International Prices and Endogenous Quality*

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Abstract

The unit value 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. We employ a demand system to model consumer demand whereby quality and quantity multiply each other in the utility function. In that case, the quality choice by firms’ is a simple cost-minimization sub-problem. We estimate this system using detailed bilateral trade data and sectoral wage data for over 150 countries for 1984-2008. Our system identifies quality-adjusted prices from which we will construct price indexes for imports and exports for each country, that will be incorporated into the next generation of the Penn World Table.

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1. Introduction

It has long been known that the unit value of internationally traded goods are heavily influenced by their quality (Kravis and Lipsey, 1974). Historically, that linkage was viewed in a negative light and is the reason why import and export prices indexes for the United States no longer use any unit-value information, but instead rely on price surveys from importers. More recently, it has been argued that the variation in unit values is systematically related to characteristics of the exporting (Schott, 2004) and importing (Hallak, 2006) countries. Such a relationship gives a positive spin to the linkage between unit values and quality because, as argued by Hummels and Klenow (2005) and Baldwin and Harrigan (2011), we can use this systematic variation to test between competing trade models.

Our goal in this paper is to estimate that portion of trade unit values that is due to quality. To achieve this we use the model identified by Baldwin and Harrigan (2011) as most consistent with the empirical observations – quality with heterogeneous firms – and extend it to allow for endogenous quality choice by firms. ¹ We are not the first to attempt to disentangle quality from trade unit values, and other recent authors with that goal include Hallak and Schott (2011) and Khandelwal (2010). ² These studies rely on the demand side to identify quality. 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. To this demand-side information we will add a supply side, drawing on the well-

¹ Other models with endogenous quality choice by heterogeneous firms include Gervias (2010), Khandelwal (2010) and Mandel (2009). The latter two paper have simultaneous choice of price and quality, as we use here. In contrast, Gervias has quality chosen for the lifetime of a product. This yields a solution where quality is proportional to firm productivity, thereby providing a micro-foundation for that assumption in Baldwin and Harrigan (2011).

known “Washington apples” effect (Alchian and Allen, 1964; Hummels and Skiba, 2004): goods of higher quality are shipped longer distances. We will find that this positive relationship between exporter f.o.b. prices and distance is an immediate implication of the first-order condition of firms for optimal quality choice. This first-order condition gives us powerful additional information from which to identify quality.

In section 2, we specify an extended monopolistic competition framework, where in addition to choosing price, firms in each country simultaneously chooses quality. Like the early work by Rodriguez (1979), we allow quality to multiply quantity in the utility function, leading to a sub-problem of quality choice for the firm: to minimize the average cost of quality. As in Verhoogen (2008), we assume a Cobb-Douglas production function for quality where firms can differ in their productivities, and let $\theta < 1$ denote the elasticity of quality with respect to skilled labor. Then we find that quality is a simple log-linear function of firm’s productivity and skilled wages, as well as the specific transport costs to the destination market. Specializing to the CES demand system, we solve for the prices charged by firms and find that an exporter’s f.o.b. price is proportional to specific transport costs, as in the Washington apples effect. So up to a constant, log quality is proportional to the log of the exporter’s f.o.b. price divided by productivity-adjusted wages, with the factor of proportionality $\theta$.

In section 3, we aggregate these firm-level results to the product level, in which case the c.i.f. and f.o.b. prices are measured by unit-values. The CES demand system demand depends negatively on the c.i.f. unit value of a product, and should depend positively on exporter’s f.o.b. unit value relative to wages, which measures quality up to the parameter $\theta$. The demand system enables us to estimate $\theta$, which comes from the supply-side of the model.

In section 4 we brieflly compare our results to what would be obtained under a non-
homothetic demand system. Non-homothetic demand plays an important role in models of international trade and quality, such as Bekkers et al (2010), Choi et al (2009), Fajgelbaum et al (2009), Simonovska (2011). We will make use of results from Deaton and Muellbauer (1980) to argue that per-capita income (or more generally, the income distribution) in the destination market will affect demand, even in a system with constant elasticity of substitution.

In section 5-7, we estimate the CES demand system using detailed bilateral trade data and sectoral wage data for over 100 countries for 1984-2008. We work with SITC 4-digit data (about 1,000 products per year) to obtain a long time-series. In addition to estimating the key parameter $\theta$, we obtain estimates of the elasticity of substitution $\sigma$ that can be compared to those in Broda and Weinstein (2006). These new estimates correct for potential correlation between demand and supply due to quality, and differ based on estimation in levels versus first-differences. While Broda and Weinstein (2006) used first-differences following Feenstra (1994), our reliance on the Washington’s apples effect here suggests that levels are more appropriate (since the distance to destination countries is lost when data are first-differenced). In fact, we find that estimates of both $\theta$ and $\sigma$ are higher when estimated in levels.

Given the estimates of $\theta$, product quality and quality-adjusted prices are readily constructed. Our interest in these is not just academic, but serve a very practical goal: to extend the Penn World Table (PWT) to incorporate the prices of traded goods. As described in Feenstra et al (2009), the prices of internationally traded goods can be used to make a distinction between real GDP on the expenditure-side and real GDP on the output-side: these differ by country’s terms of trade. But that distinction can be made only if the trade unit values are first corrected for quality. That is the goal of this study, and in section 8 we briefly described how the quality-adjusted prices will be incorporated in the next generation of PWT.
2. Optimal Quality Choice

Consumer Problem

Suppose that consumers in country \( k \) have available \( i=1, \ldots, N^k \) varieties of a differentiated product. These products can come from different source countries (including country \( k \) itself). We should really think of each variety as indexed by the triple \((i,j,t)\), where \( i \) is the country of origin, \( j \) is the firm and \( t \) is time. But initially, we will simply use the notation \( i \) for product varieties. Firms make the optimal choice of the quality \( z^k_i \) to send to country \( k \). We will suppose that the demand for the products in country \( k \) arises from utility function

\[
U(z^k_1, c^k_1, \ldots, z^k_{N^k}, c^k_{N^k})
\]

where quality \( z^k_i \) multiplies the quantity \( c^k_i \). Later we will specialize to the CES form:

\[
U(z^k_1, c^k_1, \ldots, z^k_{N^k}, c^k_{N^k}) = \sum_{i=1}^{N^k} a^k_i \left( \frac{c^k_i}{\bar{c}^k_i} \right)^{(\sigma-1)/\sigma}, \quad \sigma > 1,
\]

where \( a^k_i > 0 \) are taste parameters which we include for generality, as will be discussed later.

