Product Variety, Trade Costs and the Standard of Living Across Countries*

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Abstract

The goal of the Penn World Table (PWT) is to measure the standard of living across countries. While those calculations have been rationalized by appeal to multilateral index number methods, there is much less justification based on economic theory. We extend recent results in international trade theory, which has shown how to measure welfare differences across equilibria within a country, to also measure welfare differences between countries, incorporating product variety as well as domestic and foreign trade costs. For 19 countries we measure product variety using barcode data, and for the remaining 24 countries we must rely on the count of firms. For those countries with barcode data, we find that the consumption price index in PWT is a reasonable approximation to the model-based cost of living. For the other countries in our sample where we use the count of firms to measure variety, we find that product variety gives the United States a lower model-based cost of living relative to those countries than PWT.

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1. Introduction

The goal of the Penn World Table (PWT) is to measure the standard of living across countries. While those calculations have been rationalized by appeal to multilateral index number methods (Feenstra, Inklaar and Timmer, 2015), there is much less justification based on economic theory. We extend recent results in international trade theory, due to Arkolakis, Costinot and Rodríguez-Clare (ACR, 2012), which has shown how to measure welfare differences across equilibria within a country. We extend those results to also measure welfare differences between countries. We implement these theoretical results to measure the cost of living across 43 countries, and compare the results to those obtained from PWT.

The starting point for comparing equilibria within a country as in ACR (2012), is to focus on difference in foreign trade costs, by which we mean all foreign factors that can lead to differences in the amount of trade, including costs incurred at the border. In order to compare equilibria between countries we also need to take into account the domestic costs of doing trade, by which we mean local transportation charges, and wholesaling and retailing margins. While there are a number of notable studies examining such domestic costs, they have not been incorporated into the theoretical foundation of trade theory. It is significant that ACR treated the domestic costs of doing trade as fixed in their analysis of the gains from trade, meaning that within- or between-country differences in these costs are not examined.

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1 An exception is Neary (2004) has proposed a method to measure real consumption or welfare across countries that requires estimating the expenditure function across countries. The Neary approach was further developed by Feenstra, Ma and Rao (2009) and empirically implemented for data covering 124 countries.
2 Our theoretical analysis could also be extended to include differences in excise taxes across countries, which are incorporated into our empirical analysis through the prices of goods.
3 Anderson and van Wincoop (2004) include domestic trade costs in their survey; see also Anderson et al (2019). Atkin and Donaldson (2015) show how internal costs of transport prevent consumers in Ethiopia and Nigeria from benefiting from falling international trade barriers. There are many recent studies of how internal trade costs affects the geographic location of production, with a review by Redding and Rossi-Hansberg (2017).
Literature on the determinants of real GDP, however, finds that the cross-country differences in productivity of the wholesale and retail sectors are of primary importance (Timmer et al. 2010). In this paper, we extend the analysis of ACR to allow for differences in the domestic costs of trade, as well as in country size, productivity and fixed costs, within and between countries. Product variety responds endogenously to all these variables, in a “partial” scale effect as in Arkolakis (2010). Our goal is to determine the extent to which product variety, as well as domestic and foreign trade costs, can explain the cost of living across countries.

We begin in section 2 by re-examining the theory behind ACR while allowing the domestic costs of trade to vary as well as foreign costs. For simplicity, we focus on only one model underlying the ACR framework – that of Melitz (2003) and Chaney (2008) – though we would expect that similar results would hold in other models, too. We re-derive the expression for the welfare change when domestic costs vary between countries, and we find that the share of spending on domestic goods is no longer a sufficient statistic for the welfare change. Instead, the welfare change between two equilibria depends on: (a) the share of expenditure on domestic goods (reflecting in part foreign trade costs); (b) domestic trade costs; (c) the extent of product variety available to consumers. Implementing the theoretical expression of the cost of living between countries required data on all these variables.

The implications of our model for the gravity equation in trade are examined in section 3. Following Eaton and Kortum (2002) and Simonovska and Waugh (2014a,b), we use cross-country data from the International Comparisons Project (ICP) to measure prices. In the ICP, the country of origin for these products is unknown. Accordingly, Eaton and Kortum (2002) used the (second) largest price difference across countries to infer trade costs and then estimate the gravity equation. Simonovska and Waugh (2014a,b) extend that analysis to make use of the
entire distribution of price differences across countries to infer trade costs and estimate the
gravity equation. We rely on much the same technique as Simonovska and Waugh, though
extending it to multiple sectors.  

In section 4, we describe the data that we shall use to determine the foreign and
domestic trade costs along with product variety. For domestically-produced variety, we use
the count of firms across countries from the ORBIS global dataset. The count of firms is a
crude measure of product variety, so we supplement it with newly collected data from the
Billion Price Project (BPP, see Cavallo, et al., 2018) that provides a count of barcodes across
countries in the food and the electronics sectors in major retailers. The country of origin is
also unknown for the barcode data from BPP, so we have collected such information from
the product packages in a sample of 19 countries, and use that information to infer
domestically-produced variety.

In our results in section 5, we find that if we only consider domestic and foreign trade
costs, the many countries have lower model-based costs-of-living relative to the United States
than indicated by the consumption price index in PWT. But that result is artificial, since it
follows from the United States – as a large economy – having relatively little trade. When we
also incorporate product variety differences across countries, then for the sample 19 countries
with barcode data, PWT is a reasonable approximation to the theoretical cost of living. For the
other countries in our sample where we must rely on the count of firms to measure variety, we
find that product variety gives the United States a lower model-based cost of living relative to
those countries than in PWT. Section 6 concludes and additional results are in the Appendix.

4 Giri, Yi and Yilmazkudayz (2020) also estimate a sectoral gravity equation following Simonovska and Waugh
(2014a,b). They find that the difference in the gains from trade using heterogeneous elasticities relative to using an
aggregate elasticity are somewhat smaller than found by Ossa (2015).
2. Modeling Domestic Trade Costs

We introduce domestic costs of trade into the model of Melitz (2003) and Chaney (2008). These are modeled as iceberg costs, meaning that \( \tau_d \geq 1 \) units must be sent from the domestic firms in order for one unit to reach the consumer. Like the foreign trade costs in Melitz and Chaney, these iceberg costs use up resources. That is a plausible description of resources used in domestic transportation and in the wholesale and retail sectors, which we rely on to measure \( \tau_d \).

We consider two equilibria that can experience a domestic shock, by which we mean a change in domestic iceberg costs \( \tau_d \), or a change in domestic fixed costs or in the population. In addition, the two equilibria can experience a foreign shock, defined as changes in iceberg costs of international trade and in the foreign values of local iceberg costs, fixed costs and population. This definition of the foreign shock follows ACR, but the domestic shock is new. By introducing it here, we are able to compare equilibria within or between countries with differing values of these shock variables.

The rest of the model is familiar from Melitz and Chaney, so our exposition will be brief. We assume a CES utility function with elasticity of substitution \( \sigma > 1 \). With trade, the CES price index for the home consumer is defined over domestic and foreign goods as:

\[
P = \left[ M_d \int_{\varphi_d}^{\infty} p_d(\varphi)^{1-\sigma} \frac{g(\varphi)}{[1-G(\varphi_d)]} d\varphi + M_x^* \int_{\varphi_x^*}^{\infty} p_x^*(\varphi)^{1-\sigma} \frac{g(\varphi)}{[1-G(\varphi_x^*)]} d\varphi \right]^{1/(1-\sigma)},
\]

where the first integral reflects the consumer prices of the mass \( M_d \) of domestic firms with productivity \( \varphi \geq \varphi_d \), and the second integral reflects the import prices \( p_x^*(\varphi) \) of the mass \( M_x^* \) of foreign firms with productivity \( \varphi \geq \varphi_x^* \). The density of home and foreign productivities is Pareto distributed with \( G(\varphi) = 1 - (\varphi / A)^{-\theta} \) for \( \varphi \geq A \), and \( \theta > (\sigma - 1) > 1 \). Note that the mean
productivity is \( \int_A^\infty \phi g(\phi) d\phi = \left( \frac{1}{\sigma - 1} \right) A \). It follows that the lower-bound for productivity, \( A \), is also proportional to the mean productivity.

To obtain the share of expenditure on domestic goods, which we denote by \( \lambda_d \), we take the ratio of the first term on the right of (1) to the whole term in brackets,

\[
\lambda_d = \frac{M_d \int_{\varphi_d}^{\infty} p_d(\varphi)^{1-\sigma} \frac{g(\varphi)}{[1-G(\varphi_d)]} d\varphi}{P^{(1-\sigma)}}. \tag{2}
\]

This expression can be simplified by solving for domestic prices. The marginal costs of production at home are \( w/\sigma \), so that with the usual CES markup the consumer price is

\[
p_d(\varphi) = \frac{\sigma}{(\sigma - 1)} \left( \tau_d w/\varphi \right), \quad \text{where } \tau_d \geq 1 \text{ are the domestic iceberg costs.}
\]

Substituting these prices into the numerator of (2), we obtain:

\[
M_d \int_{\varphi_d}^{\infty} \left( \frac{\sigma}{(\sigma - 1)} \right)^{1-\sigma} \left( \frac{w\tau_d}{\varphi} \right)^{1-\sigma} \frac{g(\varphi)}{[1-G(\varphi_d)]} d\varphi = M_d \left( \frac{\theta}{(\sigma - \sigma + 1)} \right) \left( \frac{\sigma}{\sigma - 1} \right)^{1-\sigma} \left( \frac{w\tau_d}{\varphi_d} \right)^{1-\sigma}. \tag{3}
\]

Combining the above results, the share of expenditure on domestic goods is:

\[
\lambda_d = \left( \frac{\theta}{\sigma - 1} \right) \left( \frac{w\tau_d}{\varphi_d} \right)^{1-\sigma} M_d P^{1-\sigma}. \tag{4}
\]

