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Abstract

In this paper we show that price equalization alone is not sufficient to determine the barriers to international trade. There are many barrier combinations that deliver price equalization, but each combination implies a different volume of trade. We demonstrate this first theoretically in a simple two-country model. We then demonstrate the result quantitatively for the case of capital goods trade: barriers have to be large in order to be consistent with the observed trade flows even though our model implies that capital goods prices are similar across countries. Zero barriers to trade in capital goods will deliver price equalization in capital goods, but cannot reproduce the observed trade flows.

JEL-Code: F010, F020.

Keywords: international trade, capital goods trade.

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1 Introduction

The literature on purchasing power parity (PPP) relates free trade to price equalization. Based on a no-arbitrage argument, PPP suggests that an aggregate price constructed with multiple goods in each country should be the same across countries when there are no barriers to international trade. Our focus is on the reverse direction: does aggregate price equalization across countries necessarily imply that there is free trade? Our answer is negative: price equalization does not imply free trade.

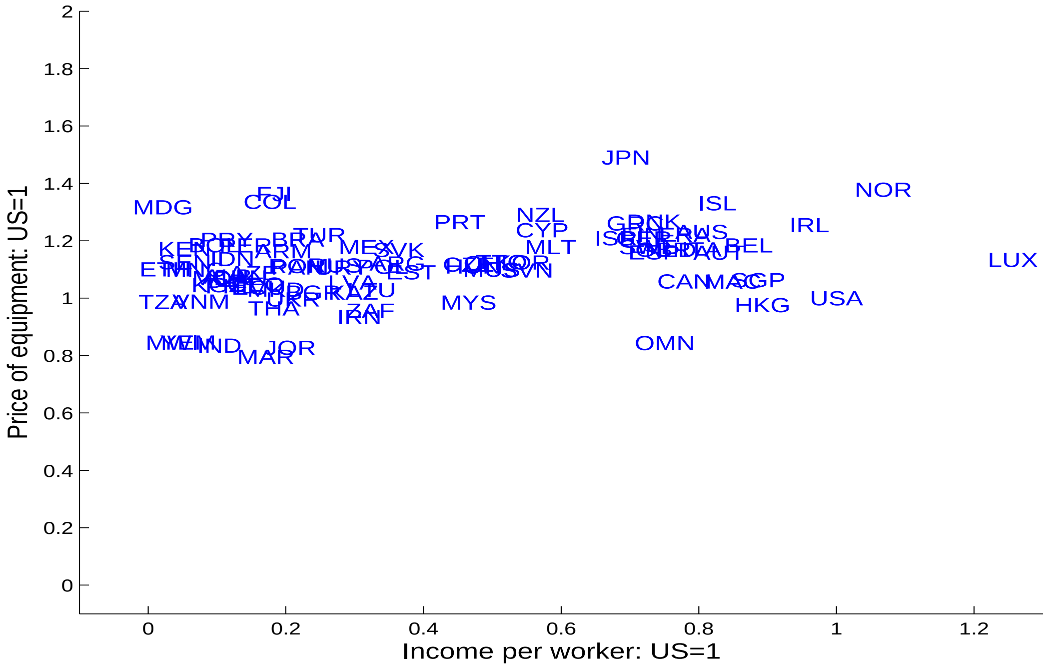
We begin by illustrating our result in the two-country model of Dornbusch, Fischer, and Samuelson (1977). We show that there exist equilibria in which there is aggregate price equalization, but there is neither free trade nor factor price equalization. Put differently, there exist many trade barrier combinations for which the aggregate prices are equal. However, each trade barrier combination delivers a different volume of trade.

Our result for the two-country case is not a mere theoretical possibility. To illustrate the empirical relevance of our result, we start with the observation that the aggregate price of capital goods looks the same across countries (see Figure 1; see also Figure 4 in Hsieh and Klenow (2007) using 1996 data). Does it then imply that there is free trade in capital goods? To answer the question we use a dynamic, multi-country model along the lines of Eaton and Kortum (2002), Alvarez and Lucas (2007), and Waugh (2010).

Our model has two tradable sectors, capital goods and non-capital goods that we label as intermediate goods. Each sector has a continuum of tradable goods. Trade is subject to iceberg costs. We calibrate the productivity and the trade barriers in each sector to deliver the observed bilateral trade flows. Even though trade barriers are not restricted in any way in our calibration, we find that the trade barriers are far from zero. This suggests that international trade in capital goods is not characterized by free trade. The barriers are positive despite the fact that the equilibrium aggregate price of capital goods in the model is roughly the same across countries. This quantitative exercise is an empirically relevant example where price equalization does not imply free trade.

To emphasize the importance of bilateral trade flows in inferring the presence (or absence) of trade barriers, suppose we assume that the trade barriers for capital goods are zero based on the fact that the *observed* capital goods prices are equal across countries, as in Hsieh and Klenow (2007). With free trade in capital goods we calibrate the productivity in each sector and the barriers in the intermediate goods sector to deliver the observed bilateral trade flows. By construction, the equilibrium capital goods prices in the model would be equal across countries. However, the capital goods trade flows in this model are much larger than the observed flows. This suggests (again) that the cross-country trade in capital goods

Figure 1: Price of capital goods (2005 international $)



is not characterized by free trade.

The rest of the paper is organized as follows. Section 2 demonstrates that in the Dornbusch, Fischer, and Samuelson two-country model it is possible to have price equalization in the presence of barriers to trade. The multi-country dynamic model is developed and solved in section 3. In section 4 we empirically implement the multi-country model and discuss the results. We consider an alternative specification in section 5 in which we assume free trade in capital goods and examine quantitatively the implications. Section 6 concludes.

2 A two-country example

We adopt the framework of Dornbusch, Fischer, and Samuelson (1977) (henceforth DFS). There are two countries, 1 and 2. Country i ($i = 1, 2$) is endowed with a labor force of size L_i, the only factor of production, which is not mobile across countries. Labor markets are competitive and labor is paid the value of its marginal product, which is denoted by w_i.

2.1 Production

In each country there is a continuum of tradable goods belonging to the unit interval indexed by $x \in [0, 1]$. The technology available to country i for producing good x is described by

$$y_i(x) = z_i(x)^{-\theta} \ell_i(x),$$

where $z_i(x)^{-\theta}$ is the productivity of good x in country i and $\ell_i(x)$ is the amount of labor used to produce good x. For each good x, $z_i(x)$ is an independent random draw from an exponential distribution with parameter λ_i. This implies that $z_i(x)^{-\theta}$ has a Fréchet distribution. The expected value of $z^{-\theta}$ is λ^θ. If $\lambda_i > \lambda_j$, then on average, country i is more efficient than country j. The parameter $\theta > 0$ governs the coefficient of variation of productivity. A larger θ implies more variation in productivity draws across countries and, hence, more room for specialization.

Since the index of the good is irrelevant, we identify goods by the vector $z = (z_1, z_2)$. So we can express y as a function of z.

$$y_i(z) = z_i^{-\theta} \ell_i(z).$$

All individual goods are used to produce a final composite good that is consumed by representative households in both countries. The technology for producing the final composite good is given by

$$Q_i = \left[\int q_i(z)^{\frac{\eta-1}{\eta}} \varphi(z) dz \right]^{\frac{\eta}{\eta-1}}, \tag{1}$$

where η is the elasticity of substitution between any two individual goods and $q_i(z)$ is the quantity of the individual good z used by country i. $\varphi(z) = \prod_j \varphi_j(z)$ is the joint density of cost draws across countries.