We suppose there are both specific and \textit{ad valorem} trade costs between the countries, which include transportation costs and tariffs. Specific trade costs are given by \( T^k_i \), which depends on the distance to the destination market \( k \). One plus the \textit{ad valorem} trade costs are denoted by \( \tau^k_i \), and for convenience we assume that these are applied to the price \textit{inclusive} of the specific trade costs.\(^3\) Then letting \( p^k_i \) denote the exporters’ f.o.b. price, the tariff-inclusive c.i.f. price is

\[
P^k_i = \tau^k_i (p^k_i + T^k_i).
\]

Thus, consumers in country \( k \) are presented with a set of \( i=1, \ldots, N^k \) varieties, with characteristics \( z^k_i \) and prices \( P^k_i \), and then choose the optimal quantity of each variety. It will be

\(^3\) Many countries apply tariffs to the transport-inclusive (c.i.f.) price of a product.
convenient to work with the quality-adjusted, tariff-inclusive c.i.f. prices, which are defined by

\[ \pi_i^k \equiv P_i^k / z_i^k = \tau_i^k (p_i^k + T_i^k) / z_i^k. \]

The higher is overall product quality \( z_i^k \), ceteris paribus, the lower are the quality-adjusted prices \( \pi_i^k \). The consumer maximizes utility subject to the budget constraint \( \sum_{i=1}^{N_k} \tau_i^k (p_i^k + T_i^k) c_i^k \leq Y^k \). The Lagrangian for country \( k \) is,

\[
L = U(z_1^k c_1^k, \ldots, z_{N_k}^k c_{N_k}^k) + \lambda \left[ Y^k - \sum_{i=1}^{N_k} \tau_i^k (p_i^k + T_i^k) c_i^k \right]
\]

\[
= U(d_1^k, \ldots, d_{N_k}^k) + \lambda (Y^k - \sum_{i=1}^{N_k} \pi_i^k d_i^k),
\] (2)

where the second line of (2) follows by defining \( d_i^k \equiv z_i^k c_i^k \) as the quality-adjusted demand, and also using the quality-adjusted prices \( \pi_i^k \equiv \tau_i^k (p_i^k + T_i^k) / z_i^k \). This re-writing of the Lagrangian makes it clear that instead of choosing \( c_i^k \) given c.i.f. prices \( \tau_i^k (p_i^k + T_i^k) \) and quality \( z_i^k \), we can instead think of the representative consumer as choosing \( d_i^k \) given quality-adjusted c.i.f. prices \( d_i^k \), \( i = 1, \ldots, N_k \). Let us denote the solution to problem (2) by \( d_i(\pi^k, Y^k), i = 1, \ldots, N_k \), where \( \pi^k \) is the vector of quality-adjusted prices.

**Firms’ Problem**

We now add the subscript \( j \) for firms, while \( i \) denotes their country of origin, so that \((i,j)\) denotes a unique variety. We will denote the range of firms exporting from country \( i \) to \( k \) by \( j = 1, \ldots, N_i^k \). Similarly to Verhoogen (2008), we assume that the skilled labor needed to produce one unit of a good with product quality \( z_{ij}^k \) arises from a Cobb-Douglas function:

\[
z_{ij}^k = (L_{ij}^k \varphi_{ij})^\theta,
\] (3)
where $0 < \theta < 1$ reflects diminishing returns to quality and $\varphi_{ij}$ denotes the productivity of firm $j$ in country $i$. The marginal cost of producing a good of quality $z_{ij}^k$ is then,

$$g_{ij}(z_{ij}^k, w_i) = w_i L_{ij}^k = w_i (z_{ij}^k)^{1/\theta} / \varphi_{ij}.$$  

(4)

where $w_i$ are skilled wages in the exporting country $i$. Firms simultaneously choose f.o.b. prices $p_{ij}^k$ and characteristics $z_{ij}^k$ for each destination market. Then the profits from exporting to country $k$ are:

$$\max_{p_{ij}^k, z_{ij}^k} \left[ p_{ij}^k - g_{ij}(z_{ij}^k, w_i) \right] c_{ij}^k = \max_{p_{ij}^k, z_{ij}^k} \left[ p_{ij}^k - \frac{g_{ij}(z_{ij}^k, w_i)}{z_{ij}^k} \right] d_{ij}^k(\pi^k, Y^k)$$

$$= \max_{\pi_{ij}^k, z_{ij}^k} \left\{ \frac{\pi_{ij}^k}{\tau_i^k} - \left[ \frac{g_{ij}(z_{ij}^k, w_i) + T_i^k}{z_{ij}^k} \right] \right\} d_{ij}^k(\pi^k, Y^k)$$

(5)

The first equality in (5) converts from observed to quality-adjusted consumption, while the second line converts to quality-adjusted, tariff-inclusive, c.i.f. prices $\pi_{ij}^k = \tau_i^k (p_{ij}^k + T_i^k) / z_{ij}^k$, along with demands $d_{ij}^k$. The latter transformation relies on our assumption that prices and characteristics are chosen simultaneously, as well as our assumption that quality multiplies quantity in the utility function (but (5) does not rely on the CES form in (1)).

It is immediate that to maximize profits in (5), the firms must choose $z_{ij}^k$ to minimize $[g_{ij}(z_{ij}^k, w_i) + T_i^k] / z_{ij}^k$, which is interpreted as the minimizing the average cost per unit of quality inclusive of specific trade costs. The same optimality condition appears in Rodriguez (1979), who also assumes that quantity multiplies quality in the utility function. Differentiating this

4 Verhoogen (2008) further distinguishes between skilled production and skilled nonproduction labor.
objective w.r.t. \( z_{ij}^k \), we obtain the first-order condition:

\[
\frac{[g_{ij}(z_{ij}^k, w_i) + T_{ij}^k]}{z_{ij}^k} = \frac{\partial g_{ij}(z_{ij}^k, w_i)}{\partial z_{ij}^k}.
\]  

(6)

so that the average cost equals the marginal cost when average costs are minimized. The second-order condition for this cost-minimization problem is that \( \partial^2 g_{ij} / \partial (z_{ij}^k)^2 > 0 \), so there must be increasing marginal costs of improving quality. An increase in the distance to the destination market raises \( T_{ij}^k \), so to satisfy (6) firms will choose a higher quality \( z_{ij}^k \), as readily shown from \( \partial^2 g_i / \partial (z_{ij}^k)^2 > 0 \). This is the well-known “Washington apples” effect, whereby higher quality goods are sent to more distant markets.

