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Price Equalization, Trade Flows, and Barriers to Trade

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Abstract

In this paper we show that price equalization does not imply zero barriers to 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 and then quantitatively for the case of capital goods trade in a multi-country model. To be quantitatively consistent with the observed capital goods trade flows across countries, our model implies that trade barriers must be large, yet our model delivers capital goods prices that are similar across countries. The absence of barriers to trade in capital goods delivers price equalization in capital goods but cannot reproduce the observed trade flows.

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1 Introduction

Prices are an important ingredient in many cross-country quantitative analyses. For instance, in the literature on economic development, observed dispersion in aggregate prices has been used to study differences in cross-country income and investment rate (see Restuccia and Urrutia, 2001; Hsieh and Klenow, 2007; Armenter and Lahiri, 2012). In the international trade literature, the dispersion in prices is used to measure departures from "one world price" and these departures are presumed to reflect trade barriers (see, for instance, Anderson and van Wincoop, 2004). Hence, price equalization across countries has led to the inference that trade barriers are absent. We show that such an inference may not be correct in the context of aggregate prices.

We begin with the two-country model of Dornbusch, Fischer, and Samuelson (1977) and show that there exist many trade barrier combinations for which aggregate price indices are equal. But each trade barrier combination delivers a different volume of trade. In the two-country case, trade barriers must be systematically related to productivity to result in price equalization: The country with high productivity must have a lower trade barrier.

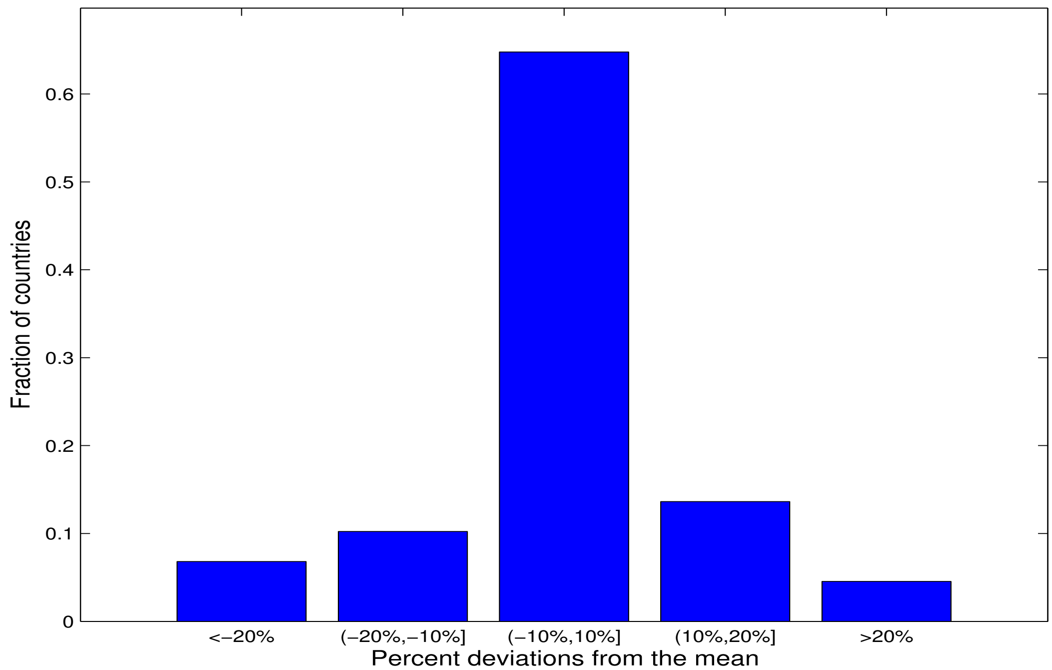
We then demonstrate empirically that the theoretical result— aggregate price index equalization (henceforth, price equalization) does not imply zero barriers to trade— is more than a curiosum in the case of capital goods trade. Figure 1 plots the cross-country distribution of the price of capital goods relative to the U.S. for 2005 (see also Figure 4 in Hsieh and Klenow, 2007, using 1996 data). There is little variation in the price of capital goods.[1] The prices in 65 percent of the countries are concentrated within 10 percent of the sample mean; 74 percent of the countries, accounting for more than 70 percent of the capital goods trade, are within one standard deviation around the mean (the standard deviation is less than 12 percent of the sample mean). For traded non-capital goods, on the other hand, only 19 percent of the countries fall within 10 percent of the mean price; the standard deviation of the price is more than 36 percent of its sample mean.[2] Does price equalization in the capital goods market imply there are no barriers to capital goods trade? To answer the question we use a standard multi-country model as in Eaton and Kortum (2002), Alvarez and Lucas (2007), and Waugh (2010).

Our model has two tradable sectors: capital goods and non-capital goods (or intermediate

[1] Crucini, Telmer, and Zachariadis (2005) show that the price of each good in a set of retail goods and services traded between European Union member countries deviates from its world price. They also show that in each country the central tendency of deviations from the world price is close to zero.