Now consider two equilibria, with the second equilibrium denoted by a prime. The ratio of CES price indexes is denoted by \( P'/P \), and it measures the change in the cost of living between the two equilibria, i.e. the inverse of the change in welfare. Then the ratio \( P'/P \) is readily obtained by re-arranging (4) as:

\[
\frac{P'}{P} = \left[ (M_d')^{1-\sigma} \frac{w\tau_d'}{\varphi_d'} \right] \left( \frac{\lambda_d'}{\lambda_d} \right)^{\sigma-1}. \tag{5}
\]
This expression can be interpreted as an exact price index according to Proposition 1 of Feenstra (1994). Specifically, we treat the domestic goods as the “common” goods over the two equilibria, and we treat all imported products as new or disappearing, with $\lambda_d$ and $\lambda'_d$ denoting the share of expenditure on domestic goods in the two equilibria. The first bracketed term on the right of (5) is the ratio of the CES price index of domestic goods, where the variety term $M_d^{-\sigma}$ (and likewise in the prime equilibrium) is the welfare effect of any change in the mass of domestic varieties, while $w\tau_d / \varphi_d$ is proportional to the average price of these domestic varieties (using equation (3)). The second term on the right of (5) is the ratio of the share spending on domestic goods, or one minus the share of spending on new imported varieties. This term reflects that potential gain due to new import varieties, which would result in $\lambda'_d < \lambda_d$ and lower the price index in (5), or the welfare loss from disappearing import varieties, which would result in $\lambda'_d > \lambda_d$ and raise the price index.

With CES demand using the consumer price $p_d(\varphi) = [\sigma/(\sigma - 1)] (w\tau_d / \varphi)$, and total home expenditure of $X$, the home demand for a firm with productivity $\varphi$ is:

$$y_d(\varphi) = \frac{X}{P^{1-\sigma}} \left[ \frac{w\tau_d\sigma}{\varphi(\sigma - 1)} \right]^{-\sigma}.$$  \hfill (6)

Multiplying by price minus variable cost, $p_d(\varphi) - (w\tau_d / \varphi) = [1/(\sigma - 1)] (w\tau_d / \varphi)$, profits in the home market are,

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5 Proposition 1 of Feenstra (1994) measures the price index of the “common” good using a Sato-Vartia price index. It is equivalent to use the ratio of the CES price index of domestic goods, where this CES domestic price index is defined as expression (3) raised to the power $1/(1 - \sigma)$.
\[ \pi_d(\varphi) = \frac{X}{\sigma} \left( \frac{w_r_d}{P(\sigma-1)} \right)^{1-\sigma} \varphi^{\sigma-1} - w_f_d, \]

where \( f_d \) are the fixed costs in the domestic market. It follows that the zero-cutoff-profit (ZCP) condition in the domestic market is,

\[ \pi_d(\varphi_d) = B_d \varphi_d^{\sigma-1} - w_f_d = 0 \quad \Rightarrow \quad \varphi_d^{\sigma-1} = \frac{w_f_d}{B_d} = \frac{w_f_d \sigma^\sigma}{X} \left( \frac{w_r_d}{P(\sigma-1)} \right)^{\sigma-1}. \quad (7) \]

We do not describe the rest of the equilibrium conditions here, but they are outlined in the Appendix. An analogous ZCP condition holds for home exporters, too, as well as for domestic sales in the foreign country and for export sales from abroad. We also describe the full employment condition at home, but we do not insist on trade balance, so the model in this section can be thought of as a single sector in a larger economy.\(^6\)

We consider two equilibria that can experience both a domestic and a foreign shock, meaning different values of the iceberg costs, fixed costs, and population in both countries. In this way, we can examine the impact on one country from a change in the foreign variables (following ACR), or we can compare the equilibria between two countries that have differing values for the home and foreign shock variables. The equilibrium conditions that we have described above are enough to obtain results on the sources of welfare differences between the two equilibria. We take the ratio of the ZCP productivity in (7) between the two equilibria, and substitute that into (4) to obtain,

\[ \left( \frac{M_d' / \lambda_d'}{M_d / \lambda_d} \right) = \left( \frac{X' / w_f_d'}{X / w_f_d} \right). \quad (8) \]

\(^6\) In specifying the full employment condition, we assume that the fixed costs of entry, domestic production and exporting are all paid using home labor.
The expression on the right of (8) is the inverse of the domestic variety and share terms appearing in (5). Expression (8) therefore measures the welfare gain between the two equilibria due to any expansion of import varieties, resulting in \( \lambda'_d < \lambda_d \), relative to the welfare loss due to any reduction in domestic varieties, so that \( M'_d < M_d \). Comparing two equilibria with the same values of expenditure \( X \) relative to fixed costs \( wf_d \), then \textit{there will be no welfare difference due to variety}: equation (8) shows that \( M'_d / \lambda'_d = M_d / \lambda_d \) when \( X'/wf'_d = X/wf_d \), which means that there is no difference due to variety in the relative price indexes in (5). That is the case in the one-sector Melitz-Chaney model in ACR (2012), for example, where trade balance ensures that expenditure equals labor income, \( X = wL \), and changes in \( L \) and \( f_d \) are ruled out, so that

\[
X'/wf'_d = w'L/wf_d = L/f_d = X/wf_d.
\]

It follows from (8) that \( M'_d / \lambda'_d = M_d / \lambda_d \) so there is no welfare difference due to change in overall product variety, including both domestic and import variety as measured by the ratio \( M_d / \lambda_d \). By allowing for domestic shocks, this ratio will differ between countries and we are thus permitting welfare gains from overall variety.

Expression (8) shows us that the cost of living in (5) is determined by overall product variety and by the ZCP productivity levels appearing there. As mentioned, we assume a Pareto distribution for firm productivity given by \( G(\varphi) = 1 - (\varphi / A)^{-\theta} \), \( \varphi \geq A \). The mass of operating domestic firms equals \( M_d = M_e[1 - G(\varphi_d)] = M_e(\varphi_d / A)^{-\theta} \) where \( M_e \) is the mass of entering firms. Then using this in (8), we obtain,

\[
\frac{\lambda'_d}{\lambda_d} = \left( \frac{X'/wf'_d}{X/wf_d} \right)^{-1} \left( \frac{M'_e}{M_e} \right) \left( \frac{\varphi'_d / A'}{\varphi_d / A} \right)^{-\theta} = \left( \frac{X'/w'L'}{X/wL} \right)^{-1} \left( \frac{f'_d / f'_e}{f_d / f_e} \right) \left( \frac{\varphi'_d / A'}{\varphi_d / A} \right)^{-\theta}, \tag{9}
\]
where the final equality uses the fact that the mass of entering firms is inversely proportional to the effective population size, \( M_e \propto L / f_e \), as shown in the Appendix, where \( f_e \) are the sunk costs of obtaining a productivity draw. The ratio of fixed to sunk costs that appears in (9) is difficult to identify from the data, so we simplify our model by assuming that it is the same across countries. We state this assumption formally by adding a country superscript \( i = 1, \ldots, C \):

**Assumption 1:**

The fixed and sunk costs of producing for the home market are proportional, \( f_d / f_d^i = f_e / f_e^i \) for all countries \( i = ' \) and \( i = 1, \ldots, C \).

Assumption 1 ensures that the ratio \( (f_d^i / f_e^i) / (f_d / f_e) \) vanishes in (9). We will also consider the following stronger version, which implies Assumption 1:

**Assumption 1':**

The fixed and sunk costs of producing for the home market are proportional to \( L^\alpha \), \( 0 \leq \alpha \leq 1 \), \( f_d / f_d^i = f_e / f_e^i = L^\alpha / L^{i\alpha} \) for all countries \( i = ' \) and \( i = 1, \ldots, C \).

This stronger version is motivated by the fixed market penetration costs discussed by Arkolakis (2010), which in a simplified version of his model are \( L^\alpha \). The extreme case with \( \alpha = 1 \) has been used by Simonovska and Waugh (2014b) in their analysis of the Melitz-Chaney model. With the above assumptions, we obtain:

**Proposition 1:**

(a) Under Assumption 1, the ratio of the real wages between two equilibria is:

\[
\frac{w'/ P'}{w / P} = \left( A' / A \right) \left( \frac{\lambda_{d}'}{\lambda_{d}} \right)^{\frac{1}{\beta}} \left( \frac{\tau_{d}'}{\tau_{d}} \right)^{-1} \left( \frac{M_{d}'}{M_{d}} \right) \left( \frac{X'/ w'L'}{X / wL} \right)^{\frac{1}{\beta}}.
\]  

(10)
(b) Under Assumption 1’, this expression becomes:

\[
\left( \frac{w' / P'}{w / P} \right) = \left( \frac{A'}{A} \right) \left( \frac{\lambda'_d}{\lambda_d} \right)^{1 - \theta} \left( \frac{\tau'_d}{\tau_d} \right)^{-1} \left( \frac{M' / \lambda'_d}{M / \lambda_d} \right)^{1 - \frac{1}{\theta}} \left( \frac{L'}{L} \right)^{(1 - \alpha) / \theta},
\]

(11)

and product variety is determined by,

\[
\left( \frac{M' / \lambda'_d}{M / \lambda_d} \right) = \left( \frac{L'}{L} \right)^{1 - \alpha} \left( \frac{X' / w'L'}{X / wL} \right).
\]

(12)

To interpret these results, the first term on the right of (10) and (11) is the ratio of overall productivity levels. The second term on the right is the ratio of the share of expenditure on domestic goods, with a negative exponent: as that share falls, indicating that more varieties are available from abroad, then the gains from trade are higher. This is the “sufficient statistic” identified by ACR for a foreign shock.