Making use of the Cobb-Douglas production function for quality in (3), and associated cost function in (4), the second-order conditions are satisfied if and only if \( 0 < \theta < 1 \), which we have already assumed. The first-order condition (6) can be simplified as:

\[
\ln z_{ij}^k = \theta \left[ \ln T_{ij}^k - \ln(w_i / \varphi_{ij}) + \ln(\theta / (1 - \theta)) \right].
\]  

(7)

Conveniently, the Cobb-Douglas production function and specific trade costs give us a log-linear form for the optimal quality choice. We see that more distant markets, with higher transport costs \( T_{ij}^k \), will have higher quality, but that log quality is only a fraction \( \theta < 1 \) of the log transport costs. This parameter is the factor of proportionality that we referred to in section 1 and which we will estimate. In addition, higher firm productivity \( \varphi_{ij} \) leads to lower effective wages \( (w_i / \varphi_{ij}) \), and also leads to higher quality. Finally, substituting (7) into the cost function (4), we immediately obtain \( g_{ij}(z_{ij}^k, w_i) = [\theta / (1 - \theta)]T_{ij}^k \). Thus, the marginal costs of production are proportional to the specific trade costs, which we will use repeatedly.
Now suppose that demand $d_{ij}^k$ arises from the CES utility function in (1). Solving (3) for the optimal choice of the quality-adjusted price $q_{ij}^k$, we obtain the familiar markup:

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

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

$$\ln p_{ij}^k = \ln T_i^k + \ln \left[ \frac{1}{1 - \theta} \left( \frac{\sigma}{\sigma - 1} \right) - 1 \right] \equiv \ln \bar{p}_i^k, \quad (8a)$$

$$\ln P_{ij}^k = \ln r_i^k + \ln T_i^k + \ln \left[ \frac{1}{1 - \theta} \left( \frac{\sigma}{\sigma - 1} \right) \right] \equiv \ln \bar{P}_i^k. \quad (8b)$$

Thus, both the f.o.b. and c.i.f. prices vary across destination markets $k$ in direct proportion to the specific transport costs to each market, and are independent of the productivity of the firm $j$, as indicated by the notation $\ln \bar{p}_i^k$ and $\ln \bar{P}_i^k$. This result is obtained because more efficient firms sell higher quality goods, leading to constant prices to each destination market.

Combining (7) and (8) we obtain:

$$\ln z_{ij}^k = \theta \left[ \ln p_{ij}^k - \ln(w_i / \varphi_{ij}) \right] + \kappa_1, \quad (9)$$

where $\kappa_1$ is a parameter depending on $\theta$ and $\sigma$. Thus, quality $z_{ij}^k$ depends on the ratio of the f.o.b. price $p_{ij}^k$ to the productivity-adjusted wages $(w_i / \varphi_{ij})$ of the exporting firm. It follows that the quality-adjusted price $\pi_{ij}^k = P_{ij}^k / z_{ij}^k$ is:

$$\ln \pi_{ij}^k = \ln P_{ij}^k - \theta \left[ \ln p_{ij}^k - \ln \left( w_i / \varphi_{ij} \right) \right] - \kappa_1.$$
Since from (8) the c.i.f. and f.o.b. prices do not differ across firms selling to each destination market, then the quality-adjusted price is decreasing in the productivity \( \phi_{ij} \) of the exporter, as in the original Melitz (2003) model.

3. Aggregation and Demand

In the equations above we explicitly distinguish firms \( j \) in each country \( i \), but in our data we will not have firm-level information for every country. Accordingly, we need to aggregate to the product level. We form the CES average of the quality-adjusted prices:

\[
\bar{\pi}_i^k \equiv \left( \frac{1}{N_i^k} \sum_{j=1}^{N_i^k} (\pi_{ij}^k)^{1-\sigma} \right)^{1/(1-\sigma)}. \tag{10}
\]

Since the c.i.f. and f.o.b. prices are constant across firms \( j \) selling to country \( k \), from (8), then this price equals, up to a constant:

\[
\ln \bar{\pi}_i^k = \ln \bar{P}_i^k - \theta \left[ \ln \bar{p}_i^k - \ln \left( w_i / \bar{\phi}_i \right) \right], \tag{11}
\]

where the final term above is the average productivity of exporting country \( i \):

\[
\bar{\phi}_i \equiv \left( \frac{1}{N_i^k} \sum_{j=1}^{N_i^k} \phi_{ij}^{\theta(1-\sigma)} \right)^{1/\theta(1-\sigma)}.
\]

Notice that this expression for average productivity should actually depend on the destination country \( k \), since it is averaged over the number of firms \( N_i^k \) selling from \( i \) to \( k \). That is, our model includes a selection effect, whereby productivity and therefore quality can differ for each destination market depending on the set of firms selling there. But we will have no way in our data to measure such destination-specific productivities, so we omit the superscript \( k \) on \( \bar{\phi}_i \). This
is more than just a notational matter, and indicates that we are ignoring the selection effect on quality stressed by Baldwin and Harrigan (2010, section III), for example.\(^5\)