[2] There is also substantially more variation across countries in the price of structures and the price of consumption: For structures, only 17 percent of the countries fall within 10 percent of the mean price; for consumption only 16 percent of the countries fall within 10 percent of the mean. The standard deviations of the price of structures and the price of consumption are nearly 64 and 47 percent of their respective means.

Figure 1: Price of capital goods relative to the U.S. (2005 international $)



goods). Capital goods augment the stock of capital that is used for future production. Intermediate goods, on the other hand, are used for contemporaneous production. 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 these trade barriers are far from zero. The barriers are positive despite the fact that the model's equilibrium price of capital goods is roughly similar across countries. Furthermore, the negative correlation between calibrated trade barriers and productivity levels predicted by the Dornbusch, Fischer, and Samuelson (1977) model also holds true in the multi-country model. This quantitative exercise presents an empirically relevant example in which price equalization does not imply zero barriers to trade.

The unique combination of productivities and trade barriers calibrated to deliver the observed bilateral trade flows is consistent with capital goods price equalization. An alternative approach is to exogenously set the trade barriers for capital goods to zero, as assumed by Armenter and Lahiri (2012), so that the price of capital goods is equalized across countries by design. When we use this approach, the capital goods trade flows are much larger than the observed flows. This suggests that international trade in capital goods is not characterized by zero barriers.

The rest of the paper is organized as follows. Section 2 demonstrates that it is possible to have price equalization in the presence of barriers to trade in the Dornbusch, Fischer, and Samuelson (1977) two-country model. The multi-country model is described and solved in Section 3. In Section 4 we empirically implement the multi-country model and discuss the results. In Section 5 we assume zero barriers to trade in capital goods and examine the quantitative implications for trade flows. 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 in country i is paid the value of its marginal product.

2.1 Production

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

$$y_i(x) = z_i(x)^{-\theta} \ell_i(x), \tag{1}$$

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 cost 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 room for specialization.

Since the index of the good is irrelevant, we identify goods in the two countries 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 in country i is given by

$$Q_i = \left[\int q_i(z)^{\frac{\eta-1}{\eta}} \varphi(z) dz \right]^{\frac{\eta}{\eta-1}}, \tag{2}$$

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 $\frac{w_j}{z_j^{-\theta}}$, where w_j is the wage rate in country j. Let $\tau_{ij} \geq 1$ be the trade barrier 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 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 in the continuum 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: $w_1 L_1 \pi_{12} = w_2 L_2 \pi_{21}$, where π_{ij} is the fraction of country $i's$ spending devoted to goods produced by country j. 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

$$\pi_{ij} = \frac{1}{1 + \left(\frac{w_i}{w_j}\right)^{-1/\theta} \tau_{ij}^{1/\theta} \left(\frac{\lambda_i}{\lambda_j}\right)} . \tag{3}$$

The trade shares given by equation (3) are clearly between zero and one, i.e., each country will specialize in some goods along the continuum.[3]

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

$$\frac{w_1}{w_2} = \left(\frac{L_2}{L_1}\right)\left(\frac{1+\left(\frac{w_1}{w_2}\right)^{-1/\theta}\tau_{12}^{1/\theta}\left(\frac{\lambda_1}{\lambda_2}\right)}{1+\left(\frac{w_1}{w_2}\right)^{1/\theta}\tau_{21}^{1/\theta}\left(\frac{\lambda_2}{\lambda_1}\right)}\right). \tag{4}$$

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 (i.e., price of the composite good described in equation (2)) in country i by P_i. Since the composite good uses a CES aggregator (2), the aggregate price is given by

$$P_i = \left[\int p_i(z)^{1-\eta}\varphi(z)dz\right]^{\frac{1}{1-\eta}}. \tag{5}$$

In this simple two-country environment, the aggregate price 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 trade barrier from 1 to 2. A larger barrier 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 trade barrier 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 the 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

$$\frac{P_1}{P_2} = \left[\frac{1+\left(\frac{w_2}{w_1}\right)^{-1/\theta}\tau_{12}^{-1/\theta}\frac{\lambda_2}{\lambda_1}}{\tau_{21}^{-1/\theta}+\left(\frac{w_2}{w_1}\right)^{-1/\theta}\frac{\lambda_2}{\lambda_1}}\right]^{-\theta}. \tag{6}$$

If there are no trade barriers, then all goods are traded and PPP holds, i.e., if $\tau_{12} =$

[3] See Mutreja et al. (2012) for details of this and other derivations in this section.

$\tau_{21} = 1$, 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 (4) and (6) 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 $\tau_{12} \neq \tau_{21}$. Suppose that $\theta = 0.2$ and that the ratio of average productivity is $(\lambda_1^\theta/\lambda_2^\theta) = 2$. 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 barriers are *not* zero and are asymmetric. Moreover, factor prices are not equalized: $w_1/w_2 = 1.95$. The combination of trade barriers that delivers price equalization is not unique. For instance, another combination that delivers 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 price is equal to 1 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.

