Capital Goods Trade, Relative Prices, and Economic Development

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Abstract

International trade in capital goods has quantitatively important effects on economic development through capital formation and aggregate TFP. Capital goods trade enables poor countries to access more efficient technologies, leading to lower relative prices of capital goods and higher capital-output ratios. Furthermore, poor countries can use their comparative advantage—non-capital goods production—and increase their TFP. We quantify these channels using a multi-sector, multicountry, Ricardian model of trade with capital accumulation. The model matches several trade and development facts within a unified framework. Frictionless trade in capital goods reduces the income gap between rich and poor countries by 40 percent. More than half of the reduction in the income gap is due to the TFP channel.

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

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1 Introduction

Cross-country differences in income per worker are large. Development accounting exercises (e.g., Caselli [2005]) show that differences in factors of production—capital and labor—account for roughly 50 percent of the income differences and aggregate total factor productivity (TFP) differences account for the rest.

We provide a quantitative theory of economic development where international trade in capital goods is an important component. Two facts motivate our emphasis on capital goods trade: (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.\footnote{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.} Imports-to-production ratio for capital goods is negatively correlated with income per worker. Malawi imports 14 times as much capital goods as it produces, Australia imports almost twice as much, while the US imports just over half as much.

In our theory, international trade in capital goods affects economic development through two channels: capital and TFP. First, reductions in barriers to capital goods trade enables poor countries to access more efficient technologies in rich countries. This reduces their relative price of investment and increases their investment rate and capital-output ratio. Second, by importing more capital goods, poor countries efficiently use their comparative advantage—non-capital goods production—which increases their TFP. Both channels reduce the cross-country income differences. Quantitatively, the removal of capital goods trade frictions results in a 40 percent reduction in the income gap between rich and poor countries. More than half of the reduction is due to the TFP channel.

Our framework is a multicountry Ricardian trade model, á la Eaton and Kortum [2002], embedded into a multisector neoclassical growth model.
tries differ in their technologies for producing a continuum of tradeable capital goods and a continuum of tradeable intermediate goods (i.e., non-capital goods). Trade is subject to frictions. Other domestic distortions affect non-tradeable final goods productivity. Differences in income per worker in our model are a function of differences in trade frictions and productivities.

The main quantitative discipline for calibrating the trade frictions in our model is the observed bilateral trade flows across 102 countries. We calibrate the productivities to be consistent with the observed relative prices of capital goods and intermediate goods, and income per worker.

Our model reconciles several trade and development facts in a unified framework. First, we account for the fact that 10 countries produce 80 percent of the capital goods in the world. Poor countries are net importers of capital goods and net exporters of non-capital 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, our model delivers the facts on investment rates and prices. For instance, in the model and in the data, the price of capital goods is uncorrelated with income per worker.

Comparing the calibrated steady state to a counterfactual steady state with frictionless trade in capital goods, the gap in income per worker decreases from roughly 28 to almost 17, or by 40 percent. Ignoring changes in TFP, the change in the capital-output ratio would have decreased the income gap to almost 24, a reduction of less than 15 percent. In other words, the change in TFP contributes more to the reduction in the income gap. This TFP effect is absent in the standard neoclassical growth model. (See Restuccia and Urrutia, 2001, for a model with exogenous relative price of capital.)

Change in the relative price of investment is an important channel for the change in cross-country income differences in our theory, so we have to confront two noteworthy facts. (i) 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 and (ii) the price of investment relative to consumption is negatively correlated with income per worker, but this negative correlation is entirely due to the
behavior of the price of consumption (see Restuccia and Urrutia [2001], Hsieh and Klenow [2007]). Our theory is quantitatively consistent with both facts and is based on factors that affect investment, not factors that affect saving.

Contrary to Hsieh and Klenow (2007), trade costs play a major role in our theory. In their model, trade frictions affect the price of capital goods but not the price of consumption. However, since the observed price of capital goods is uncorrelated with economic development, their inferred capital goods trade frictions are unrelated to development. As a result, frictionless trade in capital goods in their model does not alter the cross-country differences in relative price of investment and in investment rates. In our model, (i) the inferred capital goods trade costs are systematically higher for poor countries and (ii) the trade costs affect the relative price mainly through the price of consumption. Despite the higher trade cost in poor countries, the price of capital goods is roughly the same across countries in our model because productivity in the capital goods sector is lower in poor countries. Frictionless capital goods trade increases the price of consumption goods in poor countries relative to rich countries due to a more efficient allocation of resources and higher measured productivity in all sectors (i.e., the Balassa-Samuelson effect). The resulting decline in the relative price in poor countries leads to an increase in their investment rates.

In related work, Eaton and Kortum (2001) also quantify the role of capital goods trade frictions in accounting for cross-country income differences. They construct a “trade-based” price of capital goods using a gravity regression and a relative price of investment using the observed price of final goods. As noted by Hsieh and Klenow (2007), the trade-based price is negatively correlated with economic development whereas in the data the price is uncorrelated. In our structural model, both capital goods prices and final goods prices are endogenous and consistent with the observed prices. Furthermore, removal of trade frictions affects TFP in our model and reduces the income gap, a quantitatively important channel that is absent in their model.

In Armenter and Lahiri (2012), policies that affect relative prices and investment rates also affect measured TFP, as in our model. However, they
assume frictionless trade in capital goods in order deliver the observed prices of capital goods. As noted in Mutreja et al. (2014), frictionless trade is not necessary for price equalization and does not deliver the observed trade flows. We deliver the observed prices as well as bilateral trade flows in a model with trade frictions. Our model is also consistent with the concentration of capital goods production in the world. Furthermore, our counterfactual with frictionless capital goods trade suggests a 40 percent reduction in the income gap between rich and poor countries; in their model, by construction, frictions in capital goods trade play no role in economic development.

The experience of Korea offers some favorable evidence. Korea’s trade reforms starting in 1960s reduced the restrictions on imports of capital goods (see Westphal, 1990; Yoo, 1993). Subsequently, imports of capital goods increased substantially. Nam (1995) documents that the relative price of capital in Korea decreased and the investment rate increased. Hsieh (2001) provides a contrast between Argentina and India. India reduced barriers to capital goods imports in 1990s which led to a fall in the relative price of capital and a surge in capital goods imports and investment rate. Argentina restricted imports of capital goods after the Great Depression, which led to an increase in the relative price of capital and a decline in the investment rate.

The rest of the paper is organized as follows. Section 2 develops the multicountry 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 Alvarez and Lucas (2007), Eaton and Kortum (2002), and Waugh (2010) to two tradable sectors and embeds it into a neoclassical growth framework (see also Mutreja, 2016).

There are $I$ countries indexed by $i = 1, \ldots, I$ and time is discrete, running from $t = 1, \ldots, \infty$. There are four sectors: final goods (consumption), intermediates, capital goods, and structures, denoted by $f, m, e$ and $s$, respectively.
Neither consumption goods nor structures are tradable. There is a continuum of intermediate \textit{varieties} and a continuum of capital goods \textit{varieties} that are tradable. Each country’s efficiency in producing each tradable variety is a realization of a random draw from a sector- and country-specific distribution. Trade is subject to iceberg costs. Each country purchases each tradable variety from its lowest-cost supplier and all of the varieties in each sector are aggregated into a sector-specific \textit{composite} good. The composite intermediate good is used with capital and labor to produce the consumption good, the investment good, and the intermediate varieties. The composite capital good is used to augment the stock of producer durables. (We use “producer durables” and “capital goods” interchangeably.)

Each country has a representative household that owns its country’s stocks of producer durables and structures, and labor, which it supplies inelastically. It purchases consumption and investment goods.

We assume that trade is balanced, but allow for trade imbalances at the sectoral level. We consider only steady states.

2.1 Endowments

The representative household in country \( i \) is endowed with a labor force of size \( L_i \) and an initial stock of capital per worker, \( k_{0i} \).

