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Capital Goods Trade and Economic Development

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Abstract

We argue that international trade in capital goods has quantitatively important effects on economic development through two channels: (i) capital formation and (ii) aggregate TFP. We embed a multi country, multi sector Ricardian model of trade into a neoclassical growth model. Barriers to trade result in a misallocation of factors both within and across countries. Our model matches several trade and development facts within a unified framework. It is consistent with the world distribution of capital goods production, cross-country differences in investment rate and price of final goods, and cross-country equalization of price of capital goods. The cross-country income differences decline by more than 50 percent when trade frictions are eliminated, with 80 percent of the change in each country's income attributable to change in capital.

Keywords: Income differences; Capital goods trade; Investment rate; TFP.
JEL Classification: O11, O4, F11, E22.

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1 Introduction

Cross-country differences in income per worker are large: The income per worker in the top decile is more than 50 times the income per worker in the bottom decile (Penn World Tables version 8.0; see Feenstra, Inklaar, and Timmer, 2013). Development accounting exercises such as those by Caselli (2005), Hall and Jones (1999), and Klenow and Rodríguez-Clare (1997) show that roughly 50 percent of the differences in income per worker are accounted for by differences in factors of production (capital and labor) and the rest is attributed to differences in aggregate total factor productivity (TFP).

One strand of the literature on economic development explains the income differences via misallocation of factors in *closed economies*. For instance, in Buera, Kaboski, and Shin (2011) and Greenwood, Sanchez, and Wang (2013), financial frictions prevent capital from being employed efficiently.[1] We argue that closed economy models can provide only part of the reason for cross-country differences in capital. Two facts motivate our argument: (i) capital goods production is concentrated in a few countries (noted in Eaton and Kortum (2001)) and (ii) the dependence on capital goods imports is negatively related to economic development. Ten countries account for almost 80 percent of world capital goods production. Capital goods production is more concentrated than gross domestic product (GDP) and other manufactured goods.[2] The second fact is that the imports-to-production ratio for capital goods is negatively correlated with income per worker, with a correlation coefficient of -0.27. Malawi imports 47 times as much capital goods as it produces, Argentina imports twice as much as it produces, while the US imports only half as much as it produces.

In this paper, international trade in capital goods has quantitatively important effects on cross-country income differences through two channels: capital formation and aggregate TFP. International trade enables poor countries to access capital goods produced in rich countries. Barriers to capital goods trade result in less capital accumulation in poor countries since, relative to the world frontier, the rate of transformation of consumption into investment is lower. Barriers to trade also result in countries producing goods for which they do not have a comparative advantage. Poor countries, for instance, do not have a comparative advantage in producing capital goods, but they allocate too many resources to producing capital goods relative to non-capital goods.

[1]Restuccia and Rogerson (2008) study misallocation of labor in a closed economy.

[2]Sixteen countries account for 80 percent of the world's GDP while seventeen countries account for 80 percent of the global output of intermediate goods.

Thus, trade barriers result in an inefficient allocation of factors across sectors within a country and affect the country's aggregate TFP. A reduction in barriers would induce higher capital formation in poor countries. It would also induce each country to specialize more in the direction of its comparative advantage, resulting in a reduction in cross-country factor and TFP differences.

We embed a multi country Ricardian model into a neoclassical growth model. Our Ricardian framework builds on Dornbusch, Fischer, and Samuelson (1977), Eaton and Kortum (2002), Alvarez and Lucas (2007), and Waugh (2010). Each country is endowed with labor that is not mobile internationally. In contrast to the above papers, capital is an endogenous factor of production in our model. Each country has technologies for producing a final consumption good, structures, a continuum of capital goods, a continuum of intermediate goods (i.e., non-capital goods), and a composite intermediate good. All of the capital goods and intermediate goods can be traded. Neither the final consumption good nor structures can be traded. Countries differ in their distributions of productivities in both capital goods and intermediate goods. Trade barriers are assumed to be bilateral iceberg costs. We model other domestic distortions via final goods productivity in each country.

Differences in income per worker in our model are a function of (i) differences in development accounting elements, such as final goods productivity and capital per worker, and (ii) differences in additional elements, such as barriers to trading capital goods and intermediate goods, and productivities in capital goods and intermediate goods sectors. Trade barriers and sectoral productivities affect how much of the investment in a country is due to domestic capital goods production and how much is due to trade, which in turn affects the amount of capital per worker in the country. Furthermore, in our model, measured TFP is directly affected by trade barriers and sectoral productivities, similar to Waugh (2010).

We calibrate the model to be consistent with the observed bilateral trade in capital goods and intermediate goods, the observed relative prices of capital goods and intermediate goods, and income per worker. Our model fits these targets well. For instance, the correlation in home trade shares between the model and the data is 0.97 for both capital goods and intermediate goods; the correlation between model and data income per worker is 0.99.

Our model reconciles several trade and development facts in a unified framework. First, we account for the fact that a few countries produce most of the capital goods in the world: In our model and in the data, 10 countries account for 80 percent of the world capital goods production. The pattern of comparative advantage in our model is such that poor countries are net importers of capital goods and net exporters of intermediate goods.

Second, the contribution of factor differences in accounting for cross-country income differences in our model is similar to the contribution in the data.

Third, we deliver the facts that the investment rate measured in domestic prices is uncorrelated with income per worker and the investment rate measured in international prices is positively correlated with income per worker, facts noted previously by Restuccia and Urrutia (2001) and Hsieh and Klenow (2007).

Fourth, our model is consistent with observed prices. As Hsieh and Klenow (2007) point out, the price of capital goods is roughly the same across countries and the relative price of capital is higher in poor countries because the price of the nontradable consumption good is lower in poor countries. Both in our model and in the data, the elasticity of the price of capital goods with respect to income per worker is 0.03. The elasticity of the price of consumption goods is 0.37 in the model and 0.32 in the data. Our model is also consistent with the fact that the price of structures is positively correlated with economic development.

To quantify the effect of trade barriers, we first compare our benchmark specification to a world that has no trade frictions. The world with frictionless trade allocates capital (and other factors) optimally, both across countries and across sectors within a country. Relative to this world, countries with a comparative disadvantage in capital goods in our benchmark model allocate too many resources to the production of capital goods, which leads to both reduced capital formation and lower aggregate TFP in poor countries. In the world with frictionless trade, the gap in capital per worker between countries in the top decile (rich) and those in the bottom decile (poor) of the income distribution is 5; the corresponding gap is 38 in the benchmark. Consequently, the income difference between the rich and poor countries is smaller in the frictionless world: The gap is less than 14, while in the benchmark it is more than 30. In each country, roughly 80 percent of the increase in income from the benchmark to the frictionless world is accounted for by the increase in capital. That is, eliminating all trade frictions increases income predominantly through increases in capital, a channel that is absent in Waugh (2010).

We then compare our benchmark model to a world with no frictions in capital goods trade but with the calibrated barriers in the trade of other goods. In this counterfactual experiment, the gap in capital per worker between rich and poor countries decreases from 38 to 24 and the gap in income per worker decreases from more than 30 to 25.

In both of these counterfactuals, the relative price of capital plays a key role. As trade barriers are reduced, the relative price of capital decreases. That is, the amount of consumption good that a household has to give up in order acquire a unit of investment decreases. This, in turn, increases the investment rate in poor countries. In the benchmark model, the aggregate investment rate in the rich countries is 1.3 times that in the poor countries, whereas the ratio is 0.36 in the world with frictionless trade and 0.94 in the world without trade frictions only in the capital goods sector. Consequently, the capital per worker increases in poor countries and so does income.

Hsieh (2001) provides evidence on the channel in our model via a contrast between Argentina and India. During the 1990s, India reduced barriers to capital goods imports that resulted in a 20 percent fall in the relative price of capital between 1990 and 2005. This led to a surge in capital goods imports, and the investment rate increased 1.5-fold during the same time period. After the Great Depression, Argentina restricted imports of capital goods. From the late 1930s to the late 1940s, the relative price of capital doubled and the investment rate declined.

The experience of Korea also presents some evidence in favor of the channel in our model. Korea's trade reforms starting in 1960s reduced the restrictions on imports of capital goods (see Westphal, 1990; Yoo, 1993). During 1970-80, Korea's imports of capital goods increased 11-fold. Over a period of 40 years, the relative price of capital in Korea decreased by a factor of almost 2 and the investment rate increased by a factor of more than 4 (Nam, 1995). (See also Rodriguez and Rodrik, 2001, for a discussion of trade policies affecting relative prices.)

Eaton and Kortum (2001) also quantify the role of capital goods trade barriers in accounting for cross-country income differences. They construct a "trade-based" price of capital goods using a gravity regression. As noted by Hsieh and Klenow (2007), the trade-based price of capital goods is negatively correlated with economic development whereas in the data the price is practically uncorrelated with economic development. And, the negative correlation between the *relative* price of capital goods and economic development is mainly due to the fact that price of final goods is positively correlated with economic development. Changes in capital goods trade barriers affect the relative price of capital in Eaton and Kortum (2001) only through the changes in the absolute price of capital since they hold fixed the price of final goods. In our model, removing capital goods trade barriers changes mainly the cross-country distribution of the final good price. The resulting change in the relative price of capital affects the investment rates in our model and the cross-country distribution of income.

In Hsieh and Klenow (2007), eliminating capital goods trade barriers has no effect on the investment rate in poor countries relative to rich countries for two reasons. First, in their model, the inferred capital goods trade barriers are no different in poor countries than in rich countries, so a removal of these barriers has essentially no effect on the *difference* in the absolute price of capital between rich and poor countries. Second, the trade barriers in their model do not affect the price of the final consumption good. As a result, removing barriers to trade in capital goods does not alter the cross-country differences in relative price of capital and, hence, does not affect the cross-country differences in investment rates. In our model, removal of capital goods trade barriers leads to an increase in the price of final goods in poor countries relative to rich countries. The resulting decline in the relative price of capital in poor countries leads to an increase in their investment rates relative to the investment rates in rich countries.

The rest of the paper is organized as follows. Section 2 develops the multi country Ricardian trade model and describes the equilibrium. Section 3 describes the calibration. The quantitative results are presented in Section 4. Section 5 concludes.

2 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 (see also Mutreja, 2013). 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 intermediates (or non-capital goods), and two nontradable sectors, structures and final goods. (We use "producer durables" and "capital goods" interchangeably.) The capital goods and intermediate goods sectors are denoted by e and m, respectively, while the structures and final goods sectors are denoted by s and f. Within each tradable sector there is a continuum of varieties. Individual capital goods varieties are aggregated into a composite producer durable, which augments the stock of producer durables. Individual intermediate goods varieties are aggregated into a composite intermediate good. The composite intermediate good is an input in all sectors. Final goods are consumed locally.

Each country i has a representative household with a measure L_i of workers.[3] Labor is immobile across countries but perfectly mobile across sectors within a country. The household owns its country's stock of producer durables and stock of structures. The respective capital stocks in period t are denoted by K^e_{it} and K^s_{it}. They are rented to domestic firms. Earnings from capital and labor are spent on consumption and investments in producer durables and structures. The two investments augment the respective capital stocks. Henceforth, all quantities reported using lower case letters denote per worker values, i.e., $k^e_{it} = K^e_{it}/L_{it}$ and, where it is understood, country and time subscripts are omitted and we focus only on the solution to the steady state of the model.

2.1 Endowments

The representative household in country i supplies its labor L_{it} at time t inelastically to all domestic firms.

2.2 Technology

There is a unit interval of varieties in the two tradable sectors: capital goods and intermediate goods. Each individual variety within each sector is tradable and is indexed along the unit interval by $v_b \in [0, 1]$ for $b \in \{e, m\}$.

Composite goods Within each tradable sector, all of the varieties are combined with constant elasticity in order to construct a sectoral composite good according to

$$q_{ei} = \left[\int_0^1 q_{ei}(v_e)^{1-1/\eta} dv_e\right]^{\eta/(\eta-1)} \quad \text{and } q_{mi} = \left[\int_0^1 q_{mi}(v_e)^{1-1/\eta} dv_m\right]^{\eta/(\eta-1)}$$

where η is the elasticity of substitution between any two varieties.[4] The term $q_{bi}(v_b)$ is the quantity of variety v_b used by country i to produce the sector b composite intermediate good. The composite intermediate good, q_{bi}, is used by domestic firms in

[3]We have also solved the model using efficiency units of labor constructed via years of schooling and Mincer returns. We also allowed for growth over time in the number of workers, as well as growth in the efficiency units of labor. None of these extensions affect our quantitative results.

[4]The value of η plays no quantitative role other than satisfying technical conditions which ensure convergence of the integrals.

country i as an intermediate input in production in all sectors. The composite capital good augments the domestic stock of producer durables.

