this elasticity is higher in absolute value when the extensive margin is taken into account.

Continuing with heterogeneous firms case, we can substitute the demand-side equation (17) into the supply-side equation (13) to eliminate exports X_i^k , in which case the mass of firms M_i again cancels out. Taking the ratio of relative quality-adjusted prices $\overline{P}_i^k/\overline{P}_j^k$ we obtain exactly the same expression as equation (16), which now applies to the *average* quality-adjusted prices, that

19. Of course, if the number of firms takes on their equilibrium values, then equations (15) and (16) would give the same solution for the relative quality-adjusted export price. The problem in practice is that it is very difficult to have a parsimonious specification for the number of firms that gives a similar solution in equations (15) and (16), as we demonstrate in Section V.

is, integrating over all firms with productivities above the ZCP exporter:

$$(18) \quad \frac{\overline{P}_i^k}{\overline{P}_j^k} = \left(\frac{\overline{p}_i^k / \left(\overline{tar}_i^k \overline{P}_i^{*k} e^{\beta' F_i^k} \right)^{\alpha^k \theta}}{\overline{p}_j^k / \left(\overline{tar}_j^k \overline{P}_j^{*k} e^{\beta' F_j^k} \right)^{\alpha^k \theta}} \right)^{\frac{1}{1 + \alpha^k \theta (\sigma - 1)}}$$

We use this ratio to measure the relative quality-adjusted export prices of countries i and j selling to each market k . This relative price is similar in spirit to Khandelwal (2010) and Hallak and Schott (2011), who measure export prices to the United States. We repeat this for each destination market k , and then aggregate over destinations and over goods, as discussed in Online Appendix D. The key message from this section is that when measuring quality-adjusted *export* prices, we can go beyond the pure demand-side measurement in equation (15) by also using the ZCP condition on the supply side, thereby obtaining the tight solution in equation (18).

III.B. Quality-Adjusted Import Prices

We also want to measure quality-adjusted import prices, which has not been done before in the literature. In that case, we consider each source county i selling to two destination markets k and l , and form the ratio $\overline{P}_i^k / \overline{P}_i^l$, which measures the quality-adjusted import price for country k relative to l . We rely on the supply-side equation (13) to obtain the ratio $\overline{P}_i^k / \overline{P}_i^l$, and we find once again that the mass of exporters M_i cancels out. We still find, however, that the ratio of equation (13) involves two different taste parameters α^k and α^l , reflecting the differing weights that destination markets k and l put on quality. We do not want our measurement of quality-adjusted prices to depend on differing preferences across countries, so we replace the taste parameters α^k and α^l with the average value $\bar{\alpha}$ for all countries importing the good.²⁰ We measure the ratio of equation (13) for a country

20. According to Fisher and Shell (1972), with changing preferences (in this case changing between countries), a suitable approach is to compute a geometric mean of price indexes that first uses one country's preferences and then uses the other's. We have also implemented the Fisher-Shell approach for our import indexes, as discussed in Online Appendix D, and find similar results to using the average preference for quality $\bar{\alpha}$.

i selling to two destinations k and l as:

$$(19) \quad \frac{\overline{P}_i^k}{\overline{P}_i^l} = \left(\frac{\overline{p}_i^k / (\kappa_1^k \overline{p}_i^{*k})^{\bar{\alpha}\theta}}{\overline{p}_i^l / (\kappa_1^l \overline{p}_i^{*l})^{\bar{\alpha}\theta}} \right) \left(\frac{X_i^k / \kappa_2^k \text{tar}_i^k \left(\frac{Y^k}{p^k}\right)^{\beta_0} e^{\beta' F_i^k}}{X_i^l / \kappa_2^l \text{tar}_i^l \left(\frac{Y^l}{p^l}\right)^{\beta_0} e^{\beta' F_i^l}} \right)^{\frac{\bar{\alpha}\theta}{(1+\gamma)}} \left(\frac{\kappa_2^k}{\kappa_2^l} \right)^{\frac{1}{1-\sigma}}$$

Comparing the relative export price in equation (18) with the relative import price in equation (19), it is apparent that the export prices in equation (18) have the smaller exponent $1/[1 + \alpha^k \theta(\sigma - 1)] < 1$ on the ratio of c.i.f. to f.o.b. prices. In our estimates, this exponent has a median value less than 0.25 and over 98 percent of estimates across industries and countries are less than 0.5. This is one reason we find that the quality-adjusted export prices differ by less than the quality-adjusted import prices across countries; another reason is the extra terms appearing on the right of equation (19), discussed shortly. The smaller exponent on the c.i.f./f.o.b. ratio of export prices occurs because we find that consumers in a given destination market have a high degree of substitution between the goods from different countries: to have the level of trade consistent with the data, we find that quality-adjusted export prices cannot differ by that much. But this intuition does not apply to the relative quality-adjusted import prices in equation (19), which compare country i selling to two destinations k and l . In that case there is no direct consumer substitution between the products, and the quality-adjusted import prices are instead based on the supply relation from equation (13). It follows that these import prices will have greater dispersion across countries than the relative export prices.

The relative import prices also depend on a number of additional terms besides the c.i.f./f.o.b. price ratio. Most important, the relative import prices depend on destination market expenditure Y^k in two ways. On one hand, higher expenditure leads to greater exports X_i^k to that country. The marginal exporters will be less efficient, producing lower quality with higher quality-adjusted price. That is the negative supply-side relation between exports and quality that we have already discussed. This effect is offset by higher real expenditure (Y^k/p^k) in equation (19) leading to higher fixed costs. In that case the marginal exporter must be more efficient, leading to higher quality and lower

quality-adjusted price. The strength of these two opposing forces depends on the parameter β_0 . That parameter is estimated with firm-level export data by Arkolakis (2010), Eaton, Kortum, and Kramarz (2011), and Eaton, Kortum, and Sotelo (2012), who obtain $\beta_0 \approx 0.35$. In Online Appendix C we discuss how our specification of fixed costs in equation (11)—depending on the productivity of the cutoff exporter—maps into the same firm-level data and conclude that β_0 in our model lies between 0 and 0.35, depending on the Pareto parameter γ for the good in question. We use this calibration for β_0 in the calculation of the relative import prices in equation (19). The estimation of the Pareto parameter, the elasticity of substitution σ , and the quality parameter θ are discussed in the next section.

IV. DATA AND ESTIMATION

IV.A. Data

Our primary data set is the UN Comtrade Database, used to obtain export and import data for 185 countries from 1984 to 2011. We compute the bilateral f.o.b. unit values of traded goods using reports from the exporting country. By focusing on the exporters' reports, we ensure that these unit values are calculated prior to the inclusion of any costs of shipping the product. The bilateral c.i.f. unit values are calculated similarly using importers' trade reports. Because these unit values include the costs of shipping, we need only add the tariff on the good to produce a tariff-inclusive c.i.f. unit value. To do this we obtain the ad valorem tariffs associated with most favored nation status or any preferential status from raw TRAINS data and from the World Trade Organization's (WTO) Integrated Data Base (IDB), which we have expanded on using tariff schedules from the *International Customs Journal* and the texts of preferential trade agreements obtained from the WTO's website and other online sources. We provide further details in Online Appendix C.

Independent variation in the importing country's c.i.f. unit value and the exporting country's f.o.b. unit value is essential to identifying their distinct effects in the estimating equation, discussed later. But we must admit that there is a large amount of measurement error in these unit values from the Comtrade Database. In fact, it is not unusual for the c.i.f. unit value to be less than the f.o.b. unit value (as can never occur in theory

because the former exceeds the latter by transport costs). As an initial step toward correcting for such measurement error, we omitted observations where the ratio of the c.i.f. unit value reported by the importer and the f.o.b. unit value reported by the exporter, for a given four-digit SITC product and year, was less than 0.1 or exceeded 10. In addition, we omitted such bilateral observations where the c.i.f. value of trade was less than \$50,000 in constant 2005 dollars.

More generally, to reconcile the wide variation in the observed unit values with our model, we assume that the f.o.b. and duty-free c.i.f. unit values, denoted by uv_{igt}^{*k} and uv_{igt}^k with goods subscript g and time subscript t , are related to the f.o.b. and tariff-inclusive c.i.f. prices by:

$$(20) \quad \ln uv_{igt}^{*k} = \ln \overline{p_{igt}^{*k}} + u_{igt}^{*k} \quad \text{and} \quad \ln uv_{igt}^k = \ln(\overline{p_{igt}^k} / \overline{tar_{igt}^k}) + u_{igt}^k,$$

where u_{igt}^{*k} and u_{igt}^k are the measurement errors that are independent of each other and have variances σ_{ig}^* and σ_{ig}^k , respectively. In other words, we are assuming that the measurement error in the f.o.b. unit value for exporter i does not depend on the importer k , whereas the measurement error in the c.i.f. unit value for importer k does not depend on the source country i , and that these errors are independent of each other. We argue in Online Appendix E that our estimation method is robust to this measurement error in the unit values, which ends up being absorbed by importer and exporter fixed effects in the estimation. But the errors must be independent for this claim to hold, which is therefore an identifying assumption.

