Foreign and Domestic Trade Costs and the Standard of Living Between Countries

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We extend the analysis of Arkolakis, Costinot and Rodríguez-Clare (ACR, 2012) to allow for differences in domestic trade costs in addition to foreign trade costs. The domestic trade costs are measured by local transportation charges, wholesaling and retailing margins, and taxes on goods, which are modeled simply as iceberg costs. By allowing for differences in domestic trade costs, as well as in country size, productivity and in fixed costs, we are able to model both the welfare change between two equilibria and the welfare difference between two countries. We find that the extended ACR formula 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. We measure the extent to which differences in the cost of living between countries are explained by these terms, and we find that domestic trade costs are of comparable importance to foreign trade costs.

1. Introduction

Since at least McCallum (1995), it has been know that the extent of international trade is surprisingly small as compared to intra-national trade.[1] That observation has led researchers to incorporate the costs of international trade in modern models, such as the time spent clearing customs, transport costs, language differences, the difficulty of making contracts across countries, etc. Such foreign trade costs play a key role, for example, in the various models described by Arkolakis, Costinot and Rodríguez-Clare (ACR, 2012), which lead to a gravity equation for international trade.

Less examined are the consequences of the *domestic* costs of doing trade, by which we mean local transportation charges, wholesaling and retailing margins, and taxes on goods. While there are a number of notable studies examining such domestic costs,[2] 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. 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.[3] 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. Our goal is to determine the extent to which domestic trade costs, in addition to foreign trade costs, can explain the differences in the cost of living between countries.

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[1] McCallum (1995) found that international trade across the Canada-U.S. border was about 6 percent of cross-state trade in the U.S., even when correcting for distance.

[2] For example, 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).

[3] See Timmer, Inklaar, O'Mahony, and van Ark (2010).

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-drive the expression for the welfare change when domestic parameters change, 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. Applying this result across countries, we cannot look only to their openness to inform us about their cost of living or welfare, but we must also consider their domestic trade costs and the extent of product variety.

The implications of our model for the gravity equation in trade are described in section 3. In section 4, we describe the data that we shall use to determine the foreign and domestic trade costs. Following Eaton and Kortum (2002) and Simonovska and Waugh (2014a,b), we use cross-country price data from the International Comparisons Project (ICP). In addition, we use newly collected data from the Billion Price Project (BPP) that provides cross-country online prices on a sample of products from the food, electronics and energy sectors (see Cavallo, et al., 2018). The BPP is an alternative source of cross-country prices from the ICP, and importantly, it allows us to infer *product variety* across countries. Whether using the BPP or ICP prices, the country of origin for these products is unknown, so Eaton and Kortum (2002) used the (second) largest price difference across countries to infer trade costs, which are used to 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 and allowing for differences in fixed costs across countries.[4]

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2. Trade Model with 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, both of which we rely on to measure τ_d. We also include local taxes on goods within these domestic trade costs, but we do not account for the redistribution of tax revenue, so we are assuming that the taxes are spent on some public goods that we do keep track of in welfare. We consider two equilibria that can experience a *domestic shock,* by which we mean a change domestic iceberg costs τ_d, or a change in domestic fixed costs or in the population. In addition, the two equilibria can experiences a *foreign shock,* defined as changes in the foreign values foreign iceberg costs, fixed costs, or 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 (but with the same values of all other model parameters).

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

[4] Giri, Yi and Yilmazkudayz also estimate a sectoral gravity equation following Simonovska and Waugh (2014a,b).

index for the home consumer is defined over domestic and foreign goods as:

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

where the first integral reflects the consumer prices $p_d(\varphi)$ 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 $G(\varphi) = 1 - \varphi^{-\theta}$ for $\varphi \geq 1$, and $\theta > (\sigma - 1) > 1$.

To obtain the share of expenditure on domestic goods, which we denote by λ_d, we take the exponent $(1-\sigma)$ of (1) and then the ratio of the first term on the right to the price index,

$$\lambda_d = \left[M_d \int_{\varphi_d}^{\infty} p_d(\varphi)^{1-\sigma} \frac{g(\varphi)}{[1-G(\varphi_d)]} d\varphi \right] \Big/ P^{(1-\sigma)}.$$

This expression can be simplified by solving for domestic prices. The marginal costs of production at home are w/φ, so that with the usual CES markup the consumer price is $p_d(\varphi) = [\sigma/(\sigma - 1)](\tau_d w/\varphi)$, where $\tau_d \geq 1$ are the domestic iceberg costs. Substituting these prices into the above expression, it is convenient to define $\bar{\varphi}_d$ as *average* domestic productivity,

$$\bar{\varphi}_d \equiv \left[\int_{\varphi_d}^{\infty} \varphi^{(\sigma-1)} \frac{g(\varphi)}{[1-G(\varphi_d)]} d\varphi \right]^{1/(\sigma-1)} = \left(\frac{\theta}{\theta - \sigma + 1} \right)^{1/(\sigma-1)} \varphi_d.$$