2.2 Technology

There is a unit interval of varieties in both the intermediates and capital goods sectors. Each variety is tradable and is indexed by \( v_b \in [0, 1] \), for \( b \in \{ e, m \} \).

\textbf{Composite goods} \quad Within each tradable sector, all of the varieties are combined with constant elasticity to construct a sectoral composite good:

\[
q_{ei} = \left[ \int_0^1 q_{ei}(v_e)^{1-1/\eta} dv_e \right]^{\eta/(\eta-1)} \quad \text{and} \quad q_{mi} = \left[ \int_0^1 q_{mi}(v_m)^{1-1/\eta} dv_m \right]^{\eta/(\eta-1)}
\]
where $\eta$ is the elasticity of substitution between any two varieties, $q_{ba}(v_b)$ is the quantity of variety $v_b$ used by country $i$ to construct the sector $b$ composite good, and $q_{ba}$ is the quantity of the composite good available in country $i$.

**Varieties** Each variety is produced using capital, labor, and the composite intermediate good. The technologies for producing each variety are:

$$y_{ei}(v_e) = z_{ei}(v_e) \left[ (k_{ei}(v_e)^\mu k_{es}(v_e)^{1-\mu})^\alpha \ell_{ei}(v_e)^{1-\alpha} \right]^{\nu_e} m_{ei}(v_e)^{1-\nu_e},$$

$$y_{mi}(v_m) = z_{mi}(v_m) \left[ (k_{mi}(v_m)^\mu k_{ms}(v_m)^{1-\mu})^\alpha \ell_{mi}(v_m)^{1-\alpha} \right]^{\nu_m} m_{mi}(v_m)^{1-\nu_m}.$$

The term $m_{bi}(v_b)$ denotes the quantity of the composite intermediate good used by country $i$ to produce $y_{bi}(v_b)$ units of variety $v_b$, while $k_{bi}^e(v_b)$, $k_{bi}^s(v_b)$, and $\ell_{bi}(v_b)$ denote the quantities of producer durables, structures, and labor used.

The parameter $\nu_b \in [0, 1]$ denotes the share of value added in total output in sector $b$ and $\alpha$ denotes capital’s share in value added. These parameters are constant across countries and over time.

The term $z_{bi}(v_b)$ denotes country $i$’s productivity for producing variety $v_b$ in sector $b$. The productivity draw comes from independent Fréchet distributions with shape parameter $\theta$ and country-specific scale parameter $T_{bi}$. The c.d.f. for productivity in sector $b$ in country $i$ is $F_{bi}(z) = \exp(-T_{bi}z^{-\theta})$.

In country $i$, the expected value of productivity is $\gamma^{-1}T_{bi}^{\frac{1}{\theta}}$, where $\gamma = \Gamma(1 + \frac{1}{\theta}(1 - \eta))^{\frac{1}{\theta}}$ and $\Gamma(\cdot)$ is the gamma function, and $T_{bi}^{\frac{1}{\theta}}$ is the fundamental productivity in country $i$. If $T_{ei} > T_{ej}$, then on average, country $i$ is more efficient than country $j$ at producing capital goods. A country with a relatively large ratio $T_e/T_m$ 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 productivity. A smaller value of $\theta$ implies more variation in productivity and, hence, more room for specialization.

**Nontradable goods** Each country produces a final consumption good using capital, labor, and intermediates according to

$$y_{fi} = A_{fi} \left[ (k_{fi}^e)^\mu (k_{fi}^s)^{1-\mu} \ell_{fi}^{1-\alpha} \right]^{\nu_f} m_{fi}(v_f)^{1-\nu_f}.$$
Country-specific TFP in final goods is given by $A_{fi}$.

Structures are produced similarly:

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

### 2.3 Trade

International trade is subject to frictions that take the iceberg form. Country $i$ must purchase $\tau_{bij} \geq 1$ units of any sector-$b$ variety from country $j$ in order for one unit to arrive; $\tau_{bij} - 1$ units melt away in transit. As a normalization, we assume that $\tau_{bii} = 1$ for all $i$.

### 2.4 Preferences

The representative household’s lifetime utility is given by

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

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

**Capital accumulation** The representative household enters period $t$ with a stock of producer durables, $k^e_{it}$, and a stock of structures, $k^s_{it}$. Investment, $x^e_{it}$ and $x^s_{it}$ add to the respective stocks of capital, which depreciate at the rates $\delta_e$ and $\delta_s$.

$$k^e_{t+1} = (1 - \delta_e)k^e_t + x^e_t,$$

$$k^s_{t+1} = (1 - \delta_s)k^s_t + x^s_t.$$  

We define the aggregate capital stock per worker as

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

A competitive equilibrium satisfies the following conditions: (i) the representative household maximizes utility taking prices as given, (ii) firms maximize profits taking prices as given, (iii) each country purchases each good from its least cost supplier, and (iv) markets clear and trade is balanced. We take world GDP as the numéraire: $\sum_i (r_i k_i + w_i) L_i = 1$ and focus on steady state.

**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, $x^e_i$ and $x^s_i$, which have prices $P_{ei}$ and $P_{si}$, respectively.

The household faces a standard consumption-savings problem, that is characterized by two Euler equations, a budget constraint, and two capital accumulation equations. In steady state, these conditions are:

\[
\begin{align*}
    r_{ei} &= \left[ \frac{1}{\beta} - (1 - \delta_e) \right] P_{ei}, \\
    r_{si} &= \left[ \frac{1}{\beta} - (1 - \delta_s) \right] P_{si}, \\
    P_{fi} c_i + P_{ei} x^e_i + P_{si} x^s_i &= w_i + r_{ei} k^e_i + r_{si} k^s_i, \\
    x^e_i &= \delta_e k^e_i, \text{ and} \\
    x^s_i &= \delta_s k^s_i.
\end{align*}
\]

**Firm optimization** Denote the price of variety $z_b$, 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 variety $z_b$ in country $j$. Since country $i$ purchases variety $z_b$ from the country that can deliver it at the lowest price, the price in country $i$ is $p_{bi}(z_b) = \min_{j=1,...,I} [p_{bjj}(z_b) \tau_{bij}]$. The price of the
sector $b$ composite good in country $i$ is then

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

where $u_{bi} = \left( \frac{x_i^e}{c_i \alpha v_b} \right)^{(1-\mu)\alpha v_b} \left( \frac{x_i^s}{(1-\mu)\alpha v_b} \right)^{(1-\alpha)\alpha v_b} \left( \frac{P_{mi}}{1-\nu_b} \right)^{1-\nu_b}$ is the unit cost in sector $b$ in country $i$.

Next we define sectoral aggregates for inputs and output.

$$k^e_{bi} = \int k^e_{bi}(z_b) \varphi_b(z_b) dz_b,$$

$$k^s_{bi} = \int k^s_{bi}(z_b) \varphi_b(z_b) dz_b,$$

$$\ell_{bi} = \int \ell_{bi}(z_b) \varphi_b(z_b) dz_b,$$

$$m_{bi} = \int m_{bi}(z_b) \varphi_b(z_b) dz_b,$$

$$y_{bi} = \int y_{bi}(z_b) \varphi_b(z_b) dz_b,$$

where $\varphi_b = \prod_i \varphi_{bi}$ is the joint density for productivity draws across countries in sector $b$ ($\varphi_{bi}$ is country $i$’s density function). For instance, $\ell_{bi}(z_b)$ denotes the quantity of country $i$’s labor used in the production of variety $z_b$. If country $i$ imports variety $z_b$, then $\ell_{bi}(z_b) = 0$. Hence, $\ell_{bi}$ is country $i$’s of labor used in sector $b$. Similarly, $m_{bi}$, $k^e_{bi}$, and $k^s_{bi}$ denote the quantity of the composite intermediate 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.
Trade flows  In sector $b$, the fraction of country $i$’s expenditures allocated to varieties produced by country $j$ is given by

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

Market clearing  The domestic market clearing conditions are:

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

The first condition requires 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 inputs in each sector, its supply consists of both domestically- and foreign-produced varieties.