IV.B. Estimation

We adapt Feenstra's (1994) generalized method of moments (GMM) method to estimate the parameters of the model. To achieve this we take the ratio of the demand equation (17) for two countries i and j selling to destination k , and substitute for the relative quality-adjusted export prices in equation (19), while adding subscripts for goods g and time t . Because the demand equation contains the unobserved mass of potential exporters, we need to control for this mass. We estimate the labor force L_{igt} employed in producing exports of good g in country i as country i population multiplied by country i exports of good g divided

by country i GDP. We then model the mass of potential exporters as depending on L_{igt} and country fixed effects:

$$(21) \quad \ln[M_{igt}(\varphi_{igt}/w_{igt})^\gamma] = \delta_{0g} \ln L_{igt} + \delta_{igt} + \varepsilon_{igt}^k,$$

where ε_{igt}^k is a random error. We also use equation (20) to replace the c.i.f. and f.o.b. prices with their respective unit values. Then from equations (17) and (19)–(21), we obtain the difference between exports from countries i and j selling to destination k :

$$(22) \quad \begin{aligned} \ln X_{igt}^k - \ln X_{jgt}^k &= -A_g^k \left[(\ln(\text{tar}_{igt}^k uv_{igt}^k) - \ln(\text{tar}_{jgt}^k uv_{jgt}^k)) \right. \\ &\quad \left. - \alpha_g^k \theta_g (\ln uv_{igt}^{*k} - \ln uv_{jgt}^{*k}) \right] + \delta_{0g} (\ln L_{igt} - \ln L_{jgt}) \\ &\quad + \delta_{ig} - \delta_{jg} - B_g^k [\ln \text{tar}_{igt}^k + \beta'_g (F_i^k - F_j^k)] + \varepsilon_{igt}^k - \varepsilon_{jgt}^k, \end{aligned}$$

where

$$(23) \quad A_g^k \equiv \frac{(\sigma_g - 1)(1 + \gamma_g)}{1 + \alpha_g^k \theta_g (\sigma_g - 1)}, \quad \text{and} \quad B_g^k \equiv \frac{\gamma_g - \alpha_g^k \theta_g (\sigma_g - 1)}{1 + \alpha_g^k \theta_g (\sigma_g - 1)}.$$

We add a simple supply specification in Online Appendix E, whereby the specific and iceberg trade costs depend on distance and the quantity traded, and iceberg trade costs also depend on ad valorem tariffs. Feenstra (1994) assumed that the supply shocks and demand shocks are uncorrelated. That assumption seems unlikely to hold with unobserved quality, since a change in quality could shift both supply and demand. But here, the demand errors and the supply errors are the residuals after *taking into account* quality. So the assumption that they are uncorrelated seems much more acceptable, and is the basis for the GMM estimation.

Two features of the estimating equation (22) deserve attention. First, notice that the c.i.f. unit values appear with the negative coefficient $-A_g^k$ in this gravity equation, whereas the f.o.b. unit values appear with a *positive* coefficient $A_g^k \alpha_g^k \theta_g$. The f.o.b. unit values reflect product quality in the equation, and conditional on the c.i.f. unit value, higher quality leads to higher demand, which explains why the f.o.b. coefficient is positive. The key to successful estimation will be to obtain this sign pattern on the unit values.

Second, not all the parameters are identified without additional information. It is especially difficult to empirically distinguish the elasticity of substitution and the Pareto parameter,

σ_g and γ_g . We resolve this issue as in Chaney (2008), by using estimates of $\zeta_g^{US} = \gamma_g / [\alpha_g^{US} \theta_g (\sigma_g - 1)]$ from regressions of firm rank on size for each SITC sector in the United States, where we further normalize $\alpha_g^{US} \equiv 1$.²¹ Then for other countries, $\zeta_g^k = \gamma_g / [\alpha_g^k \theta_g (\sigma_g - 1)] \Leftrightarrow \zeta_g^k \alpha_g^k = \gamma_g / [\theta_g (\sigma_g - 1)] = \zeta_g^{US} \alpha_g^{US} = \zeta_g^{US}$. It follows that γ_g is obtained as $\zeta_g^{US} \theta_g (\sigma_g - 1)$.

A final parameter that is difficult to identify without additional information is α_g^k , which is the preference for quality in the expenditure function (1). Conveniently, this parameter can be estimated from simple price regressions, estimated in Online Appendix E. From equation (7a), the f.o.b. price is increasing in the destination country's preference for quality α_g^k , which we can model as an increasing function of the destination country's per capita real income with coefficient λ_g . It is well known from Hallak (2006) that the unit value of imports is positively related to a country's per capita income, which identifies α_g^k . These price regressions depend on having preliminary estimates of σ_g and θ_g that come from estimating equation (22) when all countries have the same preference for variety, $\alpha_g^k \equiv 1$. Using these preliminary estimates of σ_g and θ_g , we then estimate the price regressions to obtain improved values for α_g^k . These improved values of α_g^k are substituted into equation (23), and we reestimate equation (22) to obtain new estimates for σ_g and θ_g . We iterated this procedure several times and found that the distribution of estimates for σ_g and θ_g quickly converged.

IV.C. Parameter Estimates

Estimation is performed for each four-digit SITC Rev. 2 good (which we also refer to as an industry) using bilateral trade between all available country pairs during 1984–2011. There are 12.5 million observations with data on both the c.i.f. and f.o.b. unit values that passed the data-cleaning criteria already detailed, excluding those goods with fewer than 50 observations. We perform the GMM estimation on 712 industries as shown in

21. We thank Thomas Chaney for providing these estimates for three-digit SITC Rev. 3 sectors for the United States, which we conformed to three-digit SITC Rev. 2 sectors. In Chaney (2008), this parameter equals $\zeta^k = \gamma / (\sigma - 1)$, and we discuss in Online Appendix B why it equals $\zeta^k = \gamma / [\alpha^k \theta (\sigma - 1)]$ in our model. The normalization $\alpha_g^{US} \equiv 1$ is harmless because α_g^k always appears multiplied by θ , so $\alpha_g^{US} \equiv 1$ fixes the value for θ in our estimates.

TABLE I
 MEDIAN PARAMETER ESTIMATES

GMM estimation method with:	Number of SITC industries	σ	γ	θ
Dropping SITC4 with <50 observations	712	6.07	8.43	0.61
No. of inadmissible parameters	8	7	7	4
Filling in SITC4 with <50 observations or inadmissible parameters	924	5.82	7.78	0.61

the first row of Table I.²² The median estimate of σ_g is 6.07, not counting seven industries with an inadmissible value less than unity; the median estimate of γ_g is 8.43, not counting the same seven industries with an inadmissible value; and the median estimate of θ_g is 0.61, not counting four cases with an inadmissible value less than 0 or greater than unity. For inadmissible values or for SITC industries with fewer than 50 observations, we replace the parameter estimates with the median estimate from the same three-digit or two-digit SITC industry, after which we find the median estimates shown in the last row of Table I for 924 industries.

The frequency distributions of parameter estimates are illustrated in Figures I–III. Our median estimate for the elasticity of substitution σ_g is higher than estimated by Broda and Weinstein (2006) for the United States. We have found that our higher value comes from using worldwide trade data and correcting for quality, and from using an empirical specification that is more robust to measurement error because we do not take differences over time and instead include source-country fixed effects in our estimation of equation (22).²³ Our median estimate for the Pareto parameter γ is quite close to that reported by Eaton and Kortum (2002), who also considered bilateral trade between many countries.²⁴

22. In each industry we use only the most common unit of measurement, which is nearly always kilograms.

23. Destination country fixed effects are implicitly included, too, because equation (22) is specified as the difference between countries i and j exporting to country k .

24. This median estimate is higher, however, than the recent results of Simonovska and Waugh (2011, 2012).

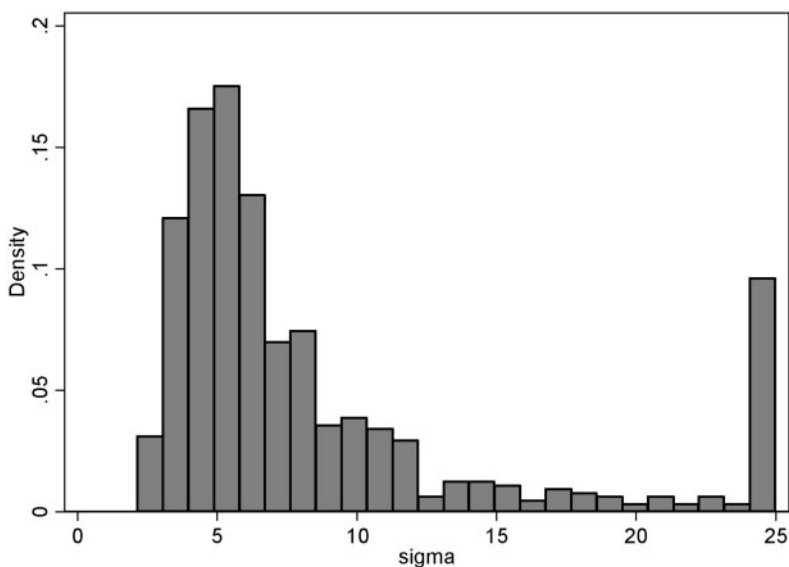


FIGURE I

Frequency Distribution for Estimates of σ_g

Estimates are right-censored for presentation purposes only

We know of no other estimate of θ_g . Crozet, Head, and Meyer (2012) study firm-level data for the champagne industry to estimate key parameters of a Melitz (2003) model with quality. They combine export data with expert ratings of the overall quality of each champagne producer on a 1- to 5-star scale. The estimated cost (proportional to f.o.b. price) for 5-star producers is 68% higher than for 1-star producers. Though there is no translation of the discrete star rating to how consumers evaluate the quality of champagne, this estimate appears consistent with a fairly high value of θ —quality increases quite substantially with the use of more or better inputs.

V. INDEXES OF QUALITY-ADJUSTED PRICE AND QUALITY

The quality-adjusted relative export prices are obtained from equation (18) and import prices from equation (19), where we replace the c.i.f. price appearing there by the tariff-inclusive

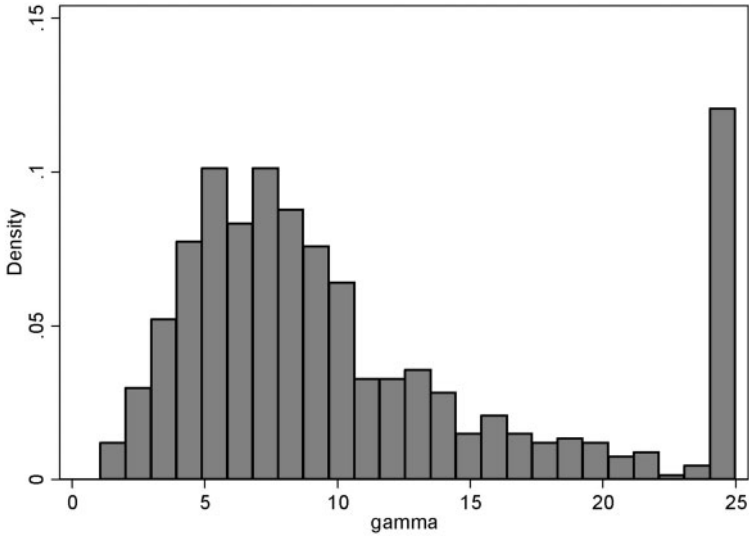


FIGURE II

Frequency Distribution for Estimates of γ_g

Estimates are right-censored for presentation purposes only.