Individual goods Each variety can be produced by any country using the stock of structures, the stock of producer durables, labor, and the composite intermediate good. The technologies for producing individual varieties in sectors e and m are

$$\begin{aligned} y_{ei}(v_e) &= z_{ei}(v_e)\left[(k^e_{ei}(v_e)^{\mu}k^s_{ei}(v_e)^{1-\mu})^{\alpha}\ell_{ei}(v_e)^{1-\alpha}\right]^{\nu_e} m_{ei}(v_e)^{1-\nu_e}, \\ y_{mi}(v_m) &= z_{mi}(v_m)\left[(k^e_{mi}(v_m)^{\mu}k^s_{mi}(v_m)^{1-\mu})^{\alpha}\ell_{mi}(v_m)^{1-\alpha}\right]^{\nu_m} m_{mi}(v_m)^{1-\nu_m}. \end{aligned}$$

The term $m_{bi}(v_b)$, for $b \in \{e, m\}$, denotes the quantity of the composite intermediate good used by country i as an input to produce variety v_b, $\ell_{bi}(v_b)$ denotes the quantity of labor employed, and $k^e_{bi}(v_b)$ and $k^s_{bi}(v_b)$ denote the stocks of producer durables and structures capital.

The parameter $\nu_b \in [0, 1]$, for $b \in \{e, m\}$, denotes the share of value added in total output in sector b. The share of capital in the value added is determined by α, while $\mu \in [0, 1]$ denotes the share produce durables in the capital stock composite. Each of these coefficients is constant across countries, and α and μ are constant across sectors.

Following Eaton and Kortum (2002), the terms $z_{bi}(v_b)$ determine the productivity for each variety v_b. The productivity is drawn from independent country- and sector-specific Fréchet distributions. The shape parameter θ that is the same across sectors and countries; the scale parameter, T_{bi}, for $b \in \{e, m\}$, and $i = 1, 2, \ldots, I$ is sector- and country-specific. The c.d.f. for productivity draws in sector b in country i is $F_{bi}(z) = \exp(-T_{bi}z^{-\theta})$. Once the vector of cost draws is known, the country-specific index for the good becomes irrelevant. So from now on each individual good in sector b is denoted by its vector of productivity draws z_b as in Alvarez and Lucas (2007).

Within each sector, the expected value of productivity across the continuum is $\gamma^{-1}T_{bi}^{\frac{1}{\theta}}$, where $\gamma = \Gamma(1 + \frac{1}{\theta}(1 - \eta))^{\frac{1}{1-\eta}}$ and $\Gamma(\cdot)$ is the gamma function. We refer to $T_{bi}^{\frac{1}{\theta}}$ as the fundamental productivity in sector b in country i.[5] If $T_{ei} > T_{ej}$, then on average, country i is more efficient than country j at producing capital goods. Average productivity at the sectoral level determines specialization across sectors. A country

[5]As discussed in Finicelli, Pagano, and Sbracia (2012), fundamental productivity differs from measured productivity because of selection. In a closed economy, country i produces all goods in the continuum so its measured productivity is equal to its fundamental productivity. In an open economy, country i produces only the goods for which it has a comparative advantage, and imports the rest. So its measured productivity is higher than its fundamental productivity.

that has a large ratio of T_e/T_m will tend to be a net exporter of capital goods and a net importer of intermediate goods. The parameter $\theta > 0$, governs the coefficient of variation of the productivity draws. A larger θ implies more variation in productivity draws across varieties and, hence, more room for specialization within each sector; i.e., more intra-sectoral trade.

Nontradable goods Final goods and structures are nontradable. The final good is produced domestically using capital, labor, and intermediates according to

$$y_{fi} = A_{fi} \left[((k_{fi}^e)^\mu (k_{fi}^s)^{1-\mu})^\alpha \ell_{fi}^{1-\alpha} \right]^{\nu_f} m_{fi}(v_f)^{1-\nu_f}.$$

Country-specific TFP in final goods is given by A_{fi}.

Structures are produced similarly according to

$$y_{si} = \left[((k_{si}^e)^\mu (k_{si}^s)^{1-\mu})^\alpha \ell_{si}^{1-\alpha} \right]^{\nu_s} m_{si}(v_s)^{1-\nu_s}.$$

Capital accumulation As in the standard neoclassical growth model, the representative household enters each period with predetermined stocks of producer durables and structures. The stocks accumulate according to

$$k_{t+1}^e = (1-\delta_e)k_t^e + x_t^e,$$
$$k_{t+1}^s = (1-\delta_s)k_t^s + x_t^s.$$

The rate of depreciation of the stock of producer durables is given by δ_e, and that for structures is given by δ_s. The terms x_t^e and x_t^s denote the investment flow in period t.

We define the aggregate capital stock per worker as

$$k = (k^e)^\mu (k^s)^{1-\mu}.$$

International trade Trade is Ricardian: country i purchases each individual good z_b from its least cost supplier. All international trade is subject to barriers that take the iceberg form and vary across sectors. Country i must purchase $\tau_{bij} \geq 1$ units of sector b goods from country j in order for one unit to arrive; $\tau_{bij} - 1$ units *melt* away in transit. We assume that $\tau_{bii} = 1$ for all (b, i).

2.3 Preferences

The representative household values the stream of consumption according to

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

where $\beta < 1$ is the period discount factor.

2.4 Equilibrium

A competitive equilibrium satisfies the following conditions: 1) the representative household maximizes utility taking prices as given, 2) firms maximize profits taking input prices as given, 3) each country purchases each good from its least cost supplier and 4) markets clear. We take world GDP as the numéraire: $\sum_i (r_i k_i + w_i) L_i = 1$. Recall that we focus on steady states.

2.4.1 Household optimization

In each period, the stocks of producer durables and structures are rented to domestic firms at the competitive rental rates r_{ei} and r_{si}. The household splits its income between consumption, c_i, which has price P_{fi}, and investments in producer durables and in structures, x_i^e and x_i^s, which have prices P_{ei} and P_{si}, respectively.

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

$$r_{ei} = \left[\frac{1}{\beta} - (1 - \delta_e)\right] P_{ei},$$
$$r_{si} = \left[\frac{1}{\beta} - (1 - \delta_s)\right] P_{si},$$

$$P_{fi} c_i + P_{ei} x_i^e + P_{si} x_i^s = w_i + r_{ei} k_i^e + r_{si} k_i^s,$$

$$x_i^e = \delta_e k_i^e, \text{ and}$$
$$x_i^s = \delta_s k_i^s.$$

2.4.2 Firm optimization

Since markets are perfectly competitive, firms set prices equal to marginal costs. Denote the price of good z_b, produced by country j and purchased by country i, by $p_{bij}(z_b)$. Then $p_{bij} = p_{bjj}(z_b)\tau_{bij}$, where $p_{bjj}(z_b)$ is the marginal cost of producing good z_b in country j. Since country i purchases good z_b from the country that can deliver it at the lowest price, the price in country i must be $p_{bi}(z_b) = \min_{j=1,\ldots,I}[p_{bjj}(z_b)\tau_{bij}]$. The price of the sector b composite good in country i is then

$$P_{bi} = \gamma_b \left[\sum_k (u_{bk}\tau_{bik})^{-\theta} T_{bk} \right]^{-\frac{1}{\theta}} \tag{1}$$

where $u_{bi} = \left(\frac{r_i^e}{\mu\alpha\nu_b}\right)^{\mu\alpha\nu_b} \left(\frac{r_i^s}{(1-\mu)\alpha\nu_b}\right)^{(1-\mu)\alpha\nu_b} \left(\frac{w_i}{(1-\alpha)\nu_b}\right)^{(1-\alpha)\nu_b} \left(\frac{P_{mi}}{1-\nu_b}\right)^{1-\nu_b}$ is the unit cost for a bundle of inputs for producers in sector b in country i.

Next we define sectoral aggregates for inputs and output.

$$\begin{aligned}
k_{bi}^e &= \int k_{bi}^e(z_b)\varphi_b(z_b)dz_b, \\
k_{bi}^s &= \int k_{bi}^s(z_b)\varphi_b(z_b)dz_b, \\
\ell_{bi} &= \int \ell_{bi}(z_b)\varphi_b(z_b)dz_b, \\
m_{bi} &= \int m_{bi}(z_b)\varphi_b(z_b)dz_b, \\
y_{bi} &= \int y_{bi}(z_b)\varphi_b(z_b)dz_b,
\end{aligned}$$

where $\varphi_b = \prod_i \varphi_{bi}$ is the joint density for productivity draws across countries in sector b (φ_{bi} is country i's density function). For instance, $\ell_{bi}(z_b)$ denotes the quantity of country i's labor employed in the production of variety z_b. If country i imports variety z_b, then $\ell_{bi}(z_b) = 0$. Hence, ℓ_{bi} is country i's of labor employed in sector b. Similarly, m_{bi}, k_{bi}^e, and k_{bi}^s denote the quantity of the intermediate composite good and the quantities of the stocks of producer durables and structures that country i uses as an input in sector b. Lastly, y_{bi} is the quantity of sector b output produced by country i.

Cost minimization by firms implies that factor usage at the sectoral levels exhausts the value of output.

$$
\begin{aligned}
r_i^e k_{bi}^e &= \mu(1-\alpha)\nu_{bi} P_{bi} y_{bi}, \\
r_i^s k_{bi}^s &= (1-\mu)(1-\alpha)\nu_{bi} P_{bi} y_{bi}, \\
w_i \ell_{bi} &= (1-\alpha)\nu_{bi} P_{bi} y_{bi}, \\
P_{mi} m_{bi} &= (1-\nu_{bi}) P_{bi} y_{bi}.
\end{aligned}
$$

2.4.3 Trade flows

In sector b, the fraction of country i's expenditures allocated to goods produced by country j is given by

$$\pi_{bij} = \frac{(u_{bj}\tau_{bij})^{-\theta} T_{bj}}{\sum_k (u_{bk}\tau_{bik})^{-\theta} T_{bk}} \tag{2}$$

2.4.4 Market clearing conditions

We begin by describing the domestic market clearing conditions.

$$
\begin{aligned}
\ell_{ei} + \ell_{si} + \ell_{mi} + \ell_{fi} &= 1, \\
k_{ei}^e + k_{si}^e + k_{mi}^e + k_{fi}^e &= k_i^e, \\
k_{ei}^s + k_{si}^s + k_{mi}^s + k_{fi}^s &= k_i^s, \\
m_{ei} + m_{si} + m_{mi} + m_{fi} &= q_{mi}.
\end{aligned}
$$

The first condition imposes that the labor market clears in country i. The second and third conditions require that the stocks of producer durables and structures be equal to the sum of the stocks used in production in all sectors. The last condition requires that the use of composite intermediate good equals its supply: Its use consists of intermediate inputs by firms in each sector, its supply consists of both domestically- and foreign-produced varieties.

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

$$c_i = y_{fi},\ x_i^e = q_{ei},\ \text{and}\ x_i^s = y_{si}.$$

The next market clearing condition requires that the value of output produced by country i equals the value that all countries (including i) purchase from country i.

$$L_i P_{bi} y_{bi} = \sum_j L_j P_{bj} q_{bj} \pi_{bji},\ b \in \{e, m\}.$$

The left hand side is the value of gross output in sector b produced by country i. The right hand side is the world expenditures on sector b goods: $L_j P_{bj} q_{bj}$ is country j's total expenditure on sector b goods, and π_{bji} is the fraction of those expenditures sourced from country i. Thus, $L_j P_{bj} q_{bj} \pi_{bji}$ is the value of trade flows in sector b from country i to country j.

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

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

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; however, a surplus in capital goods must be offset by an equal deficit in intermediates and vice versa.

2.5 Discussion of the model

Our model provides a tractable framework for studying how trade affects capital formation, measured TFP, and income per worker. The real income per worker in our model is $y = (w + rk)/P_f$. In country i,

$$y_i \propto A_{fi} \left(\frac{T_{mi}}{\pi_{mii}} \right)^{\frac{1-\nu_f}{\theta \nu_m}} k_i^{\alpha}. \tag{3}$$

In equation (3), T_m and A_f are exogenous. The remaining components on the right-hand side of (3), namely, π_{mii} and k_i, are equilibrium objects.

Standard development accounting exercise would have the income per worker in the form $y = Z\, k^{\alpha}$ and measure TFP by Z. In our model, measured TFP is endogenous since the home trade share, π_{mii}, is an equilibrium object in equation (3). Cross-country differences in fundamental productivities and trade barriers affect the home trade shares in each country.

Cross-country differences in productivities and trade barriers also imply differences in steady state capital per worker in our model. (Recall that the capital in equation (3) is a Cobb-Douglas aggregate of the stock of producer durables and the stock of structures: $k = (k^e)^\mu (k^s)^{1-\mu}$.) Appendix A shows that the capital per worker is a function of home trade shares and productivity parameters in the capital goods and intermediate goods sectors:

$$k_i \propto \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1-\mu\nu_e-(1-\mu)\nu_s}{\theta\nu_m(1-\alpha)}} \left(\frac{T_{ei}}{\pi_{eii}}\right)^{\frac{\mu}{\theta(1-\alpha)}}. \tag{4}$$

The final goods sector productivity, A_f, does not affect the trade shares and, hence, does not affect the capital per worker; A_f simply scales income per worker.