The second equality makes use of a convenient property of the Pareto distribution, namely, that the integral shown above is a constant multiple of the lower bound of integration. Combining the above results, the share of expenditure on domestic goods is:

$$\lambda_d = \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}\left(\frac{\theta}{\theta-\sigma+1}\right)\left(\frac{w\tau_d}{\varphi_d}\right)^{1-\sigma}\frac{M_d}{P^{(1-\sigma)}}. \quad (2)$$

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 (2) as:

$$\frac{P'}{P} = \left(\frac{(M_d')^{\frac{1}{1-\sigma}} w'\tau_d' / \varphi_d'}{M_d^{\frac{1}{1-\sigma}} w\tau_d / \varphi_d}\right)\left(\frac{\lambda_d'}{\lambda_d}\right)^{\frac{1}{\sigma-1}}. \quad (3)$$

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 λ_d and λ_d' denoting the share of expenditure on domestic goods in the two equilibria. The first term appearing on the right of (3) is just the ratio of the *CES price index* of domestic goods, where the variety term $M_d^{\frac{1}{1-\sigma}}$ and likewise in the prime equilibrium is the welfare effect of any change in the mass of domestic varieties,[5] while $w\tau_d / \varphi_d$ represents the *average price* of these varieties (recalling that the cutoff productivity is proportional to the average productivity). The second term on the right 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 (3), or the welfare loss from disappearing import varieties, which would result in $\lambda_d' > \lambda_d$.

[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, as we do in (3), where this CES domestic price index is defined as the first term on the right of (1) raised to the power $1/(1-\sigma)$.

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

$$y_d(\varphi) = \frac{X}{P^{1-\sigma}}\left[\frac{w\tau_d\sigma}{\varphi(\sigma-1)}\right]^{-\sigma}. \tag{4}$$

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,

$$\pi_d(\varphi) = \underbrace{\left[\frac{X}{\sigma^\sigma}\left(\frac{w\tau_d}{P(\sigma-1)}\right)^{1-\sigma}\right]}_{B_d}\varphi^{\sigma-1} - wf_d,$$

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,

$$\pi_d(\varphi_d) = B_d\varphi_d^{\sigma-1} - wf_d = 0 \quad \Rightarrow \quad \varphi_d^{\sigma-1} = \frac{wf_d}{B_d} = \frac{wf_d\sigma^\sigma}{X}\left(\frac{w\tau_d}{P(\sigma-1)}\right)^{\sigma-1}. \tag{5}$$

We do not describe the rest of the equilibrium conditions here, but they are outlined in the Appendix. A ZCP condition analogous to (5) 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 as we make explicit in the next section.[6] As explained above, 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 parameters (following ACR), or we can compare the equilibria across two countries that have

[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.

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 (5) between the two equilibria, and substitute that into (2) to obtain,

$$\left(\frac{X'/w'f'_d}{X/wf_d}\right)^{\frac{1}{\sigma-1}} = \left(\frac{M'_d/\lambda'_d}{M_d/\lambda_d}\right)^{\frac{1}{\sigma-1}}. \qquad (6)$$

The expression on the right of (6) 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, $M'_d < M_d$. Comparing two countries with the same market size, defined by expenditure X relative to fixed costs wf_d, then *there will be no welfare difference due to variety*: equation (6) shows that $M'_d/\lambda'_d = M_d/\lambda_d$ when $X'/w'f'_d = X/wf_d$, which means that there is no welfare difference due to variety even if foreign or domestic trade costs differ between the countries. That is the case in the one-sector Melitz-Chaney model in ACR (2012), for example, because with trade balance expenditure will equal labor income, X=wL, and domestic shocks are ruled out, so that $X'/w'f'_d = w'L/w'f_d = L/f_d = X/wf_d$. By allowing for domestic shocks, in contrast, we are therefore permitting welfare gains from variety across equilibria, either within or between countries.

Expression (6) shows us how to interpret the variety terms appearing in (3), but we still need to solve for ZCP productivity level appearing there. To do so, we assume a Pareto distribution for firm productivity given by:

$$G(\varphi) = 1 - (\varphi/A)^{-\theta}, \quad \varphi \geq A, \qquad (7)$$

where A is the lower bound of the productivity of each firm. 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 (6), we obtain,

$$\frac{\lambda'_d}{\lambda_d} = \left(\frac{X'/w'f'_d}{X/wf_d}\right)^{-1}\left(\frac{M'_e}{M_e}\right)\left(\frac{\varphi'_d/A'}{\varphi_d/A}\right)^{-\theta} = \left(\frac{X'/w'L'}{X/wL}\right)^{-1}\left(\frac{f'_d/f'_e}{f_d/f_e}\right)\left(\frac{\varphi'_d/A'}{\varphi_d/A}\right)^{-\theta}. \qquad (8)$$

The final equality above 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 (8) 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,…,C:

Assumption 1:
The fixed and sunk costs of producing for the home market are proportional, $f_d^i \propto f_e^i$, for all countries i=1,…,C and for $i = '$.