Because we have aggregated over firms, for convenience we now let the subscript \(j\) denote another country, and also add a time subscript \(t\). Then for the CES utility function in (1), the share of expenditure in country \(k\) spent on varieties from country \(i\), denoted by \(s^k_{it}\), relative to the share spent on varieties from country \(j\), is:

\[
\ln s^k_{it} - \ln s^k_{jt} = - (\sigma - 1) \left( \ln \pi^k_{it} - \ln \pi^k_{jt} \right) + \ln N^k_{it} - \ln N^k_{jt} + \sigma (\ln a^k_{it} - \ln a^k_{jt}),
\]

where \(a^k_{it}\) reflects the taste parameters introduced in (1), while \(N^k_{it}\) and \(N^k_{jt}\) are the number of firms – or product varieties – exported from country \(i\) and \(j\) to country \(k\). The intuition for (12) is that if there are more firms/product varieties selling from country \(i\) to \(k\), or a taste preference for the products of country \(i\), then the share of demand \(s^k_{it}\) will be higher. The presence of these product variety terms plagues all attempts to measure quality, because either greater variety or higher quality (leading to lower quality-adjusted prices) will raise demand. This problem is dealt with in different ways by Hallak and Schott (2011), Hummels and Klenow (2005), and Khandelwal (2010): the latter author, for example, uses exporting country population to measure \(N^k_{it}\). We will suppose instead that variety and the taste parameter depend on country fixed effects, distance, and tariffs, in a gravity-type equation:

\[
\ln N^k_{it} + \alpha \ln a^k_{it} = \alpha_i + \alpha^k + \beta_1 \text{dist}^k_i + \beta_2 \ln \tau^k_{it} + \epsilon^k_{it}.
\]

\(^5\) That is, while Baldwin and Harrigan (2010, section III) do not have firms endogenously choosing quality, they still obtain a “Washington applies” effect because only the highest productivity firms – which also have high quality by assumption – ship to the furthest markets. Such a selection effect on quality would also hold in our model, though we do not make use of it. Harrigan and Shlychkov (2010) further argue that for U.S. exporters this selection effect is the only factor leading to quality differences across destination markets; but different results are obtained for Portuguese exporters by Bustos and Silva (2010).
Substituting (11) and (13) into the demand equation (12), we obtain:

\[
\ln s^k_{it} - \ln s^k_{jt} = -(\sigma - 1) \left\{ \left( \ln \tilde{P}^k_{it} - \ln \tilde{P}^k_{jt} \right) - \theta \left( \ln \frac{\tilde{P}^k_{it}}{w_{it}} / \tilde{\phi}_{it} - \ln \frac{\tilde{P}^k_{jt}}{w_{jt}} / \tilde{\phi}_{jt} \right) \right\} + \alpha_i - \alpha_j + \beta_1 (\text{dist}^k_i - \text{dist}^k_j) + \beta_2 (\ln \tau^k_{it} - \tau^k_{jt}) + \epsilon_{it}^k - \epsilon_{jt}^k. 
\]

In this demand equation, the c.i.f. prices \( \tilde{P}^k_{it} \) enter with a negative coefficient, but the f.o.b. prices relative to wages \( \frac{\tilde{P}^k_{it}}{w_{it}} / \tilde{\phi}_{it} \) enter with a positive coefficient. This sign pattern arises because the f.o.b. prices relative to wages are capturing quality. The empirical challenge will be to obtain the expected signs can be obtained on these two prices, while also controlling for the endogeneity of shares and prices.

4. Non-homothetic Demand

Recent literature including Bekkers et al (2010), Choi et al (2009), Fajgelbaum et al (2009), and Simonovska (2011) analyze models of international trade and quality where non-homothetic demand plays a central role. We have ignored this aspect of demand thus far, and in this section make use of results from Deaton and Muellbauer (1980a,b) to show how the non-homothetic demand affects our estimating equation (14).

Start with the CES utility function (1), and write the taste parameters \( a^k_i \) as just \( a_i \). Then using the quality-adjusted prices, the expenditure needed to obtain utility of one is,

\[
e^k(a, \pi^k) = \left[ \sum_{i=1}^{N^k_i} a_i^\sigma (\pi^k_i)^{-\sigma(\sigma - 1)} \right]^{-1/(\sigma - 1)}, \quad \sigma > 1.
\]
Define a function \( e^k(b, \pi^k) \) analogously, but with taste parameters \( 0 \leq b < a \). Deaton and Muellbauer (1980a, pp. 154-158) describe a general class of expenditure functions known at \textit{price independent generalized linear} (PIGL) defined by:

\[
E^k(u^k, \pi^k) = \left[ e^k(a, \pi^k)^\alpha (1 - u^k) + e^k(b, \pi^k)^\alpha u^k \right]^{1/\alpha},
\]

where \( \alpha \) is a scalar and \( u^k \) is the utility level of the representative consumer in country \( k \).\(^6\) This is a valid expenditure function provided that \( \partial E^k / \partial u^k > 0 \), which holds from our assumption that \( b < a \) so that \( e^k(b, \pi^k) > e^k(a, \pi^k) \). Deaton and Muellbauer show that (15) allows for exact aggregation of consumers within a country, so that the expenditure of the representative consumer depends on the distribution of income.\(^7\) We will instead start with a representative consumer in each country, and show what (15) implies for aggregate demand.

Let us consider the special case where \( \alpha = -(\sigma - 1) \). Then differentiating the log of (15) to obtain the expenditure shares, we have:

\[
s^k_i = \frac{\partial \ln E^k(u^k, \pi^k)}{\partial \ln \pi^k_i} = \frac{a^k_i (\pi^k_i)^{-(\sigma - 1)}}{\sum_{i=1}^{N^k_k} a^k_i (\pi^k_i)^{-(\sigma - 1)}}, \text{ where } a^k_i \equiv \left[ a^\sigma_i (1 - u^k) + b^\sigma_i u^k \right].
\]

Thus, we find that the shares take the standard CES form with elasticity of substitution \( \sigma \), but that the taste parameters \( a^k_i \) defined in (16) are declining in the utility level of country \( k \). The utility of the representative consumer depends on the distribution of income within the country.

\(^6\) Without loss of generality, we can normalize utility so that \( 0 \leq u^k \leq 1 \), as discussed in Deaton and Muellbauer (1980b, Appendix). They define the PIGL class (17) for any increasing and linearly homogeneous functions \( e^k(a, \pi^k) \) and \( e^k(h, \pi^k) \), simply denoted by \( a(\pi^k) \) and \( b(\pi^k) \), not restricted to CES functions.