The next three conditions require that the quantities 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 condition requires that the value of output produced by country
\[ L_i P_{bi} y_{bi} = \sum_j L_j P_{bj} q_{bj} \pi_{bji}, \ b \in \{e, m\}. \]

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 \( \pi_{bji} \) 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 in each 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.

### 2.6 Role of capital goods trade

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 \( i \),

\[ y_i \propto A_{fi} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\frac{1-\nu_f}{\theta_m}} k_i^{\alpha}. \]  

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

The expression for income per worker can be written more conveniently as
In steady state, the capital-output ratios for equipment and structures are proportional to the respective investment rates: \( \frac{k^b}{y_i} \propto \frac{x^b_i}{y_i} \) for \( b \in \{e, s\} \). Moreover, the investment rate is proportional to the inverse of the relative price: \( \frac{x^b_i}{y_i} \propto \frac{P_{fi}}{P_{bi}} \). Therefore, the (aggregate) capital-output ratio is given by

\[
\frac{k_i}{y_i} = \left( \frac{k^e_i}{y_i} \right)^{\mu} \left( \frac{k^s_i}{y_i} \right)^{1-\mu} \propto \left( \frac{x^e_i}{y_i} \right)^{\mu} \left( \frac{x^s_i}{y_i} \right)^{1-\mu} \propto \left( \frac{P_{fi}}{P_{ei}} \right)^{-\mu} \left( \frac{P_{fi}}{P_{si}} \right)^{\mu-1}.
\]  

(5)

All else equal, any trade policy that affects the relative price of capital will affect economic development via the investment rate and, hence, the capital-output ratio.

In equilibrium, the price of capital goods relative to final goods is given by

\[
\frac{P_{ei}}{P_{fi}} \propto \left( \frac{A_{fi}}{T_{ei}/\pi_{eii}} \right)^{\frac{\nu_e-\nu_s}{\nu_m}} \left( \frac{T_{ei}}{\pi_{mii}} \right)^{\frac{\nu_s}{\nu_m}}
\]  

(see Appendix A for the derivations). The first term in equation (6) is the ratio of productivity in final goods, \( A_{fi} \), to the measured productivity in capital goods, \( \frac{T_{ei}}{\pi_{eii}} \). A reduction in frictions to trade capital goods reduces the relative price of capital goods via a fall in the home trade share, \( \pi_{eii} \). Lower barriers improve specialization and lead to higher measured productivity in the capital goods sector, and hence, a lower relative price of capital goods.\footnote{Sposi (2015) discusses the effect of trade barriers on measured productivity and how the cross-country difference in the relative price is affected primarily by the price of the nontraded good.}

Equations (4), (5), and (6) imply that eliminating frictions in capital goods
trade reduces the relative price of capital goods which increases the capital-output ratio and, hence, the income per worker.

The reduction in the relative price is typically greater for poor countries than for rich countries because (i) the responsiveness of the home trade share to otherwise identical reductions in trade frictions are larger for poor countries and (ii) the trade frictions are larger in poor countries. Our calibration, combined with equations (4) and (5), implies that a one percent reduction in a country's relative price of capital goods would increase its income per worker by \( \frac{\alpha \mu}{1-\alpha} \approx 0.28 \) percent. In the data, the relative price of capital goods in poor countries is three times that in rich countries. The extreme scenario of reducing the relative price in poor countries by two-thirds would equalize the relative prices across countries and would increase the income per worker in poor countries by 19 percent relative to that in rich countries. We should note that eliminating trade frictions in our model does not equalize the relative price of capital goods across countries, so this calculation provides an upper bound for the quantitative importance of the capital-output ratio channel.

Eliminating frictions in capital goods trade also reduces the intermediate goods home trade share, \( \pi_{mii} \), in poor countries in equilibrium. Equation (4) then implies that measured TFP gap shrinks and, hence, the income gap shrinks. It turns out that the TFP channel is quantitatively more important than the capital-output ratio channel. It is easy to see from equation (4) that, for our calibrated value of \( \alpha \), a one percent increase in a country's measured TFP increases its income per worker by \( \frac{1}{1-\alpha} = 1.5 \) percent.

Equations (4), (5), and (6) also reveal that measured TFP and capital-output ratio covary due to the link via trade. In contrast, in the neoclassical growth model, the capital-output ratio is orthogonal to measured TFP.

To summarize, capital goods trade affects economic development via measured TFP and capital formation. Comparative advantage parameters and international trade frictions affect the extent of specialization in each country, which affects the measured TFP and the relative price of investment. In response to the changes in relative prices the household alters its investment rate that changes the steady-state capital-output ratio. 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 102 countries for the year 2011. This set includes both developed and developing countries and accounts for about 90 percent of world GDP in version 8.1 of the Penn World Tables (see Feenstra, Inklaar, and Timmer 2015, PWT 8.1 hereafter). Our calibration strategy uses cross-country data on income per worker, bilateral trade, output for capital goods and intermediate goods sectors, and prices of capital goods, intermediate goods, structures, 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 mapping disaggregate data to sectors in the model. 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 in our model 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 2011 benchmark study of the Penn World Table. We construct the price of intermediates
by aggregating across all nondurable goods categories (excluding services) in
the 2011 benchmark study. The price of final goods corresponds to “Price
level of consumption” in PWT 8.1.

Our measure of income per worker is constructed the same way as in the
model using PWT 8.1 data: GDP at current U.S. dollars, deflated by the
price level of consumption using PPP exchange rates, divided by the number
of workers.

3.1 Common parameters

We begin by describing the parameter values that are common to all countries
(Table 1). The discount factor $\beta$ is set to 0.96 so that the steady-state real
interest rate is about 4 percent. 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 aggregate capital per worker in our model is $k =
(k_e)^\mu(k_s)^{1-\mu}$. The share of capital in GDP, $\alpha$, is set to 1/3, as in [Gollin
(2002)]. Using data from the Bureau of Economic Analysis (BEA), [Green-
wood, Hercowitz, and Krusell (1997)] estimate the rates of depreciation for
both producer durables and structures. We set $\delta_e = 0.12$ and $\delta_s = 0.06$, in
accordance with their estimates. We also set the share of producer durables,
$\mu$, at 0.56 in accordance with [Greenwood, Hercowitz, and Krusell (1997)].

We compute $\nu_m$ and $\nu_e$ using input-output tables for 40 countries in the
World Input-Output Database (see [Timmer et al. 2015]). In the data,
non-capital goods manufactures account for only part of the total intermediate
inputs, while services account for a large share of intermediate inputs. We fold
the intermediate service inputs into the value added share of gross output. We
take the average of the value added shares across countries to get $\nu_m =
0.67$. Similarly, $1 - \nu_e$ is computed as the average ratio of non-capital goods
manufactures to gross output of capital goods. We fold the intermediate service
inputs into the value added in capital goods and arrive at $\nu_e = 0.80$.