Notice that price equalization in the asymmetric case occurs when the trade barriers have a specific pattern: The high average productivity country is precisely the one that has a lower trade barrier i.e., $\lambda_1^\theta > \lambda_2^\theta$ and $\tau_{21} < \tau_{12}$. This negative correlation between average productivity and trade barrier is an object of interest for the case of capital goods in our multi-country quantitative exercise in Section 4.[4]

Summary Price equalization is not sufficient to conclude that there are zero barriers to trade. Moreover, price equalization does not guarantee that the factor prices are equalized.

An obvious corollary is that departures from price equalization are not sufficient to pin down departures from zero barriers, i.e., small deviations from PPP do not necessarily imply that the world is mostly integrated.

To determine if the barriers to trade are zero, we also need information on trade flows. This additional piece of information helps pin down the barriers uniquely.

[4]In our model, trade barriers and productivities are exogenous parameters, and wages and prices are endogenous functions of these parameters. The higher productivity country has a higher wage relative to the lower productivity country. Higher export barrier implies a lower price: All else equal, as the export barrier in country 2, τ_{12}, increases, P_2 decreases relative to P_1 according to equation (6).

Our theoretical results for the two-country case extend to the multi-country case. Our numerical example might lead one to suspect that the trade barriers have to line up in a very precise way to deliver price equalization. In other words, the two-country example is unlikely to occur in reality. In the next section, we show that our results are empirically relevant. In particular, we use 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.

3 Multi-country model

We use the model in Mutreja (2013), which 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 model. 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.[5] 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 sectors. Individual capital goods are aggregated into a composite capital good, which is used to augment the capital stock.

Relative to existing models of trade, such as Waugh (2010), we model trade in capital goods separately from the rest of manufactured goods. In our model, capital goods are durable and are used only in future production. Current capital stock is determined endogenously by past purchases of capital goods and, hence, capital stock is an endogenous factor of production in our model. Intermediate goods, on the other hand, are not durable and are used for current production.

Each country i has a representative household endowed with a measure L_{it} of workers at time t, 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. To cap-

[5] Recall that price equalization is a property of the capital goods sector, but not of the non-capital goods sector. To discuss price equalization and the role of trade barriers, at the very least we need a model with two sectors one of which has to be the capital goods sector. Furthermore, to demonstrate the price equalization result empirically, it is convenient to use a multi country trade model and the bilateral trade share data instead of using a two-country model, dividing the observations on prices and trade flows into two subsamples, and aggregating the observations.

ture the intertemporal tradeoffs faced by the household in choosing the optimal investment, we use a dynamic model, although our analysis is confined to steady states.

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

3.1 Technologies

Each individual capital good is indexed by v, while each individual intermediate good is indexed by u. As in the previous section, the indices u and v represent idiosyncratic cost draws from country-specific and sector-specific distributions, with densities 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 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, 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. 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

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

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

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

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

3.3 International Trade

Country i purchases capital goods 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 $b \in \{e, m\}$.

Unlike the two-country model, specialization in production of a 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 U.S. may export tractors to Mexico. Even if the production cost of the tractor is the same in Germany and the U.S., Egypt may find it cheaper to import from Germany while Mexico may find it cheaper to import from the U.S. due to the structure of bilateral trade barriers.

We focus on a steady-state competitive equilibrium. Informally, the 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 per worker 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.

In what follows, 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:

$$r_{ei} = \left[\frac{1}{\beta} - (1-\delta)\right] P_{ei}, \tag{7}$$

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

$$x_i = \delta k_i. \tag{8}$$

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 $p_{mi}(u) = \min_{j=1,\dots,I}\{p_{mjj}(u)\tau_{mij}\}$. Similarly, the price of capital good v is $p_{ei}(v) = \min_{j=1,\dots,I}\{p_{ejj}(v)\tau_{eij}\}$.

The price of each composite good then is

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

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

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

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 in each sector spent on goods in that sector from country j is given by

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

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:

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

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 total factor usage, while the right-hand side is 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 in each sector are:

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

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:

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

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.

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 88 countries for the year 2005 (see Table 2 in Appendix B for the list of countries). This set includes both developed and developing countries and accounts for about 93 percent of the world GDP as computed from version 8 of the Penn World Tables (see Feenstra, Inklaar, and Timmer, 2013).

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 two-digit ISIC revision 3 categories. Production data are taken from INDSTAT 2, a database maintained by UNIDO (2013). The corresponding trade data are available from UN Comtrade at the four-digit SITC revision 2 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 describe in Table 1 the parameter values that are common to all countries. 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. Neither of these parameters — β nor η — are quantitatively important for the question addressed in this paper. However, they must satisfy the following assumptions: $\beta < 1$ and $1 + \theta(1 - \eta) > 0$.

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 productivity levels	0.25
β	discount factor	0.96
η	elasticity of subs in aggregator	2

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.[6]

The parameter θ controls the dispersion in productivity levels. We follow recent estimates by Simonovska and Waugh (2014) and set this parameter at 0.25.[7]

[6]Different values of δ lead to different volumes of trade in capital goods, but do not affect the *share* of capital goods that country i imports from country j. The same is true for β. Furthermore, neither parameter affects our price equalization result.