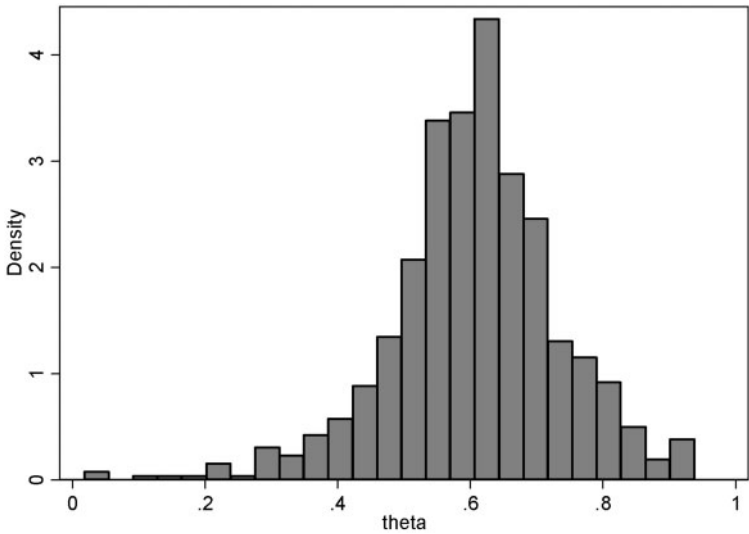


FIGURE III

Frequency Distribution for Estimates of θ_g

c.i.f. unit value, $uv_{igt}^k tar_{igt}^k$ as in equation (20), and the f.o.b. price by the f.o.b. unit value uv_{igt}^{*k} . Each of these are then aggregated over partner countries, and from four-digit SITC to the Broad Economic Categories (BEC), to obtain overall indexes of quality and quality-adjusted prices of exports and imports for each country and year in our data set. The formula we use for aggregation is the so-called GEKS method,²⁵ which is a many-country generalization of Fisher ideal indexes. We apply a two-stage aggregation procedure over partner countries and then over goods, resulting in an aggregate export and import unit value for each country relative to the United States. We refer to the GEKS index of unit values as the “price index” and the GEKS index of quality-adjusted unit values as the “quality-adjusted price index.” Our final step is to divide the former by the latter—for each country, year, and BEC—to obtain the index of export or import quality.

V.A. *Export Prices and Quality*

Before showing our results on the export side, we begin by using only the demand side of our model to construct the quality-adjusted prices in equation (15) for 2007. It is evident that this formula is very sensitive to the specification of the number of exporting firms in each country, or N_i in the homogeneous firms case. We illustrate this by making two different assumptions about N_i : (i) N_i is proportional to countries’ population (similar to Khandelwal, 2010); and (ii) N_i is proportional to countries’ aggregate nonservices value-added.²⁶ In Figure IV we show the raw unit value indexes (top panel) together with export quality indexes when N_i is assumed proportional to population (second panel) and nonservices value-added (third panel). In all cases we normalize the world average unit value to unity. The second panel of Figure IV reveals quality to be positively correlated with per capita GDP (correlation coefficient = .41), while the

25. Named after Gini, Eltetö and Köves, and Szulc. We refer the reader to Balk (2008) and Deaton and Heston (2010) for a modern treatment and details of these historical references. We employ the GEKS procedure here because it is commonly used by statistical agencies, including the ICP and PWT. See Online Appendix D.

26. With either homogeneous firms or heterogeneous firms and a Pareto distribution, the mass of firms is proportional to the labor input divided by the fixed costs of entry (see Melitz and Redding, 2014, eq. 22). If those fixed costs depend on firm or country productivity, then value-added becomes a better measure for the mass of firms.



FIGURE IV

Raw Export Prices and Demand-Side Estimates of Export Quality, 2007

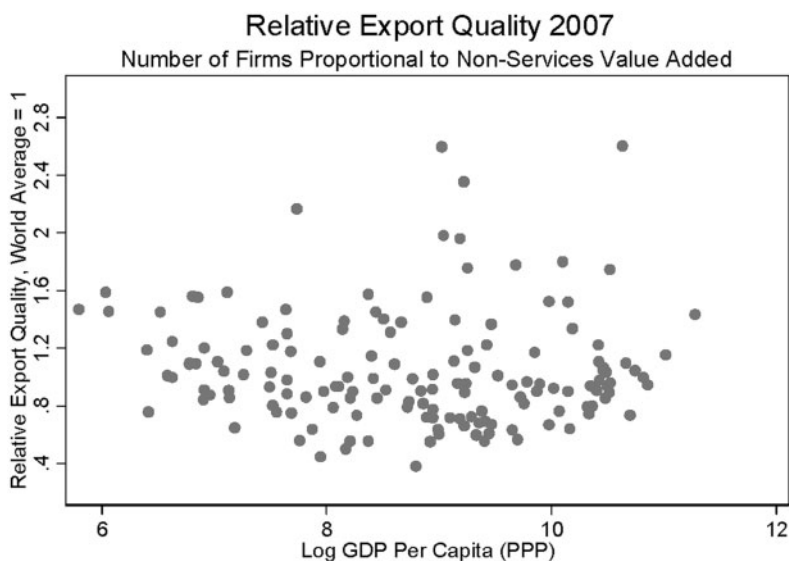


FIGURE IV
Continued

third panel exhibits virtually no correlation (correlation coefficient = $-.03$).²⁷

In fact, the sensitivity of quality estimates to our assumptions about N_i may be greater than appears in Figure IV. Excluding small countries (population less than 1 million) that account for the bulk of outliers, these correlations become .49 and $-.34$, respectively. Without good information, demand-side estimates of quality may largely reflect the researcher's assumptions about the number of firms. Comparing the last two panels of Figure IV with the top panel, it is visually apparent that both demand-side quality estimates vary much more than the unit value indexes. As a result, the quality-adjusted price indexes in Figure V (first using population to proxy the number of exporters, and then nonservices value added) show substantial variation across countries: greater than the original unit value indexes in the top panel of Figure IV.

27. In all figures we exclude St. Vincent and the Grenadines, which has very high export prices driven by exports (likely reexports) of yachts to Greece and Italy and color televisions to Trinidad and Tobago.

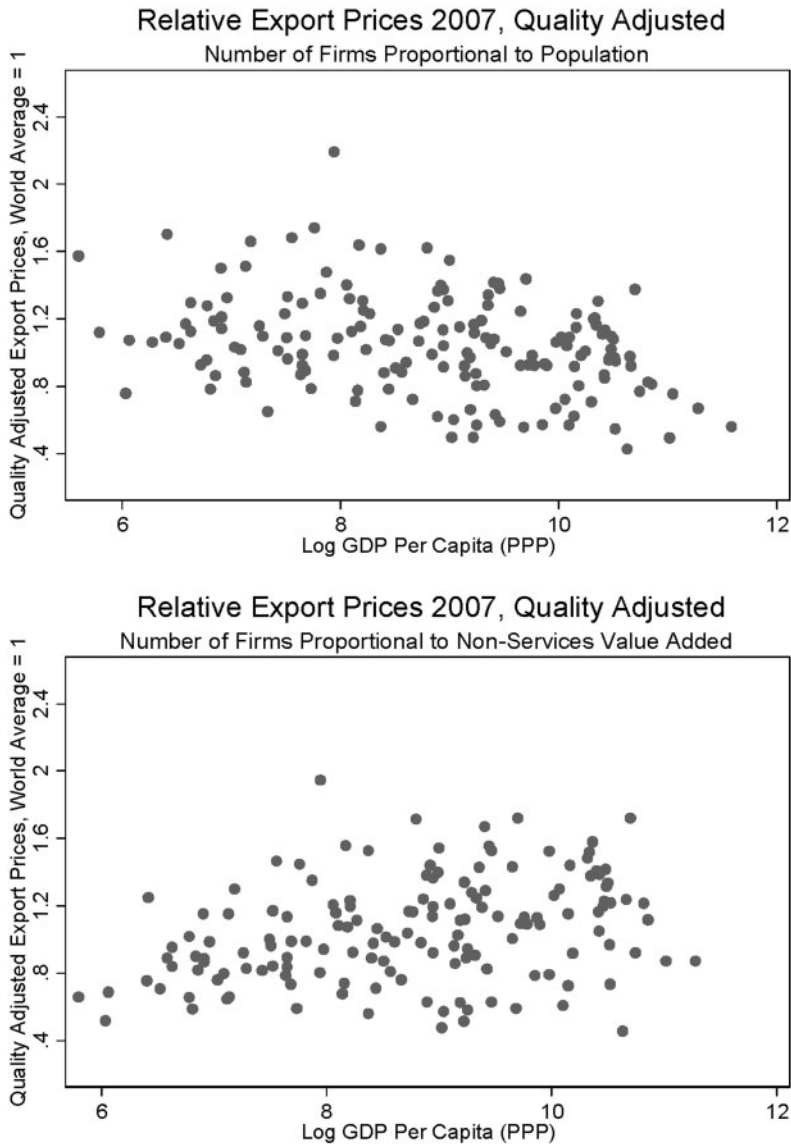


FIGURE V

Demand-Side Estimates of Quality-Adjusted Export Prices, 2007

We can contrast these results obtained from the demand side of our model with the quality-adjusted prices in equation (18), obtained from the demand and supply sides. The quality indexes and the quality-adjusted price indexes for 2007 are shown in Figure VI. Comparing the top panel of Figure VI with the top panel of Figure IV, it is visually apparent that the quality indexes are now similar to the unit-value indexes, and as a result, the quality-adjusted prices (second panel in Figure VI) show much less variation than those obtained from the demand side only (in Figure IV). We offer two reasons for this difference in results. First, the demand-side formula in equation (15) depends on trade *values* on the right, which can differ by many orders of magnitude for two countries selling to a given destination; in contrast, the c.i.f. and f.o.b. prices appearing on the right of equation (18) do not differ as much in the data. Second, although this potentially large difference in trade values can be offset by the estimated number of firms exporting from each country, in practice it is difficult to get reliable estimates of that number, limiting researchers' ability to construct quality-adjusted prices from the demand side alone.²⁸

Turning to other results, we notice that developed countries tend to export more expensive goods (top panel of Figure IV), and we estimate these goods to be of higher than average quality (top panel of Figure VI). The quality adjusted-price (second panel of Figure VI), about which we have less strong priors, tends to be only slightly higher for developed countries, indicating that most of the higher export price for developed countries is explained by quality.