The third term on the right of (10) and (11) is the inverse ratio of domestic trade costs, so that a country with higher domestic trade costs will have correspondingly lower welfare. It is surprising that the domestic trade costs do not involve an exponent reflecting the share of expenditure on domestic goods. To explain this, consider two countries where the only difference between them is that one has higher domestic trade costs, \( \tau'_d > \tau_d \). That country will have higher domestic prices and therefore lower real wages and welfare, depending on its consumption of the domestic good. But that country will also have lower expenditure on its domestic goods, \( \lambda'_d < \lambda_d \), due to the higher prices. So, from (10) and (11), the higher domestic trade costs are offset by the lower domestic share, meaning that country welfare does not fall in direct proportion to the higher domestic trade costs.\(^7\)

\(^7\) There is one parameterization, however, where the welfare will fall in direct proportion to the domestic trade costs, and that is where the domestic costs apply equally well to domestic and imported goods.
The fourth term appearing on the right of (10) and (11) measures the welfare gain from domestic and import varieties available to consumers, as discussed just after (8), but this term appears with differing exponents in (10) and (11). The fifth terms are an adjustment for trade imbalance in (10), and an adjustment for the size of the labor force in (11). To see why this final terms are needed, consider the sources of consumer gains from variety. In the first case, suppose that trade is balanced (so the final term in (10) is unity) and that the labor force of the home and foreign country both double, with fixed costs held constant (\(\alpha = 0\)). This will lead to a doubling in the mass of entering firms \(M_e \propto L / f_e\) in both countries, and it turns out that there is no change in the ZCP productivities at home or abroad. Along with the doubling in the mass of entering firms there is also a doubling in the mass of available products \(M^*_x\) at home, which lowers the price index in (1) by \(2^{1/(1-\sigma)} < 1\). It follows that real wage increases by the inverse of that amount, which is exactly what we compute from (10) and (11) with \(\alpha = 0\). This captures the case of new variety due to firm entry.

In contrast, suppose that the labor force at home doubles but \(\alpha = 1\), so that fixed costs increase in proportion. Then the mass of entering firms \(M_e \propto L / f_e\) is constant. With trade balance, the doubling of expenditure \(X\) in (7) can be expected to reduce the ZCP productivity \(\varphi_d\), which would lead to an increase in the available domestic products \(M_d = M_e[1 - G(\varphi_d)]\). But that extra variety will be from lower-productivity domestic goods. In expression (11), the increase in home variety, \(M'_d / M_d > 1\), is therefore evaluated with a reduced exponent
\[
0 < [1 / (\sigma - 1)] - (1 / \theta) < 1 / (\sigma - 1).
\]
The final term in (11) reflecting the relative labor force does not appear because \(\alpha = 1\).
To summarize, the two different exponents on the produce variety term shown in parts (a) and (b) of Proposition 1 reflect different sources of variety. The first source (in part a) are pure scale differences between countries, with larger countries having more variety. The second source (in part b) is product variety due to a shift from less productive to more productive firms, which has a reduced exponent as compared with pure scale differences. When $\alpha < 1$ then scale effects re-emerge by having the relative labor force appear as the final term in (11). The coefficient on the labor force can be obtained from a regression of produce variety on the labor force and the trade imbalance, as shown in (12). After measuring product variety and estimating the equation, we will use expression (11) from Proposition 1(b) in our empirical work.

3. Sectoral Gravity Equation

In order to implement Proposition 1, we need an estimate of the Pareto parameter $\theta$ from a gravity equation, as well as the elasticity of substitution $\sigma$. Following Eaton and Kortum (EK, 2002) and Simonovska and Waugh (2014a,b), we obtain $\theta$ from a gravity equation that is estimated using cross-country price data from the ICP. While Eaton and Kortum derive and estimate the gravity equation in the context of their EK model, Simonovska and Waugh (2014b) are the first to estimate the Melitz-Chaney model using ICP data. To show their results, we again distinguish countries with the superscript $i$, and assume:

**Assumption 2:**

The fixed costs of domestic production in country, $f_{di}$, equals the fixed costs of exporting to country $i$ from any other source country $j$, for $i, j = 1, ..., C$.

This assumption is most natural in the case where the fixed costs are viewed as marketing costs paid in the destination country, which we are assuming are equal for all domestic and foreign
firms selling there. With this assumption, we obtain a gravity equation that is somewhat simpler than derived in Chaney (2008) because it does not involve any fixed cost terms:

**Proposition 2:**

(a) Under Assumptions 1 and 2, the value of exports $X_{ij}$ from country $i$ to $j$ relative to total expenditure $X_j$ in country $j$ is,

$$
\chi_{ij} \equiv \frac{X_{ij}}{X_j} = \frac{T^i (w^i \tau^ij)^{-\theta}}{\sum_{k=1}^C \tau^k (w^k \tau^{kj})^{-\theta}},
$$

(13)

where $T^i \equiv M^i_e (w^i)^{1-\theta}$. 

(b) Under Assumptions 1' with $\alpha = 1$ and Assumption 2, and with the fixed costs of exporting paid in the destination country, then (13) holds with $T^i \equiv M^i_e$ and its denominator is proportional to the country $j$ price index raised to the power,

$$(P^j)^{-}\theta \propto \sum_{k=1}^C M^k_e (w^k \tau^{kj})^{-\theta}.$$ 

(14)

Simonovska and Waugh (2014b) use conditions equivalent to Assumptions 1' and 2, so part (b) just reproduces their result; nevertheless, we provide a proof of both parts (a) and (b) in the Appendix. Part (a) shows that the same gravity equation in (13) holds under the weaker Assumption 1 along with Assumption 2. The difference between parts (a) and (b) is in the definition of the parameter $T^i$, and importantly, in the interpretation of the denominator of (13). Using the interpretation as the price index shown in (14), Simonovska and Waugh (2014a,b) follow Eaton and Kortum in measuring the denominator by an country average price from ICP data. We will follow their approach, but we use more disaggregate data from the ICP than what was available to them, which is explained as follows.

The ICP provides prices at the “basic heading” level, which we denote by $h$; for example, “rice” is a basic heading. There are 62 basic headings for traded products included in the ICP.
2005 that Simonovska and Waugh (2014a,b) used, so they took the simple geometric mean of these prices to form the country price index in (14). For the ICP 2011 round we have more detailed data available, which are the “items” denoted by \( n \) within each basic heading: for example, “basmati rice” is an item. We denote the prices for items \( n \), consumed in country \( i \), by \( p^i_n \) and we distinguished the items \( n \in \Omega(s) \) belonging to each broad sector \( s \). The average log price for each country and sector is defined by:

\[
D^i_s \equiv \frac{1}{N_s} \sum_{n \in \Omega(s)} \ln p^i_n ,
\]

where \( N_s \) is the number of elements in \( \Omega(s) \). Based on the results of Proposition 2(b), we can use \( \exp D^i_s \) as an estimate of the sectoral price index \( P^i_s \), so that according to (14), \(-\theta D^i_s\) can be used to replace the log of the denominator of (13) when needed.

Let us now turn to the estimation of the gravity equation. Taking the log ratio \( \frac{\lambda_{ns}^{ij}}{\lambda_{ns}^{ii}} \) from (13), for items \( n \in \Omega(s) \) in sector \( s \), and using \(-\theta_s D^i_s\) to replace the log of the denominator of (13), we obtain the canonical form of the gravity equation:

\[
\ln \left( \frac{\lambda_{ns}^{ij}}{\lambda_{ns}^{ii}} \right) = -\theta_s \left( \ln \tau_{s}^{ij} - \ln \tau_{s}^{ii} + D^i_s - D^j_s \right), \tag{15}
\]

where \( \tau_{s}^{ij} \) denotes the iceberg costs to ship items \( n \) in sector \( s \) from country \( i \) to \( j \). A limitation of the ICP price data is that the country of origin is not known, however, so trade costs cannot be inferred by the distance between countries or any similar variable. Instead, Eaton and Kortum and Simonovska and Waugh used the largest (or second largest) price difference across countries to infer trade costs. They estimate this cost by,

\[
\begin{align*}
\text{\textsuperscript{8}} \text{Notice that the fixed effects } \lambda_{ns}^{ij} \text{ and } \lambda_{ns}^{ii} \text{ in (15) will absorb the domestic costs } \ln \tau_{s}^{ii} \text{ and } \ln \tau_{s}^{jj} .
\end{align*}
\]
\[
\ln \tilde{\tau}_s^{ij} = \max_{n \in \Omega(s)} \left\{ \ln p_n^j - \ln p_n^i \right\}.
\]  

(16)

The idea behind this approach is that only items that are produced in country \(i\) and sold in \(j\) would be expected to have \(\ln p_n^j - \ln p_n^i > 0\). Since we do not know the country of origin, we take the maximum over those log differences (which may be positive or negative depending on the direction of trade) to estimate the trade costs.

Simonovska and Waugh (2014a) show that the method used by EK to estimate the gravity equation results in a consistent but upward biased estimate of \(\theta_s\). They propose a simulated method of moment estimator that yields unbiased (and smaller) \(\theta_s\) estimates.

Simonovska and Waugh (2014b) extend that analysis to the Melitz-Chaney model. Proposition 2 above tells us that the structure of gravity equation in our model – even with domestic shocks – is much that same as in their analysis. Accordingly, we will follow their method to obtain estimates of \(\theta_s\). Our estimates will be sensitive to estimating \(\theta_s\) separately across sectors versus pooling the data across sectors; in the latter case the max operator in (16) is taken across all items \(n\) and sectors \(s\). When pooling we compare the estimates of \(\theta\) from the EK and the Melitz-Chaney model, whereas when estimating \(\theta_s\) across sectors we shall find that only the estimates from the EK model converge.