We impose that $\nu_s = \nu_f$ in the model, which implies that the price of
Table 1: Parameters common across countries

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>$k$’s Share</td>
<td>0.33</td>
</tr>
<tr>
<td>$\nu_m$</td>
<td>$k$ and $\ell$’s Share in intermediate goods</td>
<td>0.67</td>
</tr>
<tr>
<td>$\nu_e$</td>
<td>$k$ and $\ell$’s Share in capital goods</td>
<td>0.80</td>
</tr>
<tr>
<td>$\nu_s$</td>
<td>$k$ and $\ell$’s Share in structures</td>
<td>0.58</td>
</tr>
<tr>
<td>$\nu_f$</td>
<td>$k$ and $\ell$’s Share in final goods</td>
<td>0.58</td>
</tr>
<tr>
<td>$\delta_e$</td>
<td>Depreciation rate of producer durables</td>
<td>0.12</td>
</tr>
<tr>
<td>$\delta_s$</td>
<td>Depreciation rate of structures</td>
<td>0.06</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Variation in (sectoral) factor productivity</td>
<td>4</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Share of producer durables in composite capital</td>
<td>0.56</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Discount factor</td>
<td>0.96</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Elasticity of substitution in aggregator</td>
<td>2</td>
</tr>
</tbody>
</table>

Structures relative to final goods is $A_fi/A_{si}$. Computing $\nu_f$ is slightly more involved since there is no clear industry classification for consumption goods. We infer this share by interpreting the national accounts through the lens of our model. Each country’s expenditures on intermediate goods must equal the value of intermediate inputs used across sectors in that country,

$$P_{mi}q_{mi} = (1 - \nu_f)P_{fi}c_{fi} + (1 - \nu_s)P_{si}x_{i}^s + (1 - \nu_e)P_{ei}x_{i}^e + (1 - \nu_m)P_{mi}y_{mi}.$$ 

Rearranging the above expression yields

$$(GO_{mi} - EXP_{mi} + IMP_{mi}) = (1-\nu_f)(CON_i + INV_{si}) + (1-\nu_e)GO_{ei} - (1-\nu_m)GO_{mi},$$

where $CON_i$ is consumption expenditures in country $i$, $INV_{si}$ is gross capital formation for structures, $GO_{bi}$ is gross output of sector $b \in \{e, m\}$ and $EXP_{mi}$ and $IMP_{mi}$ are gross exports and imports of intermediates. Using a standard method of moments estimator, our estimate of $\nu_f$ is 0.58.

**Estimating the trade elasticity** The parameter $\theta$ in our model controls the dispersion in productivity and, hence, the trade elasticity. We follow the
procedure of Simonovska and Waugh (2014) to estimate $\theta$ (see Appendix C). We estimate $\theta$ 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.

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 parameters in the final goods and structures sectors, $A_f$ and $A_s$, respectively; and the bilateral trade frictions, $\tau_e$ and $\tau_m$. We take the labor force in each country from PWT 8.1. The other country-specific parameters are calibrated to match a set of targets.

**Bilateral trade frictions** Using data on prices and bilateral trade shares, we calibrate the bilateral trade frictions in each sector using a structural relationship implied by our model:

$$\frac{\pi_{bij}}{\pi_{bji}} = \left(\frac{P_{bj}}{P_{bi}}\right)^{-\theta} \tau_{bij}^{-\theta}, b \in \{e, m\}. \quad (7)$$

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

Poor countries have larger frictions to export capital goods than rich countries. One way to summarize this feature is to compute a trade-weighted export friction for country $i$ as $\frac{1}{X_{bi}} \sum_{j \neq i} \tau_{bij} X_{bji}$, 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 friction in the capital goods sector for poor countries is 3.99, while it is 2.04 for rich countries. The intermediate goods sector displays a similar pattern: The trade-weighted export friction is 6.33 for poor countries and is 1.81 for rich countries.
Productivities Using data on relative prices, home trade shares, and income per worker, we use the model’s structural relationships to calibrate \( T_{ei}, T_{mi}, A_{fi}, \) and \( A_{si}, \) relative to the United States (denoted by subscript \( U \)). The structural relationships are:

\[
\frac{P_{mi}/P_{fi}}{P_{eU}/P_{fU}} = \left( \frac{A_{fi}}{A_{fU}} \right) \left( \frac{T_{mi}/\pi_{mii}}{T_{mU}/\pi_{mUU}} \right)^{-\frac{1}{\theta}} \left( \frac{T_{mU}/\pi_{mUU}}{T_{mU}/\pi_{mUU}} \right)^{\nu_m-\nu_f}, \tag{8}
\]

\[
\frac{P_{ei}/P_{fi}}{P_{eU}/P_{fU}} = \left( \frac{A_{fi}}{A_{fU}} \right) \left( \frac{T_{ei}/\pi_{eii}}{T_{eU}/\pi_{eUU}} \right)^{-\frac{1}{\theta}} \left( \frac{T_{mU}/\pi_{mUU}}{T_{mU}/\pi_{mUU}} \right)^{\nu_e-\nu_f}, \tag{9}
\]

\[
\frac{P_{si}/P_{fi}}{P_{sU}/P_{fU}} = \left( \frac{A_{fi}}{A_{fU}} \right) \left( \frac{A_{sU}}{A_{si}} \right) \left( \frac{T_{mi}/\pi_{mii}}{T_{mU}/\pi_{mUU}} \right)^{\nu_s-\nu_f}, \tag{10}
\]

\[
y_i/y_U = \left( \frac{A_{fi}}{A_{fU}} \right) \left( \frac{T_{ei}/\pi_{eii}}{T_{eU}/\pi_{eUU}} \right)^{\nu_e-\nu_f} \left( \frac{A_{si}}{A_{sU}} \right)^{\frac{1}{\theta}} \times \left( \frac{T_{mU}/\pi_{mUU}}{T_{mU}/\pi_{mUU}} \right)^{\frac{1-\nu_f}{\theta}}. \tag{11}
\]

We normalize \( T_{eU}, T_{mU}, A_{sU}, \) and \( A_{fU} \) to 1 and solve for \( T_{ei}, T_{mi}, A_{si}, \) and \( A_{fj} \) for each country \( i \) (see Appendix A for derivations of the equations).

Table E.1 in the Appendix 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 14.1. In the intermediate goods sector, the average productivity gap is 5.3. 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.

---

\(^3\)The productivity gap in each sector is in terms of gross-output productivity. This can be a misleading comparison in terms of labor productivity when value added shares differ across sectors. To adjust for this, we compute the value-added productivity gap across countries in each sector. The gap in value-added productivity for the capital goods sector, \( T^{\gamma_e/\theta} \), is 8.3 and that for the intermediate goods sector is 3.1.
4 Results

This section provides results on how well the model fits the data and quantifies the role of capital goods trade in economic development.

4.1 Model fit

Calibration of the trade frictions uses $2I(I - 1) = 20,604$ observations on trade shares and $2(I - 1) = 202$ observations on prices of intermediate goods and capital goods (relative to the U.S.) in order to pin down $2I(I - 1) = 20,604$ trade frictions—equation (7). Calibration of the productivities uses $I - 1 = 101$ observations on income per worker (relative to the U.S.) and $3(I - 1) = 303$ observations on relative prices (relative to the U.S.) in order to compute $4(I - 1) = 404$ productivity parameters—equations (8)-(11), respectively. As such, the model utilizes 202 more data points than there are parameters and will not match all of the data exactly. Table 2 reports the correlations between model and data for each targeted variable.

Table 2: Model fit for targeted data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income per worker, $y$</td>
<td>1.00</td>
</tr>
<tr>
<td>Price of capital goods, $P_e$</td>
<td>0.87</td>
</tr>
<tr>
<td>Price of final goods, $P_f$</td>
<td>0.93</td>
</tr>
<tr>
<td>Price of intermediate goods, $P_m$</td>
<td>0.99</td>
</tr>
<tr>
<td>Price of structures, $P_s$</td>
<td>0.99</td>
</tr>
<tr>
<td>Bilateral trade shares for capital goods, $\pi_{eij}(i \neq j)$</td>
<td>0.93</td>
</tr>
<tr>
<td>Bilateral trade shares for intermediate goods, $\pi_{mij}(i \neq j)$</td>
<td>0.91</td>
</tr>
<tr>
<td>Home trade shares for capital goods, $\pi_{eii}$</td>
<td>0.90</td>
</tr>
<tr>
<td>Home trade shares for intermediate goods, $\pi_{eii}$</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Notes: Correlations for each variable (relative to the U.S.) are between the model and the data.
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 0.87, 0.86, 0.99, and 0.84, respectively.

Income per worker Figure 1 plots the income per worker in the model against that in the data. The fit for income per worker is perfect by construction since we choose the final good sector productivity, $A_f$, to match the observed income per worker (see equation (11)).

Figure 1: Income per worker, US=1

Notes: The vertical axis corresponds to the model and the horizontal axis corresponds to the data. Our calibration is designed to perfectly match income per worker in each country.