Equations (3) and (4) help us quantify the effect of trade barriers. Holding capital per worker and the productivity parameters fixed, a reduction in trade barriers reduces π_{mii} which increases measured TFP and income per worker, according to equation (3). A reduction in trade barriers also increases capital per worker via (i) a reduction in π_{mii} and (ii) a reduction in π_{eii}, according to equation (4). In our benchmark calibration (Section 3), the effect of trade barriers on economic development through capital per worker is as large as the effect through measured TFP in our model.

In standard trade models, capital is treated as an exogenous factor of production, so changes in trade barriers have no effect on cross-country differences in capital and the effect on income per worker implied by equation (4) is absent. As an extreme case, if ν_f equals 1 then traded intermediate goods are not used in the production of final goods, so a change in trade barriers will have no effect on economic development in such models, whereas there will be an effect in ours through capital per worker.

The neoclassical growth model also allows for endogenous capital formation as we do, but in that model the capital-output ratio is independent of TFP; in our model it is not. To see this, the income per worker in the neoclassical growth model can be written more conveniently as $y = Z^{\frac{1}{1-\alpha}}\left(\frac{k}{y}\right)^{\frac{\alpha}{1-\alpha}}$. In steady state, the gross marginal product capital, which is a function of just $\frac{k}{y}$, is pinned down by the discount factor, so changes in Z have no effect on $\frac{k}{y}$.

The corresponding expression for income per worker in our model is

$$y_i \propto \left(A_{fi}\left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1-\nu_f}{\theta\nu_m}}\right)^{\frac{1}{1-\alpha}} \left(\frac{k_i}{y_i}\right)^{\frac{\alpha}{1-\alpha}},$$

where the capital-output ratio is given by

$$\frac{k_i}{y_i} \propto \frac{1}{A_{fi}} \left(\frac{T_{ei}}{\pi_{eii}}\right)^{\frac{\mu}{\theta}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_f - \mu\nu_e - (1-\mu)\nu_s}{\theta\nu_m}} \tag{5}$$

(see Appendix A). In our model, measured TFP is positively correlated with capital-output ratio (as in the data).

To summarize, trade affects economic development via measured TFP and capital formation. Comparative advantage parameters and barriers to international trade affect the extent of specialization in each country, which affects measured TFP and the relative price of capital goods. The price, in turn, affects the investment rate and, hence, the capital stock. In our quantitative exercise we discipline the model using relative prices, bilateral trade flows, and income per worker to explore the importance of capital goods trade.

3 Calibration

We calibrate our model using data for a set of 88 countries for the year 2005. This set includes both developed and developing countries and accounts for about 90 percent of world GDP in version 8.0 of the Penn World Tables (see Feenstra, Inklaar, and Timmer, 2013). Our calibration strategy uses cross-country data on income per worker, bilateral trade, and output for capital goods and intermediate goods sectors, and prices of capital goods, intermediate goods, and final goods. Next we describe how we map our model to the data; details on specific countries, data sources, and data construction are described in Appendix B.

We begin by grouping disaggregate data such that the groups correspond to the model sectors. Capital goods and structures in the model correspond to the categories "Machinery and equipment" and "Construction", respectively, in the World Bank's International Comparisons Program (ICP).

For production and trade data on capital goods, we use two-digit International Standard Industrial Classification (ISIC) categories that coincide with the definition of "Machinery and equipment" used by the ICP; specifically, we use categories 29-35 in revision 3 of the ISIC. Production data are from INDSTAT2, a UNIDO database. The corresponding trade data are available at the four-digit level from Standard International Trade Classification (SITC) revision 2. We follow the correspondence created by Affendy, Sim Yee, and Satoru (2010) to link SITC with ISIC categories.

Intermediate goods correspond to the manufacturing categories other than capital goods, i.e., categories 15-28 and 36-37 in revision 3 of the ISIC. We repeat the above procedure to assemble the production and trade data for intermediate goods.

Prices of capital goods and structures come directly from the 2005 benchmark study of the Penn World Tables (PWT). We construct the price of intermediate goods by aggregating across all nondurable goods categories (excluding services) in the 2005 benchmark study. The price of final goods corresponds to "Price level of consumption" in version 8.0 of PWT.

Our measure of income per worker is also from version 8.0 of PWT.

3.1 Common parameters

We begin by describing the parameter values that are common to all countries (Table 1). The discount factor β is set to 0.96, in line with values in the literature. Following Alvarez and Lucas (2007), we set $\eta = 2$ (this parameter is not quantitatively important for the questions addressed in this paper).

As noted earlier, the capital stock in our model is $k = (k^e)^\mu (k^s)^{1-\mu}$. The share of capital in GDP, α, is set to 1/3, as in Gollin (2002). Using capital stock data from the Bureau of Economic Analysis (BEA), Greenwood, Hercowitz, and Krusell (1997) measure the rates of depreciation for both producer durables and structures. We set our values in accordance with their estimates: $\delta_e = 0.12$ and $\delta_s = 0.06$. We also set the share of producer durables in composite capital, μ, at 0.56 in accordance with Greenwood, Hercowitz, and Krusell (1997).

The parameters ν_m, ν_e, ν_s, and ν_f, respectively, control the shares of value added in the production of intermediate goods, capital goods, structures, and final goods, respectively. To calibrate ν_m and ν_e, we use the data on value added and total output available in the INDSTAT2 2013 database. To determine ν_s, we compute value added shares in gross output for construction for a set of 32 countries in Organization for Economic Cooperation and Development (OECD), and average across these countries. Data on value added and gross output for OECD countries are from input-output tables in the STAN database maintained by OECD for the period "mid 2000s" (http://stats.oecd.org/Index.aspx). We set the value of ν_s at 0.39. To calibrate ν_f we use the same input-output tables. The share of intermediates in final goods is $1 - \nu_f$. Our estimate of ν_f is 0.9. (Alvarez and Lucas, 2007, compute a share of 0.82 by exclud-

Table 1: Parameters common across countries

Parameter	Description	Value
α	k's Share	0.33
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_s	k and ℓ's Share in structures	0.39
ν_f	k and ℓ's Share in final goods	0.90
δ_e	Depreciation rate of producer durables	0.12
δ_s	Depreciation rate of structures	0.06
θ	Variation in (sectoral) factor productivity	4
μ	Share of producer durables in composite capital	0.56
β	Discount factor	0.96
η	Elasticity of substitution in aggregator	2

ing agriculture and mining from the final goods sector. Since we include agriculture and mining in final goods we obtain a larger estimate.)

Estimating θ The parameter θ in our model controls the dispersion in factor productivity. We follow the procedure of Simonovska and Waugh (2014) to estimate θ (see Appendix C for a description of their methodology).

We estimate θ for (i) all manufactured goods (producer durables + intermediate goods), (ii) only intermediate goods, and (iii) only producer durables. Our estimate for all manufactured goods is 3.7 (Simonovska and Waugh, 2014, obtain an estimate of 4). Our estimate for the capital goods sector is 4.3; for the intermediate goods sector it is 4. In light of these similar estimates, we set $\theta = 4$ for both sectors.[6]

3.2 Country-specific parameters

Country-specific parameters in our model are labor force, L; productivity parameters in the capital goods and intermediate goods sectors, T_e and T_m, respectively; productivity in the final goods sector, A_f; and the bilateral trade barriers, τ_e and τ_m. We take the labor force in each country from version 8.0 of PWT. The other country-specific parameters are calibrated to match a set of targets.

[6] Our estimate of θ and the parameters in Table 1 satisfy the restriction imposed by the model: $\beta < 1$ and $1 + (1 - \eta)/\theta > 0$.

Bilateral trade barriers Using data on prices and bilateral trade shares, in both capital goods and intermediate goods, we calibrate the bilateral trade barriers in each sector using a structural relationship implied by our model:

$$\frac{\pi_{bij}}{\pi_{bjj}} = \left(\frac{P_{bj}}{P_{bi}}\right)^{-\theta} \tau_{bij}^{-\theta}, b \in \{e, m\}. \tag{6}$$

We set $\tau_{bij} = 100$ for bilateral country pairs where $\pi_{bij} = 0$.

Countries in the bottom decile of the income distribution have larger barriers to export capital goods than countries in the top decile. One way to summarize this feature is to compute a trade-weighted export barrier for country i as $\frac{1}{X_{bi}} \sum\limits_{j \neq i} \tau_{bij} X_{bji}$, where X_{bji} is country i's exports to country j in sector $b \in \{e, m\}$ and X_{bi} is country i's total exports in that sector. The trade-weighted export barrier in the capital goods sector for countries in the bottom income decile is 3.99 while for countries in the top decile it is 2.04. The calibrated trade barriers in intermediate goods display a similar pattern: The trade-weighted export barrier for poor countries is 6.33 while for rich countries it is 1.81.

Productivities Using data on relative prices, home trade shares, and income per worker, we use the model's structural relationships to calibrate T_{ei}, T_{mi}, and A_{fi}. The structural relationships are given by

$$\frac{P_{mi}/P_{fi}}{P_{eUS}/P_{fUS}} = \frac{A_{fi}}{A_{fUS}} \left(\frac{T_{mi}/\pi_{mii}}{T_{mUS}/\pi_{mUSUS}}\right)^{-\frac{1}{\theta}} \left(\frac{T_{mi}/\pi_{mii}}{T_{mUS}/\pi_{mUSUS}}\right)^{\frac{\nu_m - \nu_f}{\theta \nu_m}}, \tag{7}$$

$$\frac{P_{ei}/P_{fi}}{P_{eUS}/P_{fUS}} = \frac{A_{fi}}{A_{fUS}} \left(\frac{T_{ei}/\pi_{eii}}{T_{eUS}/\pi_{eUSUS}}\right)^{-\frac{1}{\theta}} \left(\frac{T_{mi}/\pi_{mii}}{T_{mUS}/\pi_{mUSUS}}\right)^{\frac{\nu_e - \nu_f}{\theta \nu_m}}, \tag{8}$$

$$\frac{y_i}{y_{US}} = \frac{A_{fi}}{A_{fUS}} \left(\frac{T_{ei}/\pi_{eii}}{T_{eUS}/\pi_{eUSUS}}\right)^{\frac{\mu\alpha}{\theta(1-\alpha)}} \left(\frac{T_{mi}/\pi_{mii}}{T_{mUS}/\pi_{mUSUS}}\right)^{-\frac{1-\nu_f + \frac{\alpha}{1-\alpha}(1+\mu\nu_e + (1-\mu)\nu_s)}{\theta \nu_m}}. \tag{9}$$

We normalize T_{eUS}, T_{mUS}, and A_{fUS} to 1 and simultaneously solve for T_{ei}, T_{mi}, and A_{fi} for each country i (see Appendix A for derivations of the equations). None of our results depend on this normalization. For instance, the value of T_{eUS}/A_{fUS} does not affect our results so long as T_{ei}/A_{fi} is scaled proportionally in every country i.

These structural relationships reveal the intuition for how we identify productivity.

The expression for income per worker tells us something about "aggregate" productivity, i.e., a combination of A_{fi}, T_{ei}, and T_{mi}. The two expressions for relative prices reveal how the aggregate productivity is split across the sectors. That is, consider the expression for the relative price of capital goods, P_e/P_f in equation (8). There are two key components. The first is the ratio of productivity in final goods, A_f, to the measured productivity in capital goods, $(T_e/\pi_e)^{\frac{1}{\theta}}$, which is the Balassa-Samuelson effect. Note that the measured productivity is endogenous; more specifically, it is a function of both exogenous productivity as well as trade barriers.[7]

The second is the effect of the intensity of intermediate goods used in the production of both final goods and capital goods. Suppose that measured productivity of intermediate goods goes up. Then, all else equal, the price of intermediates will fall. If the production of final goods is less intermediate-intensive than the production of capital goods, i.e., $\nu_e - \nu_f < 0$, then the marginal cost of producing capital goods will fall more than the marginal cost of producing final goods and the relative price of capital goods will fall. If the two sectors have the same factor intensity, i.e., $\nu_e - \nu_f = 0$, then this effect vanishes and the relative price is uniquely determined by the ratio of measured productivity.

Table D.1 in Appendix D presents the calibrated productivity parameters. The average gap in fundamental productivity in the capital goods sector between countries in the top and bottom deciles is 4.4. In the intermediate goods sector, the average productivity gap is 1.8. That is, rich countries have a comparative advantage in capital goods production, while poor countries have a comparative advantage in intermediate goods production. Thus, the model is consistent with the observation that poor countries are net importers of capital goods.

4 Results

4.1 Model fit

The first step of the calibration uses $2I(I-1) = 15,312$ observations on trade shares and $2(I-1) = 174$ observations on prices of intermediate goods and capital goods (relative to the U.S.) in order to pin down $2I(I-1) = 15,312$ barriers—equation

[7] Sposi (2015) discusses the effect that trade barriers have on the measured productivity, and in turn, how the cross-country difference in the relative price is affected primarily through the price of the nontraded good.