The marginal cost of producing one unit of good z in country j is $\frac{w_j}{z_j^{-\theta}}$. Let $\tau_{ij} \geq 1$ be the trade cost for sending a unit from country j to country i. For example, τ_{12} is the number of units that country 2 must ship in order for one unit to arrive in country 1. We assume that $\tau_{11} = \tau_{22} = 1$ and allow for the possibility that $\tau_{12} \neq \tau_{21}$. So for country j to supply one unit of good z to country i the cost is $\frac{w_j \tau_{ij}}{z_j^{-\theta}}$. Prices are denoted as follows: $p_{ij}(z)$ is the price, in country i, of good z, when the good was produced in country j.

To summarize, exogenous differences across countries are described by the productivity parameters λ_i, the endowments L_i, and the trade barriers τ_{ij}, $i \neq j$. The parameter θ is common to both countries.

2.2 International trade

Each good is purchased from the country that can deliver it at the lowest price. Hence, the price in country i of any good z is simply $p_i(z) = \min[p_{i1}(z), p_{i2}(z)]$. At this point it is useful to recall the implications for specialization in the DFS model. Define $A(x) = \frac{z_1(x)^{-\theta}}{z_2(x)^{-\theta}}$ and order the goods so that $A(x)$ is decreasing in x, i.e., the goods are ordered in terms of declining comparative advantage for country 1. (In DFS, $z_i(x)^{-\theta}$ is labeled as $1/a_i(x)$, where $a_i(x)$ is the unit labor requirement for good x.)

Country 1 will produce any good x so long as $p_{11}(x) \leq p_{12}(x) \Leftrightarrow \frac{w_1}{z_1(x)^{-\theta}} \leq \frac{w_2}{z_2(x)^{-\theta}}\tau_{12} \Leftrightarrow A(x)\tau_{12} \geq \frac{w_1}{w_2}$. This inequality helps us obtain a value $\bar{x}_1$ such that country 1 produces all goods $x \in [0, \bar{x}_1]$. Similarly, country 2 will produce any good x so long as $p_{22}(x) \leq p_{21}(x) \Leftrightarrow \frac{A(x)}{\tau_{21}} \leq \frac{w_1}{w_2}$ and we obtain a value $\bar{x}_2$ such that country 2 produces all goods $x \in [\bar{x}_2, 1]$.

Although all goods along the continuum are potentially tradable, goods in the range $[\bar{x}_2, \bar{x}_1]$ are not traded. Country 2 will import all goods $x \in [0, \bar{x}_2]$, which are precisely the goods they do not produce, while country 1 will import all goods $x \in [\bar{x}_1, 1]$. Put differently, specialization is not complete when there are trade barriers.

Equilibrium Equilibrium is characterized by a trade balance condition: $w_1L_1\pi_{12} = w_2L_2\pi_{21}$, where π_{ij} is the fraction of country $i's$ spending devoted to goods produced by country j. π_{ij} also denotes the probability that for any good z, country j's price is less than country i's. The home trade shares are $\pi_{11} = 1 - \pi_{12}$ and $\pi_{22} = 1 - \pi_{21}$.

The fraction of country i's spending devoted to goods produced by j is given by

$$\pi_{ij} = \frac{1}{1 + \left(\frac{w_i}{w_j}\right)^{-1/\theta} \tau_{ij}^{1/\theta} \left(\frac{\lambda_i}{\lambda_j}\right)} . \tag{2}$$

The trade shares given by equation (2) are clearly between zero and one, i.e., each country will specialize in some goods along the continuum.[1]

The trade shares together with the trade balance condition determine the equilibrium relative wage:

$$\frac{w_1}{w_2} = \left(\frac{L_2}{L_1}\right) \left(\frac{1 + \left(\frac{w_1}{w_2}\right)^{-1/\theta} \tau_{12}^{1/\theta} \left(\frac{\lambda_1}{\lambda_2}\right)}{1 + \left(\frac{w_1}{w_2}\right)^{1/\theta} \tau_{21}^{1/\theta} \left(\frac{\lambda_2}{\lambda_1}\right)}\right) . \tag{3}$$

It is clear that given the exogenous variables, there exists a unique relative wage $\frac{w_1}{w_2}$ that satisfies this condition.

2.3 Implications for Prices

We denote the aggregate price in country i by P_i. Since the final composite good uses a CES aggregator (1), the aggregate price is given by

$$P_i = \left[\int p_i(z)^{1-\eta} \varphi(z) dz\right]^{\frac{1}{1-\eta}} . \tag{4}$$

[1]See Mutreja, Ravikumar, Riezman, and Sposi (2012) for details of this and other derivations in this section.

In this simple two-country environment, the aggregate price for the continuum of goods in the unit interval is an *average* of the prices over three subintervals: goods produced by country 1 only, goods produced by country 2 only, and goods produced by both countries (not traded). Consider first the goods produced by country 1 only. For each of these goods the price in country 2 is equal to the price in country 1 times the barrier of shipping from 1 to 2. A larger barrier of shipping from 1 to 2 amplifies the difference in price for each of these goods, which in turn increases the aggregate price in country 2 relative to country 1. Second, consider the goods produced by country 2 only. Using a similar argument, a larger barrier of shipping from 2 to 1 decreases the aggregate price in country 2 relative to country 1. Finally, consider the goods produced by both countries. These are the goods that are not traded. The difference in the price of each of these goods is determined by the difference in the cost of factor inputs, in this case the wage. An increase in the trade barrier in either country increases the range of these nontraded goods and results in a larger increase in the aggregate price for the country that has higher costs of production.

The relative aggregate price is

$$\frac{P_1}{P_2} = \left[\frac{1 + \left(\frac{w_2}{w_1}\right)^{-1/\theta} \tau_{12}^{-1/\theta} \frac{\lambda_2}{\lambda_1}}{\tau_{21}^{-1/\theta} + \left(\frac{w_2}{w_1}\right)^{-1/\theta} \frac{\lambda_2}{\lambda_1}}\right]^{-\theta}. \tag{5}$$

If there are no trade costs, then all goods are traded and PPP holds, i.e., if $\tau_{12} = \tau_{21} = 1$, then $\bar{x}_1 = \bar{x}_2$ and $P_1/P_2 = 1$, no matter what the equilibrium factor prices are. This holds regardless of whether there is asymmetry in λ_i or in L_i.

For the case of symmetric countries (i.e., $\lambda_1 = \lambda_2, L_1 = L_2$ and $\tau_{12} = \tau_{21}$) it is easy to see from (3) and (5) that $\frac{P_1}{P_2} = \frac{w_1}{w_2} = 1$. Note that the relative aggregate price equals one even if there are trade barriers, i.e., $\tau_{12} = \tau_{21} > 1$.

An empirically relevant example is when the two countries are asymmetric. That is, $L_1 \neq L_2$, $\lambda_1 \neq \lambda_2$ and $\tau_{12} \neq \tau_{21}$. Fix $\theta = 0.5$ and suppose that the ratio of average efficiency is $(\lambda_1/\lambda_2)^\theta = 2$. For simplicity, let $L_1 = L_2 = 1$. For these parameters, aggregate prices in the two countries are equal when $\tau_{12} = 1.5$ and $\tau_{21} = 1.34$; trade is not free and the trade barriers are asymmetric. Moreover, factor prices are not equalized: $w_1/w_2 = 1.95$. The combination of trade barriers that delivers aggregate price equalization is not unique. For instance, another combination that delivers aggregate price equalization is $\tau_{12}^{'} = 2$ and $\tau_{21}^{'} = 1.75$. Under these barriers the relative factor price is $w_1^{'}/w_2^{'} = 1.99$.