4. Estimating the Gravity Equation

To estimate \(\theta_s\) for the different sectors based on sectoral gravity equations (15) requires, first, data on trade flows by sector and, in particular, trade flows of consumption goods as assumed in our model. Trade data are taken from the World Input-Output Database (WIOD, Timmer et al. 2015, 2016), which provides trade flows not only by product but also by type-of-use, so that we can distinguish trade flows of consumption goods. Traded products are
categorized by industry and we allocate these products to the corresponding consumption sectors. The 2016 release of WIOD covers 43 countries, including all 28 countries in the European Union and 15 other major countries around the world, including the United States, China, India and Indonesia.

The second piece of information consists of the prices needed to implement the trade cost estimator in equation (16). The 2011 round of the International Comparison Program (ICP) is based on detailed surveys of prices of consumption and investment products, both traded and non-traded (World Bank, 2014). We restrict ourselves to the list of (potentially) traded goods for household consumption, of which there are 490. These products span seven sectors of consumption, defined at the two-digit level of the classification of individual consumption by purpose (COICOP), with the number of products varying between 23 (other goods, COICOP 12) and 205 (food, beverages and tobacco, COICOP 01 and 02). In these sectors, the share of expenditure on traded products – meaning goods rather than services – varies between 25 percent (other goods) and 100 percent (food, beverages and tobacco); see Table 1, below. Four sectors of consumption are omitted because the products in those sectors are either all non-traded (education, hotels and restaurants) or contain so few traded products that the gravity equation estimation is not feasible (housing and utilities, communication). In ICP, not every product is priced in every country, as some products may be atypical of that country’s consumption bundle. Of the maximum of 490 consumption products, coverage varies between 213 and 326 products.

Table 1 shows the consumption sectors we include in our analysis. Consumption of traded products represents half of overall household consumption, on average for our set of 43 countries. As discussed above, the share of traded products varies by sector, as does the (maximum) number of products covered in the ICP data. The subsequent column shows the
estimates of $\theta$, based on the method of Simonovska and Waugh (2014a,b). Their method can be adapted to a variety of trade models, including the EK and the Melitz-Chaney model that is the basis of our theoretical framework. Shown in Table 1 are estimates of $\theta$ based on the EK model, estimated with overidentifying restrictions and allowing for measurement error in the price data.\footnote{We are grateful to Mike Waugh for providing us with the programs required to run these estimates, see https://github.com/mwaugh0328.}

We also estimated $\theta$ based on the Melitz-Chaney model, and pooling the data we obtain $\theta=5.12$. However, at the sectoral level, the features of the theoretical model and the smaller number of priced products led to problems with convergence of the estimates or estimates of $\theta$ in excess of 80. We therefore rely on the estimates from the EK model as shown in the table.

Table 1: Consumption sectors, estimated trade elasticity $\theta_s$ and elasticity of substitution $\sigma_s$

<table>
<thead>
<tr>
<th>Sector</th>
<th>Code</th>
<th>Traded share (%)</th>
<th># Products</th>
<th>$\theta_s$</th>
<th>Measurement error</th>
<th>$\sigma_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total traded consumption</td>
<td></td>
<td>47</td>
<td>490</td>
<td>3.51</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Food, beverages &amp; tobacco</td>
<td>01-02</td>
<td>100</td>
<td>205</td>
<td>3.46</td>
<td>0.00</td>
<td>4.2</td>
</tr>
<tr>
<td>Clothing &amp; footwear</td>
<td>03</td>
<td>97</td>
<td>47</td>
<td>2.96</td>
<td>0.00</td>
<td>3.5</td>
</tr>
<tr>
<td>Furnishing, household equipment</td>
<td>05</td>
<td>88</td>
<td>69</td>
<td>4.77</td>
<td>0.00</td>
<td>2.5</td>
</tr>
<tr>
<td>Health</td>
<td>06</td>
<td>46</td>
<td>52</td>
<td>4.00</td>
<td>0.08</td>
<td>2.5</td>
</tr>
<tr>
<td>Transport</td>
<td>07</td>
<td>59</td>
<td>31</td>
<td>11.43</td>
<td>0.33</td>
<td>7.8</td>
</tr>
<tr>
<td>Recreation and culture</td>
<td>09</td>
<td>51</td>
<td>59</td>
<td>6.76</td>
<td>0.23</td>
<td>2.2</td>
</tr>
<tr>
<td>Other goods</td>
<td>12</td>
<td>25</td>
<td>23</td>
<td>14.77</td>
<td>0.23</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Notes: Code is the COICOP code for the sector, traded share is the share of total sectoral expenditure on traded products, averaged over the 43 countries, # Products is the total number of products in each sector, $\theta_s$ is the estimates of the trade elasticity from equation (15), estimated using the Simulated Method of Moments estimator of Simonovska and Waugh (2014a,b) for the Eaton/Kortum model with overidentifying restrictions and allowing for measurement error in prices. The estimated degree of measurement error is shown in the subsequent column. The final column, $\sigma_s$, is the median elasticity of substitution with each sector. These are based on the estimates by Broda and Weinstein (2006) at the HS10 level of detail using the concordance from HS10 to End Use from Feenstra and Jensen (2012).
Simonovska and Waugh (2014b), using the estimation method employed for Table 1, found $\theta=4.05$ for manufacturing. One important difference with their setup is that our price data are for individual product items, while Simonovska and Waugh (2014a,b) use relative price estimates for “basic heading” product categories, which span multiple individual product items. If we estimate a single $\theta$, pooled over all consumption sectors, based on basic heading price data rather than product items, we find $\theta=5.58$. As Table 1 shows, moving to pooled estimation over individual product items leads to a lower value of 3.51. This lower estimate reflects the greater variability in prices of individual items compared to more aggregate basic heading categories, corresponding to higher implied trade costs and thus, for given trade flows, a lower elasticity.

Turning to the sectoral results, we find higher estimates of $\theta$ in all but two sectors than when pooling the data for overall consumption. This reflects lower variation in prices at the sectoral level than for consumption as a whole, and the fact that most sectors have a higher $\theta$. This implies that there are systematic price differences between sectors. This observation fits with the Balassa-Samuelson hypothesis, in which differential productivity improvements across sectors lead to differential prices. For most sectors, $\theta$ is between 3 and 5, a similar magnitude as found in Simonovska and Waugh (2014a,b). For transport, recreation and culture and other goods we find notably higher estimates. This is because these are also the sectors where the model identifies substantial measurement error in the price data, following the technique of Simonovska and Waugh (2014b). With less variation in prices (after accounting for measurement error) trade costs are smaller and the estimated trade elasticity is larger.

The final column shows the elasticity of substitution $\sigma$, which is the other key parameter in equation (10). These elasticities are based on Broda and Weinstein (2006), who estimate $\sigma$ for traded products at the HS-10 level of product detail. We use a concordance from HS-10 to
BEA’s End Use classification (Feenstra and Jensen, 2012) to allocate the trade-based $\sigma$ to each consumption sector and the median within each sector is taken as the $\sigma$ shown in the table. Comparing the $\theta_i$ and $\sigma$ columns shows that the condition $\theta_i > \sigma_i - 1$ holds for all sectors.

5. The Cost of Living

Measurement framework

We shall use Proposition 1(b) to compare the cost of living across countries. To achieve that, we invert (11) to obtain the cost of living between countries $i$ and $j$:

$$\left( \frac{P_i}{P_j} \right) = \left( \frac{w^i / A^i}{w^j / A^j} \right)^\theta \left( \frac{\lambda_i^{ii}}{\lambda_j^{jj}} \right)^\frac{1}{\theta} \left( \frac{\tau_j^{ii}}{\tau_j^{jj}} \right)^{\frac{1}{\theta} - 1} \left( \frac{M^i / \lambda_i^{ii}}{M^j / \lambda_j^{jj}} \right)^{\frac{1}{\theta} - 1} \left( \frac{L_i^i}{L_j^j} \right)^{(1-\alpha)/(\alpha - \theta)}.

(17)

where we have dropped the subscript $d$, so that $\lambda_i^{ii}$ is understood as the share of expenditure in country $i$ coming from domestic production, $\tau_j^{ii}$ are domestic trade costs in country $i$, and $M^i$ is the mass of domestic products. We can compare this theoretical cost-of-living index across countries to the price level of consumption, which we denote by $PL_c^i$ in country $i$. The price level of consumption is measured in the Penn World Table (PWT) as reflecting the observed prices of consumption goods in each country, converted to US$ using the nominal exchange rate and measured relative to the US prices of the same goods. By construction, then, $PL_c^i$ in country $i$ in measured relative to the United State as country $j$ (i.e. $PL_c^{US}^i \equiv 1$). Many countries in the world have $PL_c^i < 1$, reflecting low prices, but a handful of European countries (especially the Scandinavian countries) have $PL_c^i > 1$, indicating that they have higher US$ prices that the United States.
Several adjustments to (17) are needed to bridge the gap between our stylized model and the data we shall apply to it. First, while our model has only labor, there are many factors of production in reality. This feature is readily incorporated by consideration of the terms $\frac{w^i}{A^i}$ and likewise for country j (i.e. the United States). Let $w^i$ denote a weighted average of factor prices used in production. The term $A^i$ is the lower bound to productivity in (7), and as such it also reflects the mean productivity in country $i$ (as discussed just below equation (1)). Suppose we measure country productivity using a dual approach, which would equal the ratio of the weighted average of factor prices to the aggregate output price. Then the ratio $\frac{w^i}{A^i}$ would equal the output price level, which we denote by $PL^i_y$, which is again taken from PWT.\(^{10}\)

Second, we shall apply formula (17) at the sectoral level, and within each sector we want to distinguish potentially traded goods $T$ from those that are non-traded, denoted with $N$. The transportation sector, for example, includes taxi rides which are a non-traded service. Such services typically do not have domestic trade costs, so that (17) applies only to the potentially traded portion of each sector, which we can measure in practice by the manufacturing portion. The domestic shares $\lambda_{ds}^i$, in particular are measured for manufactured goods in each sector $s$. Denoting the traded (non-traded) good expenditure in each sector by $X^T_s$ ($X^N_s$), we suppose that there are CES preferences over these portions of expenditure and across sectors. We let $W^{T_i}_s$ equal the Sato-Vartia weight of traded goods in sector $s$ relative to the US (see the Appendix for a definition of these terms). Then (17) is re-written as the cost of living in sector $s$ and country $i$.