(6). The second step involves using $I - 1 = 87$ observations on income per worker (relative to the U.S.) and $2(I-1) = 174$ observations on relative prices (relative to the U.S.) in order to compute $2(I-1) = 174$ fundamental productivity parameters, and $I - 1 = 87$ final goods productivity parameters—equations (7)-(9), respectively. As such, the model utilizes 174 more data points than there are parameters and will not match all of the data exactly.

Prices The correlations between the model and the data for the absolute price of capital goods, the relative price of capital goods, the absolute price of intermediate goods, and the relative price of intermediate goods are 0.95, 0.90, 0.98, and 0.76, respectively.

To see why the model prices do not exactly match the data exactly, note that the absolute prices of intermediate goods and capital goods in the model must satisfy:

$$P_{bi} = \gamma B_b \left(\sum_j (u_{bj} d_{bij})^{-\theta} T_{bj} \right)^{-\frac{1}{\theta}}. \tag{10}$$

(See Appendix A for the derivation.) Since equation (10) is independent from the set of equations used to calibrate the trade barriers and productivity parameters, the absolute prices implied by (10) need not be the same as the observed prices.

Income per worker Figure 1 illustrates the relative income per worker in the model and in the data. The correlation between the model and the data is 0.99. Log variance in the final goods sector productivity (A_f) accounts for 31 percent of the log variance in income per worker. (Recall from equations (3) and (4) that changes in A_f do not affect home trade shares and capital per worker.) This does *not* imply that factors account for the remaining 69 percent since measured TFP is not just A_f but includes exogenous components, T_{mi}, and endogenous components, π_{mii}.

Trade shares Figure 2 plots the home trade shares in capital goods, π_{eii}, in the model against the data. The observations line up close to the 45-degree line; the correlation between the model and the data is 0.97. The home trade shares for intermediate goods also line up closely with the data; the correlation is 0.97. The correlation between bilateral trade shares (excluding the home trade shares) in the model and that in the data is 0.94 in the capital goods sector and 0.90 in the intermediate goods sector.

Figure 1: Income per worker, US=1

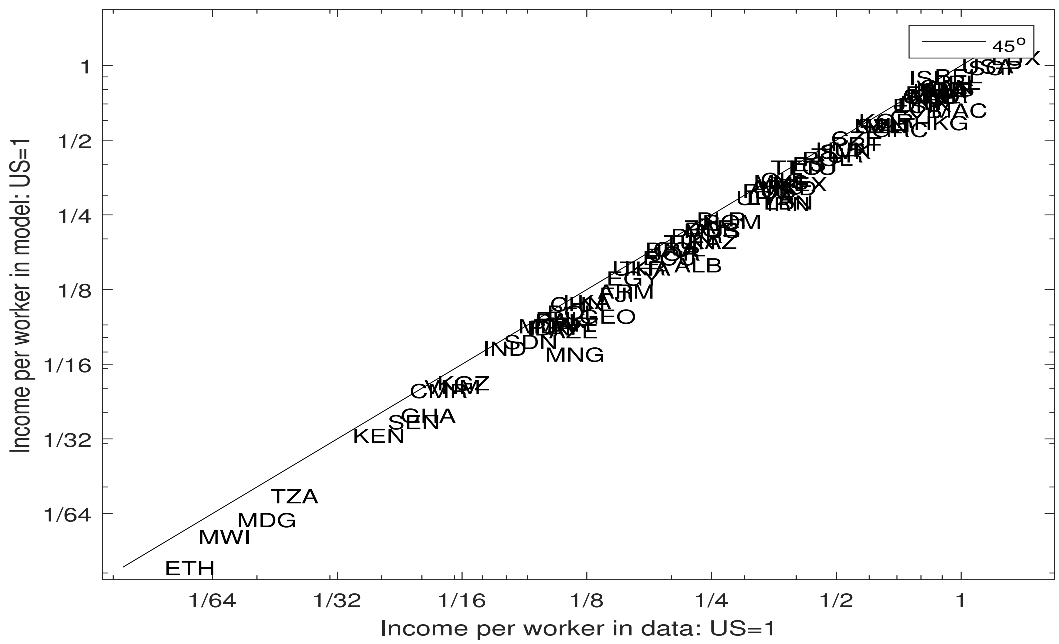
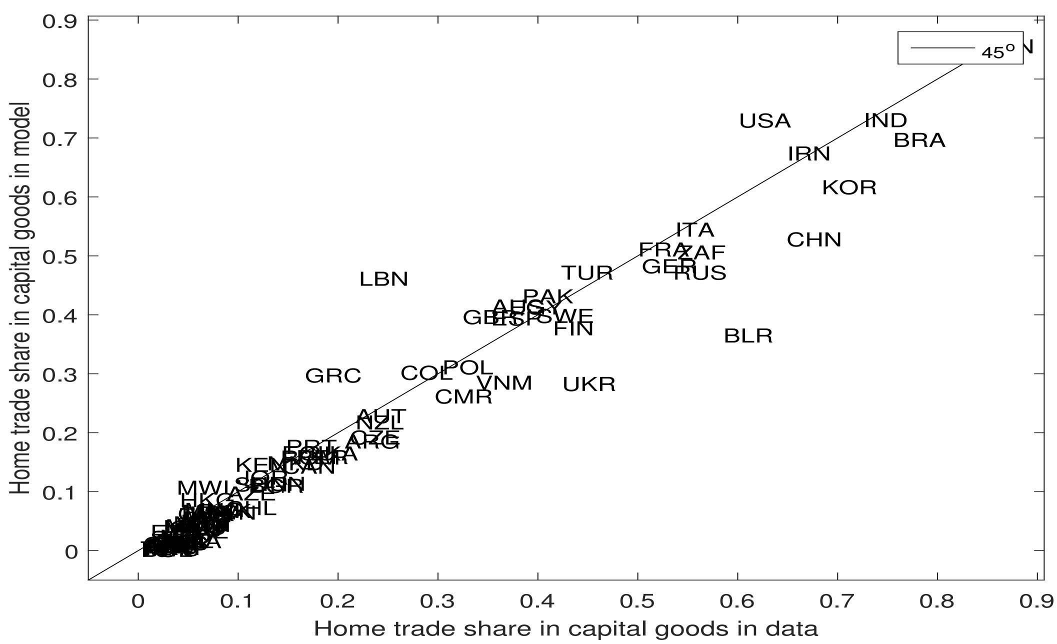


Figure 2: Home trade share in capital goods



4.2 Implications

Development accounting Suppose we conduct a development accounting exercise along the lines of Caselli (2005) using the model's output: What fraction of the log variance in income per worker is accounted for by the log variance in factors? Given the model's fit for the income per worker (see Figure 1), the fraction attributed by the model would helps us gauge the counterfactual exercises later. Log variance in y accounted for by k^α is 14 percent in the model and 12 percent in the data. Measured TFP, which includes final goods sector productivity A_f, accounts for 40 percent of log variance in income per worker in the model and 45 percent in the data. These results are consistent with the evidence in King and Levine (1994) who argue that capital is not a primary determinant of economic development.

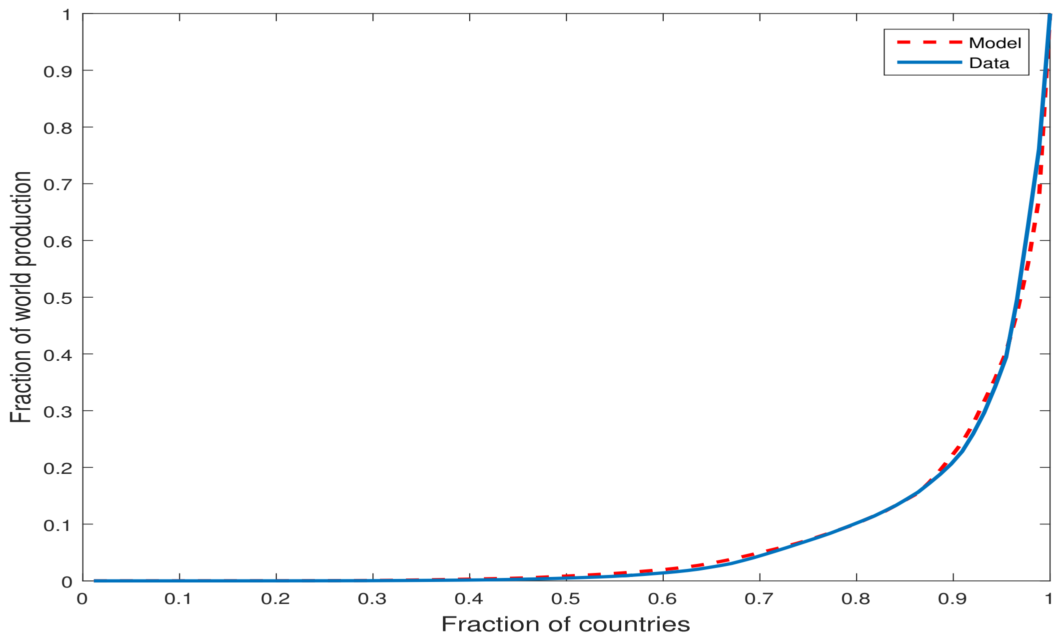
Capital goods production and trade flows Figure 3 illustrates the cdf for capital goods production. The model captures the observed skewness in production: In the model and in the data, 10 countries account for 80 percent of the world's capital goods production. The correlation between model and data for capital goods production is 0.95, so the countries do in fact line up correctly in Figure 3. Furthermore, poor countries are net importers of capital goods in the model and in the data and, as noted earlier, our model is consistent with the observed bilateral trade flows.

Relative prices and investment rates In the data, while the *relative* price of capital is higher in poor countries, the absolute price of capital goods does not exhibit such a systematic variation with level of economic development. As noted in Section 4.1, our model is consistent with data on the absolute price of capital goods and the price relative to consumption goods. The elasticity of the absolute price with respect to income per worker is 0.03 in the model and in the data; the elasticity of the relative price is -0.34 in the model and -0.29 in the data.

Eaton and Kortum (2001) construct a "trade-based" price of capital goods using a gravity regression. Hsieh and Klenow (2007) point out that the constructed prices are not consistent with the data on capital goods prices. In particular, the constructed prices are higher in poor countries than in rich countries.

Hsieh and Klenow (2007) also note that the negative correlation between the relative price of capital goods and economic development is mainly due to the price of consumption, which is lower in poor countries. Our model is consistent with this fact:

Figure 3: Distribution of capital goods production



The elasticity of the price of consumption goods is 0.37 in our model and 0.32 in the data.

Finally, the price of structures (not one of the calibration targets) is positively correlated with income per worker; the elasticity of the price of structures is 0.53 in the model and 0.44 in the data.

In our model, the investment rate measured in domestic prices is constant across countries, which is consistent with the data. Our model implies that in steady state $P_{ei}x_i^e = \phi_e r_{ei}k_i^e$ and $P_{si}x_i^s = \phi_s r_{si}k_i^s$, where $\phi_b = \frac{\delta_b}{1/\beta-(1-\delta_b)}$ for $b \in \{e, s\}$. Recall $k_i = (k_i^e)^\mu (k_i^s)^{1-\mu}$, so $r_{ei}k_i^e = \mu r_i k_i$ and $r_{si}k_i^s = (1-\mu)r_i k_i$. Since capital income $r_i k_i = w_i\alpha/(1-\alpha)$, it follows that $P_{ei}x_i^e = \phi_e \mu w_i \alpha/(1-\alpha)$ and $P_{si}x_i^s = \phi_s(1-\mu)w_i\alpha/(1-\alpha)$. Therefore, aggregate investment per worker is $P_{ei}x_i^e + P_{si}x_i^s = [\mu\phi_e + (1-\mu)\phi_s]w_i\alpha/(1-\alpha)$. Income is $w_i + r_i k_i = w_i/(1-\alpha)$, so the investment rate in domestic prices is

$$\frac{P_{ei}x_i^e + P_{si}x_i^s}{w_i + r_i k_i},$$

which is a constant $\alpha[\mu\phi_e + (1-\mu)\phi_s]$.

Our model also captures the systematic variation in investment rates measured in purchasing power parity (PPP) prices. Rich countries have higher investment rates than poor countries; the correlation between the investment rate and income per worker is 0.22 in the data. The investment rate in PPP prices for country i is

$$\frac{\frac{P_{ei}}{P_{xi}} x_i^e + \frac{P_{si}}{P_{xi}} x_i^s}{y_i},$$

where P_{xi} is the price index for aggregate investment in country i (see Appendix A). The investment rate is positively correlated with economic development; the correlation is 0.57 in our model. We account for 84 percent of the observed log variance in investment rates measured in PPP prices.