Assumption 1 ensures that $f'_d / f'_e = f_d / f_d$ so that the ratio of these terms vanishes in (8). We will also consider a stronger version of Assumption 1:

Assumption 1′:
The fixed and sunk costs of producing for the home market are proportional to the labor force, $f_d^i \propto f_e^i \propto L^i$, for all countries i=1,…,C and for $i = '$.

This stronger version is has been used by Simonovska and Waugh (2014b), for example, in their discussions of the Melitz-Cheney. It can be viewed as the most extreme case of the market

penetration costs discussed by Arkolakis (2010), which he models as L^{α}, $0 \le \alpha \le 1$, where we are using the α=1 case. With these assumptions, we use (3), (6) and (8) to obtain:

Proposition 1:

Under Assumption 1 the ratio of the real wages, or welfare, between the two equilibria is:

$$\left(\frac{w'/P'}{w/P}\right)=\left(\frac{A'}{A}\right)\left(\frac{\lambda_d'}{\lambda_d}\right)^{-\frac{1}{\theta}}\left(\frac{\tau_d'}{\tau_d}\right)^{-1}\left(\frac{M_d'/\lambda_d'}{M_d/\lambda_d}\right)^{\frac{1}{\sigma-1}}\left(\frac{X'/w'L'}{X/L}\right)^{-\frac{1}{\theta}}. \quad (9)$$

Under Assumption 1′, this expression is simplified as:

$$\left(\frac{w'/P'}{w/P}\right)=\left(\frac{A'}{A}\right)\left(\frac{\lambda_d'}{\lambda_d}\right)^{-\frac{1}{\theta}}\left(\frac{\tau_d'}{\tau_d}\right)^{-1}\left(\frac{M_d'/\lambda_d'}{M_d/\lambda_d}\right)^{\frac{1}{\sigma-1}-\frac{1}{\theta}}. \quad (10)$$

The first term on the right of (9) is the ratio of overall productivity levels. The second term on the right of (9) 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 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 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 (9), the higher domestic trade costs are *offset* by the lower domestic share, meaning that country welfare does not actually fall in direct proportion to the higher domestic trade costs.

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 of transport, wholesale and retail trade, and taxes on goods, *apply equally well to domestic and imported goods*. In this case, the iceberg costs faced by foreign exports would be $\tau_d \tau_x^*$, so that a higher value of τ_d would *equally impact* both domestic and import prices. In that case, the domestic share λ_d would not be affected, and so it is not surprising that welfare is inversely proportional to domestic trade costs in (9). We will continue with this parameterization in the next section.

The fourth term appearing on the right of (9) measures the welfare gain from domestic and import varieties available to consumers, as discussed just after (6), and the final term is an adjustment for trade imbalance. To see why this final term is needed, consider possible sources of consumer gains from variety. In the first case, suppose that an economy has lower domestic fixed costs, $f_d' < f_d$, with balanced trade and no change in expenditure or wages. Then variety gains will be higher from (6), and those are added to welfare in (9). Instead, suppose the wages, labor and domestic fixed costs do not change between equilibria, but expenditure rises, $X' > X$. Then variety gains will still rise in (6), but in this case the welfare gain are offset by the rising expenditure so that the welfare gain are as in (10). The final term in (10) has a positive exponent since $\theta > (\sigma - 1)$, but it is smaller than the exponent in (9) when trade is balanced. So the source of the variety gains will influence their welfare impact.

3. Sectoral Gravity Equation

In order to implement Proposition 1, we need an estimate of the Pareto parameter θ from a gravity equation.[7] Following Eaton and Kortum (EK, 2002) and Simonovska and Waugh

[7] We will also need as estimate of the elasticity of substitution σ, though we defer that discussion to section 4.

(2014a,b), we obtain that estimate from a gravity equation that is estimated using cross-country data from the International Comparisons Project (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 now distinguish countries with the superscript i, and make the assumption:

Assumption 2:

The fixed costs of domestic production in country i, f_d^i, equals the fixed costs of exporting to country i from any source, $f_x^i = f_d^i$ for i=1,…,C and for $i = '$.

With this simplifying assumption, we obtain the gravity equation:

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,

$$\lambda^{ij} = \frac{X^{ij}}{X^j} = \frac{T^i (w^i \tau^{ij})^{-\theta}}{\sum_{k=1}^{C} T^k (w^k \tau^{kj})^{-\theta}} \quad , \tag{11}$$

where $T^i \equiv M_e^i (w^i)^{1-\frac{\theta}{\sigma-1}}$.