[7]We have calibrated our model for values as low as $\theta = 0.10$ and as high as $\theta = 0.30$, which is the plausible range used in Eaton and Kortum (2002). The estimated trade barriers were still large and the distribution of prices was similar to the one with our baseline value of $\theta = 0.25$. We also constructed our own estimates of θ for capital goods and intermediate goods, using the methodology of Simonovska and Waugh (2014) and found the results to be indistinguishable from using a common $\theta = 0.25$.

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 UNIDO (2013) 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.

4.2 Country-specific parameters

We take the labor force L from Penn World Tables version 8. The remaining parameters include the productivities λ_{ei} and λ_{mi} as well as the bilateral trade barriers τ_{eij} and τ_{mij}. We calibrate these using the methodology in Eaton and Kortum (2002) and Waugh (2010). The basic idea is to pick these parameters to match the bilateral trade flows using a *parsimonious* specification that links trade barriers to gravity variables such as distance, common borders and language (see details in Appendix C). Because of the parsimonious specification, the model cannot possibly match every bilateral trade share perfectly. Note that (i) we do not use the price data in our calibration and (ii) the specification allows for the possibility of zero barriers.

4.3 Model fit

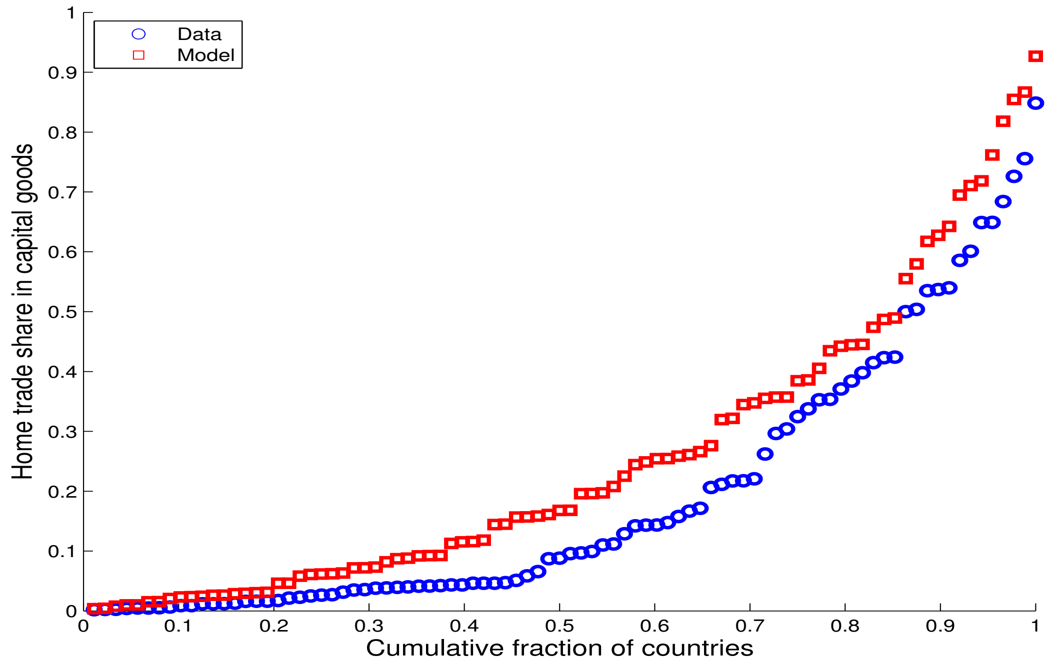
The model generates the observed home trade shares in capital goods (see Figure 2). For instance, in the model 24 percent of the countries have a capital goods home trade share higher than 0.40, while the data counterpart for the same home trade share is 18 percent of the countries; 17 percent of the countries in the model have a share lower than 0.03, while 26 percent of the countries in the data have a share of less than 0.03. The correlation between model and data for capital goods home trade shares is 0.81.

Our model is also consistent with the observed overall trade, measured as real imports + real exports, across countries. The correlation between the model and the data is 0.78. The correlation between the model and the data for overall trade as a fraction of real GDP is 0.65.[8]

Barriers to trade Trade barriers implied by our model are significant. Figure 3 plots the calibrated capital goods trade barriers τ_{eij}. The median barrier is 6.8. More than 90

[8]It is easy to match the trade to GDP ratio by adding a TFP term to the final good production technology. A country-specific TFP in the final good sector has no effect on prices of capital goods, prices of intermediate goods, or trade shares, but it scales GDP up or down in each country.

Figure 2: Home trade share in capital goods across countries



percent of the bilateral relationships involve the source country exporting at least 1.5 units of capital goods in order for one unit to arrive in the destination country.[9] Export-weighted trade barriers in our model (computed as $\frac{1}{X_i}\sum_{j\neq i}\tau_{ji}X_{ji}$, where X_{ji} is exports from i to j and X_i is i's total exports) are also substantial: The median is 6.2. (We construct an alternative measure of trade barriers in Appendix D using data on transport costs and tariff rates; the alternative measure is positively correlated with our benchmark barriers.)