While the relative aggregate price is the same under both combinations of trade barriers, the volume of trade is different. When $\tau_{12} = 1.5$ and $\tau_{21} = 1.34$, country 1 produces 90 percent of the goods and exports 20 percent of them ($\pi_{11} = 0.90$ and $\pi_{21} = 0.20$) while country 2 produces 80 percent of the goods and exports 10 percent. When $\tau_{12}^{'} = 2$ and $\tau_{21}^{'} = 1.75$, country 1 produces 97 percent of the goods and exports only 6 percent of them while country 2 produces 94 percent of the goods and exports only 3 percent.

Summary Aggregate price equalization is not suffcient to determine whether or not there is free trade. Moreover, aggregate price equalization does not guarantee that the factor prices would be equalized.

An obvious corollary is that departures from price equalization are not sufficient to pin down departures from free trade, i.e., small deviations from PPP do not necessarily imply that the world is mostly integrated. It is also easy to see that our results for the two-country case extend to the multi-country case.

Our numerical example in the asymmetric two-country case might lead one to suspect that the trade barriers have to line up in a very precise way to deliver aggregate price equalization. In other words, the two-country example is a mere theoretical curiosity and is unlikely to occur in reality. In the next section, we show that our results are empirically relevant. In particular, we develop a multi-country model and show that when we discipline the model with observed bilateral trade flows, there are significant barriers to international trade in capital goods. Yet, capital goods prices in the model look similar across countries, as in Figure 1.

3 Multi-country dynamic model

Our model extends the framework of Eaton and Kortum (2002), Alvarez and Lucas (2007), and Waugh (2010) to two tradable sectors and embeds it into a neoclassical growth framework. There are I countries indexed by $i = 1, \ldots, I$. Time is discrete and runs from $t = 0, 1, \ldots, \infty$. There are two tradable sectors, capital goods and non-capital goods; we label the latter as intermediate goods. The capital goods and intermediate goods sectors are denoted by e and m, respectively. The final good in each country, denoted by f, is non-tradable and is used only for consumption. Within each tradable sector, there is a continuum of tradable individual goods. Individual intermediate goods are aggregated into a composite intermediate good, and the composite intermediate good is used as an input in all other sectors. Individual capital goods are aggregated into a composite capital good, which is used to augment the capital stock.

Each country i has a representative household endowed with a measure N_{it} of workers at time t. The measure grows over time at the rate n. Each worker has human capital h_{it} that grows over time at the rate g. Effective labor is denoted by $L_{it} = N_{it}h_{it}$, which is immobile across countries but perfectly mobile across sectors. The representative household owns its country's capital stock, denoted by K_{it}, which is rented to domestic firms. Earnings from capital and labor are spent on consumption and investment. Investment augments the capital stock.

From now on, all quantities are reported in efficiency units (e.g., $k = K/L$ is the capital stock per effective worker); and, country and time subscripts are omitted when there is no confusion.

3.1 Technologies

Each individual capital good is indexed along a continuum by v, while each individual intermediate good is indexed along a continuum by u. As in the previous section, the indices u and v represent idiosyncratic *cost* draws that are random variables drawn from country- and sector-specific distributions, with densities denoted by φ_{bi} for $b \in \{e, m\}$ and $i = 1, \ldots, I$. We denote the joint density across countries for each sector by φ_b.

Composite goods All individual capital goods along the continuum are aggregated into a composite capital good E according to

$$E = \left[\int q_e(v)^{\frac{\eta-1}{\eta}} \varphi_e(v) dv \right]^{\frac{\eta}{\eta-1}},$$

where $q_e(v)$ denotes the quantity of good v. Similarly, all individual intermediate goods along the continuum are aggregated into a composite intermediate good M according to

$$M = \left[\int q_m(u)^{\frac{\eta-1}{\eta}} \varphi_m(u) du \right]^{\frac{\eta}{\eta-1}}.$$

Individual tradable goods The technologies for producing individual goods in each sector are given by

$$\begin{aligned} e(v) &= v^{-\theta} \left[k_e(v)^{\alpha} \ell_e(v)^{1-\alpha} \right]^{\nu_e} M_e(v)^{1-\nu_e} \\ m(u) &= u^{-\theta} \left[k_m(u)^{\alpha} \ell_m(u)^{1-\alpha} \right]^{\nu_m} M_m(u)^{1-\nu_m}. \end{aligned}$$

For each factor used in production, the subscript denotes the sector that uses the factor, and the argument in the parentheses denotes the index of the good along the continuum. For example, $k_m(u)$ is the amount of capital used to produce intermediate good u. The parameter $\nu \in (0, 1)$ determines the value added in production, while $\alpha \in (0, 1)$ determines capital's share in value added.

As in the two-country example of section 2, v has an exponential distribution with parameter $\lambda_{ei} > 0$, while u has an exponential distribution with parameter $\lambda_{mi} > 0$, in country i. Countries for which $\lambda_{ei}/\lambda_{mi}$ is high will tend to be net exporters of capital goods and net importers of intermediate goods. We assume that the parameter θ is the same across the two sectors and in all countries.

Final good The non-tradable final good is produced using capital, labor, and intermediate goods according to

$$F = \left(k_f^{\alpha} \ell_f^{1-\alpha}\right)^{\nu_f} M_f^{1-\nu_f}.$$

Capital accumulation Capital goods augment the stock of capital according to

$$(1+n)(1+g)k_{t+1} = (1-\delta)k_t + x_t,$$

where δ is the rate at which capital depreciates each period and x_t denotes the quantity of the composite capital good in period t.

3.2 Preferences

The representative household in country i derives utility from consumption of the final good according to

$$\sum_{t=0}^{\infty} \beta^t (1+n)^t \log(c_t),$$

where c_t is consumption of the final good at time t, and β is the period discount factor, which satisfies $1/\beta > 1+n$.

3.3 International Trade

Country i purchases all capital and intermediate goods from the least cost suppliers. The purchase price depends on the unit cost of the producer, as well as trade barriers.

Barriers to trade are denoted by τ_{bij}, where $\tau_{bij} > 1$ is the amount of good in sector b that country j must export in order for one unit to arrive in country i. As a normalization we assume that $\tau_{bii} = 1$ for all i and $b \in \{e, m\}$. We also assume that the triangle inequality holds: $\tau_{bij}\tau_{bjl} \geq \tau_{bil}$.

Unlike the two-country model, specialization in production of any single good is not confined to just one country. With multiple countries, there may be multiple exporters of the same good. For example, Germany may export tractors to Egypt, while the US may export tractors to Mexico. Even if the production cost of the tractor is the same in Germany and the US, Egypt may find it cheaper to import from Germany while Mexico may find it cheaper to import from the US due to the structure of bilateral trade costs.

We focus on a steady-state competitive equilibrium. Informally, a steady-state equilibrium is a set of prices and allocations that satisfy the following conditions: 1) The representative household maximizes its lifetime utility, taking prices as given; 2) firms maximize profits, taking factor prices as given; 3) domestic markets for factors and final goods clear; 4) total trade is balanced in each country; and 5) quantities in efficiency units are constant over time. Note that condition 4 allows for the possibility of trade imbalances at the sectoral level, but a trade surplus in one sector must be offset by an equal deficit in the other sector.