(b) Under Assumptions 1′ and 2, and with the fixed costs of exporting paid in the destination country, then (11) holds with $T^i \equiv M_e^i$ and the denominator of (11) is proportional to the price index,

$$(P^i)^{-\theta} \propto \sum_{k=1}^{C} M_e^k (w^k \tau^{ki})^{-\theta} . \tag{12}$$

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 (11) holds under the much 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 (11). Using the interpretation as the price index shown in (12), 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 what is called the "basic heading" level, which we denote by h; for example, "rice" is a basic heading. There are ??? basic headings 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 (12). 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.[8] We denote the prices for items n, consumed in country i, by p_n^i 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:

$$D_s^i \equiv \frac{1}{N_s} \sum_{n \in \Omega(s)} \ln p_n^i , \qquad (13)$$

where N_s is the number of elements in $\Omega(s)$. Based on the results of Proposition 2(b), we can use $\exp D_s^i$ as an estimate of the sectoral price index P_s^i, so that according to (12) in log terms, $-\theta D_s^i$ can be used to replace the denominator of (11) when needed.

Let use turn now to the estimation of the gravity equation. Taking the log ratio $\lambda_{ns}^{ij} / \lambda_{ns}^{ii}$

[8] In addition, we have prices at the barcode level that we obtain from Billion Price Project (BPP), which we view as comparable in the level of disaggregation to the ICP item-level prices.

from (11), for items $n \in \Omega(s)$ in sector s, and using $-\theta D_s^i$ to replace the log of the denominator of (11), we obtain the canonical form of the gravity equation:

$$\ln\left(\frac{\lambda_{ns}^{ij}}{\lambda_{ns}^{ii}}\right) = \theta D_s^i - \theta D_s^j - \theta \ln \tau_s^{ij} , \qquad (14)$$

where τ_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,

$$\ln \hat{\tau}_s^{ij} = \max_{n \in \Omega(s)} \left\{ \ln p_n^j - \ln p_n^i \right\}. \qquad (15)$$

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.

Equation (15) is intended to measure the *foreign* costs of trade, since these are used in the gravity equation (14). As it stands, however, the estimate in (15) also includes domestic trade costs if these are applied to imported goods. That will be the case in our country data, and so we state it formally as:

Assumption 3:

In sector s, the trade costs of selling from country i to j are $\tau_s^{ij} \equiv \rho_s^{ij} \tau_s^{jj}$, with $\rho_s^{ij} \geq 1$ and $\rho_s^{ii} = 1$.

In this assumption, we use ρ_s^{ij} to measure the *pure foreign* trade costs of shipping from country i to j, while τ_s^{jj} denotes the *domestic* trade cost of selling either imported or home-produced goods in country j.

To illustrate the impact of this assumption, suppose that good n is exported from the set of countries $k \in K(n)$, so that using our notation from the previous section, the prices in country i and country j of that good are $p_n^i = [\sigma/(\sigma - 1)]\,(w^k \tau^{ki}/\varphi_n)$ and $p_n^j = [\sigma/(\sigma - 1)]\,(w^k \tau^{kj}/\varphi_n)$. Then using Assumption 3, the inferred iceberg costs become:

$$\begin{aligned} \ln \hat{\tau}_s^{ij} = \max_{n \in \Omega(s)} \left\{ \ln p_n^j - \ln p_n^i \right\} &= (\ln \tau_s^{jj} - \ln \tau_s^{ii}) + \max_{k \in K(n), n \in \Omega(s)} \left\{ \ln \rho_s^{kj} - \ln \rho_s^{ki} \right\} \\ &\leq (\ln \tau_s^{jj} - \ln \tau_s^{ii}) + \ln \rho_s^{ij}. \end{aligned} \tag{16}$$

The second line of (16) follows from arbitrage, since the costs of shipping from k to i, ρ_s^{kj}, must be less than the costs of shipping from k to i and then from i to j, which is $\rho_s^{ki}\rho_s^{ij}$. It follows that $\ln \rho_s^{kj} \leq \ln \rho_s^{ki} + \ln \rho_s^{ij}$, so the inequality in (16) is obtained.