Figure VII reveals that export-quality estimates from the supply and demand sides ("full model") are correlated with our demand-side estimates. The top panel includes demand-side estimates where the number of firms producing in a country is assumed to be proportional to population, whereas the bottom panel assumes that number to be proportional to nonservices value added.²⁹ Figure VII's most striking feature is the smaller

28. As explained in note 19, if we obtained estimates of the number of firms that equaled their equilibrium values, then the quality-adjusted prices obtained from equations (15) and (18) would be identical.

29. The proxy for the number of firms in our supply and demand approach remains fixed in this comparison as the labor input to each sector in equation (21), but it would make little difference to change it to value added, since equation (21) includes country fixed effects.

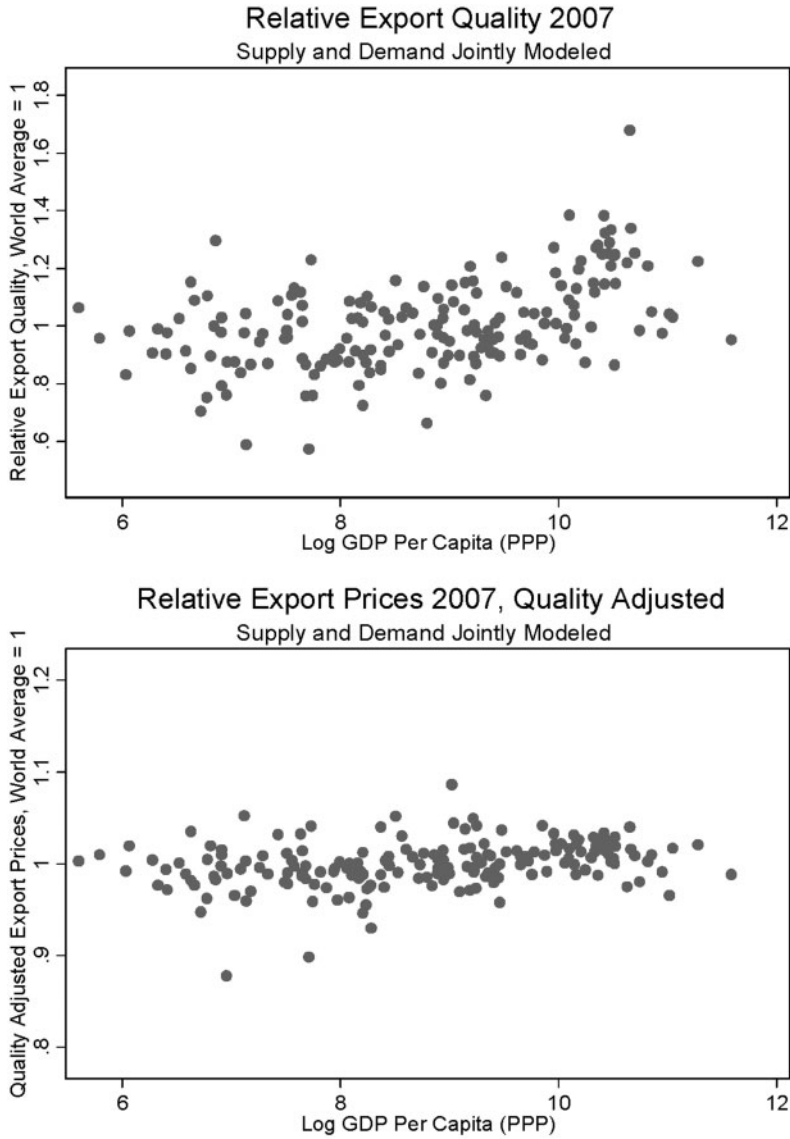


FIGURE VI

Supply- and Demand-Based Estimates of Export Quality and Quality-Adjusted Export Prices, 2007

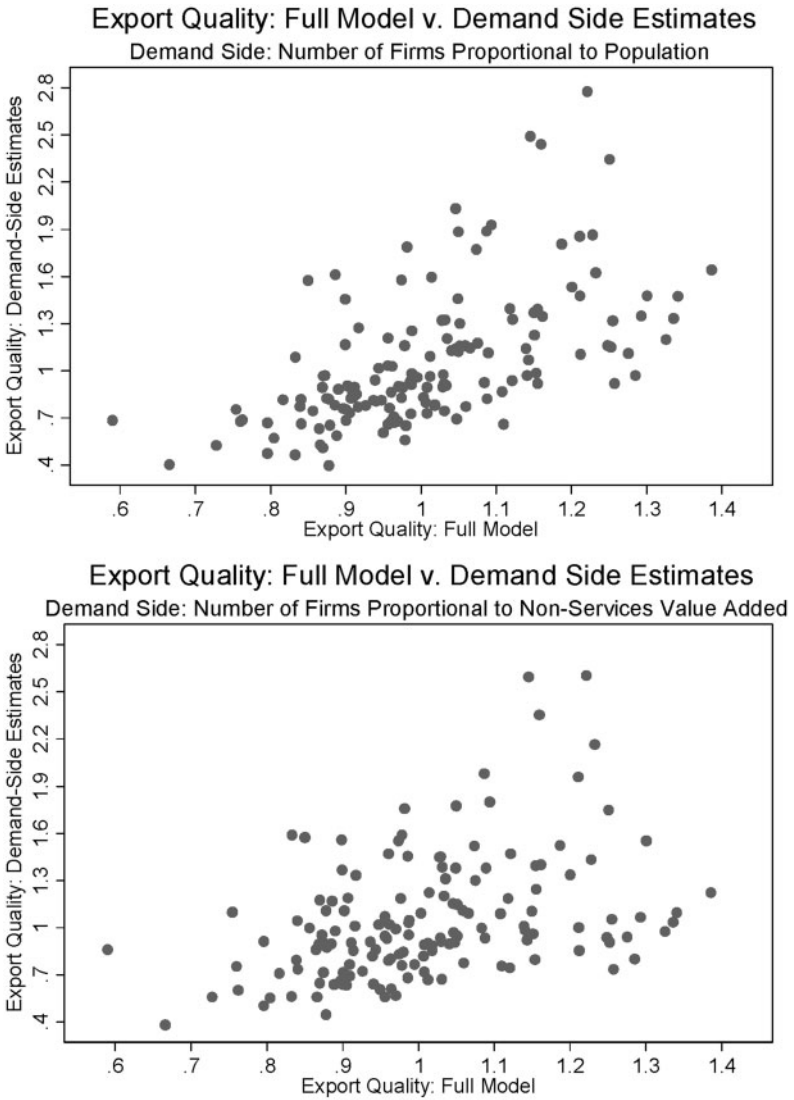


FIGURE VII

Comparison of Full Model versus Demand-Side Estimates of Export Quality, 2007

variance of quality estimates when we exploit the model's supply side.

V.B. *Import Prices and Quality*

We illustrate a similar exercise for import prices in Figure VIII, but we do not attempt a comparison with the demand side alone.³⁰ Developed countries import more expensive items (top panel) that are of higher quality (second panel). Quality-adjusted import prices (third panel) increase noticeably with the importing country's GDP per capita. This pattern is due to an interaction of preferences for quality and the rising marginal cost of producing quality. Rich countries tend to prefer higher quality goods, which enter the import quality-adjusted price in equation (19) via κ_{1g}^k and κ_{2g}^k . But our estimates of θ_g between 0 and unity means, from equation (3), that there is an amplified effect of quality on increasing the marginal cost, so that higher quality induced by a preference for quality leads to a higher quality-adjusted price.

It is evident that the variation in quality-adjusted import prices in Figure VIII is much greater than for export prices in Figure VI. Numerically, this occurs for two reasons. First, as noted, the c.i.f./f.o.b. ratio of export unit values on the right of equation (18) has an exponent significantly less than unity, which reflects substitution between suppliers and tends to mute those prices differences on the export side, but that does not occur on the import side, where only the f.o.b. price on the right of equation (19) has an exponent less than unity. Hence, the raw differences in unit values across countries show up more in the quality-adjusted prices for imports than exports.

Second, the preference for quality affects import prices in equation (19), along with bilateral imports X_{igt}^k and total import expenditure Y_{gt}^k , none of which enter the export-side formula in equation (18). The economic intuition for these terms comes because relative import prices are obtained by comparing a given exporter i selling to two destinations k and l , so that expenditure

30. As noted earlier, since Schott (2004), Hallak and Schott (2011), and Khandelwal (2010) all focus on exports to the United States, they do not construct indexes of import prices calculated by comparing prices for a given country selling to two destinations. More generally, it is not possible to go immediately from equation (14) to a simple specification of quality-adjusted import prices, because the CES price index as well as income of each destination country would enter the formula.

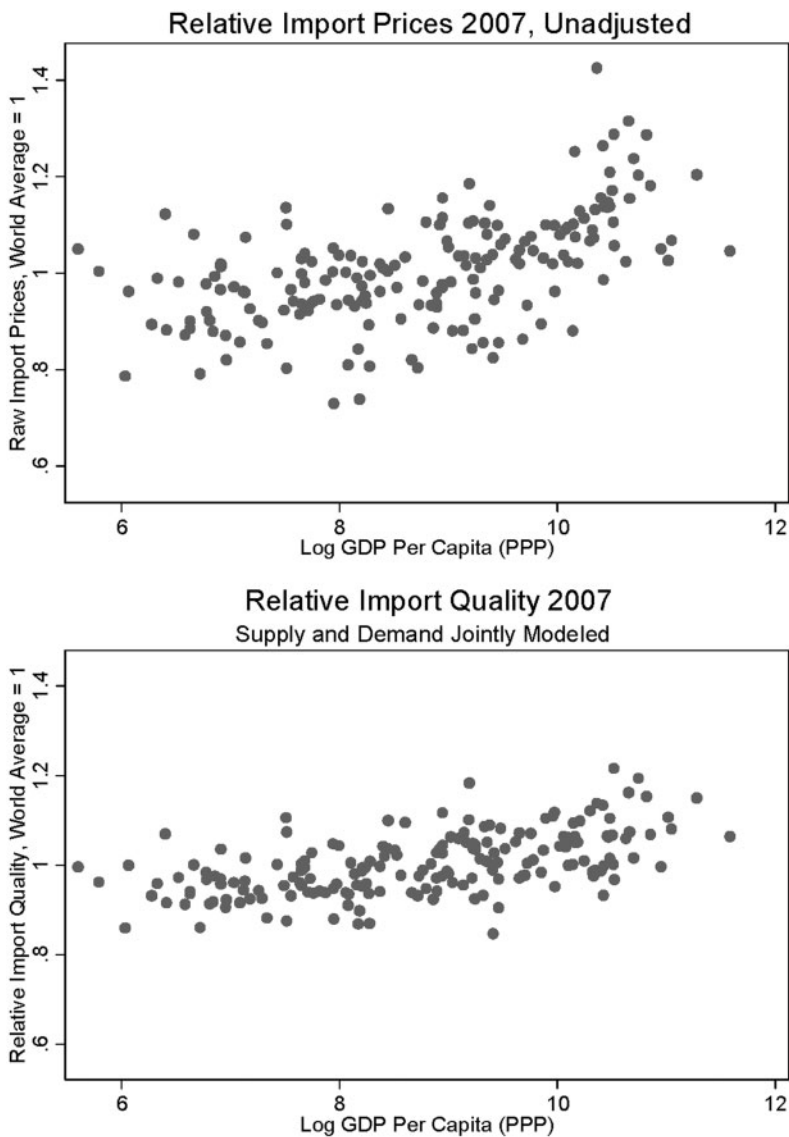


FIGURE VIII

Raw Import Prices and Supply- and Demand-Based Estimates of Import Quality and Quality-Adjusted Import Prices, 2007