---

\(^{10}\) In contrast to the price level of consumption, the price level of output price level of output reflects the prices of produced goods in each country, relative to the US. In particular, export prices are included in the price level of output, whereas import prices are included in the price level of consumption.
$CoL^j$, relative to the US as country $j$:

$$CoL^j = \left( PL^L_s \right)^{W^T_i} \prod_{s=1}^{S} \left( \frac{M^i_s/\lambda^i_s}{M^US/\lambda^US} \right)^{w^T_i} \left( \frac{L^s}{L^US} \right)^{\frac{1}{\sigma_s}} \left( PL^{NL}_{cs} \right)^{w^N_i}, \quad (18)$$

where the first term on the right of (18) is the price level of output in each country, obtained from PWT, and it is weighted by the overall share of traded goods in the economy, $W^T_i = \sum_{s=1}^{S} W^T_i$.

In next three terms on the right of (18) we have added the sectoral subscript $s$. Those three terms and their sector-specific exponents are identified in Proposition 1 as determining the relative price of traded goods, and they are weighted by the traded share in expenditure $W^T_i$ relative to the United States. The final term in (18) reflects the price level of non-traded consumption goods for each sector, $PL^{NL}_{cs}$, which are aggregated across sectors using the non-traded shares, $W^N_i$. By construction, the cost of living in (18) applies to the entire basket of consumption in each country (i.e. traded and non-traded products), so it can be used to deflate consumption expenditures in each country to obtain a measure of consumer welfare.

It is instructive to compare the cost of living that we construct in (18), $CoL^j$, to the price level of consumption from PWT, $PL^L_c$, which measures the difference in consumption prices across countries. That PWT price level makes no adjustments for the factors entering our extended-ACR formula, i.e. $PL^L_c$ does not adjust for productivity or variety differences across countries or domestic trade costs. We should thus view $CoL^j$ as a more accurate measure of the “true” cost of living for consumers. To the extent that it differs systematically from $PL^L_c$, then that would indicate that the simple price level from PWT is an inadequate measure of the cost of living, so that real consumption from PWT is an inadequate measure of the living standards.
Domestic and Foreign Trade Costs

We implement equation (18) as follows. The output price level \( P_{iy} \) is drawn from PWT 9.0 and the nontraded consumption prices \( P_{iNi} \) and the expenditure data needed to compute the Sato-Vartia weights are from ICP2011. The share of consumption expenditure on domestic products, \( \lambda_s^{ii} \), is computed based on WIOD, as are the trade flows for the gravity equation estimation. Domestic trade costs \( \tau_s^{ii} \) in sector \( s \) are measured as consumption expenditure at purchaser’s prices divided by consumption expenditure at basic prices: this ratio reflects the margin earned in transportation and retail trade and also includes taxes on products, notably sales tax, VAT and excise taxes. For most countries, we obtain consumption at purchaser’s prices and at basic prices from the margins and tax tables (sometimes also referred to as valuation tables) provided by Eurostat and the OECD. For the remainder of countries, we use data from national input-output tables, from Eurostat’s Structural Business Statistics for retail trade, or WIOD to approximate trade margins.\(^{11}\) To estimate consumption taxes by sector for these other countries, we use information on total taxes on products by sector and ensure that the tax rate (taxes as a share of consumption expenditure at purchaser’s prices) does not exceed that country’s indirect tax rates.\(^{12}\)

To illustrate the data, define the first three terms on the right of (18) in logs as,

\(^{11}\) We rely on national input-output data for China, Japan, Indonesia, Russia, Taiwan; Eurostat retail survey data for Germany, Spain and Switzerland; and WIOD data for India. The retail survey data abstracts from transportation margins, but most transportation costs are registered as intermediate inputs rather than as margins.

\(^{12}\) Country-level indirect tax rates are from the OECD Consumption Tax Trends 2018 publication. On average across European countries with the requisite data, only 60 percent of taxes on products are borne directly by consumers, so scaling is important. Excise taxes on alcoholic beverages, tobacco and fuel lead to higher tax rates in the food and transport sectors so in those sectors, the tax rate is allowed to exceed the national indirect tax rate, though not by more than the maximum excess rate observed in other European countries. In Japan, a uniform VAT rate of 5 percent is applied to all sectors, which is increased by an additional 5.8 percent in the food and transport sectors based on estimates of the revenue from excise taxes relative to VAT in the OECD Consumption Tax Trends 2018 publication.
\[
\ln Z_1^i = W^{Ti} \ln PL_y^i ,
\]
\[
\ln Z_2^i = \sum_{s=1}^{S} \frac{w_{s}^{Ti}}{\theta_{s}} \ln(\lambda_s^{ii} / \lambda_{s}^{US} ) ,
\]
\[
\ln Z_3^i = \sum_{s=1}^{S} \frac{W_s^{Ti}}{\theta_{s}} \ln(\tau_s^{ii} / \tau_{s}^{US} ) .
\]

Figure 1 plots the terms for foreign trade costs as in (20) (measured by the log ratio of domestic expenditure shares, with its exponent), and domestic trade costs as in (21). The first panel, for foreign trade costs, shows that the small open economies of the Netherlands (NLD), Denmark (DMK) and Luxembourg (LUX) have a notably lower cost of living due to low foreign trade costs, with all other countries showing effects between -10 percent and +5 percent. Except for Japan and Italy, all countries with higher consumption price levels than the United States at (0,0) have lower cost of living than the US due to foreign trade costs.

**Figure 1: The impact of foreign and domestic trade costs on the cost of living**

*Notes:* The figure shows \( \ln Z_2^i \) and \( \ln Z_3^i \) from equations (21) and (22) for foreign trade costs and domestic trade, plotted against the consumption price level \( \ln PL_c^i \).
The second panel of Figure 1 plots the domestic trade costs. The United States has one of the highest measure of domestic trade costs measured *net* of product and consumption taxes, i.e. of the margin earned in transportation and retail trade. When we also include product and consumption taxes, however, then the United States is roughly in the middle of the other countries in our sample. Measuring these domestic trade costs relative the United States, then, we obtain the scatter of countries shown in the second panel. India (IND), Indonesia (IDN) and China (CHN) have the lowest domestic trade costs, and Ireland (IRL) and Denmark (DNK) have the highest.

The next three terms in (18) as defined in logs as:

\[
\ln Z_4^i = \sum_{s=1}^{S} W_s^{Ti} \left[ \frac{1}{\theta_s} - \frac{1}{(\sigma_s-1)} \right] \ln \left( \frac{M_s^i / \lambda_s^i}{M_s^{US} / \lambda_s^{US}} \right), \tag{22}
\]

\[
\ln Z_5^i = \left( \frac{L^i}{L^{US}} \right)^{\frac{(1-\sigma_s)W_s^{Ti}}{\theta_s}} \tag{23}
\]

\[
\ln Z_6^i = \sum_{s=1}^{S} W_s^{Ni} \ln \left( P_{c,s}^{Ni} \right). \tag{24}
\]

The term in (24) is the price of non-traded goods (i.e. mainly services) relative to the United States as taken from PWT9.0. Suppose that we construct the model-based cost of living by using the first three term (19)-(21) and also non-trade prices in (24), but we *exclude* the contribution of overall product variety in (22) the scale effect of relative population in (23). Then the resulting partial measure of the model-based cost of living is illustrated in Figure 2, where we compare it to the price level of consumption. From PWT. The left-hand side plots the log of both variables with a 45-degree line, the right-hand side plots the log difference between the two measures. Note that the measures of the cost of living and the consumption price level compare each country to the United States, so the United States is at point (0,0) in both panels.
Figure 2. The relative cost of living versus the consumption price level in 2011

Notes: The left-hand figure plots $\log{Col}^i$ versus $\log{PL_c}^i$ for the 43 countries in our analysis, with $\log{Col}^i$ as defined in equation (18) and $\log{PL_c}^i$ from PWT 9.0 (Feenstra et al., 2015), normalized to USA=1. The right-hand figure plots $\log{Col}^i/PL_c^i$ versus $\log{PL_c}^i$.

The figure shows a few countries like Luxembourg (LUX) and several other European countries lie above the 45-degree line in the first panel, but all other countries lie below that line. From the second panel, we see that differences between the two measures can be substantial, with Indonesia having a model-based cost-of-living that is over 40 percent lower than indicated by PWT, Bulgaria (BGR) and China (CHN) have model-based cost-of-living that is over 30 percent lower indicated by PWT, Indonesia (IDN) is nearly 25 percent lower, and all other countries except for seven European nations are also lower. Why can so many countries have model-based cost-of-living that is lower than PWT? The answer is that we are using the United States as the comparison country, and because it has a relatively high value of $\lambda_s^{US}$, nearly all other countries will have a lower lambda-ratio (20) and therefore lower foreign trade costs. As a result, nearly all countries have lower model-based cost of living than in PWT, and sometimes by a very
substantial amount. These results are artificial, though, and they would not occur if rather than using the entire United States as the comparison country, we used only one state within the U.S., which would have a much lower value of $\lambda_s^{US}$ for that state (and more similar to some European country). These findings tell us that the results from ignoring product variety are artificial, and that it is essential to correct for product variety differences before accepting the model-based relative cost-of-living as valid.