Two remarks are in order here. First, we have two tradable sectors in the model to be consistent with the fact that some countries are net exporters of capital goods while others are net exporters of non-capital goods. Second, capital goods in our model are durable while intermediate goods are not. To capture the intertemporal tradeoffs faced by the household in choosing the optimal quantity of capital goods, we use a dynamic model.

In the remainder of this section we describe each steady state condition from country i's point of view.

3.4 Household optimization

At the beginning of each time period, the capital stock is predetermined and is rented to domestic firms in all sectors at the competitive rental rate r_{eit}. Each period the household splits its income between consumption, c_{it}, which has price P_{fit}, and investment, x_{it}, which has price P_{eit}.

The household is faced with a standard consumption-savings problem, the solution to which is characterized by an Euler equation, the budget constraint, and a capital accumulation equation. In steady state these conditions are as follows:

$$r_{ei} = \left[\frac{1+g}{\beta} - (1-\delta)\right] P_{ei},$$

$$P_{fi}c_i + P_{ei}x_i = w_i + r_{ei}k_i,$$

$$x_i = [(1+n)(1+g) - (1-\delta)]k_i.$$

3.5 Firm optimization

Denote the price for an individual intermediate good u that was produced in country j and purchased by country i by $p_{mij}(u)$. Then, $p_{mij}(u) = p_{mjj}(u)\tau_{mij}$, where p_{mjj} is the marginal cost of production in country j. Since each country purchases each individual good from the least cost supplier of the good, the actual price in country i for the individual intermediate good u is $p_{mi}(u) = \min_{j=1,\ldots,I}[p_{mjj}(u)\tau_{mij}]$. Similarly, the price of capital good v is $p_{ei}(v) = \min_{j=1,\ldots,I}[p_{ejj}(v)\tau_{eij}]$.

The price of each composite good then is

$$P_{ei} = \left[\int p_{ei}(v)^{1-\eta}\varphi_e(v)dv\right]^{\frac{1}{1-\eta}} \quad \text{and} \quad P_{mi} = \left[\int p_{mi}(u)^{1-\eta}\varphi_m(u)du\right]^{\frac{1}{1-\eta}}.$$

We explain how we derive the aggregate prices for each country in appendix A. Given the assumption on the country-specific densities, φ_{mi} and φ_{ei}, our model implies

$$P_{ei} = AB_e\left[\sum_j (d_{ej}\tau_{eij})^{-1/\theta}\lambda_{ej}\right]^{-\theta} \quad \text{and} \quad P_{mi} = AB_m\left[\sum_j (d_{mj}\tau_{mij})^{-1/\theta}\lambda_{mj}\right]^{-\theta},$$

where the unit cost d_{bi} for sector b is given by $d_{bi} = \left(r_{ei}^{\alpha}w_i^{1-\alpha}\right)^{\nu_b} P_{mi}^{1-\nu_b}$. The terms B_b for each sector are constant across countries and are given by $B_b = (\alpha\nu_b)^{-\alpha\nu_b}((1-\alpha)\nu_b)^{(\alpha-1)\nu_b}(1-\nu_b)^{\nu_b-1}$. Finally, the constant term $A = \Gamma(1+\theta(1-\eta))^{\frac{1}{1-\eta}}$, where $\Gamma(\cdot)$ is the gamma function. We restrict parameters such that $A > 0$.

The price of the non-traded final good is simply its marginal cost, which is given by

$$P_{fi} = B_f d_{fi}.$$

For each tradable sector the fraction of country i's expenditure spent on goods from country j is given by

$$\pi_{eij} = \frac{(d_{ej}\tau_{eij})^{-1/\theta}\lambda_{ej}}{\sum_l (d_{el}\tau_{eil})^{-1/\theta}\lambda_{el}} \quad \text{and} \quad \pi_{mij} = \frac{(d_{mj}\tau_{mij})^{-1/\theta}\lambda_{mj}}{\sum_l (d_{ml}\tau_{mil})^{-1/\theta}\lambda_{ml}}.$$

An alternative interpretation of π_{bij} is that it is the fraction of sector b goods that j supplies to i. We describe how to derive trade shares in appendix A.

3.6 Equilibrium

We first define total factor usage in the intermediate goods sector in country i as follows:

$$\ell_{mi} = \int \ell_{mi}(u)\varphi_{mi}(u)du$$
$$k_{mi} = \int k_{mi}(u)\varphi_{mi}(u)du$$
$$M_{mi} = \int M_{mi}(u)\varphi_{mi}(u)du,$$

where $\ell_{mi}(u)$, $k_{mi}(u)$, and $M_{mi}(u)$ refer to the amount of labor, capital, and composite intermediate good used in country i to produce the individual intermediate good u. Note that each of $\ell_{mi}(u)$, $k_{mi}(u)$, and $M_{mi}(u)$ will be zero if country i imports good u. Total factor usage in the capital goods sector (ℓ_{ei}, k_{ei}, and M_{ei}) are defined analogously.

The factor market clearing conditions are

$$\begin{aligned} \ell_{ei} + \ell_{mi} + \ell_{fi} &= 1 \\ k_{ei} + k_{mi} + k_{fi} &= k_i \\ M_{ei} + M_{mi} + M_{fi} &= M_i. \end{aligned}$$

The left-hand side of each of the previous equations is simply the factor usage by each sector, while the right-hand side is the factor availability.

The next two conditions require that the quantity of consumption and investment goods purchased by the household must equal the amounts available:

$$c_i = F_i \text{ and } x_i = E_i.$$

Aggregating over all producers of individual goods in each sector of country i and using the fact that each producer minimizes costs, the factor demands at the sectoral level are described by

$$\begin{aligned} L_i w_i \ell_{bi} &= (1-\alpha)\nu_b Y_{bi} \\ L_i r_{ei} k_{bi} &= \alpha \nu_b Y_{bi} \\ L_i P_{mi} M_{bi} &= (1-\nu_b) Y_{bi}, \end{aligned}$$

where Y_{bi} is the nominal value of output in sector b. Imposing the goods market clearing condition for each sector implies that

$$\begin{aligned} Y_{ei} &= \sum_{j=1}^{I} L_j P_{ej} E_j \pi_{eji} \\ Y_{mi} &= \sum_{j=1}^{I} L_j P_{mj} M_j \pi_{mji} \\ Y_{fi} &= L_i P_{fi} F_i. \end{aligned}$$

The total expenditure by country j on capital goods is $L_j P_{ej} E_j$, and π_{eji} is the fraction spent by country j on capital goods imported from country i. Thus, the product, $L_j P_{ej} E_j \pi_{eji}$, is the total value of capital goods trade flows from country i to country j.

To close the model we impose balanced trade country by country.

$$L_i P_{ei} E_i \sum_{j \neq i} \pi_{eij} + L_i P_{mi} M_i \sum_{j \neq i} \pi_{mij} = \sum_{j \neq i} L_j P_{ej} E_j \pi_{eji} + \sum_{j \neq i} L_j P_{mj} M_j \pi_{mji}$$

The left-hand side denotes country i's imports of capital goods and intermediate goods, while the right-hand side denotes country i's exports. This condition allows for trade imbalances at the sectoral level within each country.