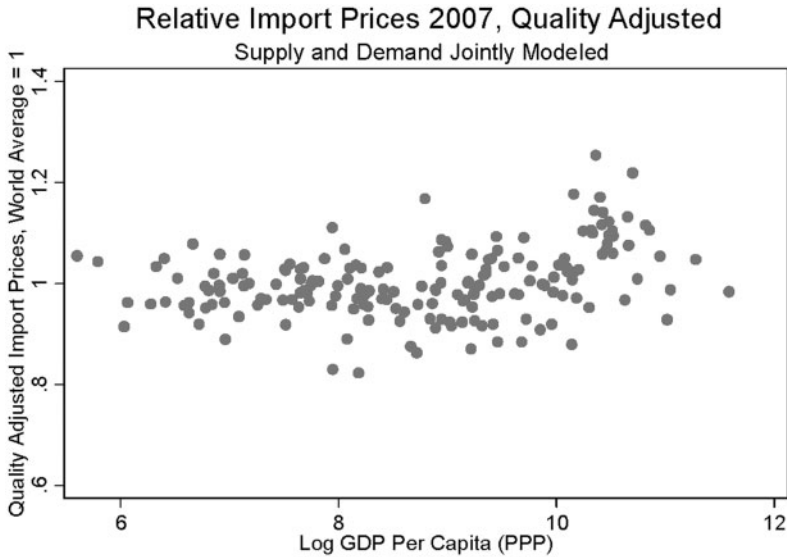


FIGURE VIII
Continued

and tastes of the importer will matter. In our model, any difference in the f.o.b. price from a given exporting firm must be due to quality. As noted earlier in equation (8), log quality is only a fraction of the log f.o.b. price, with the remaining difference in f.o.b. prices in equation (9) attributed to the quality-adjusted price. This pattern is illustrated on the import side in Figure VIII.

V.C. Terms of Trade

Figure IX shows terms of trade estimates for 2007. Terms of trade estimates constructed using raw export and import prices fluctuate substantially across countries and lie between 0.53 and 1.45.³¹ Terms of trade estimates constructed from quality-adjusted prices move in a much narrower band, between 0.79 and 1.21.³² Notably, the terms of trade decline in real GDP per capita, as wealthier countries are trading higher-quality goods at higher quality-adjusted prices, but this effect is much stronger for

31. 0.53 and 1.89 including St. Vincent and the Grenadines. See note 27.

32. 0.79 and 1.34 including St. Vincent and the Grenadines. See note 27.

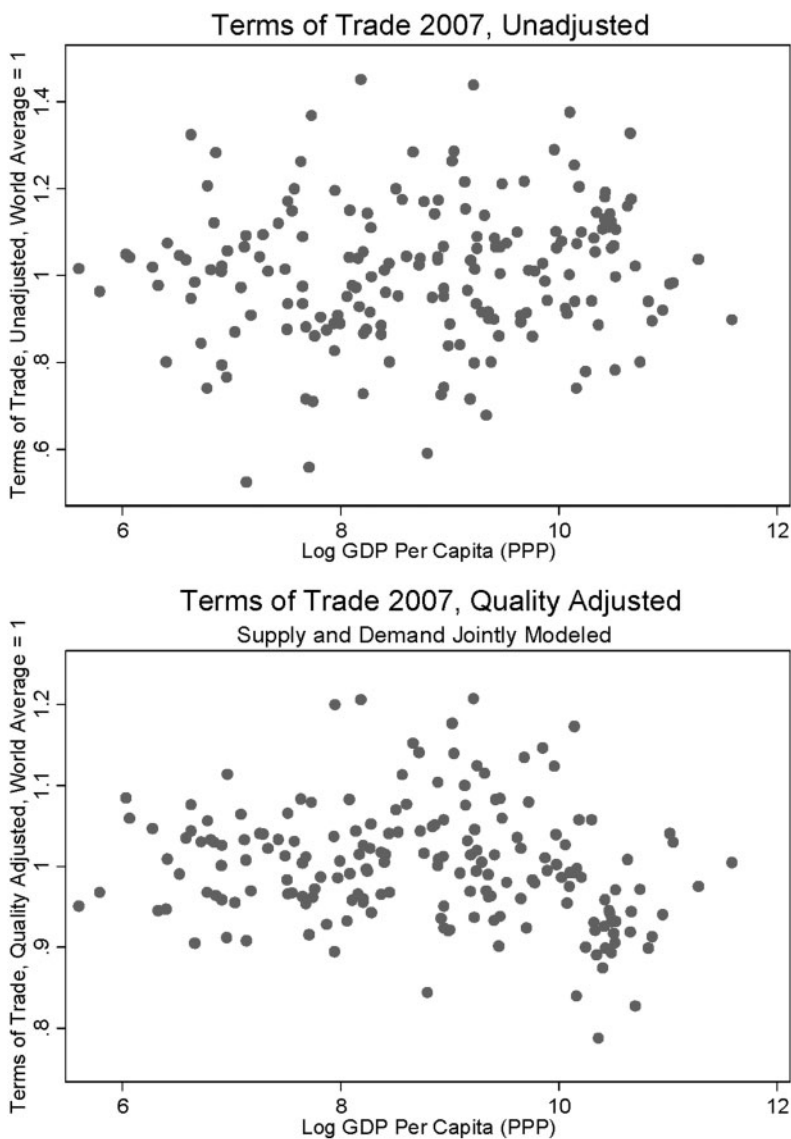


FIGURE IX
Terms of Trade: Unadjusted and Quality Adjusted, 2007

imports than for exports. This result is due in part to the lower unit value of imports and exports for poor countries, which have a greater effect on reducing the quality-adjusted import price in equation (19) than the adjusted export price in equation (18) because of the smaller exponent on the c.i.f./f.o.b. ratio on the right of equation (18). But this result also relies on the supply-side intuition from our model: only more efficient exporters can overcome the fixed costs of selling to countries with small markets, and these firms sell higher quality. Working against this effect is the mechanism of Arkolakis (2010), whereby smaller markets with lower real expenditure (Y^k/p^k) have their fixed costs reduced in equation (11) and also the reduced demand for quality in low-income countries. In all years quality-adjusted export prices have a modest and usually insignificant relationship with income, while quality-adjusted import prices are usually positively associated with income, and from the mid-1990s significantly so. The terms of trade are consistently significantly negatively related to income from 1993 onward.³³

We report estimates for aggregate export quality for 1987, 1997, and 2007 in Table II for the 52 largest traders measured by their average value of exports from 1984 to 2011. Swiss exports have the highest quality, on average 66% higher than the world average in 2007, followed by Israel and Finland with quality 37% higher than the average country. Japan, the United States, and other wealthy European countries usually have 15% to 30% higher export quality than average. Of note are the recent quality increases for several Eastern European countries that have joined the EU, especially those proximate to Germany: Czech Republic, Hungary, Poland, and Slovakia. Most wealthy industrial countries also exhibit improving relative quality over the 1987–2007 period. Poor large Asian countries have notably lower quality, with Indian and Chinese export quality, respectively, 13% and 34% lower than average levels. Vietnam and Indonesia do little better, with quality lagging average levels in 2007 by 12% and 21%, respectively.

It is interesting that China's relative export quality appears to have declined despite substantial economic progress. This does not imply that its *absolute* export quality has declined, because other countries may have raised quality. China's substantial exports of relatively low-quality products may have in fact caused

33. See Figure XIV and the related discussion.

TABLE II
 AGGREGATE EXPORT QUALITY AND RANK IN 1987, 1997, 2007

Country	Rank				Normalized quality, world average = 1			
	1987	1997	2007	Change	1987	1997	2007	Change
Switzerland	1	1	1	0	1.54	1.61	1.66	0.12
Israel	11	3	2	9	1.18	1.36	1.37	0.19
Finland	5	7	3	2	1.22	1.28	1.37	0.15
Ireland	9	6	4	5	1.19	1.31	1.32	0.13
Austria	2	8	5	-3	1.33	1.27	1.32	-0.02
United Kingdom	12	5	6	6	1.18	1.32	1.31	0.13
Sweden	3	2	7	-4	1.24	1.37	1.28	0.04
Japan	13	4	8	5	1.17	1.33	1.27	0.10
France	8	15	9	-1	1.20	1.20	1.26	0.06
USA	4	13	10	-6	1.22	1.20	1.24	0.02
Denmark	10	9	11	-1	1.18	1.26	1.24	0.06
Germany*	6	12	12	-6	1.21	1.21	1.24	0.02
Australia	16	10	13	3	1.14	1.24	1.23	0.10
New Zealand	7	11	14	-7	1.21	1.23	1.21	0.00
Canada	21	16	15	6	1.05	1.18	1.20	0.14
Norway	14	14	16	-2	1.16	1.20	1.20	0.03
Italy	19	17	17	2	1.11	1.18	1.14	0.02
Netherlands	22	21	18	4	1.05	1.11	1.14	0.09
Belgium	17	19	19	-2	1.14	1.14	1.14	0.00
Portugal	20	24	20	0	1.06	1.05	1.13	0.07
Chile	27	20	21	6	0.98	1.12	1.12	0.15
Spain	31	18	22	9	0.95	1.15	1.11	0.15
Nigeria	28	27	23	5	0.97	1.03	1.10	0.13
Algeria	26	30	24	2	0.99	0.98	1.08	0.09
South Africa	34	28	25	9	0.93	1.02	1.05	0.12
Singapore	24	22	26	-2	1.01	1.09	1.04	0.03
Hungary	43	36	27	16	0.84	0.95	1.03	0.20
Mexico	40	41	28	12	0.89	0.90	1.02	0.13
Saudi Arabia	23	33	29	-6	1.04	0.98	1.00	-0.04
Slovakia*	50	46	30	20	0.73	0.84	1.00	0.26
Colombia	25	23	31	-6	1.00	1.09	0.99	0.00
Czech Rep.*	51	42	32	19	0.73	0.89	0.98	0.25
Argentina	39	26	33	6	0.89	1.04	0.97	0.08
UAE	18	25	34	-16	1.12	1.05	0.96	-0.15
Russia*	45	39	35	10	0.82	0.90	0.96	0.14
Turkey	29	31	36	-7	0.96	0.98	0.95	-0.01
Philippines	42	37	37	5	0.88	0.92	0.95	0.06
Iran	15	32	38	-23	1.14	0.98	0.94	-0.20
Brazil	32	29	39	-7	0.95	1.02	0.94	-0.01
Rep. of Korea	38	34	40	-2	0.89	0.97	0.93	0.04