\(^7\) Specifically, if \( y^h \) denotes the expenditure of persons \( h \) within the country, they show that market demand is equivalently obtained from a representative consumer with expenditure \( Y = \left[ \sum_{h} y^h \right]^{-1/\alpha} / \sum_{h} y^h \). The utility of the representative consumer is then obtained by solving \( Y = E^k(u^k, \pi^k) \) for \( u^k \).
(see note 7), and for simplicity, we could treat this as a decreasing function of per-capita income $Y^k$. Then we could model the taste parameters as:

$$\ln a_i^k = \ln a_i^0 + \beta_i \ln Y^k,$$

where $\beta_i < 0$ depends on the spread between $a_i$ and $b_i$. \hfill (17)

Returning to the model of the previous section, all of our prior steps go through, except that with the taste parameters modeled as above, then it would be appropriate to add the term $\beta_i \ln Y^k$ onto (13), to reflect the taste parameter in country $k$ for the products of country $i$. When expressing demand relative to country $j$, as in (14), then the term $(\beta_i - \beta_j) \ln Y^k$ should be added, to reflect the difference in demand between the products of countries $i$ and $j$. In this way, we see that there is a natural role of non-homothetic demand in our system, and we will experiment with including this extra term in our robustness exercise.

Our analysis in this section can be generalized in a number of directions, one of which would be to allow for different elasticities of substitution in the functions $e^k(a, \pi^k)$ and $e^k(b, \pi^k)$. The empirical results of Broda and Romalis (2009) suggests that higher-utility consumers might have lower elasticities of substitution, so that $\sigma_b < \sigma_a$. An assumption of this type is also used by Fajgelbaum et al (2009) in the context of a discrete-choice model. Empirically implementing such a generalization is left for future research.

5. Estimation

Our goal is to estimate the equation (14) to obtain estimates of $\theta$ and $\sigma$, while recognizing that the shares and prices appearing there are endogenous. To control for this endogeneity we will modify the GMM methodology introduced by Feenstra (1994). That methodology exploits
the moment condition that the error in demand and supply are uncorrelated. That assumption
could be violated when quality is present, however, since a change in quality could act as shift to
both supply and demand. To address this concern, we need to develop the supply side of our
model in more detail.

The f.o.b. prices are shown in (8a), depending on the specific transport costs and a
markup. We shall assume that the specific transport costs depend on distance and a measure of
the aggregate quantity \( d^k_{it} \equiv Y^k_{it} s^k_{it} / \pi^k_{it} \) exported from country \( i \) to \( k \):

\[
\ln T^k_{it} = \gamma_t + \gamma d^k_{it} + \omega \ln d^k_{it} + u^k_{it}.
\]  

(18)

We are including the quantity \( d^k_{it} \) exported to reflect possible congestion in shipping, but also so
that our model here nests that used in Feenstra (1994), who likewise assumed an upward sloping
supply curve. We also suppose that transport costs depend on a global time trend \( \gamma_t \), which can
reflect factor prices and productivity.\(^8\)

Combining this specification with (8) and (11), we solve for the quality-adjusted price as:

\[
\ln \pi^k_{it} = \ln \pi^k_{jt} + \gamma'_{r} + \gamma'_{dist^k_{it}} + \omega' \ln d^k_{it} + \theta \ln (w_{it} / \bar{\omega}_{it}) + (1 - \theta) u^k_{it} + \kappa_2,
\]

where \( \gamma'_{r} = \gamma_t (1 - \theta) \), \( \gamma' = \gamma (1 - \theta) \), \( \omega' = \omega (1 - \theta) \), and \( \kappa_2 \) depends on \( \theta \) and \( \sigma \). Differencing
with respect to source county \( j \), we obtain:

\[
\left( \ln \pi^k_{it} - \ln \pi^k_{jt} \right) = \omega' (\ln d^k_{it} - \ln d^k_{jt}) + (\ln \tau^k_{it} - \ln \tau^k_{jt}) + \gamma' (dist^k_{it} - dist^k_{jt}) + \theta [\ln (w_{it} / \bar{\omega}_{it}) - \ln (w_{jt} / \bar{\omega}_{jt})] + (1 - \theta) (u^k_{it} - u^k_{jt}).
\]  

(19)

\(^8\) Alternatively, we could assume that the specific transport costs depend on the productivity-adjusted wages of the exporter, \( (w_{it} / \bar{\omega}_{it}) \). In the Appendix, we briefly discuss how that affects our estimation.
Equations (14) and (19) are the same as the system in Feenstra (1994), except for three features: (i) the price is the quality-adjusted price; (ii) the presence of tariffs and wages in the right-hand side of (14) and (19); (iii) we do not express the system in first-differences over time, because we want to retain distance as a variable that is important for the choice of quality. As in Feenstra (1994), we simplify (19) by using the share to replace the quantity \( \frac{d_{1k}^{it}}{d_{kt}^{it}} \equiv E_{i}^{k} s_{it}^{k}/\pi_{it}^{k} \).

Expressing both equations with their errors and exogenous variables on the left, we can obtain (see the Appendix):

\[
(\varepsilon_{it}^{k} - \varepsilon_{jt}^{k}) + (\alpha_{i} - \alpha_{j}) + \beta_{1}(\text{dist}_{it}^{k} - \text{dist}_{jt}^{k}) + \beta_{2}(\ln \pi_{it}^{k} - \ln \pi_{jt}^{k})
\]
\[
= (\ln s_{it}^{k} - \ln s_{jt}^{k}) + (\sigma - 1)(\ln \pi_{it}^{k} - \ln \pi_{jt}^{k})
\]  
(20)

\[
(1 + \omega')(\delta_{it}^{k} - \delta_{jt}^{k}) + \gamma'(\text{dist}_{it}^{k} - \text{dist}_{jt}^{k}) + (\ln \pi_{it}^{k} - \ln \pi_{jt}^{k})
\]
\[
= (1 + \omega')\left(\ln \pi_{it}^{k} - \ln \pi_{jt}^{k}\right) - \omega'\left(\ln s_{it}^{k} - \ln s_{jt}^{k}\right) - \theta[\ln(w_{it}/\varphi_{it}) - \ln(w_{jt}/\varphi_{jt})]
\]  
(21)

where \( \delta_{it}^{k} \equiv \frac{(1 - \theta)}{(1 + \omega'\sigma)}u_{it}^{k} \). Multiplying these two equations and dividing by \( (1 + \omega')(\sigma - 1) \) gives a lengthy equation, reported in the Appendix, which has an error depending on the product \( (\varepsilon_{it}^{k}\delta_{it}^{k}) \) and variables that are the second moments and cross-moments of the data. This is the analogue to the demand and supply system in Feenstra (1994), extended here to endogenous quality choice. Feenstra (1994) assumed that the supply shocks are uncorrelated with the demand shocks. That assumption is unlikely to hold with unobserved quality, however, since a change in quality could shift both supply and demand. But in this paper, the errors \( \varepsilon_{it}^{k} \) and \( u_{it}^{k} \) (or \( \delta_{it}^{k} \)) refer to the residuals in demand (14) and supply (18) after taking into account quality. The assumption that \( \varepsilon_{it}^{k} \) and \( \delta_{it}^{k} \) are uncorrelated therefore seems much more acceptable.
6. Data