We see from (16) that the trade cost estimate $\ln \hat{\tau}_s^{ij}$ includes the domestic trade costs in country i and j. This "contamination" of the foreign trade costs does not matter for the estimation of the gravity equation, however. To see this, suppose that we estimate this equation using the log price means in (13) to measure D_s^i. Then the domestic trade costs will equally well enter those means, which can be writing using the prices $p_n^i = [\sigma/(\sigma - 1)]\,(w^k \tau^{ki}/\varphi_n)$ as:

$$D_s^i = \ln \tau_s^{ii} + \frac{1}{N_s} \left\{ \sum_{n \in \Omega(s)} \ln\left(\frac{\sigma/\varphi_n}{\sigma - 1}\right) + \sum_{\substack{k(n), \\ n \in \Omega(s)}} \ln(w^k \rho_s^{ki}) \right\}.$$

So the domestic trade costs $\ln \tau_s^{ii}$ appear explicitly in D_s^i, and likewise for country j, and therefore the difference between the domestic trade costs will *cancel out* from the gravity equation (14).[9]

Even with these domestic trade costs cancelling out or absorbed, (16) tells us that the estimate of the trade costs $\ln \hat{\tau}_s^{ij}$ does not necessarily reflect the foreign trade costs $\ln \rho_s^{ij}$ because of the *inequality* that appears there. This is the starting point for Simonovska and Waugh (2014a), who show that the method used by EK to estimate the gravity equation results in a consistent but upward biased estimate of θ. They propose a simulated method of moment estimator that yields unbiased (and smaller θ 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 θ_s for the various sectors s that we consider.[10]

4. Estimates of the Gravity Equation

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[9] This point was recognized by Eaton and Kortum (2002, note 26) and Simonovska and Waugh (2014a). This argument is even simpler when D_s^i and D_s^j are estimated as fixed effects, since then they will simply absorb the domestic costs $(\ln \tau_s^{ij} - \ln \tau_s^{ii})$ from (16).

[10] In this version of the paper we have used the method that Simonovska and Waugh (2014a) apply to the EK model to recover θ, but in ongoing work we are extending our analysis to use the method that Simonovska and Waugh (2014b) apply to the Melitz-Chaney model.

5. Results

We shall use Proposition 1(b) to compare the cost of living across countries. To achieve that, we invert (9) to obtain the cost-of-living between countries i and j:

$$\left(\frac{P^i}{P^j}\right)=\left(\frac{w^i/A^i}{w^j/A^j}\right)\left(\frac{\lambda_d^i}{\lambda_d^j}\right)^{\frac{1}{\theta}}\left(\frac{\tau_d^i}{\tau_d^j}\right)\left(\frac{M_d^i/\lambda_d^i}{M_d^j/\lambda_d^j}\right)^{\frac{1}{\theta}-\frac{1}{\sigma-1}}. \qquad (20)$$

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 U.S. 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. $PL_c^{US}\equiv 1$). 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 are very expensive to visit.

Several adjustments to (20) 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 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 acts as a shift-parameter to productivity and therefore reflects the mean productivity in country i. 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 w^i/A^i simply

equals the output price level, which we denote by PL_y^i, which is again taken from PWT.[11]

Second, we shall apply formula (20) 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 (20) applies only to the potentially traded portion of each sector, which we can measure in practice by the manufacturing portion. The domestic shares λ_{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_s^{Ti} (X_s^{Ni}), we suppose that there are CES preferences over these portions of expenditure and across sectors. We let W_s^{Ti} equal the Sato-Vartia weight of traded goods in sector s relative to the U.S.[12] Then (20) is re-written as the cost of living in sector s and country i, CoL^i, relative to the U.S. as country j:

$$CoL^i = \left(PL_y^i\right)^{W^{Ti}} \prod_{s=1}^{S} \left(\frac{\lambda_s^{ii}}{\lambda_s^{jj}}\right)^{\frac{W_s^{Ti}}{\theta_s}} \left(\frac{\tau_s^{ii}}{\tau_s^{jj}}\right)^{W_s^{Ti}} \left(\frac{M_s^i / \lambda_s^{ii}}{M_s^j / \lambda_s^{jj}}\right)^{\frac{W_s^{Ti}}{\theta_s} - \frac{W_s^{Ti}}{\sigma_s - 1}} \left(PL_{cs}^{Ni}\right)^{W_s^{Ni}}, \qquad (21)$$

where the first term on the right of (21) 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, $W^{Ti} \equiv \sum_{s=1}^{S} W_s^{Ti}$. In the second term we have replaced the share of expenditure on home goods λ_d^i used in (20) with the sectoral notation λ_s^{ii} used in (21); in the third term we have likewise replaced the domestic trade costs τ_d^i from (21) with the notation τ_s^{ii}, consistent with Assumption 3; and in the

[11] 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 U.S. In particular, export prices are included in the price level output, whereas import prices are included in the price level of consumption.

[12] See the Appendix for the definition of these Sato-Vartia weights for the general nested CES case.

fourth term M_s^i / λ_s^{ii} still denotes the number of home-produced varieties relative to the home expenditure share in country i and sector s. Those three variables and their sector-specific exponents product are the terms identified in Proposition 1 as determined the relative price of traded goods, and they are weighted by the *traded share* in expenditure W_s^{Ti} relative to the United States. The final term reflect the price level of *non-traded* goods for each sector, which are constructed from ICP data, and are aggregated across sectors using the *non-traded shares*. By construction, this cost of living applies to the entire basket of consumption in each country (i.e. traded and non-trade goods), so it used to deflate consumption expenditures in each country to obtain a measure of consumer welfare.