Product Variety

Our first measure of the number of domestic varieties $M_{ds}^i$ is based on an estimate of the number of domestic firms active in each sector, taken from the Bureau van Dijk’s ORBIS global dataset, which, in turn, is based on business registers in different countries. We eliminate duplicate names and drop firms with zero employees to eliminate shell companies. As a verification exercise, we also collected data on the number of firms from national enterprise statistics, primarily from the OECD Structural Business Statistics and Eurostat Enterprise Statistics, supplemented by national reports. For most countries, the correspondence between the two sources is close; the correlation of the log number of firms between both sources is 0.75, rising to 0.90 when excluding India and Indonesia. Both of those countries have very large numbers of informal firms, which would skew upwards their variety count.

The number of firms in each sector shown is obtained for 43 countries. In Table 2 we show the results for 19 countries were we have other alternative measures.\(^\dagger\) The number of firms is a very crude measure of the number of products because of multi-product firms. At one extreme, large firms produce very many products that are not counted. At the other extreme,

\(^\dagger\) See the Appendix for the number of firms in all 43 countries and 7 sectors.
certain low-income countries like India have a very large number of informal firms, as just mentioned, which include firms perhaps serving only a single city or neighborhood. We might think of these firms as producing less than a single (national) product.

To obtain a more accurate count of product variety, we rely on a count of barcodes for goods sold within all the sectors except for health and transport.¹⁴ We use micro data available at the Billion Prices Project (BPP), for all products sold by some of the largest multi-channel retailers in 19 countries: Australia, Brazil, Canada, China, Germany, Spain, France, Greece, India, Ireland, Italy, Japan, Mexico, the Netherlands, Poland, Russia, Turkey, the United Kingdom, and the United States. To compute the barcode counts at the sector level, we first take the modal daily barcode count for each retailer in the BPP sample during 2018, computed at a 3-digit COICOP level of aggregation (eg. “Fruits and Nuts”). To avoid double counting varieties sold in multiple retailers, we use the largest barcode count for each 3-digit category available across retailers, and then add up all the barcodes at the sectoral level. The number of barcodes in each sector is denoted by $N^i$, as shown in Table 2.

When collecting the count of barcodes in these sectors, we are mixing both domestically-produced and imported goods. For just two sectors – food and electronics – we further collected the country of origin information for a random sample of the total number of barcodes. Specifically, we hired freelancers to manually check 500 randomly sampled barcode items per sector in each country.¹⁵ Using a custom mobile phone application, each freelancer visited one of the retailers in the BPP sample, scanned the barcode of each product, took a photo of the country

¹⁴ For health and transport we used the number of firms to measure product variety, but the results are similar if we just product variety relative to the United States as unity in these two sectors. Barcodes in electronics are only for part of the ‘Recreation and culture’ sector, so $\lambda^i$ is adjusted to match this coverage based on WIOD data.
¹⁵ The only exceptions were electronics for India and Italy, where no data could be collected.
of origin label, and determined if the product was domestic or imported. When no country of origin is listed, then the product is treated as domestically made. For this subset of two sectors we therefore have the barcode domestic ratio, i.e. the ratio of domestically-made to the total number of sampled barcodes, which is denoted by $B_s^i$. The number of domestically-produced barcodes is therefore $M_s^i = N_s^i B_s^i$. In addition, for these sectors we also have the expenditure domestic ratio, which we have denoted by $\lambda_{s}^{ii}$. The “overall” measure of product variety is therefore,

$$
\left( \frac{M_s^i}{\lambda_{s}^{ii}} \right) = \left( \frac{N_s^i B_s^i}{\lambda_{s}^{ii}} \right).
$$

16 To test the validity of our estimates for the barcode domestic ratios, we also computed an alternative metric using country of origin information collected online for individual products in a subset of 9 countries. This information was scraped from the website of a single retailer in each country. The correlation between the online and offline barcode domestic ratios is 0.76. More details are provided in the Appendix.
Outside of food and electronics, we do not have information on the ratio of domestically-produced barcodes. In these cases we make the simple assumption that \( B_s^i \approx \lambda_s^{ii} \). That is, we are assuming that the barcode domestic share is approximately equal to the expenditure domestic share. In that case, the “overall” measure of product variety is approximated by the total count of barcodes (including domestic and imported goods) for each sector:

\[
M_s^i / \lambda_s^{ii} \approx N_s^i. \tag{26}
\]

**THESE FIGURES WILL BE DESCRIBED AT THE SEMINAR**

**Figure 3**
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Figure 4

Figure 5
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Figure 6

Figure 7
THESE FIGURES WILL BE DESCRIBED AT THE SEMINAR

Figure 8

To further examine the relationship between $Col^i$ and $Pl^i$, we perform a decomposition analysis similar to Eaton, Kortum and Kramarz (2004). We initially run the regression:

$$\ln Col^i = \alpha_0 + \beta_0 \ln Pl^i + \epsilon_0^i, i = 1, \ldots, C.$$  

(27)

This corresponds to a line of best fit for the left-hand side of Figure 1. We have already defined $Z_k^i$ for $k = 1, \ldots, 5$, as the six terms on the right of (18), as in (19)-(24). Then we also run:

$$\ln Z_k^i = \alpha_k + \beta_k \ln Pl^i + \epsilon_k^i, \quad k = 1, \ldots, 5.$$  

(28)

Because $\ln Col^i = \sum_{k=1}^5 \ln Z_k^i$, it will follow that the OLS estimates satisfy:

$$\alpha_0 = \sum_{k=1}^5 \alpha_k \quad \text{and} \quad \beta_0 = \sum_{k=1}^5 \beta_k.$$  

(29)

The individual $\beta_k$ parameters will show how the various factors used to calculated the cost of living in each country, $Col^i$, are related to the consumption price level $Pl^i$ used in PWT. The
results are shown in Table 3.

The top line in Table 3 shows that $\beta_0$ ranges between 1.15 and 1.28, depending on whether product variety is included and whether the firm-count or the barcode count is used to measure product variety. The fact that these coefficient are greater than unity indicates that the “true” cost of living increases more rapidly than the consumption price level. Much of this is due to differences in observed prices – of the output price level for traded products and for non-traded prices. Of the three remaining terms, the impact of foreign trade costs decreases significantly with the consumption price level, the impact of domestic trade costs significantly increases, while there is no significant relationship between the impact of variety and the consumption price level.

**Table 3. Cost-of-living components regressed on the consumption price level**

<table>
<thead>
<tr>
<th>Variety:</th>
<th>No variety</th>
<th>FirmCount</th>
<th>Barcode</th>
<th>FirmCount</th>
<th>Barcode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale effect:</td>
<td>n.a.</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>CoL</td>
<td>1.224</td>
<td>1.228</td>
<td>1.147</td>
<td>1.278</td>
<td>1.186</td>
</tr>
<tr>
<td></td>
<td>(0.039)</td>
<td>(0.050)</td>
<td>(0.080)</td>
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<td>Non-traded prices</td>
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<td>0.432</td>
<td>0.206</td>
<td>0.398</td>
</tr>
<tr>
<td></td>
<td>(0.089)</td>
<td>(0.096)</td>
<td>(0.076)</td>
<td>(0.069)</td>
<td>(0.061)</td>
</tr>
</tbody>
</table>

*Note:* The first line shows $\beta_0$ from equation (27) and the corresponding robust standard error in parentheses. The subsequent lines show $\beta_k$ from equations (28), $k = 1,...,6$. 
As a second method to measure the contribution of the components of the cost of living, we take the difference between the “true” cost of living in (18) and the price of consumption from PWT, \( \Delta CoL^i \equiv CoL^i - \ln PL_c^i \). Further, define the term:

\[
\Delta P^i \equiv \ln Z_1^i + \ln Z_6^i - \ln PL_c^i = W^T_i \ln PL_y^i + \sum_{s=1}^{S} W^N_i \ln (PL_{cs}^N) - \ln PL_c^i,
\]

which is the difference between the components of equation (18) due to weighted PWT output and nontraded prices as compared to the price level of consumption. Likewise, we define

\[\Delta \ln Z_k^i \equiv \ln Z_k^i - \ln PL_c^i, \quad k=2,3,4,\]

and we run the regressions:

\[
\Delta P^i = \delta_1 + \gamma_1 \Delta CoL^i \quad (31)
\]

\[
\Delta \ln Z_k^i = \delta_k + \gamma_k \Delta CoL^i, \quad k=2,3,4. \quad (32)
\]

These regressions are the counterparts to those shown in equation (22), but here the aim is to account for the cross-country variation in the difference between the relative cost of living and the consumption price level. Table 4 presents the results.

By construction, the regression coefficients shown in Table 4 sum to unity, so we can interpret them as the portion of the variation in the cost-of-living difference with respect to the consumption price index, \( \Delta CoL^j \equiv CoL^j - \ln PL_c^j \), that is explained by the dependent variable in each regression. The weighted prices of output and nontradables, differenced with respect to the consumption prices index as in (32), has a positive and significant regression coefficient of between 0.21 and 0.40 in the first row of Table 4 (but higher for the case with no variety). In other words, between 20 and 40 percent of the cost-of-living difference is explained by those prices differences \( \Delta P^i \). The foreign and domestic trade cost terms defined in (20) and (21)
Table 4. Difference between the cost of living and the consumption price level

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**Explanatory variable: log(CoL/PLc)**

<p>| | | | | | |</p>
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<tbody>
<tr>
<td>Prices</td>
<td>0.708</td>
<td>0.344</td>
<td>0.432</td>
<td>0.206</td>
<td>0.398</td>
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<tr>
<td></td>
<td>(0.089)</td>
<td>(0.096)</td>
<td>(0.076)</td>
<td>(0.069)</td>
<td>(0.061)</td>
</tr>
<tr>
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<td>(0.050)</td>
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<td>43</td>
<td>43</td>
<td>19</td>
<td>20</td>
<td>21</td>
</tr>
</tbody>
</table>

Note: Each line in the table corresponds to a $\gamma_k$ from equation (31) and (32), with $k = 1, \ldots, 4$. Robust standard errors are in parentheses.

account for much smaller (and insignificant) amounts of the cost-of-living difference, as shown in the second and third rows. The largest explanation for the cost-of-living difference is the variety term, with a regression coefficient ranging between 0.29 and 0.56 in the final row of Table 4. So variety differences across countries explain between 30 and 60 percent of the “true” cost-of-living index as compared to the consumption price index.