In the next section we show that the calibrated model produces prices of capital goods that are similar across countries.

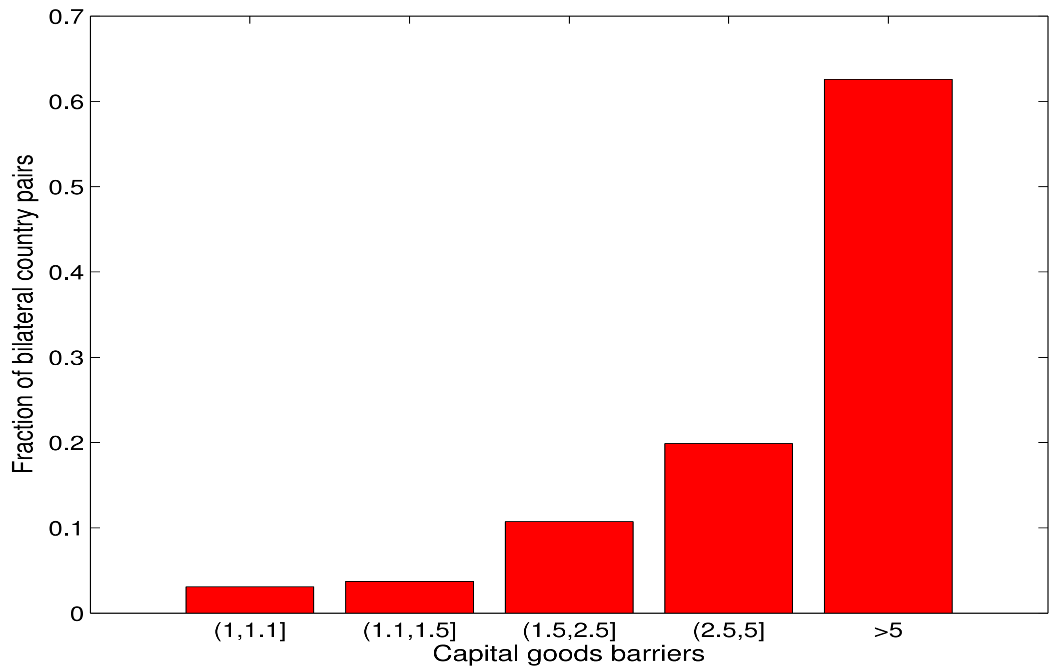
4.4 Implications for prices

Figure 4 illustrates the price of capital goods in the model and in the data. In the model, the prices of 60 percent of the countries are concentrated within one standard deviation of the sample mean, while in the data 74 percent of the countries are within one standard deviation of the sample mean. However, the standard deviation in the model is 0.18 while that in the data is 0.12 (see the remark on Price variance in Section 4.5).

Despite the fact that there are significant trade barriers across countries in the capital

[9] Roughly 15 percent of the capital goods bilateral trade shares are zeros. We use only the non-zero cells in the bilateral trade share matrix in our calibration and we assign the highest calibrated barrier to the country pairs where the matrix cell is zero. (See Appendix C for details.)

Figure 3: Trade barriers for capital goods



goods sector, the dispersion in capital goods prices is not large. As in the two-country case, countries with lower productivity have a larger export barrier. The correlation between λ_{ei}^{θ} and the trade-weighted average export barrier is -0.21.

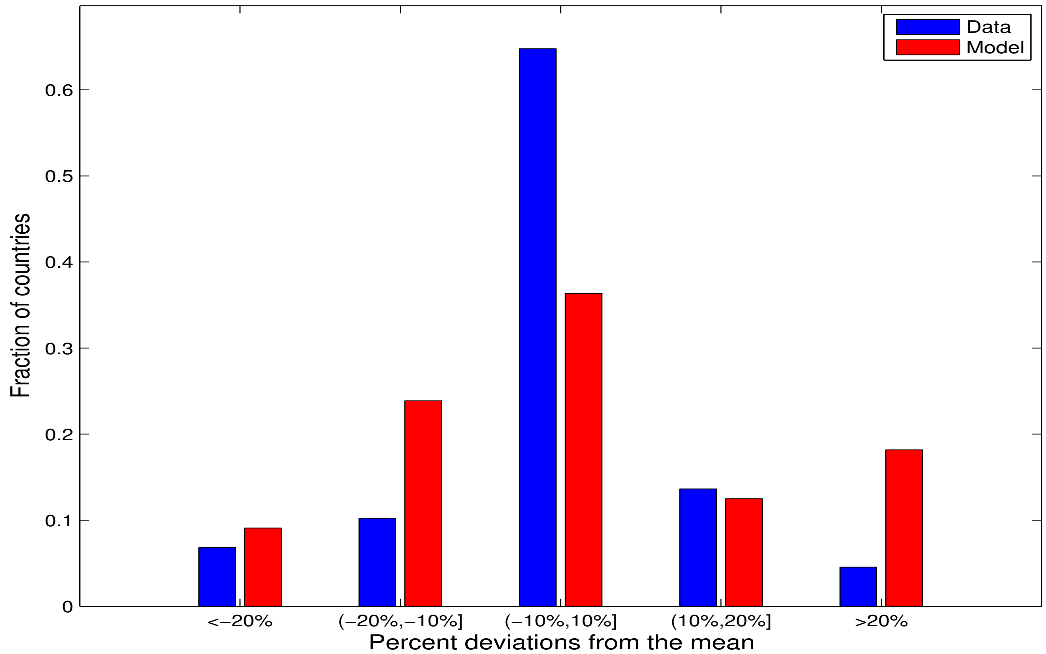
The quantitative implications of our model for prices confirm that the results in Section 2 are more than a theoretical possibility. When applied to the capital goods sector, price equalization does not imply zero barriers to trade. We close this section with a few remarks on our quantitative results.