Trade shares Figure 2 plots the bilateral trade shares in capital goods, $\pi_{eij}$, ($i \neq j$). The correlation between the model and the data is 0.93. The bilateral trade shares for intermediate goods also line up closely with the data; the correlation is 0.91. The correlation between home trade shares in the
model and that in the data is 0.90 in the capital goods sector and 0.93 in the intermediate goods sector.

Figure 2: Bilateral trade shares in capital goods

Notes: The vertical axis corresponds to the model and the horizontal axis corresponds to the data.

4.2 Implications for untargeted moments

This subsection examines the quantitative implications of the model for data that were not targeted in the calibration. Table 3 summarizes the implications.

Development accounting While the calibration directly targets income per worker in each country, it does not target either capital or measured TFP. We examine how the model distributes the burden of income differences to differences in capital and differences in TFP.

Suppose we conduct a development accounting exercise, along the lines of Caselli (2005), Hall and Jones (1999), and Klenow and Rodríguez-Clare (1997), using the model’s output. Recall that income per worker can be written as $y_i = Z_i \left( \frac{k_i}{y_i} \right)^{\frac{\alpha}{1-\alpha}}$, where $Z$ denotes measured TFP. Log variance in $(k/y)^{\frac{\alpha}{1-\alpha}}$
Table 3: Model fit for untargeted data

<table>
<thead>
<tr>
<th>Contribution to log-variance in $y$: $\ln(Z^{\frac{1}{1-\alpha}})$</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contribution to log-variance in $y$: $\ln((k/y)^{\frac{1}{1-\alpha}})$</td>
<td>3.0%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Contribution to log-variance in $y$: covariance</td>
<td>11.7%</td>
<td>14.6%</td>
</tr>
<tr>
<td>Elasticity of $x^e/y$ w.r.t. income per worker</td>
<td>0.40</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Notes: $Z$ denotes measured TFP. Each elasticity is the slope coefficient estimated by regressing $\ln(\text{variable})$ against $\ln(\text{income per worker})$.

accounts for 2.0 percent of the log variance in $y$ in the model, compared to 3.0 percent in the data. Log variance in $Z^{\frac{1}{1-\alpha}}$ counts for 83.4 percent of the log variance in $y$ in the model, compared to 85.3 percent in the data. The model and the data place a larger burden on measured TFP than on capital-output ratios to account for the cross-country income differences. This feature consistent with the evidence in King and Levine [1994] who argue that capital is not a primary determinant of economic development. Finally, in the data both measured TFP and capital-output ratio are positively correlated with economic development. Our model is consistent with this feature. The covariance between the log of the two objects accounts for 14.6 percent of the log variance in $y$ in the model, compared to 11.7 percent in the data.

**Capital goods production and trade flows** Our model also replicates well the extent to which production of capital goods is distributed across countries. Figure 3 illustrates the cdf for capital goods production. In the model and in the data, 10 countries account for almost 80 percent of the world’s capital goods production. Furthermore, poor countries are net importers of capital goods in the model and in the data.

**Relative prices and investment rates** In the data, while the relative price of capital goods is higher in poor countries than in rich countries, the absolute price of capital goods does not exhibit such a systematic variation.
with the 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 0.01 in the model and is -0.01 in the data; the elasticity of the relative price is -0.36 in the model and -0.30 in the data.

The observed 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: The elasticity of the price of consumption is 0.37 in our model and 0.31 in the data.

Finally, the price of structures is positively correlated with income per worker; the elasticity of the price is 0.41 in the model and 0.36 in the data.

In our model, the capital goods investment rate and the structures investment rate, both measured in domestic prices, are constant across countries. 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 $\phi_b = b/(\beta - (1 - \delta_b))$ 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 \( P_{ei}x_i^e + P_{si}x_i^s = [\mu \phi_e + (1 - \mu)\phi_s]w_i\alpha / (1 - \alpha) \). Factor income is \( w_i + r_i k_i = w_i / (1 - \alpha) \), so the aggregate investment rate in domestic prices is

\[
\frac{P_{ei}x_i^e + P_{si}x_i^s}{w_i + r_i k_i} = \alpha [\mu \phi_e + (1 - \mu)\phi_s],
\]

which is a constant. In the data, the investment rate measured in domestic prices is uncorrelated with income per worker.

Our model also captures the systematic variation in investment rates measured in purchasing power parity (PPP) prices. Rich countries have higher investment rates, \( \frac{x_i^e}{y_i} \), than poor countries; the elasticity of capital goods investment rate with respect to income per worker is 0.36 in the model and is 0.40 in the data.

### 4.3 Quantitative role of capital goods trade

To understand the quantitative role of capital goods trade, we conduct a counterfactual experiment: we eliminate all frictions to capital goods trade. We leave all other parameters at their calibrated values; specifically, the intermediate goods trade frictions remain at the benchmark levels.

We set \( \tau_{eij} = 1 \) for all country pairs. Table 4 reports the changes in the income gap and the components therein, relative to the benchmark. We compute the gap for each variable as the average of the 10 richest countries relative to the average of the 10 poorest countries.

The gap in capital-output ratio falls from 1.62 to 1.22. If measured TFP were held fixed, the smaller gap in capital-output ratio by itself would reduce the income gap from 27.94 to 23.75, a reduction of 15 percent. However, in the model, measured TFP is also affected by the removal of capital goods trade frictions since poor countries can now import capital goods and specialize more in intermediate goods, thus increasing their TFP. The gap in measured TFP falls from 7.62 to 6.08. The combined effect lowers gaps in capital-output ratio and measured TFP is a reduction in the income gap from 27.94 to 16.80, a reduction of 40 percent.

In the presence of capital goods trade frictions, poor countries transform
Table 4: Gap in income per worker and its components

<table>
<thead>
<tr>
<th></th>
<th>Benchmark model</th>
<th>Frictionless trade in capital goods</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y$</td>
<td>27.94</td>
<td>16.80</td>
</tr>
<tr>
<td>$Z^{\frac{1}{1-\alpha}}$</td>
<td>20.72</td>
<td>14.79</td>
</tr>
<tr>
<td>$(k/y)^{\frac{\alpha}{1-\alpha}}$</td>
<td>1.27</td>
<td>1.10</td>
</tr>
<tr>
<td>$Z$</td>
<td>7.62</td>
<td>6.08</td>
</tr>
<tr>
<td>$k/y$</td>
<td>1.62</td>
<td>1.22</td>
</tr>
<tr>
<td>$(k^c/y)^{\mu}$</td>
<td>1.90</td>
<td>1.35</td>
</tr>
<tr>
<td>$k^c/y$</td>
<td>3.14</td>
<td>1.70</td>
</tr>
</tbody>
</table>

Notes: Gaps are defined as the ratio of the average for 10 richest countries (in terms of income per worker) relative to the average for the 10 poorest countries. $y = Z^{\frac{1}{1-\alpha}} \left(\frac{k}{y}\right)^{\frac{\alpha}{1-\alpha}}$ denotes income per worker, where $Z$ is measured TFP and $\frac{k}{y}$ is the capital-output ratio. Aggregate capital is a Cobb-Douglas aggregate of the producer durables capital and the structures capital: $k = (k^c)^{\mu} (k^s)^{1-\mu}$. The ratio, $\frac{k^c}{y}$, does not change in the counterfactual.

consumption into investment at an inferior rate relative to the world frontier. In the frictionless world, poor countries can import more units of capital goods for each unit of intermediate goods that they export. That is, they transform consumption into investment at a higher rate since they have access to a superior international production possibilities frontier. The higher rate of transformation is reflected by a lower relative price of investment and leads to a higher steady-state investment rate and a higher capital-output ratio.

The relative price of capital goods is a quantitatively important channel for the higher capital-output ratio. With frictionless capital goods trade, the relative price in poor countries falls relative to that in rich countries. In particular, the elasticity of the relative price with respect to income per worker increases from -0.36 to -0.20.