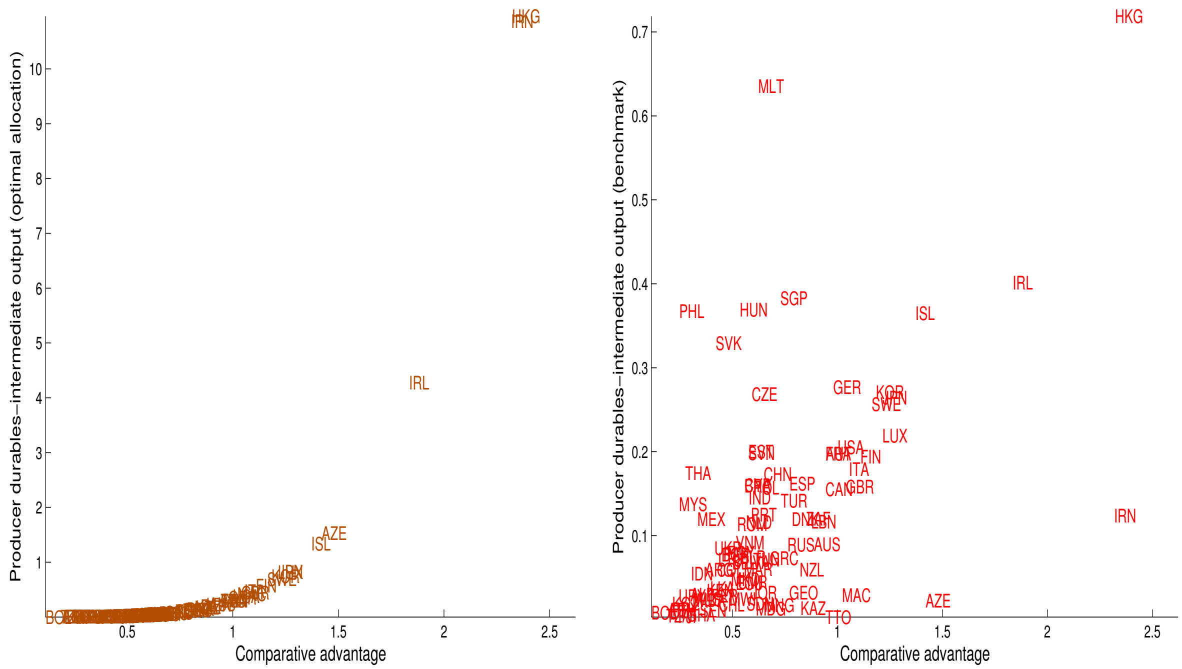
As discussed in Restuccia and Urrutia (2001), investment rates determine capital-output ratios and, hence, are crucial for understanding economic development. Taking the relative price of investment as exogenous, their model is able to account for 90 percent of the observed log variance in investment rates across countries. In our model, the relative price is endogenous; we account for 84 percent of the observed log variance.

Hsieh and Klenow (2007) infer that barriers to capital goods trade play no role in explaining investment rates across countries using the fact that capital goods prices do not exhibit strong systematic variation with income per worker. In our model, trade barriers play a key role in explaining relative price, investment rates, and the world distribution of capital goods production. In the capital goods sector, poor countries face a larger barrier to export and have lower productivity relative to rich countries. The negative correlation between trade barriers and productivity is essential to be consistent with both prices and trade flows; this is discussed in detail in Mutreja, Ravikumar, Riezman, and Sposi (2014). Our calibrated productivities imply that poor countries have a comparative advantage in intermediate goods. However, with large barriers to trade, it is costly for poor countries to export intermediate goods in exchange for capital goods. This is reflected in the high relative price of capital in poor countries, leading to low investment rates and low capital per worker. In Hsieh and Klenow (2007), there are only two tradable goods, so the specialization is complete and the model is not designed to address the pattern of trade and production in capital goods. Our model is consistent with the observed capital goods trade flows and prices.

4.3 Misallocation due to trade barriers

In the benchmark model, trade barriers result in a misallocation of resources across sectors in each country. To determine the magnitude of the misallocation, we compare the allocation in the benchmark model with the optimal allocation in a world without any trade costs. In this exercise, we remove barriers to trade in both sectors by setting $\tau_{mij} = \tau_{eij} = 1$ for all countries and leaving all other parameters at their calibrated values. Clearly, the optimal allocation would dictate that countries with a comparative advantage in capital goods should produce more capital goods relative to intermediate goods. Figure 4 plots the optimal relative size of the capital goods sector (Y_{ei}/Y_{mi}) in each country in the left panel, and that for the benchmark model in the right panel.

Figure 4: Capital goods output relative to intermediate goods output: no distortion in trade (left), benchmark (right)



Note: Comparative advantage is measured as $(T_e/T_m)^{\frac{1}{\theta}}$

In a world with barriers, the relative size of the capital goods sector is far from optimal. The production of capital goods, relative to intermediate goods, is too little in rich countries and too much in poor countries. In the benchmark economy, Thailand allocates 69 times as much labor to capital goods production relative to the optimal allocation, and France allocates only 0.72 times as much. The misallocation is drastically larger in poor countries than in rich countries.

In a world with frictionless trade, resources are allocated optimally. As a result, production of capital goods is more concentrated in countries that have a comparative advantage in capital goods production. Thus, relative price of capital decreases, more capital goods are produced and traded, and countries accumulate more capital.

The gap in income per worker between countries in the top and bottom deciles of the income distribution falls from 30.1 to 13.9. In each country, approximately 80 percent of the increase in income per worker can be attributed to increased capital and the remaining 20 percent to higher TFP (see Figure 5). The gap in capital per worker between countries in the top and bottom income deciles is a factor of only 5 in the optimal allocation, compared with a factor of 38 in the presence of trade barriers.

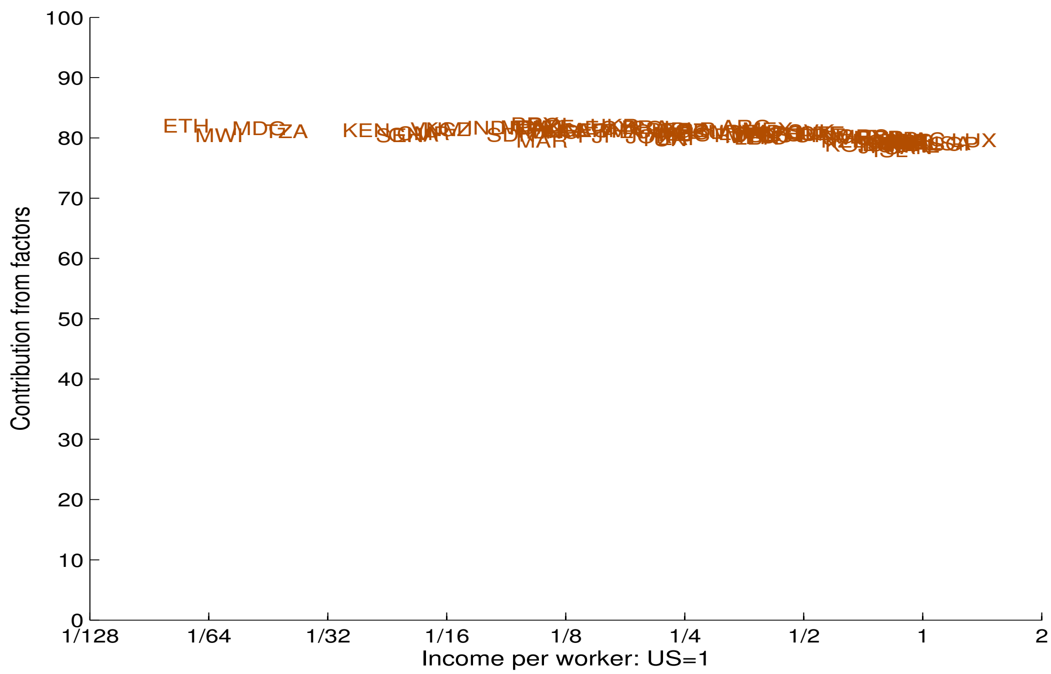
Trade barriers affect capital per worker in our model through the relative price of capital. In the presence of trade barriers, poor countries with a comparative disadvantage in capital goods production transform consumption into investment at an inferior rate relative to the world frontier. In the frictionless world, poor countries can transform consumption into investment at a higher rate since they have access to a superior international production possibilities frontier. For instance, in our benchmark, Bolivia gets 0.13 units of capital goods for every unit of consumption, but in a world with frictionless trade Bolivia gets more than 4.8 units. Furthermore, Bolivia increases its aggregate investment rate more than 20-fold in response to the higher rate of transformation. The increase in investment rate, in turn, increases Bolivia's steady state capital per worker by a factor of 200.

These results imply that capital being an endogenous factor of production is quantitatively important for studying the effect of trade barriers on development. In trade models with exogenous factors of production, reductions in trade barriers increase income per worker only through higher measured TFP via lower home trade shares in intermediate goods (equation (3)). In our model reductions in trade barriers reduce home trade shares in both intermediate goods and in capital goods and increase the income per worker both because of higher TFP and because of higher capital per worker (equation (4)). Our results indicate that the second effect is nearly four times the first.

Why is approximately 80 percent of the increase in income per worker due to increased capital in every country? Consider the equilibrium expression for income per worker $y_i = Z_i k_i^{\alpha}$. Note that $\frac{\partial \ln(Z_i)}{\partial \ln(\pi_{mii})} = -\frac{1-\nu_f}{\theta\nu_m} = -0.08$. That is, a one percentage point fall in the intermediate goods home trade share increases TFP by about 0.08 percent. Similarly, $\frac{\partial \ln(k_i^{\alpha})}{\partial \ln(\pi_{mii})} = -\alpha\frac{1-\mu\nu_e-(1-\mu)\nu_s}{\theta\nu_m(1-\alpha)} = -0.26$ and $\frac{\partial \ln(k_i^{\alpha})}{\partial \ln(\pi_{eii})} = -\frac{\alpha}{\theta}\frac{\mu}{1-\alpha} = -0.07$. The change in income per worker stemming from the change in capital per worker is approximately $\frac{\frac{\partial \ln(k_i^{\alpha})}{\partial \ln(\pi_{mii})}+\frac{\partial \ln(k_i^{\alpha})}{\partial \ln(\pi_{eii})}}{\frac{\partial \ln(Z_i)}{\partial \ln(\pi_{mii})}+\frac{\partial \ln(k_i^{\alpha})}{\partial \ln(\pi_{mii})}+\frac{\partial \ln(k_i^{\alpha})}{\partial \ln(\pi_{eii})}} \approx 0.80$. All that varies across countries is the magnitude of the changes in π_{mii} relative to π_{eii}. However, countries that have a large change in π_{mii} also have a large change in π_{eii} and vice-versa - $\partial \ln(\pi_{mii})$ is highly correlated with $\partial \ln(\pi_{eii})$. Therefore, the numerator and denominator are almost identical across countries.

Note that the elasticities in the above calculation are invariant to the value of θ. That is, the magnitude of increase in income due to reductions in trade barriers depend on θ, but to a first approximation, the relative importance of capital versus TFP does not depend on θ.

Figure 5: Fraction of change in income per worker due to change in capital per worker: benchmark to frictionless trade



The experience of Korea presents some evidence in favor of the channel in our model. Korea's trade reforms starting in 1960s reduced the restrictions on imports of capital goods (see Westphal, 1990; Yoo, 1993). During 1970-80, Korea's imports of capital goods increased 11-fold. Over a period of 40 years, the relative price of capital in Korea decreased by a factor of almost 2 and the investment rate increased by a factor of more than 4 (Nam, 1995). (See also Rodriguez and Rodrik, 2001, for a discussion of trade policies affecting relative prices.)

Hsieh (2001) provides evidence on the channel in our model via a contrast between Argentina and India. During the 1990s, India reduced barriers to capital goods imports that resulted in a 20 percent fall in the relative price of capital between 1990 and 2005. This led to a surge in capital goods imports and consequently the investment rate increased by 1.5 times during the same time period. After the Great Depression, Argentina restricted imports of capital goods. From the late 1930s to the late 1940s, the relative price of capital doubled and the investment rate declined.

Two remarks are in order regarding the counterfactual with frictionless trade. (1) Iceberg costs. Part of the increases in income per worker are due to a mechanical implication of iceberg-type trade barriers. Reduction in trade barriers imply that less tradable resources melt away in the ocean during transit. For instance, country i pays country j for τ_{eij} units of capital goods but receives only one unit; $\tau_{eij} - 1$ units melt away in transit. Some of the increases in income per worker stem from simply recouping the lost resources. (2) Technology vs. Policy. Recall that we inferred the benchmark trade barriers using equation (6) and data on prices and trade flows. Such barriers could contain technology as well as policy components, so the reduction in barriers might not be achieved purely via policy changes. In the next subsection, we decompose the quantitative implications of the change from our benchmark to a world with frictionless trade for income per worker.

4.3.1 Decompositions of the changes in income per worker

Iceberg costs To quantify the increases in income from recouping the lost resources, we perform a "scuba diving" exercise: We let the importing countries to recoup all of the capital goods and intermediate goods that were lost in transit in our benchmark model. We then compute the increase in consumption using the increases in capital goods and intermediate goods but restricting them to be allocated across sectors in the same proportion as in the benchmark. Since, in our model, consumption is proportional to income per worker, this calculation helps us quantify the misallocation.