4.5 Remarks

1. *Factor price equalization* Our results on capital goods prices are not driven in any way by factor price equalization. In our model the standard deviation of wages (relative to the mean) is more than eight times that of the capital goods prices. The wages produced by our model roughly match those in the data; the correlation is 0.82. (We measure wages by dividing the variable "Compensation of employees" from the Basic Headings data of the 2005 International Comparisons Program by the number of workers.)

2. *Calibration* Our calibration methodology is standard and is consistent with Waugh (2010). He argues that to reconcile observed bilateral trade volumes and prices within

Figure 4: Price of capital goods relative to the U.S. (model and data)



a standard gravity model, poor countries must face higher barriers to export relative to rich countries. Our calibrated trade barriers are indeed higher for poor countries.

3. *Price variance* The standard deviation of capital goods prices in the model is nearly 1.5 times the standard deviation in the data. One might argue that the inferred barriers are positive because price equalization is "less" in the model relative to the data. That is, in reality the trade barriers might be zero, but we are (mis)inferring positive barriers since the price distribution in the model is not as tightly concentrated around the mean as in the data. However, this is not the case. A direct calibration of the trade barriers using the model's structural relationship yields a better fit of the price data; such a calibration also yields positive barriers. To see this, note that bilateral trade barriers in capital goods are related to prices and trade flows of capital goods via

$$\frac{\pi_{eij}}{\pi_{ejj}} = \left(\frac{P_{ej}}{P_{ei}}\right)^{-1/\theta} \tau_{eij}^{-1/\theta}. \tag{9}$$

Thus, one can compute the bilateral trade barriers *exactly* as $\tau_{eij} = \left(\frac{\pi_{eij}}{\pi_{ejj}}\right)^{-\theta}\left(\frac{P_{ei}}{P_{ej}}\right)$. The prices implied by such a computation of the trade barriers are much closer to the data. (Note that this calibration uses both bilateral trade flows and prices, whereas our benchmark calibration uses only the trade flows.) The resulting barriers in the capital goods sector, however, are large: the median barrier is 5.8. More than 90 percent of the bilateral relationships involve the source country exporting at least 1.5 units of capital goods in order for one unit to arrive in the destination country. The median export-weighted trade barrier is 3.3.

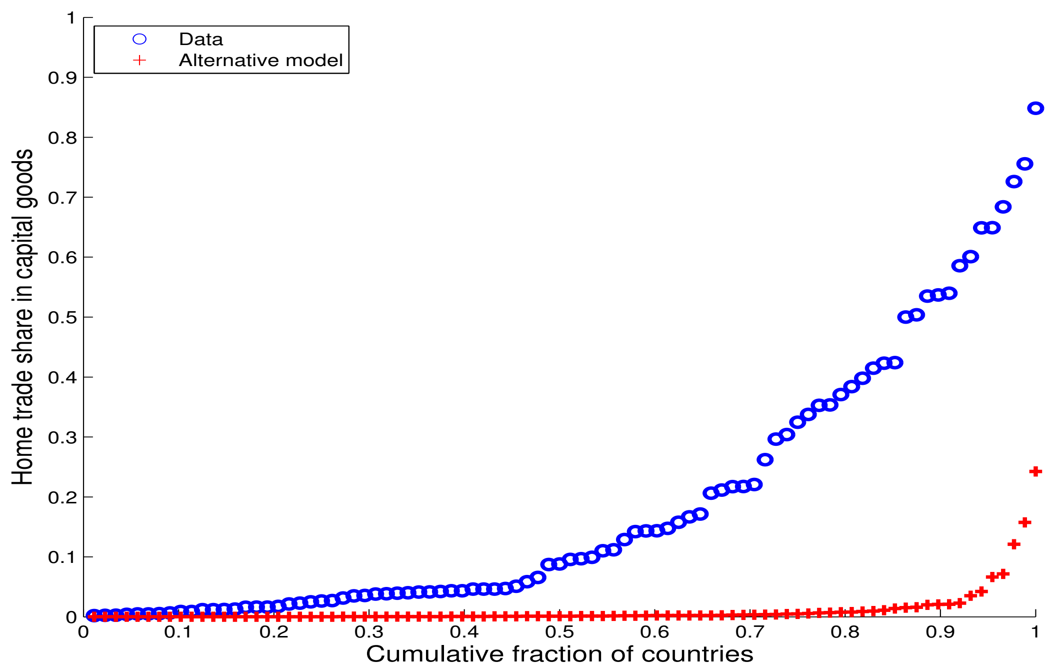
In the next section we show that assuming zero barriers to trade in capital goods will imply equal prices but will be inconsistent with the volume of trade.