The change in the elasticity is accounted for almost entirely by changes in the absolute price of final goods. The elasticity of the price of final goods decreases from 0.37 to 0.20 in the counterfactual i.e., final goods prices in poor...
Notes: The vertical axis corresponds to the model and the horizontal axis corresponds to the data. The dots indicate the counterfactual values for each country and the rust-colored line is the best linear fit for those dots. The red line for the benchmark is the 45° line.

countries increase relative to those in rich countries. With frictionless trade in capital goods, PPP holds so the elasticity of the absolute price of capital goods is zero. However, this elasticity is close to zero in the benchmark as well, see Table 5.

Table 5: Price elasticities with respect to income per worker

<table>
<thead>
<tr>
<th></th>
<th>Benchmark model</th>
<th>Frictionless trade in capital goods</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_e$</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>$P_f$</td>
<td>0.37</td>
<td>0.20</td>
</tr>
<tr>
<td>$P_e/P_f$</td>
<td>-0.36</td>
<td>-0.21</td>
</tr>
</tbody>
</table>
Empirical evidence  Starting in 1960s Korea reduced the restrictions on imports of capital goods (see [Westphal, 1990; Yoo, 1993]; the capital goods imports increased 11-fold subsequently. Over the next 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.

Wacziarg and Welch (2008) identify dates that correspond to trade liberalization for 118 countries, and show that, after such liberalizations, investment rates increase. Furthermore, Wacziarg (2001) finds that trade increases GDP primarily through an increase in investment.

4.4 Technology vs. Policy

Our calibrated trade frictions could include policy barriers as well as technological impediments (see equation (7)). Thus, when set $\tau_{eij} = 1$ in Section 4.3 we might have removed not only the policy barriers but also the technological obstacles. In this subsection, we attempt to remove only the policy barrier.

We imagine an admittedly extreme scenario that the U.S. trade friction is entirely technological. That is, even if one removes all of the policy barriers the trade friction cannot be less that of the U.S. Suppose that every country had the same trade friction as the U.S. To operationalize this experiment, we compute the average trade-weighted export barrier for the U.S.: $\bar{\tau}_e = \frac{1}{X_{eU}} \sum_{i \neq U} \tau_{eiU} X_{eiU}$, where $X_{eiU}$ are exports of capital goods from the U.S. to country $i$ and $X_{eU}$ is U.S. exports. This computation yields $\bar{\tau}_e = 1.81.$
We set capital goods trade barriers for every bilateral pair to this value (i.e., $\tau_{eij} = 1.81$). Figure 5 illustrates the cross-country distribution of income per worker in three scenarios: benchmark, counterfactual with frictionless trade in capital goods, and counterfactual with U.S. trade frictions in capital goods.

Figure 5: Income per worker, US=1

Notes: The vertical axis corresponds to the model and the horizontal axis corresponds to the data. The rust-colored line and the green line are the best linear fits for the respective counterfactual income per worker. The red line for the benchmark is the 45° line.

With the U.S. trade frictions, the income gap falls from 27.94 to 17.87, a reduction of 36 percent. Recall that in the counterfactual with frictionless capital goods trade the income gap declines from 27.94 to 16.80, so reducing the frictions to the U.S. levels achieves almost the same results as completely eliminating the trade costs. This does not imply that income per worker would not increase if we were to reduce the frictions below the U.S. levels. This simply means that the increase in income from further reductions is roughly proportionate in all countries, so the income gap remains roughly the same.
Table 6: Gap in income per worker and its components

<table>
<thead>
<tr>
<th></th>
<th>Benchmark model</th>
<th>Frictionless trade in capital goods</th>
<th>U.S. frictions in capital goods</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y$</td>
<td>27.94</td>
<td>16.80</td>
<td>17.87</td>
</tr>
<tr>
<td>$Z^{\frac{1}{\alpha}}$</td>
<td>20.72</td>
<td>14.79</td>
<td>15.27</td>
</tr>
<tr>
<td>$(k/y)^{\frac{\alpha}{1-\alpha}}$</td>
<td>1.27</td>
<td>1.10</td>
<td>1.13</td>
</tr>
<tr>
<td>$Z$</td>
<td>7.62</td>
<td>6.08</td>
<td>6.21</td>
</tr>
<tr>
<td>$k/y$</td>
<td>1.62</td>
<td>1.22</td>
<td>1.28</td>
</tr>
<tr>
<td>$(k^e/y)^\mu$</td>
<td>1.90</td>
<td>1.35</td>
<td>1.42</td>
</tr>
<tr>
<td>$k^e/y$</td>
<td>3.14</td>
<td>1.70</td>
<td>1.86</td>
</tr>
</tbody>
</table>

Notes: Gaps are defined as the ratio of the average for 10 richest countries relative to the average for the 10 poorest countries, measured in terms of income per worker. $y = Z^{\frac{1}{1-\alpha}} \left( \frac{k}{y} \right)^{\frac{\alpha}{1-\alpha}}$ denotes income per worker, where $Z$ is measured TFP and $\frac{k}{y}$ is the capital-output ratio. Aggregate capital is a Cobb-Douglas aggregate of the producer durables capital and the structures capital: $k = (k^e)^\mu (k^s)^{1-\mu}$. The ratio, $\frac{k^e}{y}$, does not change in the counterfactual.

4.5 Gravity-based trade frictions

One reason why frictionless capital goods trade reduces the income gap by 40 percent could be that the calibrated trade frictions are “too” high. Recall that the trade frictions were calibrated to be consistent with prices and trade flows (equation (7)). In this subsection we provide an alternative estimate of the trade frictions using gravity regressions that are standard in the trade literature.

Our model implies that, for each sector $b \in \{e, m\}$,

$$\frac{\pi_{bj}}{\pi_{bi}} = \left( \frac{u_{bj}}{u_{bi}} \right)^{-\theta} \left( \frac{T_{bj}}{T_{bi}} \right) (\tau_{bij})^{-\theta}. \quad (12)$$

where $u_{bi}$ denotes the unit cost in sector $b$ in country $i$. 
We specify trade frictions as follows:

\[
\log(\tau_{bij}) = \text{ex}_{b,j} + \gamma_{b,\text{dis}} \log(dis_{ij}) + \gamma_{b,\text{brd}} \text{brd}_{ij} + \gamma_{b,\text{lang}} \text{lang}_{ij} + \varepsilon_{bij},
\]

(13)

where \(\text{ex}_{b,j}\) is an exporter fixed effect dummy as in [Waugh (2010)], \(\text{dis}\) is the distance between two countries measured in miles using the great circle method, \(\text{brd}\) is a dummy for common border, \(\text{lang}\) is a dummy for common language, and \(\varepsilon\) is assumed to be orthogonal to the previous variables and captures other factors that affect trade frictions. Note that this specification requires only 105 coefficients in order to estimate 10,302 bilateral trade frictions.

Using (13) and taking logs of both sides of (12) we get

\[
\ln\left(\frac{\pi_{bij}}{\pi_{bii}}\right) = \ln\left(\frac{u_{b_j}^\theta T_{b_j}}{F_{bij}}\right) - \ln\left(\frac{u_{b_i}^\theta T_{b_i}}{F_{b_i}}\right) - \frac{1}{\theta} \left[ \text{ex}_{j} + \gamma_{b,\text{dis}} \ln(dis_{ij}) + \gamma_{b,\text{brd}} \text{brd}_{ij} + \gamma_{b,\text{lang}} \text{lang}_{ij} + \varepsilon_{bij} \right].
\]

We use OLS to estimate the bilateral trade friction in each sector. In Appendix D we describe the details of how to compute the productivities from the regression coefficients. The data for this specification, except for trade flows, are taken from the Gravity Data set available at http://www.cepii.fr.

Figure 6 illustrates the two estimates of trade frictions for the income quartiles in the data. We find that the gravity-based trade frictions for capital goods are larger than the ones in our benchmark. In addition, the difference in the gravity-based trade friction between rich and poor countries is larger than the difference in our calibrated trade frictions. Thus, if we repeated the counterfactual in Section 4.3 we would find that the income gap between rich and poor countries would reduce by more than 40 percent.