As mentioned above, it is instructive to compare the cost of living CoL^i to the price level of consumption from PWT, PL_c^i, which measures the difference in consumption prices across countries. That price level makes no adjustments for the factor entering our extended-ACR formula, i.e. productivity and variety differences across countries in traded goods, and domestic trade costs. So we should view CoL^i as a more accurate measure of the "true" cost of living for consumers, and to the extent that it differs systematically from PL_c^i, then that would indicate that the price level is an inadequate measure of the cost of living.

To assess the relationship between CoL^i and PL_c^i, we follow the approach of Eaton and Kortum [2002? or reference needed from Rob]. We can initially run the regression:

$$\ln CoL^i = \alpha_0 + \beta_0 \ln PL_c^i + \varepsilon_0^i, i=1,\ldots,C. \quad (22)$$

Next, we denote the five terms on the right of (21) as Z_k^i, k=1,...,5, where $Z_1^i = PL_y^i$ and Z_2^i through Z_5^i are the product of the other consecutive terms. Then we also run:

$$\ln Z_k^i = \alpha_k + \beta_k \ln PL_c^i + \varepsilon_k^i, \quad i=1,\ldots,C. \tag{23}$$

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

$$\alpha_0 = \sum_{k=1}^{5} \alpha_k \text{ and } \beta_0 = \sum_{k=1}^{5} \beta_k . \tag{24}$$

The individual β_k parameters will show how the various factors used to calculated the cost of living in each country, CoL^i, are related to the price level PL^i used in PWT. The results are shown in Table ?.

TO BE COMPLETED

Appendix

Proof of Proposition 1:

The final equality in (8) uses $M_e \propto L / f_e$. With this condition (8) holds, and then (9) and (10) follow quit easily. To prove this condition, we complete the description of the model.

Denoting the iceberg costs of exporting from home by τ_x, analogous to (4) the goods delivered to foreign consumers are,

$$y_x(\varphi) = \frac{X^*}{P^{*1-\sigma}}\left[\frac{w\tau_x\sigma}{\varphi(\sigma-1)}\right]^{-\sigma}. \qquad \text{(A1)}$$

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

$$\pi_x(\varphi) = \frac{w\tau_x y_x(\varphi)}{\varphi(\sigma - 1)} - wf_x.$$

Setting this expression equal to zero to obtain the ZCP productivity φ_x, it follows that

$$\tau_x\, y_x(\varphi_x) / \varphi_x = (\sigma - 1) f_x. \qquad \text{(A2)}$$

Total employment at home for domestic and export sales equals:

$$L = M_e f_e + M_d \int_{\varphi_d}^{\infty}\left[\frac{\tau_d\, y_d(\varphi)}{\varphi} + f_d\right]\frac{g(\varphi)}{[1 - G(\varphi_d)]}d\varphi + M_x \int_{\varphi_x}^{\infty}\left[\frac{\tau_x\, y_x(\varphi)}{\varphi} + f_x\right]\frac{g(\varphi)}{[1 - G(\varphi_x)]}d\varphi. \qquad \text{(A3)}$$

Notice that we have multiplied the quantity delivered to home and foreign consumers by their respective iceberg costs, τ_d and τ_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 $p_d(\varphi) = (\tau_d / \varphi)[\sigma/(\sigma-1)]$ and $p_x(\varphi) = (\tau_x / \varphi)[\sigma/(\sigma-1)]$, so that:

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

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

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

$$\left(\frac{\sigma-1}{\sigma}\right) L = M_d \int_{\varphi_d}^{\infty} \left[\frac{\tau_d\, y_d(\varphi)}{\varphi}\right] \frac{g(\varphi)}{[1-G(\varphi_d)]}\, d\varphi + M_x \int_{\varphi_x}^{\infty} \left[\frac{\tau_x\, y_x(\varphi)}{\varphi}\right] \frac{g(\varphi)}{[1-G(\varphi_x)]}\, d\varphi . \qquad \text{(A4)}$$

CES demand with prices $p_d(\varphi) = (\tau_d / \varphi)[\sigma/(\sigma-1)]$ implies that $y_d(\varphi) = (\varphi/\varphi_d)^{\sigma}\, y_d(\varphi_d)$. Also using the Pareto distribution for productivity, the first integral in (A4) is:

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

$$= \frac{\tau_d\, y_d(\varphi_d)}{\varphi_d} \int_{\phi_d}^{\infty} \left(\frac{\varphi}{\varphi_d}\right)^{\sigma-1} \frac{\theta \varphi^{-\theta-1}}{(\varphi_d)^{-\theta}}\, d\varphi$$