This completes the description of the steady-state equilibrium in our model. We next turn to calibration of the model.

4 Calibration

We calibrate our model using data for a set of 84 countries for the year 2005. This set includes both developed and developing countries and accounts for about 80 percent of the world GDP as computed from version 6.3 of the Penn World Tables (see Heston, Summers, and Aten, 2009).

Our classification of capital goods is the category "Machinery & equipment" in the International Comparisons Program (ICP). Prices of capital goods are taken from the 2005 benchmark study of the Penn World Tables. To link prices with trade and production data, we use four-digit ISIC revision 3 categories. Production data are taken from INDSTAT4, a database maintained by UNIDO. The corresponding trade data are available from UN Comtrade at the four-digit SITC revision 4 level. We follow the correspondence created by Affendy, Sim Yee, and Satoru (2010) to link SITC with ISIC categories. Intermediate goods data correspond to the manufacturing categories other than equipment, as listed by the ISIC revision 3. For details on specific sources, list of countries, and how we construct our data, see appendix B.

4.1 Common parameters

We begin by describing the parameter values that are common to all countries; see Table 1. We set the growth rate in the labor force n to 0.016. This is computed by using the average geometric growth rate in world population from 2000 through 2007. We set the growth rate of efficiency, g, equal to 0.02, the average growth rate for the US over the past 100 years. The discount factor β is set to 0.96, in line with common values in the literature. Following Alvarez and Lucas (2007), we have set η equal to 2. None of these parameters — n, g, β, or η — are quantitatively important for the question addressed in this paper. However, they must satisfy the following assumptions: $1/\beta > 1 + n$ and $1 + \theta(1 - \eta) > 0$.

Capital's share α is set at 1/3 as in Gollin (2002). Using capital stock data from the BEA, Greenwood, Hercowitz, and Krusell (1997) measure the rate of depreciation for equipment. We set $\delta = 0.12$ in accordance with their estimates.

The parameters ν_m, ν_e, and ν_f, respectively, control the value added in intermediate goods, capital goods, and final goods production. To calibrate ν_m and ν_e, we employ the data on value added and total output available in INDSTAT 4 2010 database. To calibrate ν_f we employ input-output tables for OECD countries. These tables are available through STAN, a database maintained by the OECD. We use the tables for the period "mid-2000s." The share of intermediates in non-manufacturing output is $1-\nu_f$. Our estimate of ν_f is 0.9.

The parameter θ controls the dispersion in efficiency levels. We follow Alvarez and Lucas (2007) and set this parameter at 0.15. This value lies in the middle of the estimates in Eaton and Kortum (2002).

Table 1: Common parameters

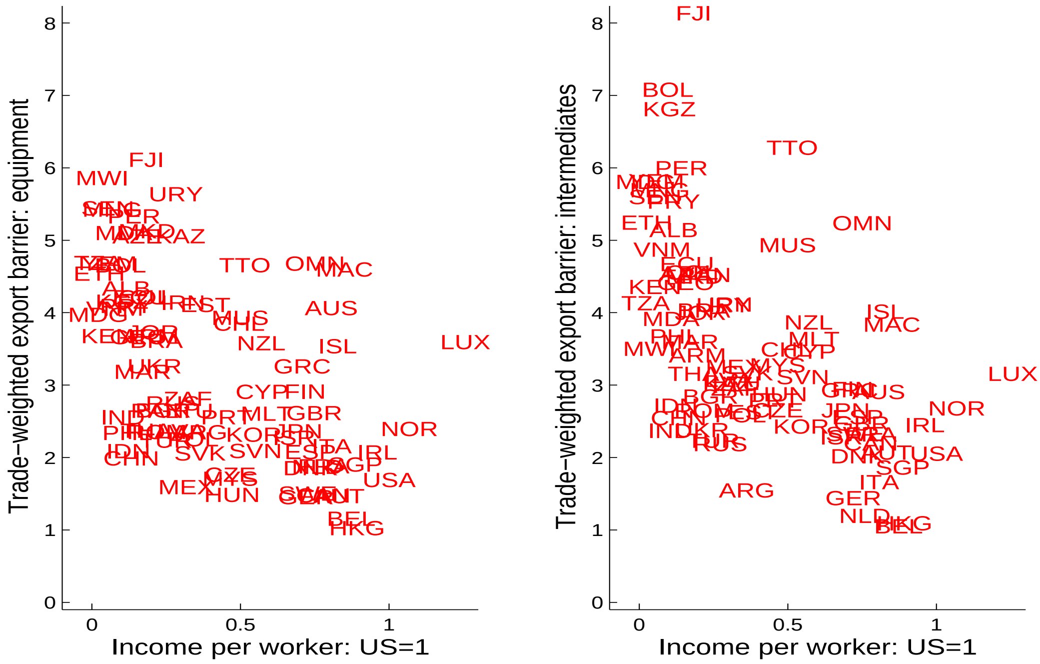
Parameter	Description	Value
α	k's share	1/3
ν_m	k and ℓ's share in intermediate goods	0.31
ν_e	k and ℓ's share in capital goods	0.31
ν_f	k and ℓ's share in final goods	0.90
δ	depreciation rate of capital	0.12
θ	variation in efficiency levels	0.15
β	discount factor	0.96
n	growth rate of labor force	0.016
g	growth rate of human capital	0.02
η	elasticity of subs in aggregator	2

4.2 Country-specific parameters

We take the labor force N from Penn World Tables version 6.3 (PWT63, see Heston, Summers, and Aten, 2009). To construct measures of human capital h, we follow Caselli (2005) by converting data on years of schooling, from Barro and Lee (2010), into measures of human capital using Mincer returns. Effective labor is then $L = Nh$; see appendix B for details.

The remaining parameters include the productivity parameters λ_{ei} and λ_{mi} as well as the bilateral trade barriers τ_{eij} and τ_{mij}. We calibrate these using the methodology employed by Eaton and Kortum (2002) and Waugh (2010). The basic idea is to pick these parameters to match the pattern of bilateral trade flows using a parsimonious specification for trade barriers. The specification allows for the possibility of free trade. See appendix C for details.

Figure 2: Trade-weighted export barriers for capital goods and intermediates



4.3 Model fit

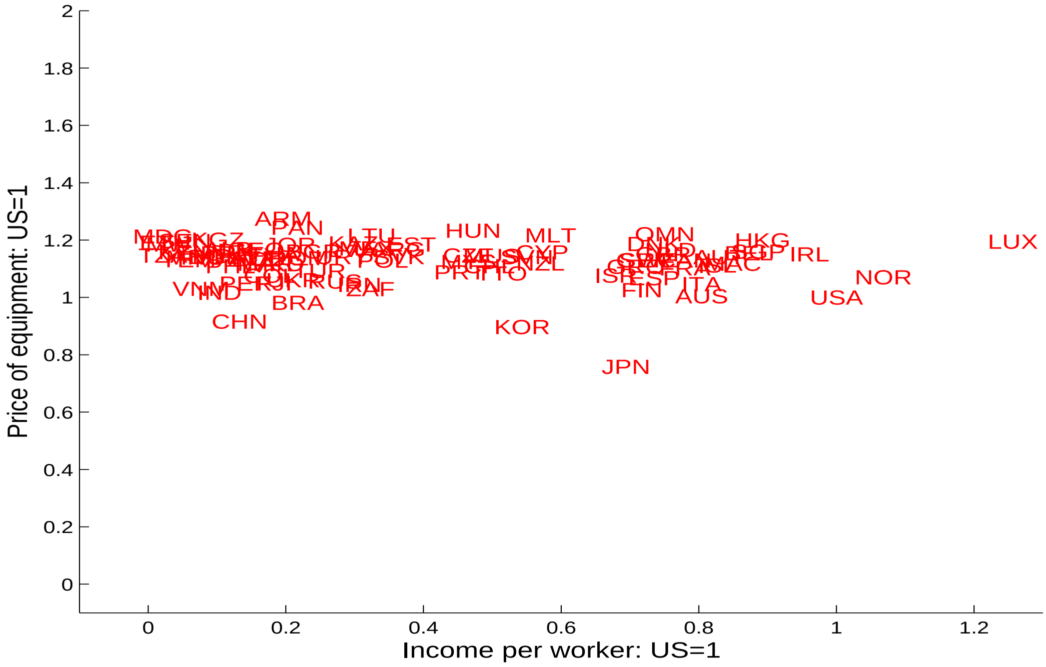
The model generates the observed home trade shares in both capital goods and intermediate goods. The correlation between model and data is 0.87 for capital goods home trade shares and 0.79 for intermediate goods home trade shares.