The primary dataset used is the United Nations’ Comtrade database. We obtain bilateral f.o.b. prices of traded goods by calculating the unit value of each bilateral transaction at the four-digit SITC industry level, as reported by the exporting country. By focusing on the exporters’ reports we ensure that these values are calculated prior to the inclusion of any costs of shipping the good. The bilateral c.i.f. prices are then calculated similarly using importers’ reports of the value of the good. Since this value includes the costs of shipping, we need only to add the value of any tariff on the good to produce a tariff-inclusive c.i.f. price. To do this we use tariff values associated with Most Favored Nation status obtained from TRAINS, which we have expanded upon using tariff schedules from the *International Customs Journal* and the texts of preferential trade agreements obtained from the World Trade Organization's website and other online sources.

In our estimation, we require country- and industry-specific wages for each year. These we construct by combining wage data from the International Labor Organization (ILO) with wages from the United Nations Industrial Development Organization (UNIDO). The ILO data was used by Freeman and Oostendorp (2000) to construct occupational wages for many countries; in contrast, we collect sectoral wages in manufacturing for many countries (Hong, 2006, chapter 3). However, even in this combined ILO and UNIDO dataset, over half of the possible year-country-industry wage values are missing. We therefore use the existing wage values to generate a new, and complete, wage series by regressing existing wages on country-year and industry-year fixed effects, and we then use the resulting coefficients to predict values for each cell. In some cases this procedure produces outlying values, in which case we drop these values and simply interpolate them from nearby wages.
We need productivity-adjusted skilled wages for each country. As a preliminary approach, we measure skilled wages as the highest observed industry wage for a country. We assume that productivity in the traded goods sector determines average wages, and therefore measure productivity as the simple average of industry wages. Our productivity-adjusted skilled wage is therefore in essence a skill-premium, calculated as the highest observed wage in a country divided by the average wage. In future work we will improve upon this measure of the skilled wage, allowing it to differ across sectors.

7. Estimation Results

Table 1 and Figures 1 and 2 summarize our regression results. The median sigma estimate is 9.1, and the median standard error of our sigma estimates is 0.13. We do not consider the mean sigma to be a useful statistic, driven as it is by very high estimates for highly substitutable goods. We instead report the mean estimated markup, at 13 percent (0.13). 1149 of the 1159 sigma estimates have admissible values (>1). Figure 1 summarizes the distribution of these estimates, where for the purposes of this figure only, estimates greater than 26 have been censored at 26. We do not adopt the grid-search algorithm used in Broda and Weinstein (2006) to replace these inadmissible values. Instead, we replace inadmissible estimates with neighboring estimates, such as the median admissible sigma for the corresponding SITC 3-digit level. Occasionally, we have to employ the median SITC 2-digit estimate.

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<th>$\theta$</th>
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Figure 1: Estimates of $\sigma$

![Figure 1: Estimates of $\sigma$](image1)

Figure 2: Estimates of $\theta$

![Figure 2: Estimates of $\theta$](image2)
Our median theta estimate is 0.60, with a median standard error of 0.002. Only 29 of our estimates lie outside the interval [0,1] and are therefore inadmissible, and for these we again substitute neighboring estimates. Figure 2 shows the distribution of our theta estimates.

Our sigma estimates are noticeably higher than those obtained by Broda and Weinstein (2006). Based on Table IV of their paper, we would expect to obtain a median elasticity at the SITC 4-digit level between 2.5 and 2.8. We instead get 8.9. We reconcile these differences in Table 2. It is not the different data source that is responsible for this difference - when we estimate our model on US imports only we obtain a median elasticity of 3.0 (first row of estimates in Table 2). We then extend our analysis to all bilateral trade, further raising the median sigma to 4.6. Since we have trade reports from both the exporting and the importing country we can drop "unreliable" observations which are most subject to measurement or reporting error and are likely to attenuate estimates of sigma. We rank all observations by the log-deviation between the reported unit values in the exporter's report and those in the importer's report, and drop 2.5 percent of observations from each tail. This raises our typical sigma to 5.4.

Estimation in levels rather than in differences raises our median estimate to 7.8. This could be due to two factors: (i) the attenuation bias from measurement error in the data is likely to be magnified by first-differencing; and (ii) sigma may be higher in the long-run than in the short-run, which will be partly captured by our levels estimation. Finally, explicitly modeling quality raises our median estimate to 8.9. Without this last step, quality improvements are falsely interpreted as price increases, biasing downwards estimates of sigma.

---

9 Ideally, to estimate both short-run and long-run elasticities we would model the dynamics of demand responses to price changes.
Table 2: Reconciling Our Estimates to Broda and Weinstein (2006)

<table>
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<tr>
<td>+ All Bilateral Trade</td>
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<td>+ Estimating in Levels</td>
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<tr>
<td>+ Modeling Quality</td>
<td>8.9</td>
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</table>

Table 3 and Figure 3 is a first attempt to check whether our quality estimates for each exporting country conform to expectations. For each 4-digit SITC product, we construct a relative price (relative to the median CIF price for that product for each year) and then a similar relative quality measure based on equation (9). We report these variables for 1984, 1996 and 2007 for the exporting countries for which we have the most observations. The data broadly conforms with our priors. Developed countries tend to export more expensive goods, and these goods are estimated to be of higher than average quality. The quality adjusted-price (unit value less quality), about which we have less strong priors, is less correlated with development, especially in more recent years. These relationships in 2007 can be more clearly seen in Figure 3, where the top value plots relative unit values against the exporting countries' GDP per capita at PPP, the middle panel plots estimated relative quality against per capita GDP, and the bottom panel plots the quality-adjusted price. Both relative unit values and quality are extremely correlated with development, but the quality-adjusted price measure is essentially uncorrelated.
A similar exercise for importing countries is performed in Table 4 and Figure 4. For large importing countries, import unit values, quality and quality-adjusted prices are moderately positively correlated with GDP per capita.