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

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

where the last line uses $\tau_d\, y_d(\varphi_d)/\varphi_d = (\sigma-1) f_d$, as seen from (4) and (5). Likewise using (A2), the second integral in (A4) is evaluated as:

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

Substituting these back into (A4) we arrive at:

$$L = \frac{\sigma\theta}{(\theta - \sigma + 1)}\left(M_d f_d + M_x f_x\right).$$

Using $L = \sigma\left(M_e f_e + M_d f_d + M_x f_x\right)$ we obtain $M_e = L(\sigma - 1)/\sigma\theta f_e$, so that $M_e \propto L/f_e$. QED

Proof of Proposition 2:

The mass of profitable domestic firms is $M_d = M_e[1 - G(\varphi_d)]$ and the mass of profitable exporters is $M_x = M_e[1 - G(\varphi_x)]$. So we can rewrite the CES price index (1) by integrating over the unconditional distribution $g(\varphi)$, and letting the mass of entrants M_e appear in front of the integrals. We will generalize our earlier exposition to allow for multiple countries, so that M_e^i are the entrants in country i and φ^{ij} is the zero-cutoff-profit (ZCP) value of productivity for selling to country j. We also allow the wages w^i 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:

$$\frac{X^{ij}}{X^j} = \frac{M_e^i \int_{\varphi^{ij}}^{\infty} p^{ij}(\varphi)^{1-\sigma} g(\varphi) d\varphi}{\sum_{k=1}^{C} M_e^k \int_{\varphi^{kj}}^{\infty} p^{kj}(\varphi)^{1-\sigma} g(\varphi) d\varphi} = \frac{M_e^i \int_{\varphi^{ij}}^{\infty} (\tau^{ij} w^i/\varphi)^{1-\sigma} g(\varphi) d\varphi}{\sum_{k=1}^{C} M_e^k \int_{\varphi^{kj}}^{\infty} (\tau^{kj} w^k/\varphi)^{1-\sigma} g(\varphi) d\varphi}, \qquad \text{(A5)}$$

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

The ZCP condition for productivity for home sales is in (5), which is written more generally for country i exporting to j as

$$(\varphi^{ij})^{\sigma-1} = \frac{w^i f^j \sigma^{\sigma}}{w^j L^j}\left(\frac{w^i \tau^{ij}}{P^j(\sigma - 1)}\right)^{\sigma-1}. \qquad \text{(A6)}$$

From Assumption 2, the fixed cost of exporting to country j is the same as the fixed cost for

domestic sales, $f_x^j = f_d^j$, so we denote them both as simply f^j in (A6). We make use of the Pareto distribution to evaluate the integral in the numerator of (A.5):

$$\begin{aligned}\int_{\varphi^{ij}}^{\infty}(\tau^{ij}\,w^i/\varphi)^{1-\sigma}g(\varphi)d\varphi &= (\tau^{ij}\,w^i)^{1-\sigma}\theta\int_{\varphi^{ij}}^{\infty}\varphi^{\sigma-\theta-2}\,d\varphi \\ &= \frac{(\tau^{ij}\,w^i)^{1-\sigma}\theta}{\sigma-\theta-1}\varphi^{\sigma-\theta-1}\Big|_{\varphi^{ij}}^{\infty} \\ &= \frac{(\tau^{ij}\,w^i)^{1-\sigma}\theta}{\theta-\sigma+1}(\varphi^{ij})^{\sigma-\theta-1},\end{aligned}$$

Combining this result with (A5) and (A6) it follows that,

$$\frac{X^{ij}}{X^j} = \frac{M_e^i(w^i\,\tau^{ij})^{-\theta}\left(w^i f^j\right)^{1-\frac{\theta}{\sigma-1}}}{\sum_{k=1}^{C}M_e^k(w^k\,\tau^{kj})^{-\theta}\left(w^k f^j\right)^{1-\frac{\theta}{\sigma-1}}}. \tag{A7}$$

Notice that f^j cancels from this expression, so we obtain (11) with $T^i \equiv M_e^i(w^i)^{1-\frac{\theta}{\sigma-1}}$.