Barriers to trade Trade barriers implied by our model are significant. For country i, we compute the trade-weighted export cost as $\frac{1}{EX_j}\sum_{i\neq j}\tau_{ij}EX_{ij}$, where EX_{ij} is exports from j to i and EX_j is j's total exports. This is done for each sector and reported in Figure 2. One can see from Figure 2 that the barriers to export both capital goods and intermediate goods are not only substantial, but are also systematically larger in poor countries. In the next section we show that the calibrated model produces prices of capital goods that are in line with the data.

4.4 Implications for prices

Figure 3 illustrates the aggregate price of capital goods in the model. The prices in the model are consistent with the data in Figure 1. The prices are roughly constant across countries despite the fact that there are significant trade barriers in the capital goods sector. The elasticity of the price of capital goods with respect to income per worker is 0.04 in the data and -0.01 in the model. This happens in spite of the fact that there are significant trade

Figure 3: Price of capital goods



barriers as well as the fact that wages are highly correlated with development: in the model, the elasticity of the wage rate with respect to income per worker is 1.81.

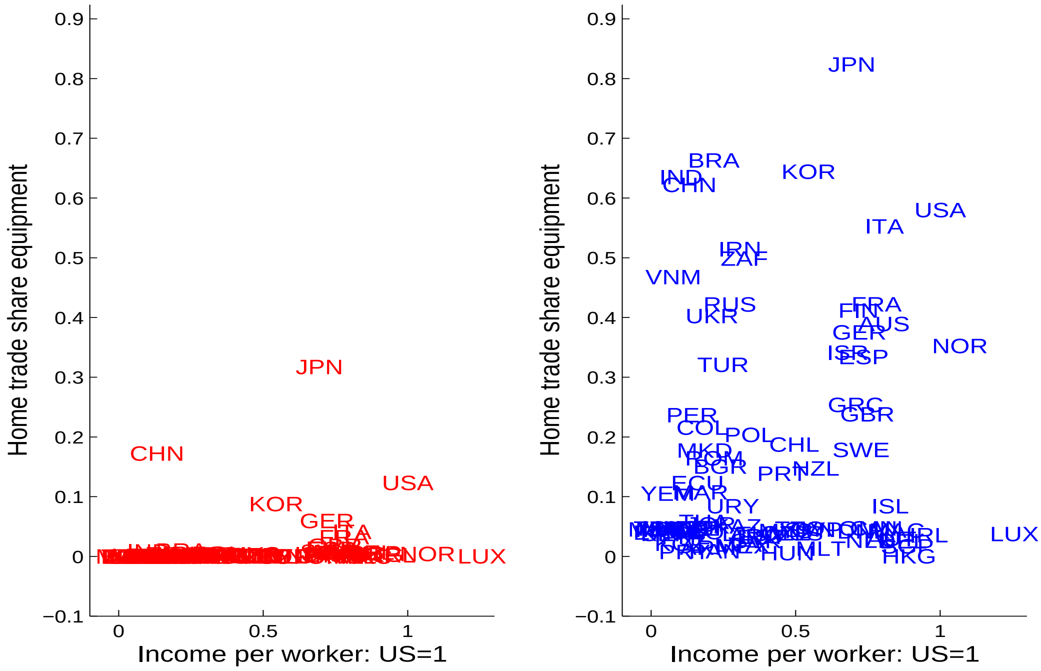
The quantitative implications of our model for prices confirm that the results in section 2 are more than a mere theoretical possibility. When applied to the capital goods sector, price equalization does not imply free trade. In the next section we show that assuming free trade in capital goods will imply, by construction, equal prices but will be inconsistent with the quantity of trade.

5 Alternative approach

In the previous section we have shown that price equalization occurs despite the existence of significant trade barriers. An alternative approach is to assume that there are no barriers to trade in capital goods since the observed price of capital goods seems to be the same across countries (see Figure 1 and Hsieh and Klenow (2007)). To understand the implications of this approach, we re-calibrate the model under the assumption that there is free trade in capital goods. That is, we set $\tau_{eij} = 1$ and re-calibrate $\lambda_{mi}, \lambda_{ei}$, and τ_{mij} to match the same targets as in the previous section.

Given our assumption, PPP applies to our model and the price of capital goods will necessarily be equal across countries. However, the model is not consistent with the observed pattern of trade in capital goods. The model implies low home trade shares and, hence, large trade flows (see Figure 4). However, the data show that home trade shares are much larger, indicating that there is far less trade in capital goods in the data than that predicted by the model. The correlation between model and data for home trade shares is 0.61 for capital goods and 0.48 for intermediate goods. Both these correlations are lower compared with the benchmark case in the previous section. The variance of capital goods home trade share in the alternative model is only 5 percent of that in the data; the corresponding number for intermediate goods is only 1 percent.

Figure 4: Home trade share in capital goods under free trade (model left, data right)



6 Conclusion

This paper begins with the observation that the aggregate price of capital goods looks similar across countries. We show theoretically, using a simple two-country model, that prices being equal across countries does not imply that there is free trade. We then demonstrate that despite roughly similar capital goods prices there is not free trade in capital goods across countries. We demonstrate this point quantitatively in two different ways.

We develop a multi-country Eaton-Kortum model with trade in capital goods and intermediate goods. Using data from 84 countries, we calibrate productivity and trade barriers to match the observed bilateral trade flows. We find that the calibrated trade barriers are substantial. We then show the same result in a second way. We assume free trade in capital goods and re-calibrate productivity and trade barriers in the intermediate goods sector to match the observed bilateral trade flows. We find that the capital goods trade flows in this model are much larger than the observed flows, suggesting that free trade in capital goods is not a reasonable assumption.

Our results demonstrate that price data alone are not sufficient to determine the barriers to trade. Trade flow data interpreted through the lens of a model can pin down the magnitude of the barriers.

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Appendix

A Derivations

In this section we show how to derive analytical expressions for aggregate prices and trade shares. The following derivations rely on three properties of the exponential distribution.

1) $u \sim \exp(\mu)$ and $k > 0 \Rightarrow ku \sim \exp(\mu/k)$.

2) $u_1 \sim \exp(\mu_1)$ and $u_2 \sim \exp(\mu_2) \Rightarrow \min\{u_1, u_2\} \sim \exp(\mu_1 + \mu_2)$.