**Table 3: Export Unit Values and Quality**

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Figure 3: Relative Export Unit Values, Quality, and Quality Adjusted Prices in 2007

- **Unit Values**
- **Quality**
- **Quality-Adjusted Price**

Log GDP Per Capita (PPP) vs. Relative Value
Table 4: Import Unit Values and Quality

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Figure 4: Relative Import Unit Values, Quality, and Quality Adjusted Prices in 2007
Appendix:

The demand equation (14) can be re-written as (20). Substituting $d_{it}^k \equiv E_{it}^k s_{it}^k / \pi_{it}^k$ into the supply equation (19), we obtain:

$$
\left( \ln \pi_{it}^k - \ln \pi_{jt}^k \right) = \omega' \left( \ln \frac{E_{it}^k s_{it}^k}{\pi_{it}^k} + \ln \frac{E_{j}^k s_{jt}^k}{\pi_{jt}^k} \right) + (\ln \tau_{it}^k - \ln \tau_{jt}^k) + \gamma'(\text{dist}_{it}^k - \text{dist}_{jt}^k)
+ \rho' \left[ \ln \left( w_{it} / \tilde{\varphi}_{it} \right) - \ln \left( w_{jt} / \tilde{\varphi}_{jt} \right) \right] + (1 - \rho' \left) (u_{it}^k - u_{jt}^k)
$$

$$
= \omega' \left( \ln s_{it}^k - \ln s_{jt}^k \right) - \omega' \left( \ln \pi_{it}^k - \ln \pi_{jt}^k \right) + (\ln \tau_{it}^k - \ln \tau_{jt}^k) + \gamma'(\text{dist}_{it}^k - \text{dist}_{jt}^k)
+ \rho' \left[ \ln \left( w_{it} / \tilde{\varphi}_{it} \right) - \ln \left( w_{jt} / \tilde{\varphi}_{jt} \right) \right] + (1 - \rho' \left) (u_{it}^k - u_{jt}^k)
$$

where the last equality substitutes for the share from (14). It follows that:

$$
\left( \ln \pi_{it}^k - \ln \pi_{jt}^k \right) = (\alpha_{i} - \alpha_{j}) + \beta_{1} (\text{dist}_{it}^k - \text{dist}_{jt}^k) + \beta_{2} (\ln \tau_{it}^k - \ln \tau_{jt}^k) + \frac{\omega'}{1 + \omega' \sigma} (\varepsilon_{it}^k - \varepsilon_{jt}^k)
+ \frac{\theta}{1 + \omega' \sigma} \left[ \ln \left( w_{it} / \tilde{\varphi}_{it} \right) - \ln \left( w_{jt} / \tilde{\varphi}_{jt} \right) \right] + (\delta_{it}^k - \delta_{jt}^k)
$$

where $\alpha_{i} \equiv \frac{\omega'}{(1 + \omega' \sigma)} \alpha_{i}$, $\beta_{1} \equiv \frac{(\gamma' + \omega' \beta_{1})}{1 + \omega' \sigma}$, $\beta_{2} \equiv \frac{(1 + \omega' \beta_{2})}{1 + \omega' \sigma}$, and $\delta_{it}^k \equiv \frac{(1 - \theta)}{(1 + \omega' \sigma)} u_{it}^k$.

This is a reduced-form supply curve. Substituting for $(\varepsilon_{it}^k - \varepsilon_{jt}^k)$ from (14) leads to:

$$
\left( \ln \pi_{it}^k - \ln \pi_{jt}^k \right) = (\alpha_{i} - \alpha_{j}) + \beta_{1} (\text{dist}_{it}^k - \text{dist}_{jt}^k) + \beta_{2} (\ln \tau_{it}^k - \ln \tau_{jt}^k)
+ \frac{\omega'}{1 + \omega' \sigma} \left[ s_{it}^k - s_{jt}^k + (\sigma - 1) \left( \ln \pi_{it}^k - \ln \pi_{jt}^k \right) - (\alpha_{i} - \alpha_{j}) - \beta_{1} (\text{dist}_{it}^k - \text{dist}_{jt}^k) - \beta_{2} (\ln \tau_{it}^k - \tau_{jt}^k) \right]
+ \frac{\theta}{1 + \omega' \sigma} \left[ \ln \left( w_{it} / \tilde{\varphi}_{it} \right) - \ln \left( w_{jt} / \tilde{\varphi}_{jt} \right) \right] + (\delta_{it}^k - \delta_{jt}^k).
$$

Since $1 - \frac{\omega'(\sigma - 1)}{(1 + \omega' \sigma)} = \frac{1 + \omega'}{(1 + \omega' \sigma)}$, this equation can be simplified as (21), shown in the text.

Multiplying (20) and (21) and dividing by $(1 + \omega')(\sigma - 1)$, we obtain:
\[
\left( \ln \pi_{it}^k - \ln \pi_{jt}^k \right)^2 = \frac{\omega'}{(1 + \omega')(\sigma - 1)} \left( \ln s_{it}^k - \ln s_{jt}^k \right)^2 + \left( \frac{\omega'}{(1 + \omega')} - \frac{1}{\sigma - 1} \right) \left( \ln s_{it}^k - \ln s_{jt}^k \right) \left( \ln \pi_{it}^k - \ln \pi_{jt}^k \right) \\
+ \frac{\theta}{(1 + \omega')(\sigma - 1)} \left( \ln \frac{w_{it}^k}{\bar{w}_{it}}^k - \ln \frac{w_{jt}^k}{\bar{w}_{jt}}^k \right) \left( \ln \frac{s_{it}^k}{\bar{s}_{it}}^k - \ln \frac{s_{jt}^k}{\bar{s}_{jt}}^k \right) + \frac{\theta}{(1 + \omega')} \left( \ln \frac{w_{it}^k}{\bar{w}_{it}}^k - \ln \frac{w_{jt}^k}{\bar{w}_{jt}}^k \right) \left( \ln \pi_{it}^k - \ln \pi_{jt}^k \right) \\
+ (\alpha_i' - \alpha_j') \gamma'(\text{dist}_i^k - \text{dist}_j^k) + (\alpha_i' - \alpha_j')(\ln r_{it}^k - \ln r_{jt}^k) + \beta_1' \gamma'(\text{dist}_i^k - \text{dist}_j^k)^2 \\
+ \beta_2'(\ln r_{it}^k - \tau_{it}^k)^2 + (\beta_1' + \beta_2')'(\text{dist}_i^k - \text{dist}_j^k)(\ln r_{it}^k - \ln r_{jt}^k) + v_{it}^k,
\]