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, as in Armenter and Lahiri (2012), since the observed price of capital goods seems to be the same across countries. To this end we re-calibrate the model under the assumption that there are zero barriers to 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 the alternative model and the price of capital goods is necessarily equal across countries. However, this specification is not consistent with the observed pattern of trade in capital goods. The alternative model implies low home trade shares and, hence, large trade flows (see Figure 5), but the data shows the opposite.

Figure 5: Home trade share in capital goods in the alternative calibration with zero barriers to trade



In the alternative model 92 percent of the countries have a share of less than 0.03, while only 26 percent of the countries in the data have a share of less than 0.03, indicating that there is far less trade in capital goods in the data than that predicted by the alternative model. The correlation between model and data for home trade shares is 0.61, which is less than that in the benchmark case. In the alternative model every country spends more than 75 percent of its capital goods expenditures on imports.

Equation (9) helps us see why the alternative model does not fit the trade flows. With zero barriers to trade in capital goods, equation (9) implies the right hand side equals 1, so $\pi_{eij} = \pi_{ejj}$ or, the home trade share in exporting country j has to be the same as the bilateral trade share flowing from country j to country i *for every* i. This implication is not satisfied by the data. For instance, the U.S. home trade share in capital goods is 0.6, while the trade shares from the U.S. to Canada, Ireland, and Spain are 0.53, 0.21, and 0.025, respectively.

6 Conclusion

This paper tests both the theoretical and empirical validity of the inference that price equalization implies zero barriers to trade. We show theoretically, using a simple two-country model, that aggregate prices being equal across countries does not imply there are zero barriers to trade. We then demonstrate that although capital goods prices are similar across countries there are barriers to trade in capital goods. We demonstrate this point quantitatively in two different ways.

We use a standard multi-country model with trade in capital goods and intermediate goods. Using data from 88 countries, we calibrate productivity and trade barriers to match the observed bilateral trade flows. We find that the calibrated trade barriers in capital goods are substantial, yet the prices look similar across countries. We then show the same result in a second way. We assume zero barriers to trade in capital goods and re-calibrate the model. We find that the capital goods trade flows in this model are much larger than the observed flows, suggesting that zero barriers to 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 $\kappa > 0 \Rightarrow \kappa u \sim \exp(\mu/\kappa)$.

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 the price in country i of the individual intermediate good u, when purchased from country j, equals the 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 $\mu_{mi} = (B_m)^{-1/\theta} \sum_j (d_{mj}\tau_{mij})^{-1/\theta} \lambda_{mj}$. Recall that $P_{mi}^{1-\eta} = \int p_{mi}(z)^{1-\eta}\varphi_m(z)dz$, thus

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

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,

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

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 two-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: 29-35. 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 Price of capital goods for each country is 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". Table 2 has the list of countries.

National Accounts The size of the workforce is taken from version 8 of the Penn World tables `emp`: number of persons engaged.

Production Data on manufacturing production is taken from INDSTAT 2, a database maintained by UNIDO (2013) at the two-digit ISIC revision 3 level. We aggregate the two-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 barriers 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 are 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.

To the extent some "final" goods are included in the trade data, we treat them as tradable goods. One way to map the model to the data is to imagine the final good in the model as an object that uses local services produced using traded goods and (non-traded) labor.

Construction of Trade Shares The empirical counterpart to the model variable π_{mij} is constructed following Bernard et al. (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

Albania	Denmark	Ireland	Mauritius	Slovenia
Argentina	Ecuador	Italy	Mexico	South Africa
Armenia	Egypt	Japan	Moldova	Spain
Australia	Estonia	Jordan	Mongolia	Sri Lanka
Austria	Ethiopia	Kazakhstan	Morocco	Sudan
Azerbaijan	Fiji	Kenya	Netherlands	Sweden
Belarus	Finland	Korea, Republic of	New Zealand	Tanzania
Belgium	France	Kyrgyzstan	Pakistan	Thailand
Bolivia	Georgia	Latvia	Paraguay	Tonga
Brazil	Germany	Lebanon	Peru	Trinidad and Tobago
Bulgaria	Ghana	Lithuania	Philippines	Tunisia
Cameroon	Greece	Luxembourg	Poland	Turkey
Canada	Hong Kong	Macao	Portugal	Ukraine
Chile	Hungary	Macedonia	Romania	United Kingdom
China	Iceland	Madagascar	Russia	United States
Colombia	India	Malawi	Senegal	Uruguay
Cyprus	Indonesia	Malaysia	Singapore	Vietnam
Czech Republic	Iran	Malta	Slovak Republic	

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}). With $I = 88$ countries, There are $2(I-1) = 174$ productivity parameters (λ_{ei} and λ_{mi}, $i = 1, \ldots, I$, with the productivities in the U.S. normalized to 1), and $2I(I-1) = 15,312$ bilateral trade barriers (τ_{eij} and τ_{mij}, for $i \neq j$). There are only $2I(I-1) = 15,312$ data points on bilateral trade shares (π_{eij} and π_{mij}, for $i \neq j$). The calibration strategy is to specify trade barriers in each sector as a function of distance, shared borders, common language, and exporter-specific fixed effects. This specification reduces the total number of parameters to be estimated to just 356 (instead of 15,486).