3) $u_1 \sim \exp(\mu_1)$ and $u_2 \sim \exp(\mu_2) \Rightarrow \Pr(u_1 \leq u_2) = \frac{\mu_1}{\mu_1+\mu_2}$.

A.1 Aggregate prices

Here we derive the aggregate price for intermediate goods, P_{mi}. The aggregate price for capital goods can be derived in a similar manner. Cost minimization by producers of tradable good u implies a unit cost of an input bundle used in sector m, which we denote by d_{mi}.

Perfect competition implies that price in country i of the individual intermediate good u, when purchased from country j, equals unit cost in country j times the trade barrier

$$p_{mij}(u) = B_m d_{mj} \tau_{mij} u_j^{\theta},$$

where B_m is a collection of constant terms. The trade structure implies that country i purchases each intermediate good u from the least cost supplier, so the price of good u is

$$p_{mi}(u)^{1/\theta} = (B_m)^{1/\theta} \min_j \left[(d_{mj}\tau_{mij})^{1/\theta} u_j \right].$$

Since $u_j \sim \exp(\lambda_{mj})$, it follows from property 1 that

$$(d_{mj}\tau_{mij})^{1/\theta} u_j \sim \exp\left((d_{mj}\tau_{mij})^{-1/\theta} \lambda_{mj} \right).$$

Then, property 2 implies that

$$\min_j \left[(d_{mj}\tau_{mij})^{1/\theta} u_j \right] \sim \exp\left(\sum_j (d_{mj}\tau_{mij})^{-1/\theta} \lambda_{mj} \right).$$

Lastly, appealing to property 1 again,

$$p_{mi}(u)^{1/\theta} \sim \exp\left(B_m^{-1/\theta} \sum_j (d_{mj}\tau_{mij})^{-1/\theta} \lambda_{mj} \right). \tag{A.1}$$

Now let $\mu_{mi} = (B_m)^{-1/\theta} \sum_j (d_{mj}\tau_{mij})^{-1/\theta} \lambda_{mj}$. Then

$$P_{mi}^{1-\eta} = \mu_{mi} \int t^{\theta(1-\eta)} \exp(-\mu_{mi} t)\, dt.$$

Apply a change of variables so that $\omega_i = \mu_{mi} t$ and obtain

$$P_{mi}^{1-\eta} = (\mu_{mi})^{\theta(\eta-1)} \int \omega_i^{\theta(1-\eta)} \exp(-\omega_i) d\omega_i.$$

Let $A = \Gamma(1 + \theta(1-\eta))^{1/(1-\eta)}$, where $\Gamma(\cdot)$ is the Gamma function. Therefore,

$$\begin{aligned} P_{mi} &= A(\mu_{mi})^{-\theta} \\ &= AB_m \left[\sum_j (d_{mj}\tau_{mij})^{-1/\theta} \lambda_{mj} \right]^{-\theta}. \end{aligned}$$

A.2 Trade shares

We now derive the trade shares π_{mij}, the fraction of i's total spending on intermediate goods that was obtained from country j. Due to the law of large numbers, the fraction of goods that i obtains from j is also the probability, that for any intermediate good u, country j is the least cost supplier. Mathematically,

$$\begin{aligned} \pi_{mij} &= \Pr\left\{ p_{mij}(u) \leq \min_l [p_{mil}(u)] \right\} \\ &= \frac{(d_{mj}\tau_{mij})^{-1/\theta} \lambda_{mj}}{\sum_l (d_{ml}\tau_{mil})^{-1/\theta} \lambda_{ml}}, \end{aligned}$$

where we have used equation (A.1) along with properties 2 and 3. Trade shares in the capital goods sector are derived identically.

B Data

This section describes our data sources as well as how we map our model to the data.

Categories Capital goods in our model to correspond with "Machinery & equipment" in the ICP, (http://siteresources.worldbank.org/ICPEXT/Resources/ICP_2011.html). We identify the corresponding categories according to 4 digit ISIC revision 3 (for a complete list go to http://unstats.un.org/unsd/cr/registry/regcst.asp?cl=2). These ISIC categories for capital goods are: 2811, 2812, 2813, 2893, 2899, 291*, 292*, 30**, 31**, 321*, 322*, 323*, 331*, 332*, 3420, 351*, 352*, 353*, and 3599. Intermediate goods are identified as all of manufacturing categories 15**-37**, excluding those that are identified as capital goods. Final goods in our model correspond to the remaining ISIC categories excluding capital goods and intermediate goods.

Prices Data on the prices of capital goods across countries are constructed by the ICP (available at http://siteresources.worldbank.org/ICPEXT/Resources/ICP_2011.html). We use the variable `PX.WL`, which is the PPP price of "Machinery & equipment", world price equals 1. The price of final goods in our model is taken to be the price consumption goods from PWT63 as the variable `PC`.

Human Capital We use data on years of schooling from Barro and Lee (2010) to construct human capital measures. We take average years of schooling for the population age 25 and up and convert into measures of human capital using $h = \exp(\phi(s))$, where ϕ is piecewise linear in average years of schooling s. This method is identical to the one used by Hall and Jones (1999) and Caselli (2005).

National Accounts PPP income per worker is taken from PWT63 as the variable `RGDPWOK`. The size of the workforce is constructed by taking other variables from PWT63 as follows: number of workers equals 1000*`POP`*`RGDPL`/`RGDPWOK`.

Production Data on manufacturing production is taken from INDSTAT4, a database maintained by UNIDO (2010) at the four-digit ISIC revision 3 level. We aggregate the four-digit categories into either capital goods or intermediate goods using the classification method discussed above. Most countries are taken from the year 2005, but for this year some countries have no available data. For such countries we look at the years 2002, 2003, 2004, and 2006, and take data from the year closest to 2005 for which it is available, then convert into 2005 values by using growth rates of total manufacturing output over the same period.

Trade barriers Trade costs are assumed to be a function of distance, common language, and shared border. All three of these gravity variables are taken from Centre D'Etudes Prospectives Et D'Informations Internationales (http://www.cepii.fr/welcome.htm).

Trade Flows Data on bilateral trade flows are obtained from UN Comtrade for the year 2005 (http://comtrade.un.org/). All trade flow data is at the four-digit SITC revision 2 level, and then aggregated into respective categories as either capital goods or intermediate goods. In order to link trade data to production data we employ the correspondence provided by Affendy, Sim Yee, and Satoru (2010) which links ISIC revision 3 to SITC revision 2 at the 4 digit level.

Construction of Trade Shares The empirical counterpart to the model variable π_{mij} is constructed following Bernard, Eaton, Jensen, and Kortum (2003) (recall that this is the fraction of country i's spending on intermediates that was produced in country j). We divide the value of country i's imports of intermediates from country j, by i's gross production of intermediates minus i's total exports of intermediates (for the whole world) plus i's total imports of intermediates (for only the sample) to arrive at the bilateral trade share. Trade shares for the capital goods sector are obtained similarly.

Table 2: List of Countries

Country	Isocode
Albania	ALB
Argentina	ARG
Armenia	ARM
Australia	AUS
Austria	AUT
Azerbaijan	AZE
Belgium	BEL
Bolivia	BOL
Brazil	BRA
Bulgaria	BGR
Canada	CAN
Chile	CHL
China	CHN
China (Hong Kong SAR)	HKG
China (Macao SAR)	MAC
Colombia	COL
Cyprus	CYP
Czech Republic	CZE
Denmark	DNK
Ecuador	ECU
Estonia	EST
Ethiopia	ETH
Fiji	FJI
Finland	FIN
France	FRA
Georgia	GEO
Germany	GER
Greece	GRC
Hungary	HUN

Continued on Next Page...