After scuba diving, the total quantity of intermediate goods available to country i becomes $\hat{M}_i = \sum_j M_i \pi_{mij} \tau_{mij}$. The quantity of capital goods available is $\hat{x}_i^e = \sum_j x_i^e \pi_{eij} \tau_{eij}$, so the steady state stock of producer durables is $\hat{k}_i^e = \hat{x}_i^e / \delta_e$. Under the restriction that in each country the intermediate goods and stock of producer durables are allocated across sectors in the same proportion as in the benchmark, the shares in the final good production are: $\hat{M}_{fi}/\hat{M}_i = M_{fi}/M_i$ and $\hat{k}_{fi}^e/\hat{k}_i^e = k_{fi}^e/k_i^e$. Final good consumption is $\hat{c}_{fi} = A_{fi} \left[\left((\hat{k}_{fi}^e)^\mu (k_{fi}^s)^{1-\mu} \right)^\alpha \ell_{fi}^{1-\alpha} \right]^{\nu_f} \hat{M}_{fi}^{1-\nu_f}$. Note that we have included only the direct effects of more intermediate goods and capital goods on the final good and excluded the indirect effects (e.g., more intermediate goods and capital goods would imply a higher stock of structures, and hence, more final good).

In country i, let $\hat{y}_i$ denote the income per worker (proportional to final good) from the above calculation and y_i^{free} denote the income per worker in the counterfactual economy with frictionless trade. Write the increase in income due to frictionless trade as $\frac{y_i^{free}-y_i}{y_i} = \frac{y_i^{free}-\hat{y}_i+\hat{y}_i-y_i}{y_i}$. Then $\frac{\hat{y}_i-y_i}{y_i^{free}-y_i}$ is the fraction of the increase that stems purely from recovering the tradable goods lost in the ocean. On average, this fraction is less than 3 percent.

On the other extreme, suppose we remove the proportionality restriction and allocate *all* of the recovered capital goods and intermediate goods to the final goods sector i.e., $\hat{M}_{fi} = M_{fi} + (\hat{M}_i - M_i)$ and $\hat{k}^e_{fi} = k^e_{fi} + (\hat{k}^e_i - k^e_i)$, where $\hat{M}_i - M_i$ is the recovered quantity of intermediate goods and $\hat{k}^e_i - k^e_i$ is the recovered quantity of capital goods. Then, calculating the gain as above, the fraction is only 9 percent, on average. This implies that almost all of the gains stem from a better allocation of resources, and not from simply recouping the resources that *melted away*.

Technology vs. Policy Suppose that every country had the same trade barrier as the U.S. That is, we imagine an admittedly extreme scenario that the U.S. trade barrier is entirely technological. To operationalize this thought experiment, we compute the average trade-weighted export barrier for the U.S. in each sector: $\bar{\tau} = \frac{1}{X_{US}} \sum_{i \neq US} \tau_{iUS} X_{iUS}$, where X_{iUS} are exports from the U.S. to country i and X_{US} is U.S. exports. This computation yields a capital goods trade barrier to every bilateral pair, $\tau_{eij} = \bar{\tau}_e = 1.77$, and an intermediate goods trade barrier, $\tau_{mij} = \bar{\tau}_m = 2.17$. With these trade barriers, the income gap between countries in the top and bottom deciles of the income distribution falls from 30.1 to 14.9. Recall that in the counterfactual with frictionless trade the gap declined from 30.1 to 13.9, so reducing the barriers to the U.S. levels achieves almost the same results as completely eliminating all trade costs.

This does not imply that income per worker would remain the same if we were to reduce the barriers below the U.S. levels. This simply means that the increase in income from further reductions is roughly proportionate in all countries.

4.4 The role of capital goods trade

Capital goods trade affects cross-country differences in income per worker in our model through two channels: (i) capital per worker, since capital stock in each country is partly a result of the trade (π_{eii} in equation (4) affects k_i), and (ii) TFP, since the trade balance condition connects capital goods trade with intermediate goods trade and the home trade share in intermediate goods, π_{mii}, affects measured TFP in equation (3). To understand the quantitative role of capital goods trade, we conduct two counterfactual experiments: (i) we eliminate all trade in capital goods by setting τ_{eij} to prohibitively high levels for all country pairs and (ii) we eliminate all frictions to capital goods trade by setting τ_{eij} equal to 1. In both experiments, we leave all other parameters at their calibrated values; specifically, the intermediate goods trade barriers remain at the benchmark levels.

Autarky in capital goods In the benchmark case, poor countries are net exporters of intermediate goods and net importers of capital goods. Once capital goods trade is shut down, all countries trade only in intermediate goods, so the trade balance condition implies that exports of intermediate goods must equal the imports of intermediate goods in each country. This distorts the world pattern of capital goods production toward countries that do not have a comparative advantage in producing them i.e., the poor countries.

Eliminating trade in capital goods induces poor countries to allocate over six times more labor toward capital goods production, relative to the benchmark. Conversely, rich countries allocate only three percent more labor toward capital goods production.

With countries diverting resources away from their sector of comparative advantage, the world GDP shrinks by almost 6 percent. In each country, almost all of the decline in income per worker is due to decreased capital per worker. Again, capital being an endogenous factor of production is quantitatively important for the result.

Countries in the bottom decile suffer an income loss of 16 percent, on average. Without access to capital goods from rich countries, some poor countries suffer a greater loss: The income in Bolivia, for instance, declines by 30 percent. Again, the relative price of capital plays a key role. In our benchmark, Bolivia gets 0.13 units of capital goods for every unit of consumption, but with no trade in capital goods Bolivia gets only 0.06 units. As a result, Bolivia's investment rate declines by more than half and its steady state capital per worker declines by two-thirds.

Zero costs to capital goods trade In this experiment, the income gap between countries in the top and bottom deciles of the income distribution falls to 25.4 (from 30.1 in the benchmark). Almost 95 percent of the reduction in the income gap stems from changes in capital per worker. The ratio of capital per worker, between countries in the top and bottom deciles of the income distribution, falls from 38 to 24.

With zero costs to capital goods trade, poor countries increase their capital per worker relative to rich countries. This is driven by an increase in the investment rate, which in turn is driven by a decline in the relative price of producer durables. The channel through which trade barriers affect relative prices is discussed in Sposi (2015). Removal of trade costs results in more specialization in the direction of comparative advantage, thereby increasing the average productivity in capital goods and intermediate goods sectors. The increased productivity in tradable sectors implies higher wages and in turn higher prices of nontradables, i.e., final goods. The prices of final goods in poor countries increase relative to rich countries for two reasons: 1) poor countries have larger trade barriers than rich countries and 2) the sensitivity of home trade shares to changes in trade barriers is larger in poor countries. Meanwhile, there is no substantial change in the distribution of the price of producer durables since they are roughly equal across countries even in the benchmark. So the relative price of producer durables declines more in poor countries than in rich countries and, hence, the aggregate investment rate increases more in poor countries than in rich countries. In the benchmark model the aggregate investment rate in rich countries is 1.3 times that in poor countries; with zero costs to trade capital goods trade this ratio is 0.94.

Eaton and Kortum (2001) quantify the role of capital goods trade barriers in accounting for cross-country income differences using the neoclassical growth framework. As noted in Section 2.5, income per worker in the neoclassical growth model is $y = Z^{\frac{1}{1-\alpha}}\left(\frac{k}{y}\right)^{\frac{\alpha}{1-\alpha}} = Z^{\frac{1}{1-\alpha}}\left(\left(\frac{k^e}{y}\right)^{\mu}\left(\frac{k^s}{y}\right)^{1-\mu}\right)^{\frac{\alpha}{1-\alpha}}$. In steady state, for each sector $b \in \{e, s\}$, $\frac{k^b}{y} \propto \frac{x^b}{y}$ and $\frac{x^b}{y} \propto \frac{P_b x^b}{P_f y}\frac{P_f}{P_b}$. Since the investment rates measured in domestic prices, $\frac{P_b x^b}{P_f y}$, are constant across countries, the capital-output ratio is proportional to the inverse of the product of relative price of capital and relative price of structures. Eaton and Kortum (2001) construct a trade-based relative price of capital where P_e is derived from coefficients in a gravity regression, and P_f and P_s are taken directly from the Penn World Tables. By design, costs to trade capital goods affect the relative price of capital in their model only through the changes in the absolute price of capital since they hold fixed the price of final goods. In our model, removing the frictions affects mainly the cross-country distribution of the final good price. In addition, in our model the frictions affect the price of structures, which is exogenous in Eaton and Kortum (2001). Lastly, as noted by Hsieh and Klenow (2007), the trade-based measure of P_e used by Eaton and Kortum (2001) is negatively correlated with economic development whereas in the data P_e is practically uncorrelated with economic development.

In Hsieh and Klenow (2007), eliminating frictions to trade capital goods trade has no effect on the investment rate in poor countries relative to rich countries for two reasons. First, since the inferred frictions to trade capital goods are no different in poor countries than in rich countries, a removal of these frictions has essentially no effect on the *difference* in the absolute price of capital between rich and poor countries. Second, the frictions in their model do not affect the price of the final consumption good. As a result, removing costs to trade in capital goods does not alter the cross-country differences in relative price of capital and, hence, does not affect the cross-country differences in investment rates. In our model, removal of costs to trade capital goods leads to an equalization of the price of capital across countries and to an increase in the price of final goods in poor countries relative to rich countries. The resulting decline in the relative price of capital in poor countries leads to an increase in their investment rates relative to the investment rates in rich countries.

5 Conclusion

In this paper, we embed a multi country, multi sector Ricardian model of trade into a neoclassical growth framework. We match several trade and development facts within a unified framework. Our model is consistent with the world distribution of capital goods production, cross-country differences in investment rate and price of final goods, and cross-country equalization of price of capital goods. We also reproduce the cross-country patterns in capital per worker and home trade shares.

Trade barriers in our model imply a substantial misallocation of resources relative to the optimal allocation: Poor countries produce too much capital goods, while rich countries produce too little. In the optimal allocation with frictionless trade, income in poor countries increases about twice as much as in rich countries. Cross-country income differences decline by more than 50 percent when we switch to a world with frictionless trade. Autarky in capital goods is costly for poor countries; they suffer an income loss of 16 percent.

Changes in trade barriers affect income in our model predominantly through changes in capital stock. This channel is quantitatively important relative to the effect of trade barriers on TFP. Roughly 80 percent of the increase in income from our benchmark to a world with frictionless trade is due to an increase in capital.

References

Affendy, Arip M., Lau Sim Yee, and Madono Satoru. 2010. "Commodity-industry Classification Proxy: A Correspondence Table Between SITC revision 2 and ISIC revision 3." MPRA Paper 27626, University Library of Munich, Germany. URL `http://ideas.repec.org/p/pra/mprapa/27626.html`.

Alvarez, Fernando and Robert E. Lucas. 2007. "General Equilibrium Analysis of the Eaton-Kortum Model of International Trade." *Journal of Monetary Economics* 54 (6):1726–1768.

Bernard, Andrew B., Jonathan Eaton, J. Bradford Jensen, and Samuel Kortum. 2003. "Plants and Productivity in International Trade." *American Economic Review* 93 (4):1268–1290.

Buera, Francisco J., Joseph P. Kaboski, and Yongseok Shin. 2011. "Finance and Development: A Tale of Two Sectors." *American Economic Review* 101 (5):1964–2002.

Caselli, Francesco. 2005. "Accounting for Cross-Country Income Differences." In *Handbook of Economic Growth*, edited by Philippe Aghion and Steven Durlauf, chap. 9. Elsevier, 679–741.

Dornbusch, Rudiger, Stanley Fischer, and Paul A. Samuelson. 1977. "Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods." *American Economic Review* 67 (5):823–839.

Eaton, Jonathan and Samuel Kortum. 2001. "Trade in Capital Goods." *European Economic Review* 45:1195–1235.

———. 2002. "Technology, Geography, and Trade." *Econometrica* 70 (5):1741–1779.

Feenstra, Robert C., Robert Inklaar, and Marcel Timmer. 2013. "The Next Generation of the Penn World Table." Working Paper 19255, National Bureau of Economic Research.

Finicelli, Andrea, Patrizio Pagano, and Massimo Sbracia. 2012. "Ricardian Selection." *Journal of International Economics* 89 (1):96–109.

Gollin, Douglas. 2002. "Getting Income Shares Right." *Journal of Political Economy* 110 (2):458–474.

Greenwood, Jeremy, Zvi Hercowitz, and Per Krusell. 1997. "Long-Run Implications of Investment-Specific Technological Change." *American Economic Review* 87 (3):342–362.

Greenwood, Jeremy, Juan M. Sanchez, and Cheng Wang. 2013. "Quantifying the Impact of Financial Development on Economic Development." *Review of Economic Dynamics* 16 (1):194–215.

Hall, Robert E. and Charles I. Jones. 1999. "Why Do Some Countries Produce So Much More Output per Worker than Others?" *Quarterly Journal of Economics* 114 (1):83–116.