6. Conclusions

[To be completed]
Appendix

Proof of Proposition 1:

The final equality in (9) uses \( M_e \propto L / f_e \). To prove this condition we complete the description of the model in part (a), and then we prove Proposition 1 in part (b).

a) Denoting the iceberg costs of exporting from home by \( \tau_x \), export demand for the home firm with productivity \( \phi \) is analogous to (6),

\[
y_x(\phi) = \frac{X^*}{P^{1-\sigma}} \left[ \frac{w \tau_x \phi}{\phi(\sigma - 1)} \right]^{-\sigma}.
\]

Multiplying by price minus variable cost, \( p_x(\phi) - (w \tau_x / \phi) = [1 / (\sigma - 1)] (w \tau_x / \phi) \), profits in the export market are,

\[
\pi_x(\phi) = \frac{X^*}{P^{1-\sigma}} \left[ \frac{w \tau_x}{\phi(\sigma - 1)} \right]^{-\sigma} \phi^{\sigma - 1} - w f_x,
\]

where \( f_x \) are the fixed costs for exporting. It follows that the zero-cutoff-profit condition in the export market is as follows, as we shall make use of later:

\[
\pi_x(\phi_x) = B_x^* \phi_x^{\sigma - 1} - w f_x = 0 \quad \Rightarrow \quad \phi_x^{\sigma - 1} = \frac{w f_x}{B_x^*} = \frac{w f_x \sigma^\sigma (w \tau_x / P^*(\sigma - 1))^{-\sigma - 1}}{X^*}.
\]

Total employment at home for domestic and export sales equals:

\[
L = M_e f_e + M_d \int_{\varphi_d}^{\infty} \left[ \frac{\tau_d y_d(\varphi)}{\varphi} + f_d \right] \frac{g(\varphi)}{[1 - G(\varphi_d)]} d\varphi + M_x \int_{\varphi_x}^{\infty} \left[ \frac{\tau_x y_x(\varphi)}{\varphi} + f_x \right] \frac{g(\varphi)}{[1 - G(\varphi_x)]} d\varphi.
\]

Notice that we have multiplied the quantity delivered to home and foreign consumers by their respective iceberg costs, \( \tau_d \) and \( \tau_x \), to obtain the quantity produced by the firm. Multiply the entire expression by wages \( w \), and then multiply and divide the production terms by \( \sigma / (\sigma - 1) \).
to obtain prices $p_d(\phi) = (\tau_d / \phi)[\sigma / (\sigma - 1)]$ and $p_x(\phi) = (\tau_x / \phi)[\sigma / (\sigma - 1)]$, so that:

$$wL = w(M_e f_e + M_d f_d + M_x f_x) + \left(\frac{\sigma - 1}{\sigma}\right) \left[ M_d \int_{\phi_d}^{\infty} \frac{p_d(\phi) y_d(\phi) g(\phi)}{[1 - G(\phi_d)]} d\phi + M_x \int_{\phi_x}^{\infty} \frac{p_x(\phi) y_x(\phi) g(\phi)}{[1 - G(\phi_x)]} d\phi \right]$$

$$= w(M_e f_e + M_d f_d + M_x f_x) + \left(\frac{\sigma - 1}{\sigma}\right) wL,$$

where the bracketed term on the first line is the total revenue earned by firms, and with zero expected profits that will equal the payment to labor, $wL$. It follows immediately that

$$L = \sigma \left( M_e f_e + M_d f_d + M_x f_x \right).$$

Then the full employment condition (A3) is simplified as

$$\left(\frac{\sigma - 1}{\sigma}\right) L = M_d \int_{\phi_d}^{\infty} \frac{\tau_d y_d(\phi)}{\phi} \frac{g(\phi)}{[1 - G(\phi_d)]} d\phi + M_x \int_{\phi_x}^{\infty} \frac{\tau_x y_x(\phi)}{\phi} \frac{g(\phi)}{[1 - G(\phi_x)]} d\phi. \quad (A4)$$

The CES demand with prices $p_d(\phi) = (\tau_d / \phi)[\sigma / (\sigma - 1)]$ implies that $y_d(\phi) = (\phi / \varphi_d)^{\sigma} y_d(\varphi_d)$.

Using the Pareto distribution for productivity, the first integral in (A4) is then:

$$\int_{\phi_d}^{\infty} \frac{\tau_d y_d(\phi)}{\phi} \frac{g(\phi)}{[1 - G(\phi_d)]} d\phi = \int_{\phi_d}^{\infty} \frac{\tau_d y_d(\phi_d)}{\phi_d} \left( \frac{\phi}{\varphi_d} \right)^{\sigma - 1} \frac{\theta \phi^{-\theta - 1}}{(\varphi_d)^{-\theta}} d\phi$$

$$= \frac{\tau_d y_d(\varphi_d)}{\varphi_d} \frac{\theta}{(\sigma - \theta - 1)} \left( \frac{\varphi_d}{\varphi_d} \right)^{\sigma - \theta - 1} \left. \right|_{\phi_d}^{\infty}$$

$$= f_d \frac{(\sigma - 1)\theta}{(\theta - \sigma + 1)},$$

where the last line uses $\tau_d y_d(\varphi_d) = (\sigma - 1) f_d$, as seen from (6) and (7). Likewise using (A1) and (A2) we have $\tau_x y_x(\varphi_x) = (\sigma - 1) f_x$, and so the second integral in (A4) is evaluated as:

$$\int_{\phi_x}^{\infty} \frac{\tau_x y_x(\varphi_x)}{\phi} \frac{g(\phi)}{[1 - G(\phi_x)]} d\phi = f_x \frac{(\sigma - 1)\theta}{(\theta - \sigma + 1)}.$$

Substituting these back into (A4) we arrive at:
\[ L = \frac{\sigma \theta}{(\theta - \sigma + 1)} (M_d f_d + M_x f_x). \]

Using \( L = \sigma (M_e f_e + M_d f_d + M_x f_x) \) we obtain \( M_e = L(\sigma - 1) / \sigma \theta f_e \), so that \( M_e \propto L / f_e \), as was to be proved.

b) Now completing the proof of Proposition 1, from (5) we have:

\[
\frac{w' / P'}{w / P} = \left( \frac{M'_d / \lambda'_d}{M_d / \lambda_d} \right)^{\frac{1}{\theta}} \left( \frac{\tau'_d}{\tau_d} \right)^{\frac{1}{1-\alpha}} \left( \frac{\varphi'_d}{\varphi_d} \right). \tag{A5}
\]

The final ratio on the right of (A5) is solved using (9) as,

\[
\frac{\varphi'_d}{\varphi_d} = \frac{A'}{A} \left( \frac{\lambda'_d}{\lambda_d} \right)^{-1/\theta} \left( \frac{X' / w'L'}{X / wL} \right)^{1-\alpha}, \tag{A6}
\]

where \( f'_d / f'_e = f'_d / f_e \) from Assumption 1. Substituting (A6) into (A5), we obtain (10).

Under Assumption 1', the final term in (10) becomes:

\[
\left( \frac{X' / w'L'}{X / wL} \right)^{\frac{1}{\theta}} = \left( \frac{X' / w'}{X / w} \right)^{\frac{1}{\theta}} \left( \frac{L^\alpha}{L'^\alpha} \right)^{\frac{1}{\alpha \theta}} = \left( \frac{X' / w'}{X / w} \right)^{\frac{1-\alpha}{\alpha \theta}} \left( \frac{X' / w'f'_d}{X / w'f'_d} \right)^{\frac{1}{\alpha \theta}},
\]

and then using (8) we obtain,

\[
\left( \frac{X' / w'L'}{X / wL} \right)^{\frac{1}{\theta}} = \left( \frac{X' / w'}{X / w} \right)^{\frac{1-\alpha}{\alpha \theta}} \left( \frac{M'_d / \lambda'_d}{M_d / \lambda_d} \right)^{\frac{1}{\alpha \theta}}. \tag{A7}
\]

We can use (A7) to solve for product variety as in (12). To obtain real wages, we use (12) to solve for \( (X' / w'L') / (X / wL) \) and substitute that into (10) to obtain (11). QED

**Proof of Proposition 2:**

The mass of profitable domestic firms is \( M_d = M_e [1 - G(\phi_d)] \) and the mass of profitable exporters is \( M_x = M_e [1 - G(\phi_x)] \). Substituting these into the CES price index (1), we can rewrite
it by instead integrating over the unconditional distribution \( g(\phi) \) and letting the mass of entrants \( M_e \) appear in front of those integrals. We use that rewritten expression as the numerator and denominator of the domestic share in (2). We will generalize our earlier exposition to allow for multiple countries, so that \( M'_e \) are the entrants in country \( i \) and \( \phi^{ij} \) is the zero-cutoff-profit (ZCP) value of productivity for selling to country \( j \). We also allow the wages \( w' \) to differ across countries. Then the value of exports \( X_{ij} \) from country \( i \) to \( j \) relative to total consumption \( X_j \) in county \( j \) is written analogously to (2) as:

\[
\frac{X_{ij}}{X_j} = \frac{M'_e \int_{\phi^{ij}}^{\infty} p^{ij}(\phi)^{1-\sigma} g(\phi)d\phi}{\sum_{k=1}^{C} M'_e \int_{\phi^{kj}}^{\infty} p^{kj}(\phi)^{1-\sigma} g(\phi)d\phi} = \frac{M'_e \int_{\phi^{ij}}^{\infty} (w' \tau^{ij} / \phi)^{1-\sigma} g(\phi)d\phi}{\sum_{k=1}^{C} M'_e \int_{\phi^{kj}}^{\infty} (w' \tau^{kj} / \phi)^{1-\sigma} g(\phi)d\phi}, \tag{A8}
\]

where the second equality follows by using the prices \( p^{ij}(\phi) = [\sigma / (\sigma - 1)](w' \tau^{ij} / \phi) \). Notice that the iceberg trade costs \( \tau^{ij} \) can be moved outside the integrals in the above expression.