When the fixed costs are paid in the destination country, then (A7) is rewritten as,

$$\frac{X^{ij}}{X^j} = \frac{M_e^i(w^i\,\tau^{ij})^{-\theta}\left(w^j f^j\right)^{1-\frac{\theta}{\sigma-1}}}{\sum_{k=1}^{C}M_e^k(w^k\,\tau^{kj})^{-\theta}\left(w^j f^j\right)^{1-\frac{\theta}{\sigma-1}}}. \tag{A8}$$

Now the term $w^j f^j$ cancels from this expression, so we obtain (11) with $T^i \equiv M_e^i$. To solve for the price index, we make use of the results from section 2. In (2) we showed the domestic share of expenditure, but it is not a gravity equation because it involves the ZCP productivity φ_d. Using the solution to that productivity from (5), along with $M_d = M_e[1-G(\varphi_d)] = M_e\varphi_d^{-\theta}$ for the Pareto distribution, we obtain the domestic share:

$$\lambda_d \propto \left(\frac{f_d}{L}\right)^{1-\frac{\theta}{\sigma-1}}\left(\frac{w\tau_d}{P_d}\right)^{-\theta} M_e, \tag{A9}$$

where the factor of proportionality depends on θ and σ and so it is constant across countries. Assumption 1′ means that (f_d /L) is also constant across countries, so we rewrite (A9) in the more general notation for countries i=1,…,C:

$$\lambda^{ii} \propto \left(\frac{w^i \tau^{ii}}{P^i} \right)^{-\theta} M_e^i \;\Rightarrow\; (P^i)^{-\theta} \propto \left(\frac{M_e^i}{\lambda^{ii}} \right) (w^i \tau^{ii})^{-\theta}. \qquad \text{(A10)}$$

With fixed costs paid in the destination country, (A7) is rewritten as (A8), and since $w^j f^j$ cancels from that expression then $\lambda^{ii} = X^{ii} / X^i$ is,

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

Substituting this into (A10), we obtain (12). 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_s^{Ni} are purchase entirely from domestic sources (e.g. taxi rides within the transportation sector), while the traded goods price index P_s^{Ti} is composed over the prices of goods that can be purchased from home, P_s^{Tii}, and those that are purchased from abroad, P_s^{Tji}, $j \neq i$:

$$P_s^{Ti} = \left[\sum_{j=1}^{C} (P_s^{Tji})^{1-\sigma} \right]^{1/(1-\sigma)}, \sigma > 1.$$

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_s^i for country i and sector s is given by:

$$P_s^i = \left[(P_s^{Ti})^{1-\gamma} + (P_s^{Ni})^{1-\gamma} \right]^{1/(1-\gamma)}, \ \gamma > 1. \tag{A11}$$

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

$$P^i = \left[\sum_{s=1}^{S} (P_s^i)^{1-\eta} \right]^{1/(1-\eta)}, \ \eta > 0. \tag{A12}$$

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:

$$\frac{P_s^i}{P_s^j} = \left(\frac{P_s^{Ti}}{P_s^{Tj}} \right)^{\omega_s^{Ti}} \left(\frac{P_s^{Ni}}{P_s^{Nj}} \right)^{\omega_s^{Ni}}, \tag{A13}$$

where the Sato-Vartia weights, $\omega_s^{Ti} + \omega_s^{Ni} = 1$, 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 $x_s^{Ti} \equiv X_s^{Ti} / X_s^i$ denotes the share of expenditure on traded goods relative to total expenditure $X_s^i \equiv (X_s^{Ti} + X_s^{Ni})$ in country i and sector s. Then the Sato-Vartia weights used in (A13) are;

$$\omega_s^{Ti} \equiv \frac{(x_s^{Ti} - x_s^{Tj})}{(\ln x_s^{Ti} - \ln x_s^{Tj})} \Bigg/ \left[\frac{(x_s^{Ti} - x_s^{Tj})}{(\ln x_s^{Ti} - \ln x_s^{Tj})} + \frac{(x_s^{Ni} - x_s^{Nj})}{(\ln x_s^{Ni} - \ln x_s^{Nj})} \right], \ \omega_s^{Ni} = 1 - \omega_s^{Ti}. \tag{A14}$$

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:

$$\frac{P^i}{P^j} = \sum_{s=1}^{S} \left(\frac{P_s^i}{P_s^j} \right)^{\omega_s^i}, \tag{A15}$$

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

$$\omega_s^i \equiv \frac{(x_s^i - x_s^j)}{(\ln x_s^i - \ln x_s^j)} \Bigg/ \left[\sum_{r=1}^{S} \frac{(x_r^i - x_r^j)}{(\ln x_r^i - \ln x_r^j)} \right]. \tag{A16}$$

Equation (21) aggregates over traded goods and non-traded services and over sectors. Substituting (A13) into (A15), that country-level relative price is:

$$\frac{P^i}{P^j} = \sum_{s=1}^{S} \left(\frac{P_s^{Ti}}{P_s^{Tj}} \right)^{\omega_s^{Ti}\omega_s^i} \left(\frac{P_s^{Ni}}{P_s^{Nj}} \right)^{\omega_s^{Ni}\omega_s^i}. \tag{A17}$$

It follows that the relevant weights that appear in (21) are $W_s^{Ti} \equiv \omega_s^{Ti}\omega_s^i$ and $W_s^{Ni} \equiv \omega_s^{Ni}\omega_s^i$. The latter weights are applied in (21) to the price levels for non-traded services in each sector that are constructed from ICP data.

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