Hsieh, Chang-Tai. 2001. "Trade Policy and Economic Growth: A Skeptic's Guide to the Cross-National Evidence: Comment." In *NBER Macroeconomics Annual 2000, Volume 15*, NBER Chapters. National Bureau of Economic Research, Inc, 325–330.

Hsieh, Chang-Tai and Peter J. Klenow. 2007. "Relative Prices and Relative Prosperity." *American Economic Review* 97 (3):562–585.

King, Robert G. and Ross Levine. 1994. "Capital Fundamentalism, Economic Development, and Economic Growth." *Carnegie-Rochester Conference Series on Public Policy* 40:259–292.

Klenow, Peter and Andrés Rodríguez-Clare. 1997. "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?" In *NBER Macroeconomics Annual 1997, Volume 12*, NBER Chapters. National Bureau of Economic Research, 73–114.

Mutreja, Piyusha. 2013. "International Trade and Composition of Capital across Countries." Syracuse University Working Paper.

Mutreja, Piyusha, B. Ravikumar, Raymond Riezman, and Michael Sposi. 2014. "Price Equalization, Trade Flows, and Barriers to Trade." *European Economic Review* 70:383–398.

Nam, Chong-Hyun. 1995. "The Role of Trade and Exchange Rate Policy in Korea's Growth." In *Growth Theories in Light of the East Asian Experience, NBER-EASE Volume 4*, NBER Chapters. National Bureau of Economic Research, Inc, 153–179.

Restuccia, Diego and Richard Rogerson. 2008. "Policy Distortions and Aggregate Productivity with Heterogeneous Plants." *Review of Economic Dynamics* 11 (4):707–720.

Restuccia, Diego and Carlos Urrutia. 2001. "Relative Prices and Investment Rates." *Journal of Monetary Economics* 47 (1):93–121.

Rodriguez, Francisco and Dani Rodrik. 2001. "Trade Policy and Economic Growth: A Skeptic's Guide to the Cross-National Evidence." In *NBER Macroeconomics Annual 2000, Volume 15*, NBER Chapters. National Bureau of Economic Research, Inc, 261–325.

Simonovska, Ina and Michael E. Waugh. 2014. "The Elasticity of Trade: Estimates and Evidence." *Journal of International Economics* 92 (1):34–50.

Sposi, Michael. 2015. "Trade Barriers and the Relative Price of Tradables." *Journal of International Economics* Forthcoming.

UNIDO. 2013. *International Yearbook of Industrial Statistics 2013*. Edward Elgar Publishing.

Waugh, Michael E. 2010. "International Trade and Income Differences." *American Economic Review* 100 (5):2093–2124.

Westphal, Larry E. 1990. "Industrial Policy in an Export-Propelled Economy: Lessons from South Korea's Experience." *Journal of Economic Perspectives* 4 (3):41–59.

Yoo, Jung-Ho. 1993. "The Political Economy of Protection Structure in Korea." In *Trade and Protectionism, NBER-EASE Volume 2*, NBER Chapters. National Bureau of Economic Research, Inc, 153–179.

A Derivations

A.1 Price indices and trade shares

We derive the price index and bilateral trade shares for intermediate goods. Expressions for prices and trade shares in the capital goods sector are analogous.

Let $\gamma = \Gamma(1+\theta(1-\eta))^{1/(1-\eta)}$, where $\Gamma(\cdot)$ is the gamma function. The price index for intermediates is

$$P_{mi} = \gamma B_m \left[\sum_j (d_{mj}\tau_{mij})^{-\theta} T_{mj} \right]^{-\frac{1}{\theta}}. \tag{11}$$

Let π_{mij} be the fraction of country i's total spending on intermediate goods that was obtained from country j. The fraction of country i's expenditures that are sourced from country j, is also the probability that country j is the least cost provider to country i. This probability is given by

$$\pi_{mij} = \Pr\left\{ p_{mij}(z_m) \le \min_l \left[p_{mil}(u) \right] \right\} = \frac{(d_{mj}\tau_{mij})^{-\theta} T_{mj}}{\sum_l (d_{ml}\tau_{mil})^{-\theta} T_{ml}}, \tag{12}$$

A.2 Relative prices

Here we derive equations for three relative prices: $P_{ei}/P_{fi}, P_{mi}/P_{fi}$, and P_{si}/P_{fi}. Equations (11) and (12) imply that

$$\begin{aligned} \pi_{mii} &= \frac{\tau_{mi}^{-\theta} T_{mi}}{(\gamma B_m)^{\theta} P_{mi}^{-\theta}} \\ \Rightarrow P_{mi} &\propto \frac{\left(\frac{r_i}{w_i}\right)^{\alpha\nu_m} \left(\frac{w_i}{P_{mi}}\right)^{\nu_m} P_{mi}}{\left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta}}}, \end{aligned}$$

which implies that $\frac{w_i}{P_{mi}} \propto \left(\frac{w_i}{r_i}\right)^{\alpha} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta\nu_m}}$. Similarly,

$$P_{ei} \propto \frac{\left(\frac{r_i}{w_i}\right)^{\alpha\nu_e} \left(\frac{w_i}{P_{mi}}\right)^{\nu_e} P_{mi}}{\left(\frac{T_{ei}}{\pi_{eii}}\right)^{\frac{1}{\theta}}}, \quad P_{si} \propto \frac{\left(\frac{r_i}{w_i}\right)^{\alpha\nu_s} \left(\frac{w_i}{P_{mi}}\right)^{\nu_s} P_{mi}}{1}, \quad P_{fi} \propto \frac{\left(\frac{r_i}{w_i}\right)^{\alpha\nu_f} \left(\frac{w_i}{P_{mi}}\right)^{\nu_f} P_{mi}}{A_{fi}}.$$

We show how to solve for P_{ei}/P_{fi}, and the other relative prices are solved for analogously. Taking ratios of the expressions above and substituting for w_i/P_{mi} we get

$$\begin{aligned}
\frac{P_{ei}}{P_{fi}} &\propto \left(\frac{r_i}{w_i}\right)^{\alpha(\nu_e-\nu_f)} \left(\frac{w_i}{P_{mi}}\right)^{\nu_e-\nu_f} \frac{A_{fi}}{(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}} \\
&= \frac{A_{fi}}{(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}} \left(\frac{r_i}{w_i}\right)^{\alpha(\nu_e-\nu_f)} \left[\left(\frac{w_i}{r_i}\right)^{\alpha} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta\nu_m}}\right]^{\nu_e-\nu_f} \\
&= \frac{A_{fi}}{(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_e-\nu_f}{\theta\nu_m}}.
\end{aligned}$$

Similarly,

$$\frac{P_{mi}}{P_{fi}} \propto \frac{A_{fi}}{(T_{mi}/\pi_{mii})^{\frac{1}{\theta}}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_m-\nu_f}{\theta\nu_m}} \text{ and } \frac{P_{si}}{P_{fi}} \propto \frac{A_{fi}}{1} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_s-\nu_f}{\theta\nu_m}}.$$

A.3 Price and quantity of aggregate investment

First, we introduce an aggregate investment good in each country i, x_i, and a corresponding price index, P_{xi}, such that total investment expenditures is $P_{xi}x_i = P_{ei}x_i^e + P_{si}x_i^s$. This requires us to construct a depreciation rate, δ_x, for the aggregate investment good. Recall that the composite capital stock is a Cobb-Douglas aggregate of producer durables and structures: $k = (k^e)^{\mu}(k^s)^{1-\mu}$. The rental rate for the composite capital is then given by $r_x = \left(\frac{r_e}{\mu}\right)^{\mu}\left(\frac{r_s}{1-\mu}\right)^{1-\mu}$. No-arbitrage implies that $P_b = \frac{r_b}{\frac{1}{\beta}-(1-\delta_b)}$ for $b \in \{e, s\}$. An identical relationship holds for aggregate investment as well. Finally, in steady state, investments in each type of capital are such that the stocks of each type of capital are constant over time: $x^b = \delta_b k^b$ for $b \in \{e, s\}$. We impose an identical condition for aggregate investment.

In sum, we have three equations to solve for three unknowns: P_x, x, and δ_x.

$$P_x x = P_e x^e + P_s x^s \tag{13}$$

$$P_x = \frac{r_x}{\frac{1}{\beta} - (1-\delta_x)} \tag{14}$$

$$x^k = \delta_x k \tag{15}$$

Investment spending on each type of capital is $P_b x^b = \frac{\delta_b}{\frac{1}{\beta}-(1-\delta_b)} r_b k^b$, denoted by

$\phi_b r_b k^b$. This can be further simplified to $P_e x^e = \mu \phi_e r_x k$ and $P_s x^s = (1-\mu)\phi_s r_x k$. Therefore, total investment spending from equation (13) is given by $P_x x = (\mu\phi_e + (1-\mu)\phi_s) r_x k = \phi_x r_x k$.

Next, combine equations (14) and (15) to get

$$P_x x = \frac{\delta_x}{\frac{1}{\beta} - (1-\delta_x)} r_x k.$$

The last two expressions imply that $\phi_x = \frac{\delta_x}{\frac{1}{\beta}-(1-\delta_x)}$, so $\delta_x = \frac{(1-\beta)\phi_x}{\beta(1-\phi_x)}$. Then we use equations (14) and (15) to solve for the price and quantity of aggregate investment since the equilibrium r and k are already determined.

A.4 Capital stock

Since $r_i k_i = \frac{\alpha}{1-\alpha} w_i$, aggregate stock of capital per worker $k_i \propto \frac{w_i}{r_i} = \frac{w_i}{r_{ei}^{\mu} r_{si}^{1-\mu}} \propto \left(\frac{w_i}{P_{ei}}\right)^{\mu} \left(\frac{w_i}{P_{si}}\right)^{1-\mu}$ ($r_{ei} \propto P_{ei}$ and $r_{si} \propto P_{si}$ come from the Euler equations). We derive w_i/P_{ei} by making use of the relative prices above:

$$\frac{w_i}{P_{ei}} = \frac{w_i}{P_{mi}} \frac{P_{mi}}{P_{ei}} \propto \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta\nu_m}} \left(\frac{w_i}{r_i}\right)^{\alpha} \frac{(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}}{(T_{mi}/\pi_{mii})^{\frac{1}{\theta}}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_m-\nu_e}{\theta\nu_m}}.$$

Analogously,

$$\frac{w_i}{P_{si}} \propto \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta\nu_m}} \left(\frac{w_i}{r_i}\right)^{\alpha} \frac{1}{(T_{mi}/\pi_{mii})^{\frac{1}{\theta}}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_m-\nu_s}{\theta\nu_m}}.$$

Again, use the fact that $k_i \propto \frac{w_i}{r_i}$ and then

$$k_i \propto \left(\left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta\nu_m}} k_i^{\alpha} \frac{(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}}{(T_{mi}/\pi_{mii})^{\frac{1}{\theta}}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_m-\nu_e}{\theta\nu_m}} \right)^{\mu}$$
$$\times \left(\left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta\nu_m}} k_i^{\alpha} \frac{1}{(T_{mi}/\pi_{mii})^{\frac{1}{\theta}}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_m-\nu_s}{\theta\nu_m}} \right)^{1-\mu}$$
$$\Rightarrow k_i \propto \left(\left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta\nu_m}} \frac{(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}}{(T_{mi}/\pi_{mii})^{\frac{1}{\theta}}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_m-\nu_e}{\theta\nu_m}} \right)^{\frac{\mu}{1-\alpha}}$$
$$\times \left(\left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta\nu_m}} \frac{1}{(T_{mi}/\pi_{mii})^{\frac{1}{\theta}}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_m-\nu_s}{\theta\nu_m}} \right)^{\frac{1-\mu}{1-\alpha}}.$$

To derive an expression for the capital-output ratio, note that investment rates at domestic prices are identical across countries in our model: $\frac{P_{ei}x_i^e}{P_{fi}y_i}$ is a constant; similarly, $\frac{P_{si}x_i^s}{P_{fi}y_i}$ is also a constant. Therefore, $x_i^e/y_i \propto P_{fi}/P_{ei}$ and $x_i^s/y_i \propto P_{fi}/P_{si}$. To solve for the capital-output ratio write $k_i = (k_i^e)^{\mu}(k_i^s)^{1-\mu}$ in terms of relative price as follows: $k_i^e \propto x_i^e, k_i^s \propto x_i^s$, $x_i^e/y_i \propto P_{fi}/P_{ei}$, and $x_i^s/y_i \propto P_{fi}/P_{si}$. Finally, use the expressions for relative prices in terms of $A_{fi}, T_{ei}, T_{si}, \pi_{eii}$, and π_{mii} given in Appendix A.2.

$$\frac{k_i}{y_i} \propto \left(\frac{A_{fi}}{(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_e-\nu_f}{\theta\nu_m}} \right)^{-\mu} \left(\frac{A_{fi}}{1} \left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{\nu_s-\nu_f}{\theta\nu_m}} \right)^{\mu-1}.$$

B Data

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

Categories Capital goods in our model corresponds to "Machinery & equipment" categories in the ICP (http://siteresources.worldbank.org/ICPEXT/Resources/ICP_2011.html). We identify the categories according to the two-digit ISIC classification (for a complete list go to http://unstats.un.org/unsd/cr/registry/regcst.asp?cl=2). The ISIC categories for capital goods are 29 through 35. Intermediate goods are identified as all of manufacturing categories 15 through 37 excluding those identified as capital goods. Structures in our model corresponds to ISIC category 45 labeled "Construction." Final goods in our model correspond to the remaining ISIC categories excluding capital goods, intermediate goods, and structures.