The ZCP condition for productivity for home sales is (7), which is written more generally for country \( i \) exporting to \( j \) as,

\[
(\phi^{ij})^{\sigma - 1} = \frac{w' f^j \sigma}{X_j} \left( \frac{w' \tau^{ij}}{P^j (\sigma - 1)} \right)^{\sigma - 1}. \tag{A9}
\]

From Assumption 2, the fixed cost of exporting to country \( j \) is the same as the fixed cost for domestic sales, \( f^j = f'^j \), so we denote them both as simply \( f' \) in (A9). We make use of the Pareto distribution to evaluate the integral in the numerator of (A8):
\[
\int_{\phi_{ij}}^{\infty} (w_i^j \tau_{ij} / \phi)^{1-\sigma} g(\phi) d\phi = (w_i^j \tau_{ij})^{1-\sigma} \theta \int_{\phi_{ij}}^{\infty} \phi^{\sigma-\theta-2} d\phi \\
= (w_i^j \tau_{ij})^{1-\sigma} \theta \phi_{ij}^{\sigma-\theta-1} \bigg|_{\phi_{ij}}^{\infty} \\
= (w_i^j \tau_{ij})^{1-\sigma} \theta (\phi_{ij})^{\sigma-\theta-1}.
\]

Combining this result with (A8) and (A9) it follows that,

\[
\frac{X_{ij}^i}{X^j} = \frac{M_e^{i} (w_i^j)^{-\theta} \left(w_i^j f_i^j \right)^{1-\frac{\theta}{\sigma-1}}}{\sum_{k=1}^{C} M_e^{k} (w_k^k \tau_{kj})^{-\theta} \left(w_k^k f_k^j \right)^{1-\frac{\theta}{\sigma-1}}}.
\]

(A10)

Notice that \( f_i^j \) cancels from this expression, so we obtain (13) with \( T_i^j \equiv M_e^{i} (w_i^j)^{1-\frac{\theta}{\sigma-1}} \).

When the fixed costs are paid in the destination country, then (A10) is rewritten as,

\[
\frac{X_{ij}^i}{X^j} = \frac{M_e^{i} (w_i^j)^{-\theta} \left(w_i^j f_i^j \right)^{1-\frac{\theta}{\sigma-1}}}{\sum_{k=1}^{C} M_e^{k} (w_k^k \tau_{kj})^{-\theta} \left(w_i^j f_i^j \right)^{1-\frac{\theta}{\sigma-1}}}.
\]

(A11)

Now the term \( w_i^j f_i^j \) cancels from this expression, so we obtain (13) with \( T_i^j \equiv M_e^{i} \). To solve for the price index, we make use of the results from section 2. In (4) we showed the domestic share of expenditure, but it is not a gravity equation because it involves the ZCP productivity \( \phi_d \).

Using the solution to that productivity from (7), along with \( M_d = M_e [1 - G(\phi_d)] = M_e \phi_d^{-\theta} \) for the Pareto distribution, we obtain the domestic share:

\[
\lambda_d \propto \left( \frac{f_d}{L} \right)^{1-\frac{\theta}{\sigma-1}} \left( \frac{w_k \tau_d}{P_d} \right)^{-\theta} M_e,
\]

(A12)
where the factor of proportionality depends on $\theta$ and $\sigma$ and so it is constant across countries.

Assumption 1’ means that $(f_d / L)$ is also constant across countries, so we rewrite (A12) in the more general notation for countries $i = 1, \ldots, C$:

$$\lambda^{ii} \propto \left( \frac{w^i \tau^{ii}}{P^i} \right)^{-\theta} M^i_e \Rightarrow (P^i)^{-\theta} \propto \left( \frac{M^i_e}{\lambda^{ii}} \right) \left( w^i \tau^{ii} \right)^{-\theta}.$$

(A13)

With fixed costs paid in the destination country, (A10) is rewritten as (A11), and since $w^j f^j$ cancels from that expression then $\lambda^{ii} = X^{ii} / X^i$ is,

$$\lambda^{ii} = \frac{M^i_e (w^i \tau^{ii})^{-\theta}}{\sum_{k=1}^{C} M^k_e (w^k \tau^{ki})^{-\theta}}.$$

Substituting this into (A13), we obtain (14).  QED

**Sato-Vartia weights:**

We consider the general case of a nested CES function, where the expenditure between traded and non-traded components of expenditure in each sector are related by a CES function, the traded goods are aggregated across countries with another CES function, and then the expenditure over the various sectors is also aggregated using a third CES function.

At the lowest level, the non-traded services included in the price index $P^T_{sNi}$ are purchase entirely from domestic sources (e.g. taxi rides within the transportation sector), while the traded goods price index $P^T_{sTi}$ is composed over the prices of goods that can be purchased from home, $P^T_{sTii}$, and those that are purchased from abroad, $P^T_{sTji}$, $j \neq i$:

$$P^T_{sTi} = \left[ \sum_{j=1}^{C} (P^T_{sTji})^{1-\sigma} \right]^{\sigma/(1-\sigma)}, \; \sigma > 1.$$
This price index is comparable to what appears in (1) in our model, though in (1) we also allow for a mass of products from each country. Above that level, the price index \( P^i_s \) for country i and sector s is given by:

\[
P^i_s = \left( \left( P^T_i \right)^{1-\gamma} + \left( P^N_i \right)^{1-\gamma} \right)^{1/(1-\gamma)}, \quad \gamma > 1. \quad (A14)
\]

Finally, we aggregate across sectors using a third CES function,

\[
P^i = \left[ \sum_{s=1}^{S} \left( P^i_s \right)^{1-\eta} \right]^{1/(1-\eta)}, \quad \eta > 0. \quad (A15)
\]

Choose country \( j \) (i.e. the United States) as the base country. Then the sectoral prices index in country i relative to j can be measured by the Sato-Vartia price index:

\[
\frac{P_s^i}{P_s^j} = \left( \frac{P_s^{T_i}}{P_s^{T_j}} \right)^{\omega_s^{T_i}} \left( \frac{P_s^{N_i}}{P_s^{N_j}} \right)^{\omega_s^{N_i}},
\]

where the Sato-Vartia weights, \( \omega_s^{T_i} + \omega_s^{N_i} = 1 \), are defined over the expenditure shares on traded and non-traded services. Since we have already used the variable \( X \) to denote expenditures and \( s \) to denote sectors, we will use \( x \) to denote expenditure shares. So \( x_s^{T_i} \equiv X_s^{T_i} / X_s^i \) is the share of expenditure on traded goods relative to total expenditure, \( X_s^i \equiv (X_s^{T_i} + X_s^{N_i}) \), in country i and sector s. Then the Sato-Vartia weights used in (A16) are;

\[
\omega_s^{T_i} = \frac{(x_s^{T_i} - x_s^{T_j})}{(\ln x_s^{T_i} - \ln x_s^{T_j})} \left[ \frac{(x_s^{T_i} - x_s^{T_j})}{(\ln x_s^{T_i} - \ln x_s^{T_j})} + \frac{(x_s^{N_i} - x_s^{N_j})}{(\ln x_s^{N_i} - \ln x_s^{N_j})} \right], \quad \omega_s^{N_i} = 1 - \omega_s^{T_i}. \quad (A17)
\]

Analogously, the overall price index in country i relative to that for in country j is constructed as the Sato Vartia index defined over sectors:

\[
\frac{P_i}{P_j} = \sum_{s=1}^{S} \left( \frac{P_s^i}{P_s^j} \right)^{\omega_s^i},
\]

(A18)
where the Sato-Vartia weights are defined over the expenditure shares $x_s^i \equiv X_s^i / X^i$:

$$\omega_s^i = \frac{(x_s^i - x_s^j)}{(\ln x_s^i - \ln x_s^j)} \left[ \sum_{r=1}^{S} \frac{(x_r^i - x_r^j)}{(\ln x_r^i - \ln x_r^j)} \right].$$  \hspace{1cm} (A19)

Equation (18) aggregates over traded goods and non-traded services and over sectors.

Substituting (A16) into (A18), that country-level relative price is:

$$\frac{P^i}{P^j} = \sum_{s=1}^{S} \left( \frac{P_s^{Ti}}{P_s^{Tj}} \right) \omega_s^{Ti} \omega_s^{ij} \left( \frac{P_s^{Ni}}{P_s^{Nj}} \right) \omega_s^{Ni} \omega_s^{ij}.$$  \hspace{1cm} (A20)

It follows that the relevant weights that appear in (18) are $W_s^{Ti} \equiv \omega_s^{Ti} \omega_s^{ij}$ and $W_s^{Ni} \equiv \omega_s^{Ni} \omega_s^{ij}$. The latter weights are applied in (18) to the price levels for non-traded services in each sector that are constructed from ICP data.
## Appendix Table A 1

<table>
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### Table A. Orbis Firm Counts in 43 Countries

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