TABLE II
(CONTINUED)

Country	Rank				Normalized quality, world average = 1			
	1987	1997	2007	Change	1987	1997	2007	Change
Romania	47	50	41	6	0.81	0.80	0.92	0.11
Malaysia	36	47	42	-6	0.91	0.84	0.90	-0.01
Poland	52	44	43	9	0.71	0.87	0.89	0.18
Thailand	44	45	44	0	0.83	0.86	0.89	0.06
Venezuela	35	43	45	-10	0.93	0.88	0.89	-0.04
Viet Nam	41	35	46	-5	0.89	0.96	0.88	-0.01
India	33	38	47	-14	0.93	0.92	0.87	-0.06
Taiwan	48	48	48	0	0.80	0.83	0.87	0.06
Hong Kong	37	49	49	-12	0.90	0.81	0.86	-0.04
Ukraine*	46	51	50	-4	0.82	0.75	0.79	-0.02
Indonesia	30	40	51	-21	0.95	0.90	0.79	-0.17
China	49	52	52	-3	0.78	0.69	0.66	-0.12
Mean:					1.01	1.06	1.07	
Standard Deviation:					0.17	0.19	0.19	

Note. * denotes 1987 data from West Germany, Czechoslovakia, Czechoslovakia, USSR and USSR respectively

most other countries to focus on higher quality goods; see Amity and Khandelwal (2009) for a discussion. We can find plenty of examples in the detailed data of rising relative quality for China, such as “computers,” rising from 0.37 in 1987 to 0.45 in 1997 and 0.75 in 2007; or “coarse ceramic housewares” (dinnerware), rising from 0.40 in 1987 and 1997 to 0.49 in 2007; or “footwear,” rising from 0.30 in 1987 to 0.57 in 1997 and 0.87 in 2007. But there are an almost equal number of examples of falling relative quality. At the SITC four-digit level the median quality estimate for China has risen modestly from 0.58 in 1987 to 0.59 in 1997 and 0.62 in 2007. What is working against China in aggregate are the weights applied to items due to compositional shifts in China’s exports. In 1987, 62% of China’s exports were in BEC categories 1 through 3: food, industrial supplies, and fuels. China’s measured quality was much closer to average levels for these products, varying from 0.87 for industrial supplies to 0.94 for fuels. By 1997 these exports had declined to 35% of China’s exports, and to just 27% by 2007. China’s exports at first were mostly reoriented toward consumer goods (BEC 6), with that

share rising from 30% in 1987 to 44% in 1997, but these declined to 27% in 2007. The more prolonged reorientation was toward capital goods and parts (BEC 4), rising from 3% of China's exports in 1987 to 17% in 1997 and 39% in 2007. It is in capital goods and parts where China's relative export quality has always been lowest, between 38% and 52% of average levels. China's reallocation from sectors of relatively high quality toward sectors with relatively low quality is also helping mask the quality improvements that we often observe as consumers.

In the Online Appendix we report export quality results for the top 20 exporters in each one-digit BEC. With a few notable exceptions, the pattern for aggregate quality holds in each of the BEC categories: rich countries tend to have high quality in all BEC categories, and poor countries tend to have notably lower quality. The main exceptions are in BEC 3, fuels and lubricants, where there is a less clear relationship between export quality and the exporter's level of development. The recent improvement in Eastern European quality is very apparent in their transport equipment exports. China's declining aggregate relative quality also appears in BEC 1, food and beverages, and BEC 2, industrial supplies.

Our export quality estimates call out for a comparison with the quality estimates of Hallak and Schott (2011) and Khandelwal (2010).³⁴ We do this in Figure X using data from Hallak and Schott (2011, table IV) and in Figure XI using the median of HS 10-digit quality results for manufactured products generously provided by Amit Khandelwal. We take logs of our Table II results to make them more comparable with Hallak-Schott and demean all series.³⁵ Figure X compares our normalized quality estimates with Hallak-Schott in 1997 for the 40 countries common to all three papers.³⁶ The correlation is very high, at .67, but there is a considerable difference in the dispersion of the two sets of estimates. The standard deviation of the Hallak-Schott quality estimates is 0.45, compared with 0.18 for our matching estimates. The lower dispersion of our estimates

34. Hallak and Schott (2011) and Khandelwal (2010) do not estimate import quality.

35. Khandelwal's quality estimates are not as directly comparable, because if translated to a CES framework they confound quality and the sensitivity of demand to price: see equation 15 of Khandelwal (2010).

36. Hallak and Schott's quality estimates are linear trends, so it is a simple matter to back out the implied 1997 results.

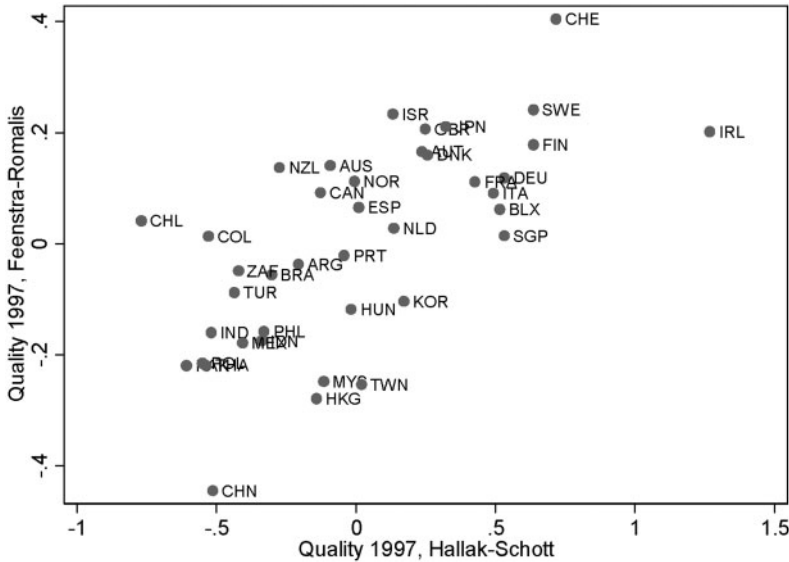


FIGURE X

Comparison with Hallak-Schott (2011)

partly reflects the “tighter” solution we get for exporter quality by exploiting the supply side of our model, but may also be due to using worldwide trade data in all products rather than just U.S. manufacturing imports, and different aggregation procedures.

Figure XI provides the equivalent comparison with Khandelwal (2010). The correlation between the two sets of estimates is lower, at .49, and the higher dispersion of Khandelwal’s estimates (the standard deviation is 0.77) cannot be directly compared with the other estimates.³⁷ The lower correlation of our estimates with Khandelwal (2010) is primarily driven by different supply-side assumptions. We implicitly solve our model for the equilibrium number of firms consistent with observed trade values, whereas Khandelwal (2010) uses country population as a proxy of the number of exporting firms.³⁸ In Figure XII we

37. See note 35.

38. Following Khandelwal (2010), we have used the estimated labor force in each SITC industry and country as a proxy for export variety, as explained beneath equation (16). Although this proxy enters into the gravity equation (22), and

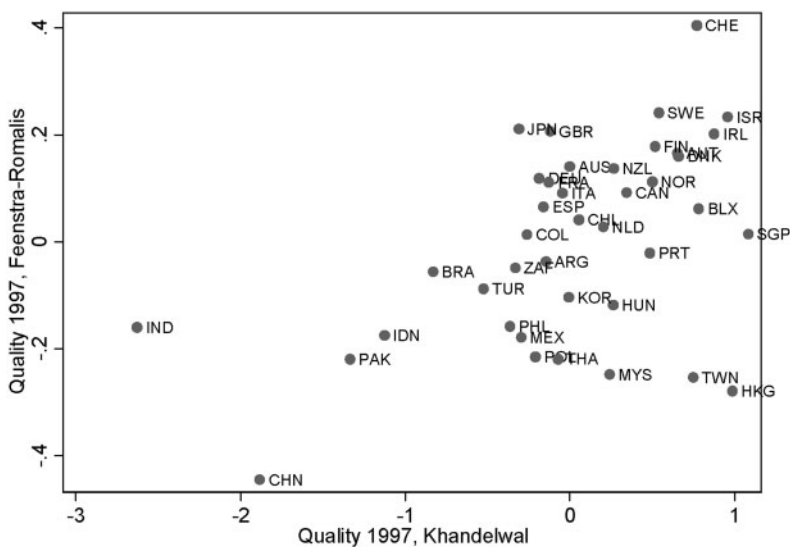


FIGURE XI
Comparison with Khandelwal (2010)

compare Khandelwal (2010) to our purely illustrative “demand-side” estimates where we also used population as the proxy for the number of exporting firms. The correlation is extremely high at .83. Because we use different trade data (worldwide rather than just U.S. imports) and different aggregation methods, the different demand systems can only be contributing a modest amount to the overall differences in our estimates from Khandelwal (2010).