While the gravity approach implies larger trade frictions, it places less burden on final goods productivity in order to reconcile the observed cross-country income differences. As a result, the gravity approach yields larger cross-country differences in the relative price of capital goods than our benchmark. Figure 7 illustrates the relative price of capital goods for the observed
Figure 6: Export-weighted trade barriers by income group

![Bar chart showing export-weighted trade barriers by income group.]

Income quartiles.

Figure 7: Relative price of capital goods by income group

![Bar chart showing relative price of capital goods by income group.]

Income quartiles.
5 Conclusion

In this paper we show 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 multicountry, multi-sector Ricardian model of trade into a neoclassical growth framework. 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 income, investment rate, and price of final goods, and cross-country equalization of price of capital goods.

Frictionless trade in capital goods allows poor countries access to more efficient technologies for capital goods production in rich countries. This reduces the relative price of investment in poor countries and increases their investment rates and steady-state capital-output ratios relative to those in rich countries. Furthermore, by importing more capital goods, poor countries allocate their resources more efficiently by using their comparative advantage and specializing more in non-capital goods production, which increases their TFP relative to rich countries. Both channels reduce the cross-country income differences. Frictionless trade in capital goods reduces the gap in income per worker between rich and poor countries by 40 percent. Setting capital goods trade frictions in every country to U.S. levels has almost the same effect on the income gap as eliminating all frictions in capital goods trade.

References


A Derivations

A.1 Price indices and trade shares

In this section, we derive the price index and bilateral trade shares for intermediate goods. The derivations for the capital goods sector follow analogously.

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

$$P_{mi} = \gamma B_m \left[ \sum_j (d_{mj} \tau_{mij})^{-\theta} T_{mj} \right]^{-\frac{1}{\theta}}. \quad (14)$$

Let $\pi_{mij}$ be the fraction of country $i$’s intermediate goods expenditure that is spent on intermediate goods sourced from country $j$. $\pi_{mij}$ is also the probability that country $j$ is the least cost provider to country $i$. Fréchet distribution for productivities implies that $\pi_{mij}$ is given by

$$\pi_{mij} = \Pr \left\{ p_{mij}(z_m) \leq \min_l [p_{mil}(u)] \right\} = \frac{(d_{mj} \tau_{mij})^{-\theta} T_{mj}}{\sum_l (d_{ml} \tau_{ml})^{-\theta} T_{ml}}, \quad (15)$$

A.2 Relative prices

Here we derive equations for the relative prices: $P_{ei}/P_{fi}$, $P_{mi}/P_{fi}$, and $P_{si}/P_{fi}$. Equations (14) and (15) imply that

$$\pi_{mii} = \frac{\tau_{mii}^{-\theta} T_{mi}}{(\gamma B_m)^{\theta} P_{mi}^{-\theta}}$$

$$\Rightarrow P_{mi} \propto \frac{\left( \frac{r_i}{w_i} \right)^{\alpha \nu_m} \left( \frac{w_y}{P_{mi}} \right)^{\nu_m} P_{mi}}{\left( \frac{T_{mi}}{\pi_{mii}} \right)^{\frac{1}{\theta}}},$$
That is, \( \frac{w_i}{P_{mi}} \propto \left( \frac{w_i}{r_i} \right)^{\alpha} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\frac{1}{\theta_{nm}}} \). Similarly,

\[
P_{ei} \propto \left( \frac{r_i}{w_i} \right)^{\alpha_{ve}} \left( \frac{w_i}{P_{mi}} \right)^{\nu_e} P_{mi},
\]

\[
P_{si} \propto \left( \frac{r_i}{w_i} \right)^{\alpha_{vs}} \left( \frac{w_i}{P_{mi}} \right)^{\nu_s} A_{si},
\]

\[
P_{fi} \propto \left( \frac{r_i}{w_i} \right)^{\alpha_{vf}} \left( \frac{w_i}{P_{mi}} \right)^{\nu_f} A_{fi}.
\]

Below we present the derivation for \( P_{ei}/P_{fi} \). Other relative prices can be derived analogously. Taking ratios of the expressions above and substituting for \( w_i/P_{mi} \), we get

\[
\frac{P_{ei}}{P_{fi}} \propto \left( \frac{r_i}{w_i} \right)^{\alpha (\nu_e - \nu_f)} \left( \frac{w_i}{P_{mi}} \right)^{\nu_e - \nu_f} \frac{A_{fi}}{(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}}.
\]

Similarly,

\[
\frac{P_{mi}}{P_{fi}} \propto \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\frac{1}{\theta}} \frac{A_{fi}}{A_{si}} \frac{(T_{mi})^{\nu_m - \nu_f}}{(\pi_{mii})^{\frac{1}{\theta}}},
\]

and

\[
\frac{P_{si}}{P_{fi}} \propto \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\frac{1}{\theta}} \frac{A_{fi}}{A_{si}} \frac{(T_{mi})^{\nu_s - \nu_f}}{(\pi_{mii})^{\frac{1}{\theta}}}.
\]

### A.3 Capital stock

Since \( r_i k_i = \frac{\alpha}{1-\alpha} w_i \), aggregate stock of capital per worker \( k_i \propto \frac{w_i}{r_i} \propto \frac{w_i}{r_i}^{\mu_{ei} r_{si}^{1-\mu}} \propto \left( \frac{w_i}{P_{ei}} \right)^{\mu} \left( \frac{w_i}{P_{si}} \right)^{1-\mu} \) (\( r_{ei} \propto P_{ei} \) and \( r_{si} \propto P_{si} \) come from the Euler equations).

Using the expressions for relative prices from above:

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

\[
\frac{w_i}{P_{si}} \propto \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\frac{1}{\theta_{m}} - \frac{1}{\theta_{e}}} \left( \frac{w_i}{r_i} \right)^{\alpha} A_{si} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{s}} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}}. \]

Now, \( k_i \propto \frac{w_i}{r_i} \), so

\[
k_i \propto \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\frac{1}{\theta_{m}} - \frac{1}{\theta_{e}}} k_i^\alpha \left( \frac{T_{ei}}{\pi_{eii}} \right)^{\frac{1}{\theta_{e}}} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}} \mu \times \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}} \mu \times \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}} \mu \times \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\nu_{m} - \nu_{e}} \right). \]

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

\[
\frac{k_i}{y_i} \propto \left( \frac{A_{fj}}{T_{ei}/\pi_{eii}^{\frac{1}{\theta_{e}}}} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\frac{\nu_{e} - \nu_{f}}{\theta_{m}} - \frac{1}{\theta_{e}}} \right)^{-\mu} \left( \frac{A_{fj}}{A_{si}} \left( \frac{T_{mi}}{\pi_{mii}} \right)^{\frac{\nu_{e} - \nu_{f}}{\theta_{m}} - \frac{1}{\theta_{e}}} \right)^{\mu-1}. 
\]

**B Data**

This section of the Appendix describes the sources of data as well as any adjustments we make to the data to map it to the model. Our sample covers
102 countries, where 5 of the countries are actually country blocks. “South-
est Europe” includes Albania, Bosnia and Herzegovina, Croatia, Montenegro, and Serbia. “BeNeLux” includes Belgium, the Netherlands, and Luxembourg. “China, Hong Kong, Macao” includes China, Hong Kong, and Macao. “East-
er Europe” includes Estonia, Latvia, Lithuania, Malta, Slovakia, and Slove-
nia. “Singapore-Malaysia” includes Singapore and Malaysia.

B.1 Production and trade

Construction of trade shares requires data on both production and interna-
tional trade flows. Our focus is on manufactured goods. We interpret man-
ufacturing broadly as defined by revision 3 of the International Standard In-
dustrial Classification (ISIC): two-digit codes 15-37. Within manufacturing, capital goods corresponds to ISIC 29-35. Intermediates corresponds to all of manufacturing not classified as capital goods. Structures are mapped into ISIC category 45. Final goods in our model correspond to all the manufacturing ISIC categories except the ones that correspond to capital goods, intermediate goods, and structures in our model.