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 PPP price of "Machinery & equipment", world price = 1. We take the price of structures also from the ICP; we use the variable PPP price of "Construction", world price = 1. The price of final goods in our model is the price level of consumption goods from PWT80. The price of intermediate goods is constructed by aggregating prices of goods across various subsectors within intermediate goods using data from the ICP. For each country, we have two pieces of information on each good in the intermediate goods basket: (i) expenditure in domestic currency converted to U.S. dollars using the exchange rate and (ii) expenditure in international dollars (PPP). We sum the exchange-rate-adjusted expenditures in domestic currency, and divide that value by the sum of expenditures in international dollars to compute the price. In fact, the prices of capital goods and structures are computed exactly the same way in the ICP.

National accounts PPP income per worker is from PWT80, defined as expenditure-side GDP at constant PPPs divided by the number of workers (also available in PWT80). We take the capital stock series from PWT80 as well.

Production Data on manufacturing production are from INDSTAT2, a database maintained by UNIDO (2013) at the two-digit level, ISIC revision 3. We aggregate the two-digit categories into either capital goods or intermediate goods using the classification method discussed above.

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

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 intermediate goods 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.

C Estimation of θ

Simonovska and Waugh (2014) build on the procedure in Eaton and Kortum (2002). We refer to these papers as SW and EK henceforth. We briefly describe EK's method before explaining SW's method. For now we ignore sector subscripts, as θ for each sector is estimated independently.

In our model (equation (6)),

$$\log\left(\frac{\pi_{ij}}{\pi_{jj}}\right) = -\theta(\log\tau_{ij} - \log P_i + \log P_j) \tag{16}$$

where P_i and P_j denote the aggregate prices in countries i and j for the sector under consideration. If we knew τ_{ij}, it would be straightforward to estimate θ, but we do not. A key element is to exploit cross-country data on disaggregate prices of goods within the sector.

Let x denote a particular variety in the continuum. Each country i faces a price, $p_i(x)$, for that good. Ignoring the source of the producer of good x, a simple no-arbitrage argument implies that, for any two counties i and j, $\frac{p_i(x)}{p_j(x)} \leq \tau_{ij}$. Thus, the gap in prices between any two countries provides a lower bound for the trade barrier between them. In our model, we assume that the same bilateral barrier applies to all goods in the continuum, so $\max\limits_{x\in X}\{\frac{p_i(x)}{p_j(x)}\} \leq \tau_{ij}$, where X denotes the set of goods for which disaggregate prices are available. One could thus obtain the bilateral trade barrier as $\log\hat{\tau}_{ij}(X) = \max_{x\in X}\{\log p_i(x) - \log p_j(x)\}$.

EK derive a method of moments estimator, $\hat{\rho}_{EK}$, as:

$$\hat{\rho}_{EK} = -\frac{\sum_i\sum_j \log\left(\frac{\pi_{ij}}{\pi_{jj}}\right)}{\sum_i\sum_j[\log\hat{\tau}_{ij}(X) - \log\hat{P}_i(X) + \log\hat{P}_j(X)]}, \tag{17}$$

where $\log\hat{P}_i(X) = \frac{1}{|X|}\sum\limits_{x\in X}\log p_i(x)$ is the average price of goods in X in country i and $|X|$ is the number of goods in X.

SW show that the EK estimator is biased. This is because the sample of disaggregate prices is only a subset of all prices. Since the estimated trade barrier is only a lower bound to the true trade barrier, a smaller sample of prices leads to a lower estimate of $\hat{\tau}_{ij}$ and, hence, a higher estimate of $\hat{\rho}_{EK}$. SW propose a simulated method of moments estimator to correct for the bias.

The SW methodology is as follows. Start with an arbitrary value of θ. Simulate marginal costs for all countries for a large number of goods as a function of θ. Compute the bilateral trade shares π_{ij} and prices $p_i(x)$. Use a subset of the simulated prices and apply the EK methodology to obtain a biased estimate of θ, call it $\rho(\theta)$. Iterate on θ until $\hat{\rho}_{EK} = \rho(\theta)$ to uncover the true θ.

The first step is to parameterize the distribution from which marginal costs are drawn. This step requires exploiting the structure of the model. The model implies that

$$\log \frac{\pi_{ij}}{\pi_{ii}} = F_j - F_i - \theta \log(\tau_{ij}), \tag{18}$$

where $F_i \equiv \log d_i^{-\theta} T_i$. The F_i governs the distribution of marginal costs in country i. In order to estimate these, SW use a parsimonious gravity specification for trade barriers:

$$\log \tau_{ij} = dist_k + brdr_{ij} + exj + \varepsilon_{ij}. \tag{19}$$

The coefficient $dist_k$ is the effect of distance between countries i and j lying in the kth distance interval.[8] The coefficient $brdr_{ij}$ is the effect of countries i and j having a shared border. The term ex_j is a country-specific exporter fixed effect. Finally, ε_{ij} is a residual that captures impediments to trade that are orthogonal to the other terms. Combining the gravity specification with equation 18, SW use ordinary least squares to estimate F_i for each country and bilateral trade barriers for all countries.

The second step is to simulate prices for every good in the "continuum" in every country. Recall that $p_{ij}(x) = \tau_{ij}\frac{d_j}{z_j(x)}$, where z_j is country j's productivity. Instead of simulating these productivities, SW show how to simulate the inverse marginal costs, $imc_j = z_j(x)/d_j$. In particular, they show that the inverse marginal cost has the following distribution: $F(imc_i) = \exp(-\tilde{F}_i imc_i^{-\theta})$, where $\tilde{F}_i = \exp(F_i)$. They discretize the grid to 150,000 goods and simulate the inverse marginal costs for each good in each country. Combining the simulated inverse marginal costs with the estimated trade barriers, they find the least-cost supplier for every country and every good and then construct country-specific prices as well as bilateral trade shares.

The third step is to obtain a biased estimate of θ using the simulated prices. Choose X to be a subset of the 150,000 prices such that X contains the same number of disaggregate prices as in the data. Call that estimate $\rho_s(\theta)$. Then perform $s = 100$

[8] The distance intervals are measured in miles using the great circle method: [0,375); [375,750); [750,1500); [1500,3000); [3000,6000); and [6000,max).

simulations. Finally, choose a value for θ such that the average "biased" estimate of θ from simulated prices is sufficiently close to the biased estimate obtained from the observed prices – that is, $\frac{1}{100}\sum_s \rho_s(\theta) = \hat{\rho}_{EK}$.

One caveat is that the number of disaggregate price categories that fall under producer durables is small. Therefore, we also include consumer durables to expand the sample size.

D Calibrated productivity parameters

Table D.1: Productivity parameters

Country	**Isocode**	A_{fi}	$T_{ei}^{\frac{1}{\theta}}$	$T_{mi}^{\frac{1}{\theta}}$	$\left(\frac{T_{ei}}{T_{mi}}\right)^{\frac{1}{\theta}}$
Albania	ALB	0.43	0.14	0.46	0.30
Argentina	ARG	0.56	0.29	0.78	0.37
Armenia	ARM	0.37	0.09	0.48	0.19
Australia	AUS	0.91	0.82	0.92	0.89
Austria	AUT	0.88	0.74	0.78	0.94
Azerbaijan	AZE	0.32	0.17	0.12	1.42
Belarus	BLR	0.53	0.32	0.59	0.54
Belgium	BEL	0.92	0.34	0.68	0.50
Bolivia	BOL	0.30	0.06	0.51	0.11
Brazil	BRA	0.36	0.41	0.73	0.56
Bulgaria	BGR	0.45	0.27	0.60	0.45
Cameroon	CMR	0.18	0.26	0.49	0.53
Canada	CAN	0.91	0.75	0.80	0.94
Chile	CHL	0.54	0.34	0.77	0.43
China	CHN	0.31	0.36	0.56	0.65
Colombia	COL	0.41	0.28	0.66	0.43
Cyprus	CYP	0.84	0.42	0.75	0.56
Czech Republic	CZE	0.72	0.44	0.75	0.59
Denmark	DNK	0.77	0.60	0.77	0.78
Ecuador	ECU	0.38	0.29	0.56	0.52
Egypt	EGY	0.38	0.28	0.59	0.48
Estonia	EST	0.61	0.32	0.55	0.58
Ethiopia	ETH	0.08	0.06	0.30	0.20
Fiji	FJI	0.30	0.12	0.50	0.24
Finland	FIN	0.82	0.95	0.86	1.11
France	FRA	0.86	0.86	0.91	0.94
Georgia	GEO	0.34	0.15	0.19	0.77
Germany	GER	0.83	0.85	0.87	0.98
Ghana	GHA	0.17	0.12	0.41	0.28
Greece	GRC	0.78	0.55	0.81	0.68
Hong Kong	HKG	0.86	0.46	0.20	2.32
Hungary	HUN	0.67	0.39	0.72	0.53
Iceland	ISL	0.82	0.54	0.39	1.37
India	IND	0.23	0.32	0.55	0.58
Indonesia	IDN	0.27	0.15	0.51	0.30
Iran	IRN	0.69	0.41	0.18	2.32
Ireland	IRL	0.93	0.59	0.32	1.83
Italy	ITA	0.86	0.95	0.90	1.05
Japan	JPN	0.85	1.06	0.88	1.22
Jordan	JOR	0.35	0.36	0.61	0.59
Kazakhstan	KAZ	0.47	0.19	0.23	0.82
Kenya	KEN	0.15	0.16	0.43	0.38
Korea, Republic of	KOR	0.79	0.94	0.80	1.18
Kyrgyzstan	KGZ	0.22	0.09	0.43	0.21
Latvia	LVA	0.53	0.26	0.47	0.56
Lebanon	LBN	0.54	0.56	0.64	0.87
Lithuania	LTU	0.62	0.28	0.64	0.43
Luxembourg	LUX	1.08	0.53	0.44	1.21
Macao	MAC	0.98	0.43	0.42	1.02
Macedonia	MKD	0.60	0.31	0.62	0.49
Madagascar	MDG	0.11	0.09	0.14	0.61
Malawi	MWI	0.08	0.16	0.34	0.49

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Table D.1 – Continued

Country	**Isocode**	A_{fi}	$T_{ei}^{\frac{1}{\theta}}$	$T_{mi}^{\frac{1}{\theta}}$	$\left(\frac{T_{ei}}{T_{mi}}\right)^{\frac{1}{\theta}}$
Malaysia	MYS	0.56	0.17	0.69	0.25
Malta	MLT	0.79	0.37	0.60	0.62
Mauritius	MUS	0.42	0.19	0.61	0.31
Mexico	MEX	0.57	0.24	0.73	0.33
Moldova	MDA	0.28	0.11	0.32	0.33
Mongolia	MNG	0.28	0.16	0.24	0.65
Morocco	MAR	0.24	0.28	0.51	0.55
Netherlands	NLD	0.82	0.37	0.66	0.56
New Zealand	NZL	0.73	0.67	0.82	0.82
Pakistan	PAK	0.29	0.25	0.55	0.46
Paraguay	PRY	0.28	0.11	0.53	0.21
Peru	PER	0.43	0.28	0.69	0.40
Philippines	PHL	0.28	0.13	0.54	0.25
Poland	POL	0.64	0.47	0.78	0.60
Portugal	PRT	0.68	0.47	0.80	0.59
Romania	ROM	0.47	0.33	0.63	0.52
Russia	RUS	0.60	0.50	0.66	0.76
Senegal	SEN	0.16	0.14	0.40	0.34
Singapore	SGP	1.12	0.33	0.45	0.73
Slovak Republic	SVK	0.71	0.21	0.49	0.42
Slovenia	SVN	0.74	0.43	0.75	0.58
South Africa	ZAF	0.40	0.59	0.70	0.85
Spain	ESP	0.81	0.70	0.91	0.77
Sri Lanka	LKA	0.31	0.23	0.59	0.39
Sudan	SDN	0.25	0.25	0.43	0.57
Sweden	SWE	0.81	0.95	0.82	1.16
Tanzania	TZA	0.11	0.07	0.36	0.18
Thailand	THA	0.37	0.16	0.58	0.27
Trinidad and Tobago	TTO	0.56	0.22	0.23	0.94
Tunisia	TUN	0.40	0.35	0.58	0.60
Turkey	TUR	0.68	0.57	0.77	0.73
Ukraine	UKR	0.39	0.24	0.59	0.41
United Kingdom	GBR	0.86	0.89	0.86	1.04
United States	USA	1.00	1.00	1.00	1.00
Uruguay	URY	0.50	0.18	0.73	0.24
Vietnam	VNM	0.19	0.22	0.43	0.52