Figure XIII reveals that these last two sets of estimates—from Khandelwal and our demand-side-only estimates—are extremely negatively correlated with population, the proxy for the number of firms. Less obviously, the Hallak-Schott estimates are closely related to the manufacturing trade balance, which is a key component of their measure of demand. These associations are made crystal clear in Table III, which reports regressions of three sets of export quality estimates (Hallak-Schott 2011, Khandelwal 2010, and our “full-model” estimates) plus our import quality and

thereby affects the estimated parameters from this equation, it does not otherwise enter into the formulas for quality or quality-adjusted prices.

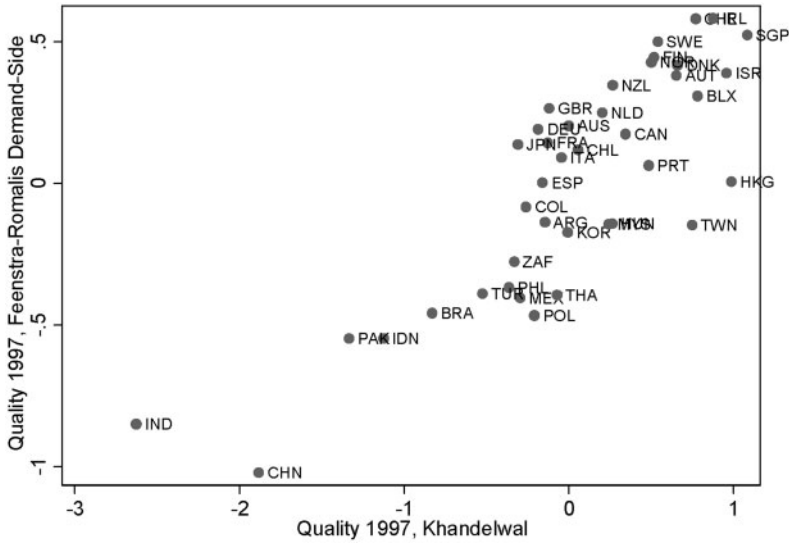


FIGURE XII

Comparison of Demand-Side Estimates with Khandelwal (2010)

terms of trade estimates on three country-level variables: log per capita income from PWT, log population, and the manufacturing trade balance from Comtrade divided by manufacturing value added from the World Bank's World Development Indicators.³⁹

All three export quality estimates are strongly positively correlated with per capita income. Khandelwal's estimates exhibit a very strong relationship to country population, and Hallak and Schott's estimates are moderately correlated with population and our estimates (derived from using both the demand and supply side) are uncorrelated with population. The Hallak-Schott quality estimates are very strongly correlated with the manufacturing trade balance, while Khandelwal's and our export quality estimates are only slightly correlated with that balance. Our import quality estimates are not significantly correlated with any of the three variables. Finally, our quality-adjusted terms of trade estimates for these countries are negatively correlated

39. Since Hallak and Schott report trend values of quality, we take an average of the manufacturing trade balance to value added ratio over their 1989–2003 sample period.

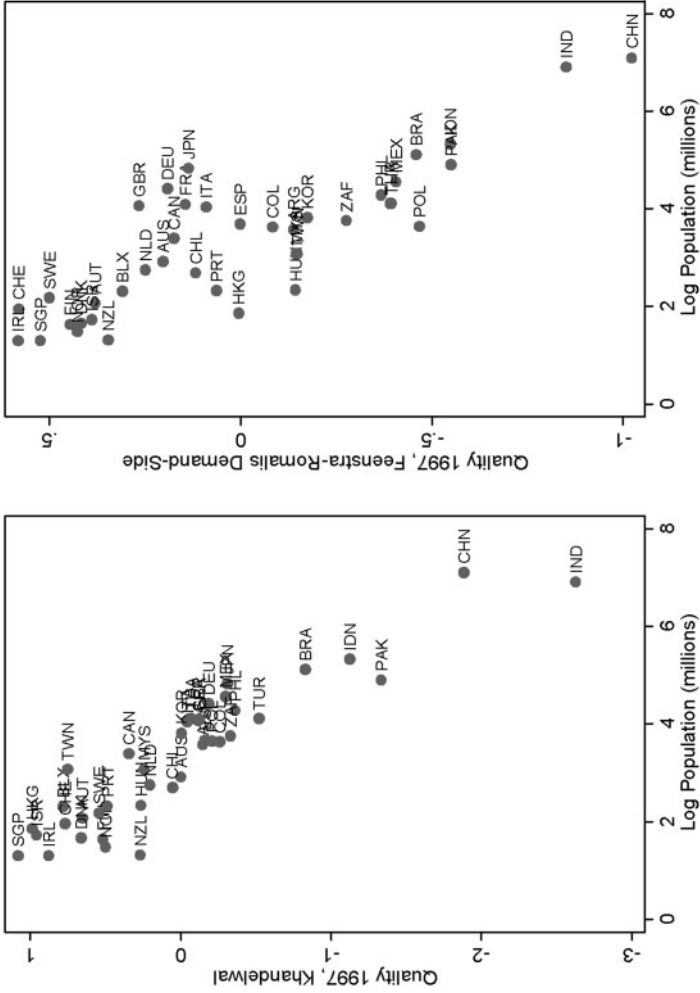


TABLE III
COMPARISON OF QUALITY ESTIMATES FOR 1997

Dependent variable:	Hallak and Schott (2011)	Khandelwal (2010)	This paper		
	Export quality	Export quality	Export quality	Import quality	Terms of trade
Independent variables:					
Log GDP per capita	0.32 (0.05)	0.30 (0.07)	0.14 (0.04)	0.02 (0.02)	-0.06 (0.01)
Log population	-0.08 (0.03)	-0.37 (0.04)	-0.01 (0.02)	-0.01 (0.01)	-0.03 (0.01)
Manufacturing trade balance/value added	0.84 (0.08)	0.18 (0.11)	0.06 (0.06)	0.02 (0.04)	-0.01 (0.02)
Observations	38	38	38	38	38
R-squared	.88	.92	.52	.20	.43

Notes. Standard errors are reported in parentheses. The ratio of the manufacturing trade balance to manufacturing value added variable has been averaged over Hallak and Schott's (2011) 1989–2003 sample period. We lose two countries, Israel and Taiwan, due to missing manufacturing value-added data in the World Development Indicators.

with per capita income and population but are not associated with the manufacturing trade balance. The key lesson we take from these comparisons is that estimates for quality are very sensitive to proxies chosen for important model variables, whether it be population as the proxy for the number of firms or the manufacturing trade balance as a measure of demand. We have reduced our sensitivity to such proxies by more fully exploiting the supply-side structure of our heterogeneous firms model, to simultaneously solve for the quality-adjusted prices and (implicitly) the number of firms that are consistent with observed trade data.

We repeat the Table III regressions on our export quality, import quality, and terms of trade results for each year, using the full sample of countries. Each coefficient on log GDP per capita is plotted in Figure XIV. Both export quality and import quality have become more positively associated with income over time, though the prolonged recession in much of the developed world may be eroding the relationship for imports from 2008. The coefficient for exports almost always lies above that for imports, suggesting that richer countries tend to be net exporters of higher quality products, consistent with the proposition of Fajgelbaum, Grossman, and Helpman (2011a). Their model generates this result because the production of high-quality goods occurs in

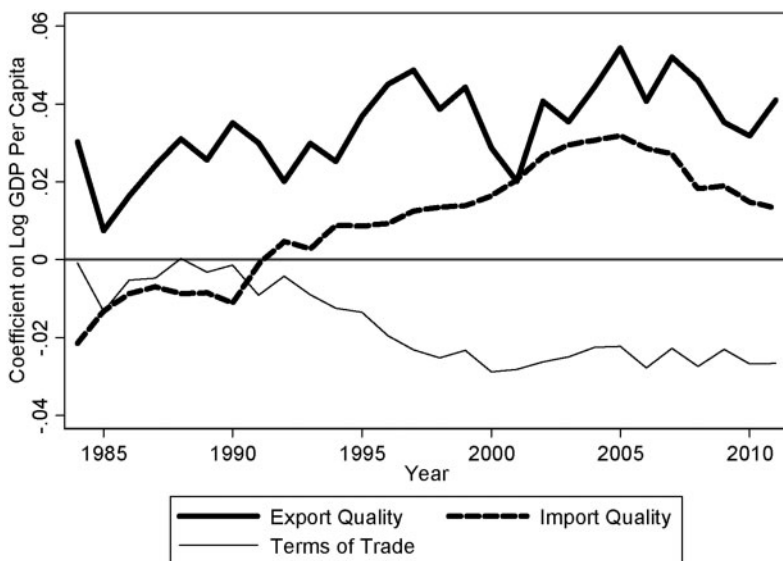


FIGURE XIV
Coefficients on Log GDP per Capita

high-income countries, where demand is greatest. We have a different supply-side mechanism at work, whereby only the most efficient exporters can cover the fixed costs of selling to countries with low import volumes (because they are poor or simply small), and these efficient exporters sell higher quality. The terms of trade become significantly negatively associated with income from 1993.

VI. CONCLUSIONS

Our goal has been to adjust observed trade unit values for quality so as to estimate quality-adjusted prices in trade. We achieve this goal by explicitly modeling the quality choice by exporting firms in an environment where consumers have nonhomothetic tastes for quality. We find a greater preference for quality in richer countries, consistent with Hallak (2006). Our key parameter estimate of the elasticity of quality with respect to the quantity of inputs almost always lies between 0 and unity, as required by our model. This implies that only a fraction of

observed import unit value differences are due to quality, with the remainder reflecting differences in quality-adjusted import prices. A key advantage we gain from more fully exploiting the supply-side structure of a heterogeneous firms model is that we reduce our reliance on proxies for some critical features of our model, notably the number of firms. Instead of arbitrarily choosing a proxy, we implicitly solve for the number of firms consistent with our model and observed trade values.⁴⁰

Our estimates of the elasticity of substitution between different varieties of the same SITC four-digit products are substantially higher than in Broda and Weinstein (2006). As a result, the observed differences in export unit values are attributed predominantly to quality, with very small remaining differences in quality-adjusted export prices. The quality-adjusted terms of trade therefore declines with country income in all years since 1993, reflecting rich countries' preferences for higher quality and therefore higher quality-adjusted prices. In that year variation in the quality-adjusted terms of trade is only one-half as large as that in the unadjusted ratio of export to import unit value indexes.