C.1 Estimating trade barriers

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

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

From this we can infer that

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

We specify a parsimonious functional form for trade barriers as follows:

$$\log\tau_{bij} = ex_j + \gamma_{b,dis,k}dis_{ij,k} + \gamma_{b,brd}brd_{ij} + \gamma_{b,lang}lang_{ij} + \varepsilon_{bij}, \tag{C.2}$$

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 kth 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 that affect trade barriers. Each of these data, except for trade flows, are taken from the Gravity Data set available at http://www.cepii.fr.

Using (C.2) and taking logs of both sides of (C.1) we obtain a form ready for estimation

$$\begin{aligned}\log\left(\frac{\pi_{bij}}{\pi_{bii}}\right) &= \underbrace{\log\left(d_{bj}^{-1/\theta}\lambda_{bj}\right)}_{F_{bj}} - \underbrace{\log\left(d_{bi}^{-1/\theta}\lambda_{bi}\right)}_{F_{bi}} \\ &\quad -\frac{1}{\theta}\left[ex_j + \gamma_{b,dis,k}dis_{ij} + \gamma_{b,brd}brd_{ij} + \gamma_{b,lang}lang_{ij} + \varepsilon_{bij}\right]. \end{aligned} \tag{C.3}$$

To compute the empirical counterpart to π_{bij}, we follow Bernard et al. (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 0.86 with 6525 usable observations (i.e., non-zero trade flows), while the regression for the intermediate goods sector produces an R^2 of 0.80 with 7037 usable observations.

C.2 Calibrating productivity

With the trade barriers $\hat{\tau}_{bij}$ 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, $\hat{r}_{ei} = \left[\frac{1}{\beta} - (1-\delta_e)\right]\hat{P}_{ei}$. 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 can recover productivity parameters.

D Transport costs and tariffs

In this section, we first compare our calibrated trade barriers to transport costs, tc, plus tariffs, trf, and then construct an alternative measure of trade barriers using transport costs and tariffs. The bilateral cost for sending a good from country j to country i is $1+tc_{ij}+trf_i$. The transport costs, tc_{ij}, are measured as the net mark-up of the $c.i.f.$ (cost of insurance and freight) reported trade flows in manufactured goods from j to i over the corresponding values $f.o.b.$ (free on board): $tc_{ij} = \frac{X_{ij}^{cif}}{X_{ij}^{fob}} - 1$. The data on $c.i.f.$ and $f.o.b.$ trade values are from the Direction of Trade Statistics maintained by the IMF and corresponds to all merchandise trade. The tariff, trf_i, we use is the weighted mean of applied tariff rate for manufactured goods for country i, available from the World Development Indicators database.[10]

The correlation between our benchmark calibrated capital goods trade barriers, τ_{eij}, and observed bilateral cost, $1 + tc_{ij} + trf_i$, is 0.02. The median bilateral cost is only 1.13. As is well known in the trade literature, observed transport costs and tariffs cannot reconcile the observed volume of trade. That is, trade models require larger barriers than the observed transport costs and tariffs.

As an alternative measure, we construct trade barriers by specifying them as a log-linear function of observed transport cost and tariffs:

$$\log \tau_{bij}^{alt} = \xi_b \log(1 + trf_i + tc_{ij}) + \varepsilon_{bij}^{alt}.$$

The parameter ξ_b is a scaling factor that magnifies the transport costs and tariffs to help reconcile the observed volume of trade. Combining this with the structural relationship in (C.1) yields the following estimation equation:

$$\begin{aligned}\log\left(\frac{\pi_{bij}}{\pi_{bii}}\right) &= \underbrace{\log\left(d_{bj}^{-1/\theta}\lambda_{bj}\right)}_{F_{bj}^{alt}} - \underbrace{\log\left(d_{bi}^{-1/\theta}\lambda_{bi}\right)}_{F_{bi}^{alt}} \\ &\quad -\frac{1}{\theta}\left[\xi_b \log(1 + trf_i + tc_{ij}) + \varepsilon_{bij}^{alt}\right].\end{aligned}$$

Our estimate of ξ_b is 2.71 for capital goods and 3.01 for intermediate goods. In this specification all of the variation in trade barriers stems from variation in transport costs and tariffs. This specification produces trade barriers that are positively correlated with the calibrated barriers from our benchmark gravity specification (C.2). The correlation is 0.70 for capital goods and 0.64 for intermediate goods.

[10] The results are similar if we construct tariffs according to 1) simple mean, most favored nation, 2) weighted mean, most favored nation, 3) simple mean, all nations, or 4) weighted mean, all nations.