Table 2 – Continued

Country	**Isocode**
Iceland	ISL
India	IND
Indonesia	IDN
Iran	IRN
Ireland	IRL
Israel	ISR
Italy	ITA
Japan	JPN
Jordan	JOR
Kazakhstan	KAZ
Kenya	KEN
Kyrgyzstan	KGZ
Latvia	LVA
Lithuania	LTU
Luxembourg	LUX
Madagascar	MDG
Malawi	MWI
Malaysia	MYS
Malta	MLT
Mauritius	MUS
Mexico	MEX
Mongolia	MNG
Morocco	MAR
Netherlands	NLD
New Zealand	NZL
Norway	NOR
Oman	OMN
Panama	PAN
Paraguay	PRY
Peru	PER
Philippines	PHL
Poland	POL
Portugal	PRT
Republic of Korea	KOR
Republic of Moldova	MDA
Romania	ROM
Russia	RUS
Senegal	SEN
Singapore	SGP
Slovak Republic	SVK
Slovenia	SVN
South Africa	ZAF
Spain	ESP
Sweden	SWE
Thailand	THA
Macedonia	MKD
Trinidad and Tobago	TTO
Turkey	TUR
Ukraine	UKR
United Kingdom	GBR
Tanzania	TZA
United States of America	USA
Uruguay	URY
Viet Nam	VNM
Yemen	YEM

C Calibrating country-specific parameters

In this section we discuss our strategy for recovering the parameters that vary across countries: average productivity (λ_{ei} and λ_{mi}) and trade barriers (τ_{eij} and τ_{mij}).

C.1 Estimating trade costs

As we show in appendix A, the fraction of sector b goods that country i purchases from country j is given by

$$\pi_{bij} = \frac{(d_{bj}\tau_{bij})^{-1/\theta}\lambda_{bj}}{\sum_l (d_{bl}\tau_{bil})^{-1/\theta}\lambda_{bl}}.$$

From this we can infer that

$$\frac{\pi_{bij}}{\pi_{bii}} = \left(\frac{d_{bj}}{d_{bi}}\right)^{-1/\theta}\left(\frac{\lambda_{bj}}{\lambda_{bi}}\right)(\tau_{bij})^{-1/\theta}. \tag{C.1}$$

We specify a parsimonious functional form for trade costs as follows

$$\log \tau_{bij} = \gamma_{b,ex} ex_j + \gamma_{b,dis,k} dis_{ij,k} + \gamma_{b,brd} brd_{ij} + \gamma_{b,lang} lang_{ij} + \varepsilon_{bij},$$

where ex_j is an exporter fixed effect dummy. The variable $dis_{ij,k}$ is a dummy taking a value of one if two countries i and j are in the k'th distance interval. The six intervals, in miles, are [0,375); [375,750); [750,1500); [1500,3000); [3000,6000); and [6000,maximum). (The distance between two countries is measured in miles using the great circle method.) The variable brd is a dummy for common border, $lang$ is a dummy for common language, and ε is assumed to be orthogonal to the previous variables, and captures other factors which affect trade costs. Each of these data, except for trade flows, are taken from the Gravity Data set available at http://www.cepii.fr.

Given this, and taking logs on both sides of (C.1) we obtain a form ready for estimation

$$\log\left(\frac{\pi_{bij}}{\pi_{bii}}\right) = \underbrace{\log\left(d_{bj}^{-1/\theta}\lambda_{bj}\right)}_{F_{bj}} - \underbrace{\log\left(d_{bi}^{-1/\theta}\lambda_{bi}\right)}_{F_{bi}}$$
$$-\frac{1}{\theta}\left[\gamma_{b,ex} ex_j + \gamma_{b,dis,k} dis_{ij} + \gamma_{b,brd} brd_{ij} + \gamma_{b,lang} lang_{ij} + \varepsilon_{bij}\right].$$

To compute the empirical counterpart to π_{bij}, we follow Bernard, Eaton, Jensen, and Kortum (2003) (see appendix B). We recover the fixed effects F_{bi} as country specific fixed effects using Ordinary Least Squares, sector-by-sector. Observations for which the recorded trade flows are zero are omitted from the regression. The fixed effects will be used to recover the average productivity terms λ_{bi} as described below.

The regression for the capital goods sector produces an R^2 of 0.79 with 5924 usable observations, while the regression for the intermediate goods sector produces an R^2 of 0.69 with 6498 usable observations.

C.2 Calibrating productivity

With the trade costs $\hat{\tau}_{bij}$ and the fixed effects $\hat{F}_{bi}$ in hand we use the model's structure to recover λ_{bi}, for $b \in \{e, m\}$. By definition $\hat{F}_{bi} = \log\left(d_{bi}^{-1/\theta}\lambda_{bi}\right)$. The recovered unit costs along with the estimated fixed effects $\hat{F}_{bi}$ allow us to infer the productivity terms, i.e., once we know d_{bi} we can infer λ_{bi}. Firstly, for $b \in \{e, m\}$, we construct auxiliary prices as follows:

$$\hat{P}_{bi} = AB_b \left[\sum_j \exp(\hat{F}_{bj})\hat{\tau}_{bij}^{-1/\theta}\right]^{-\theta}.$$

Next we use the no arbitrage (Euler) condition, $\hat{r}_{ei} = \left[\frac{1+g}{\beta} - (1-\delta_e)\right]\hat{P}_{ei}$. Since $d_{bi} = \left(r_{ei}^{\alpha}w_i^{1-\alpha}\right)^{\nu_b} P_{mi}^{1-\nu_b}$ we are left with the task of recovering an auxiliary wage w_i. To obtain these we iterate on wages by using the model's equilibrium structure, by taking the π_{bij}'s from the data and using the auxiliary prices already recovered. Once we have recovered all prices, the unit costs d_{bi} can be computed and then we may recover productivity parameters.

Disentangling exporter fixed effect from productivity According to the theoretical framework, a country with high productivity and low export cost will export to several countries and have large bilateral trade shares with most of them. How does our empirical specification disentangle these two effects? Differences in productivity are captured by the recovered fixed effects, F, while the differences in barriers to trade show up in the exporter fixed effect ex. If a country $j^\star$ is very productive, then it will have a large home trade share i.e., large $\pi_{j^\star j^\star}$. Therefore, the relative share of other countries in country $j^\star$'s absorption will be small, i.e., $\pi_{j^\star i}/\pi_{j^\star j^\star}$ will be small for most i. If country $j^\star$ faces a high export cost to country i, then $\pi_{ij^\star}/\pi_{ii}$ will be relatively small. On the other hand, if the export cost to country i is low then it will export more to them resulting in large $\pi_{ij^\star}/\pi_{ii}$. For example, Japan is highly productive in capital goods. As a result, its home trade share in capital goods is 82%. Japan faces an iceberg trade cost of 2.15 for capital goods exports to Indonesia, and thus its capital goods exports to Indonesia are 3.4 times of the amount Indonesia provides to itself. In contrast, the trade cost for Japan's exports to Armenia is 6.17 and the bilateral trade share is only a quarter of Armenia's home trade share.