There are at least two directions for further research. First, as we have noted, our results lend support to the proposition of Fajgelbaum, Grossman, and Helpman (2011a) that poor countries are net importers of high-quality goods. They argue that such a trade pattern will disproportionately benefit wealthy consumers in poor countries. It would likewise be of interest to empirically examine this. Our detailed SITC four-digit estimates of import prices and quality could be used to compute the impact of trade openness on consumers of different income groups, thereby showing how trade interacts with the income distribution of countries.

Second, our finding that the quality-adjusted terms of trade are declining with the level of development gives only a partial view on country welfare and should be combined with the impact of import variety on welfare. Hummels and Klenow (2005) argue that import variety is greater for wealthier countries, and Feenstra (2010) shows how this effect leads to a *positive* relationship between variety-adjusted terms of trade and GDP per capita. Both the quality and the variety effects should be combined to

40. We have not eliminated our reliance on such proxies, which do indirectly affect quality estimates through their impact on parameter estimates and through our fixed export cost estimates. See note 38.

obtain a more complete view of the impact of trade on countries at different levels of income.

UNIVERSITY OF CALIFORNIA, DAVIS AND NATIONAL BUREAU OF ECONOMIC RESEARCH
UNIVERSITY OF SYDNEY AND NATIONAL BUREAU OF ECONOMIC RESEARCH

SUPPLEMENTARY MATERIAL

An Online Appendix for this article can be found at QJE online (qje.oxfordjournals.org).

REFERENCES

- Acemoglu, Daron, and Jaume Ventura, "The World Income Distribution," *Quarterly Journal of Economics*, 117 (2002), 659–694.
- Alchian, Armen A., and William R. Allen, *University Economics* (Belmont, CA: Wadsworth Publishing, 1964).
- Amiti, Mary, and Amit K. Khandelwal, "Import Competition and Quality Upgrading," NBER Working Paper No. 15503, 2009.
- Antoniades, Alexis, "Heterogeneous Firms, Quality, and Trade," Mimeo, Princeton University and Georgetown University, 2012.
- Arkolakis, Costas, "Market Penetration Costs and the New Consumers Margin in International Trade," *Journal of Political Economy*, 118 (2010), 1151–1199.
- Baldwin, Richard E., and Tadashi Ito, "Quality Competition versus Price Competition Goods: An Empirical Classification," *Journal of Economic Integration*, 26 (2011), 110–135.
- Balk, Bert M. *Price and Quantity Index Numbers: Models for Measuring Aggregate Change and Difference* (New York: Cambridge University Press, 2008).
- Bekkers, Eddy, Joseph Francois, and Miriam Manchin, "Import Prices, Income, and Inequality," *European Economic Review*, 56 (2012), 848–869.
- Bilbiie, Florin, Fabio Ghironi, and Marc J. Melitz, "Endogenous Entry, Product Variety, and Business Cycles," *Journal of Political Economy*, 120 (2012), 304–345.
- Broda, Christian, "Coping with Terms-of-Trade Shocks: Pegs versus Floats," *American Economic Review*, 91 (2001), 376–380.
- Broda, Christian, and David W. Weinstein, "Globalization and the Gains from Variety," *Quarterly Journal of Economics*, 121 (2006), 541–585.
- Chaney, Thomas, "Distorted Gravity: The Intensive and Extensive Margins of International Trade," *American Economic Review*, 98 (2008), 1707–1721.
- Choi, Yo Chul, David Hummels, and Chong Xiang, "Explaining Import Quality: The Role of Income Distribution," *Journal of International Economics*, 77 (2009), 265–275.
- Crozet, Matthieu, Keith Head, and Thierry Mayer, "Quality Sorting and Trade: Firm-level Evidence for French Wine," *Review of Economic Studies*, 79 (2012), 609–644.
- Das, Satya P., and Donnenfeld Shabtai, "Trade Policy and Its Impact on the Quality of Imports: A Welfare Analysis," *Journal of International Economics*, 23 (1987), 77–96.
- Deaton, Angus, and Allen Heston, "Understanding PPPs and PPP-based National Accounts," *American Economic Journal: Macroeconomics*, 2 (2010), 1–35.
- Deaton, Angus, and John Muellbauer, *Economics and Consumer Behaviour* (Cambridge: Cambridge University Press, 1980).
- Demidova, Svetlana, and Kala Krishna, "Trade and Trade Policy with Differentiated Products: A Chamberlinian-Ricardian Model. A Comment,"

- Journal of International Trade and Economic Development*, 16 (2007), 435–441.
- Demir, F. Banu, “Trading Tasks and Quality,” Oxford University Department of Economics Discussion Paper No. 582, 2012.
- Eaton, Jonathan, and Samuel Kortum, “Technology, Geography and Trade,” *Econometrica*, 70 (2002), 1741–1779.
- Eaton, Jonathan, Samuel Kortum, and Francis Kramarz, “An Anatomy of International Trade: Evidence from French Firms,” *Econometrica*, 79 (2011), 1453–1498.
- Eaton, Jonathan, Samuel Kortum, and Sebastian Sotelo, “International Trade: Linking Micro and Macro,” NBER Working Paper No. 17864, 2012.
- Estevadeordal, Antoni, and Alan M. Taylor, “Is the Washington Consensus Dead? Growth, Openness, and the Great Liberalization, 1970s–2000s,” *Review of Economics and Statistics* forthcoming, 2014.
- Fajgelbaum, Pablo, Gene M. Grossman, and Elhanan Helpman, “Income Distribution, Product Quality, and International Trade,” *Journal of Political Economy*, 119 (2011a), 721–765.
- , “A Linder Hypothesis for Foreign Direct Investment,” NBER Working Paper No. 17550, 2011b.
- Feenstra, Robert C., “Quality Change under Trade Restraints in Japanese Autos,” *Quarterly Journal of Economics*, 103 (1988), 131–146.
- , “New Product Varieties and the Measurement of International Prices,” *American Economic Review*, 84 (1994), 157–177.
- , *Product Variety and the Gains from International Trade* (Cambridge, MA: MIT Press, 2010).
- Feenstra, Robert C., Robert Inklaar, and Marcel Timmer, “The Next Generation of the Penn World Table,” NBER Working Paper No. 19255, 2013.
- Fisher, Franklin M., and Karl Shell/Franklin Fisher, “Taste and Quality Change in the Pure Theory of the True Cost-of-Living Index,” Essay I in *Economic Theory of Price Indices: Two Essays on the Effects of Taste, Quality and Technological Change*, Franklin Fisher, ed. (New York: Academic Press, 1972), 1–48.
- Gervias, Antoine, “Product Quality, Firm Heterogeneity and International Trade,” Mimeo, University of Notre Dame, 2010.
- Hallak, Juan Carlos, “Product Quality and the Direction of Trade,” *Journal of International Economics*, 68 (2006), 238–265.
- Hallak, Juan Carlos, and Peter K. Schott, “Estimating Cross-Country Differences in Product Quality,” *Quarterly Journal of Economics*, 126 (2011), 417–474.
- Hsieh, Chang-Tai, and Peter J. Klenow, “Development Accounting,” *American Economic Journal: Macroeconomics*, 2 (2010), 207–223.
- Hummels, David L., and Peter J. Klenow, “The Variety and Quality of a Nation’s Exports,” *American Economic Review*, 95 (2005), 704–723.
- Hummels, David L., and Alexandre Skiba, “Shipping the Good Apples Out? An Empirical Confirmation of the Alchian-Allen Conjecture,” *Journal of Political Economy*, 112 (2004), 1384–1402.
- Irrarrazabal, Alfonso A., Andreas Moxnes, and Luca David Oromolla, “The Tip of the Iceberg: A Quantitative Framework for Estimating Trade Costs,” Banco de Portugal, Economics and Research Department Working Paper No. 201125, 2011.
- Johnson, Robert C., “Trade and Prices with Heterogeneous Firms,” *Journal of International Economics*, 86 (2012), 43–56.
- Khandelwal, Amit, “The Long and Short (of) Quality Ladders,” *Review of Economics Studies*, 77 (2010), 1450–1476.
- Krishna, Kala, “Tariffs versus Quotas with Endogenous Quality,” *Journal of International Economics*, 23 (1987), 97–113.
- Kugler, Maurice, and Eric Verhoogen, “Prices, Plant Size, and Product Quality,” *Review of Economic Studies*, 79 (2012), 307–339.
- Lawrence, Robert Z., and Matthew J. Slaughter, “International Trade and American Wages in the 1980s: Giant Sucking Sound or Small Hiccup?,” *Brookings Papers on Economic Activity. Microeconomics*, 2 (1993), 161–226.

- Mandel, Benjamin, "Heterogeneous Firms and Import Quality: Evidence from Transaction-Level Prices," Board of Governors of the Federal Reserve Bank System, International Finance Discussion Paper No. 991, 2010.
- Martin, Julien, and Isabelle Méjean, "Low-Wage Countries' Competition, Reallocation across Firms and the Quality Content of Exports," CEPII Working Paper No. 2012-04, 2012.
- Melitz, Marc J., "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, 71 (2003), 1695–1725.
- Melitz, Marc J., and Stephen J. Redding, "Heterogeneous Firms and Trade," NBER Working Paper no. 18652, in *Handbook of International Economics*, vol. 4, Gita Gopinath, Elhanan Helpman and Kenneth Rogoff, eds. (New York: North-Holland, 2014).
- Melitz, Marc J., "Firm Heterogeneity and Aggregate Welfare," NBER Working Paper No. 18919, 2013.
- Rodriguez, Carlos A., "The Quality of Imports and the Differential Welfare Effects of Tariffs, Quotas, and Quality Controls as Protective Devices," *Canadian Journal of Economics*, 12 (1979), 439–449.
- Schott, Peter K., "Across-Product versus Within-Product Specialization in International Trade," *Quarterly Journal of Economics*, 119 (2004), 646–677.
- , "The Relative Sophistication of Chinese Exports," *Economic Policy*, 23 (2008), 5–49.
- Simonovska, Ina, "Income Differences and Prices of Tradables," NBER Working Paper No. 16233, 2010 (revised 2013).
- Simonovska, Ina, and Michael E. Waugh, "The Elasticity of Trade: Estimates and Evidence," NBER Working Paper No. 16796, 2011.
- , "Different Trade Models, Different Trade Elasticities?," Mimeo, UC Davis and NYU Stern School of Business, 2012.
- Verhoogen, Eric, "Trade, Quality Upgrading, and Wage Inequality in the Mexican Manufacturing Sector," *Quarterly Journal of Economics*, 123 (2008), 489–530.

This page intentionally left blank