We obtain production data from multiple sources. First, we utilize value added and gross output data from the INDSTAT2, a database maintained by UNIDO (2013), which is reported at the two-digit level using ISIC. This data extends no further than 2010, and even less for many countries. We turn to data on value added output in United Nations National Accounts Main Aggregates Database which reports value added output for 2011. For countries that report both value added and gross output in INDSTAT, we use the ratio from the year that is closest to 2011, and apply that ratio to the value added from UNIDO to recover gross output. Countries for which data on gross output is not available in INDSTAT, we apply the average ratio of value-added-to-gross output across all countries, and apply that ratio to the value added figure in UNIDO for 2011. In our data set, the ratio of value-added-to-gross output does not vary significantly over time, and is also not correlated with level of development or country size.
Trade data is from the UN Comtrade Database http://comtrade.un.org. In this database, bilateral trade is reported for goods at the four-digit level of the Standard International Trade Classification (SITC), revision 2. We make use of the correspondence tables from Affendy, Sim Yee, and Satoru (2010) to map SITC2 to ISIC. We also omit any petroleum-related products from the trade data.

Using the trade and production data, we construct bilateral trade shares for each country pair by following Bernard, Eaton, Jensen, and Kortum (2003) as follows:

$$\pi_{ij} = \frac{X_{ij}}{\text{ABS}_i},$$

where $i$ denotes the importer and $j$ denotes the exporter. $X_{ij}$ denotes manufacturing trade flows from $j$ to $i$, and $\text{ABS}_i$ is country $i$’s absorption defined as gross output less net exports of manufactures.

### B.2 National accounts and price

#### PPP GDP and population
For our benchmark calibration, we collect data on output-side real GDP at current PPPs (2005 U.S. dollars) from version 8.1 of the Penn World Tables (see Feenstra, Inklaar, and Timmer, 2015, (PWT from now on)) using the variable $\text{cgdpo}$.

We use the variable $\text{emp}$ from PWT to measure the number of workers in each country. The ratio $\frac{\text{cgdpo} \times \text{pl}_{\text{gdp}}}{1 - \alpha} \times \text{emp}$ corresponds to GDP per worker, $y = w/P_f$, in our model (labor compensation in U.S. dollars deflated by the PPP price of consumption).

The sectoral prices (intermediates, capital goods, and structures) are constructed from the disaggregate price data from the World Bank’s 2011 International Comparison Program (ICP): http://siteresources.worldbank.org/ICPEXT/Resources/ICP_2011.html. The data has several categories that fall under what we classify as manufactures: “Food and nonalcoholic beverages”, “Alcoholic beverages, tobacco, and narcotics”, “Clothing and footwear”, and “Machinery and equipment”. Of these, capital goods correspond to “Machinery and equipment”, structures
correspond to “Construction”, and the remaining categories correspond to intermediate goods. The ICP reports expenditure data for above categories in both nominal U.S. dollars and real U.S. dollars. The conversion from nominal to real uses the PPP price, that is: the PPP price equals the ratio of nominal expenditures to real expenditures. The PPP for intermediates is constructed as the sum of nominal expenditures divided by the sum of real expenditures across intermediate goods categories.

C Estimation of $\theta$

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 $\theta$ for each sector is estimated independently.

A key element of the EK methodology is to exploit cross-country data on disaggregate prices of goods within the sector. In the EK model (as well as our model) (equation (7)),

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

where $P_i$ and $P_j$ denote the aggregate prices in countries $i$ and $j$ for the sector under consideration. If we know $\tau_{ij}$, it is straightforward to estimate $\theta$. But $\tau_{ij}$ is unknown.

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 $\max_{x \in X} \{\frac{p_i(x)}{p_j(x)}\} \leq \tau_{ij}$, where $X$ denotes the set of goods for which disaggregate prices are available. Thus, the bilateral trade barrier can be obtained as

$$\ln \hat{\tau}_{ij}(X) = \max_{x \in X} \{\ln p_i(x) - \ln p_j(x)\}.$$
EK derive a method of moments estimator, $\hat{\rho}_{EK}$, as:

$$\hat{\rho}_{EK} = -\frac{\sum_i \sum_j \ln \left( \frac{\pi_{ij}}{\pi_{jj}} \right)}{\sum_i \sum_j [\ln \hat{\tau}_{ij}(X) - \ln \hat{P}_i(X) + \ln \hat{P}_j(X)]},$$  \hspace{1cm} (17)

where $\ln \hat{P}_i(X) = \frac{1}{|X|} \sum_{x \in X} \ln p_i(x)$ 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 $\theta$. Simulate marginal costs for all countries for a large number of goods as a function of $\theta$. Compute the bilateral trade shares $\pi_{ij}$ and prices $p_i(x)$. Use a subset of the simulated prices and apply the EK methodology to obtain a biased estimate of $\theta$, call it $\rho(\theta)$. Iterate on $\theta$ until $\hat{\rho}_{EK} = \rho(\theta)$ to uncover the true $\theta$.

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

$$\ln \frac{\pi_{ij}}{\pi_{ii}} = F_j - F_i - \theta \ln(\tau_{ij}),$$  \hspace{1cm} (18)

where $F_i \equiv \ln d_i^{-\theta} T_i$. 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:

$$\ln \tau_{ij} = dist_k + brdr_{ij} + exj + \varepsilon_{ij}.$$  \hspace{1cm} (19)

The coefficient $dist_k$ is the effect of distance between countries $i$ and $j$ lying in the $k$th distance interval. 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, \( \varepsilon_{ij} \) 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 \( \theta \) 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 \( s = 100 \) simulations. Finally, choose a value for \( \theta \) such that the average “biased” estimate of \( \theta \) from simulated prices is sufficiently close to the biased estimate obtained from the observed prices – that is, \( \frac{1}{100} \sum_s \rho_s(\theta) = \hat{\rho}_{EK} \).

In case of our capital goods, one issue in implementing this method is that the number of disaggregate price categories that fall under producer durables is small. To circumvent this, we include consumer durables along with producer durables to expand the sample size.

### D Gravity approach

Observations for which the recorded trade flows are zero are omitted from the regression. The regression for the capital goods sector produces an \( R^2 \) of 0.85 with 8211 usable observations (i.e., non-zero trade flows) out of 10,302 bilateral trade pairs, while the regression for the intermediate goods sector
produces an $R^2$ of 0.79 with 9018 usable observations.

The OLS regression coefficients yield estimates of trade frictions, $\hat{\tau}_{bij}$, and country fixed effects, $\hat{F}_{bi}$. With these estimates in hand we use the model’s structure to recover the productivities, $T_{bi}$, for $b \in \{e, m\}$. By definition $\hat{F}_{bi} = \ln \left( u_{bi}^{-\theta} T_{bi} \right)$, so once we compute the unit costs, $u_{bi}$, we can infer $T_{bi}$.

The unit costs are given by $u_{bi} = \left( r_{ei}^{\alpha\mu s} \right)^{(1-\mu)} \frac{w_1^{1-\alpha}}{P_{mi}^{1-\alpha}}$. We use data on prices of capital goods and structures together with the no arbitrage (Euler) condition to measure the rental rates for each type of capital, $b \in \{e, s\}$, $\hat{r}_{bi} = \left[ \frac{1}{\beta} - (1 - \delta_b) \right] \hat{P}_{bi}$. We measure wages using the model’s empirical counterpart: GDP in current U.S. dollars per worker, divided by labor’s share in GDP: $w_i = (1 - \alpha) \frac{GDP_i}{L_i}$. Finally, using data on prices of intermediate goods, $P_{mi}$, we can estimate the unit costs, which yields estimates for $T_{ei}$ and $T_{mi}$.

With the estimates for $T_{ei}$ and $T_{mi}$, we compute $A_{si}$ and $A_{fi}$ to match the price of structures relative to final goods and income per worker using equations (10) and (11).

E  Calibrated productivity parameters

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