(A1)

where \( \alpha_i' \equiv \frac{\alpha_i}{(1 + \omega')(\sigma - 1)} \), \( \beta_1' \equiv \frac{\beta_1}{(1 + \omega')(\sigma - 1)} \), \( \beta_2' \equiv \frac{\beta_2}{(1 + \omega')(\sigma - 1)} \) and the error term is:

\[
v_{it}^k = \frac{(1 + \omega')(\sigma - 1)}{(1 + \omega')(\sigma - 1)} \left[ (\epsilon_{it}^k - \epsilon_{jt}^k) + (\alpha_i - \alpha_j) + \beta_1(\text{dist}_i^k - \text{dist}_j^k) + \beta_2(\ln r_{it}^k - \tau_{it}^k) \right] \\
+ \frac{(\epsilon_{it}^k - \epsilon_{jt}^k)}{(1 + \omega')(\sigma - 1)} [\gamma'(\text{dist}_i^k - \text{dist}_j^k) + (\ln r_{it}^k - \ln r_{jt}^k)].
\]

(A2)

Notice that the first row of (A1) has terms identical to those in Feenstra (1994), while the second row has interactions with the productivity-adjusted wages. In the estimation, we did not use the precise coefficients of the wage terms shown above (which equal functions of \( \theta \), \( \omega' \) and \( \sigma \)), since these coefficients are sensitive to the specification of the specific transport costs in (18) (see note 8). So those coefficients are unconstrained and the wage terms enter only as controls. The last two rows of (A1) have country fixed effects, distance and tariffs, which are further controls. These variables also enter the error term in (A2), but because we treat them as exogenous, we can assume that they are uncorrelated with the supply shocks (\( \delta_{it}^k - \delta_{jt}^k \)). We assume that the supply shocks are uncorrelated with the demand shocks, so that \( Ev_{it}^k = 0 \). This is the moment condition we use to estimate (A1).

Next, we substitute for the quality-adjusted prices \( \ln \pi_{it}^k = \ln P_{it}^k - \theta \ln \left[ \frac{w_{it}^k}{\bar{w}_{it}} \right] \).

Denote the productivity adjusted wages by \( \bar{\pi}_{it} \equiv \frac{w_{it}^k}{\bar{w}_{it}} \). Using these in (A1) we obtain:
\[
\left(\ln \frac{P_{it}^k}{P_{jt}^k} - \ln \frac{P_{jt}^k}{P_{it}^k}\right)^2 = 2\theta \left(\ln \frac{P_{it}^k}{P_{jt}^k} - \ln \frac{P_{jt}^k}{P_{it}^k}\right) - \theta^2 \left(\ln \frac{P_{it}^k}{P_{jt}^k} - \ln \frac{P_{jt}^k}{P_{it}^k}\right)^2 \\
+ \frac{\omega'}{(1 + \omega')(\sigma - 1)} \left(\ln s_{it}^k - \ln s_{jt}^k\right)^2 + \frac{\omega'}{(1 + \omega') \sigma - 1} \left(\ln s_{it}^k - \ln s_{jt}^k\right) \left(\ln \frac{P_{it}^k}{P_{jt}^k} - \ln \frac{P_{jt}^k}{P_{it}^k}\right) \\
- \theta \left(\ln \frac{P_{it}^k}{P_{jt}^k} - \ln \frac{P_{jt}^k}{P_{it}^k}\right) \left(\ln s_{it}^k - \ln s_{jt}^k\right) \left(\ln \frac{P_{it}^k}{P_{jt}^k} - \ln \frac{P_{jt}^k}{P_{it}^k}\right) \\
+ \frac{\theta}{(1 + \omega') \left(\ln \frac{P_{it}^k}{P_{jt}^k} - \ln \frac{P_{jt}^k}{P_{it}^k}\right) - \theta^2 \left(\ln \frac{P_{it}^k}{P_{jt}^k} - \ln \frac{P_{jt}^k}{P_{it}^k}\right) \left(\ln \frac{P_{it}^k}{P_{jt}^k} - \ln \frac{P_{jt}^k}{P_{it}^k}\right)} \\
+ (\alpha_i - \alpha_j)^2 (\text{dist}^k_i - \text{dist}^k_j) + (\alpha_i - \alpha_j)^2 (\ln \tau_{it}^k - \ln \tau_{jt}^k) + \beta_1' \gamma' (\text{dist}^k_i - \text{dist}^k_j)^2 \\
+ \beta_2' (\ln \tau_{it}^k - \tau_{jt}^k)^2 + (\beta_1' + \beta_2' \gamma') (\text{dist}^k_i - \text{dist}^k_j) (\ln \tau_{it}^k - \ln \tau_{jt}^k) + v_{it}^k. \\
\]

(A3)

For estimation, we average the variables in (A3) across source countries \(i\) and destination countries \(k\). This eliminates the time subscript in (A3), and gives a cross-country regression that can be estimated with nonlinear least squares (NLS). A final challenge is to incorporate the country fixed effects \((\alpha_i - \alpha_j)\) interacted with distance and tariffs as appear near the end of (A3). The list of countries varies by product, so it is difficult to incorporate these interactions directly into the NLS estimation. Instead, we first regress all other variables in (A3) on those interaction terms, and then estimate (A3) using the residuals obtained from these preliminary regressions.
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