Review of Economic Dynamics 27 (2018) 101–122

Contents lists available at ScienceDirect

Review of Economic Dynamics

www.elsevier.com/locate/red

Capital goods trade, relative prices, and economic development

Piyusha Mutreja [a], B. Ravikumar [b], Michael Sposi [c,*,1]

[a] Syracuse University, United States
[b] Federal Reserve Bank of St. Louis, United States
[c] Federal Reserve Bank of Dallas, United States

ARTICLE INFO

Article history:
Received 30 June 2017
Received in revised form 11 October 2017
Available online 11 November 2017

JEL classification:
O11
O4
F11
E22

Keywords:
Income differences
Capital goods trade
Relative prices
Investment rate

ABSTRACT

International trade in capital goods has quantitatively important effects on economic development through capital formation and 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. Moreover, poor countries use their comparative advantage and allocate their resources more efficiently, and increase their TFP. We quantify these channels using a multisector, 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.

1. Introduction

Cross-country differences in income per worker are large. Development accounting exercises (e.g., Caselli, 2005) show that differences in inputs—capital and labor—account for roughly 50 percent of the income differences and 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 (see Eaton and Kortum, 2001) and (ii) the dependence on capital goods imports is negatively related to economic

* Corresponding author.
E-mail addresses: pmutreja@syr.edu (P. Mutreja), b.ravikumar@wustl.edu (B. Ravikumar), michael.sposi@dal.frb.org (M. Sposi).

1 Previous versions of this paper were circulated under the title “Capital Goods Trade and Economic Development”. We thank Marianne Baxter, David Cook, Stefania Garetto, Bob King, Logan Lewis, Ben Moll, Samuel Pienknagura, Diego Restuccia, Andrés Rodríguez-Clare, Richard Rogerson, John Shea, Dan Trefler, and Xiaodong Zhu for valuable feedback. We are also grateful to seminar audiences at Arizona State, Boston, Carnegie Mellon, Chicago Fed, Cornell, Dallas Fed, Durham, Florida State, IMF, Indiana, ISI Delhi, Philadelphia Fed, Princeton, Ryerson University, Seoul National, St. Louis Fed, SUNY Albany, Swiss National Bank, Texas A&M, Tsinghua, Alicante, Basel, Houston, Maryland, UNC Charlotte, Notre Dame, Rochester, Southern California, Toronto, Western Ontario, York, and conference audiences at Cowles, ISI, MadMac Conference in Growth and Development, Midwest Macro, Midwest Trade, Southern Economics Association, System Committee of International Economic Analysis, Conference on Micro-Foundations of International Trade, Global Imbalances and Implications on Monetary Policy, and XVII Workshop in International Economics and Finance. The views in this paper are those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Dallas, the Federal Reserve Bank of St. Louis, or the Federal Reserve System.

https://doi.org/10.1016/j.red.2017.11.003
1094-2025/© 2017 Published by Elsevier Inc.

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 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.[3]

In our theory, international trade in capital goods affects economic development through two channels: capital formation and TFP. First, reductions in barriers to capital goods trade enable poor countries to access capital goods produced 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 allocate their resources more efficiently which increases their TFP. 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 in the income gap 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. Countries differ in their technologies for producing a continuum of tradable capital goods and a continuum of tradable intermediate goods (i.e., non-capital goods). Trade is subject to frictions. Non-tradable final goods productivity is country-specific. Relative to the neoclassical growth model, TFP is endogenous in our framework; relative to trade models such as Waugh (2010) capital formation is endogenous in our framework and depends on trade frictions.

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 is the observed bilateral trade flows across 102 countries. We calibrate the productivities to match the observed income per worker and relative prices of capital goods and intermediate goods.

Our model reconciles several trade and development facts in a unified framework. First, we account for the concentration of capital goods production in the world and for the fact that poor countries are net importers of capital goods. Second, the contribution of input differences in accounting for cross-country income differences in our model is similar to the contribution in the data. Third, we deliver 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—the ratio of top decile to bottom decile in the world income-per-worker distribution—decreases from roughly 28 to almost 17, or by 40 percent. This reduction in income gap can be decomposed into reductions in (i) TFP gap and (ii) capital–output ratio gap. The reduction in TFP gap is standard in Ricardian trade models (see Waugh, 2010): Countries reallocate resources in the direction of their comparative advantage. However, in the Ricardian trade models factors of production are fixed, so there is no effect on capital formation. The reduction in capital–output ratio gap occurs in our model because the relative price of capital decreases in poor countries leading them to increase their investment rate. Ignoring changes in TFP, the change in capital–output ratio would have decreased the income gap to almost 24, a reduction of 12 percent. In other words, the change in TFP contributes more to the reduction in the income gap. This TFP effect is absent in the 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, while the investment rate measured in international prices is positively correlated 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 or 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

[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.

[3] One strand of the literature on economic development explains the income differences via misallocation of capital in *closed economies* where cross-country differences in financial frictions imply cross-country differences in capital (e.g., Buera et al., 2011; Greenwood et al., 2013). Given the facts above, closed economy models can provide only part of the reason for cross-country differences in capital.

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 Eaton and Kortum (2001).

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 to deliver the observed prices of capital goods, so by design, frictions in capital goods trade play no role in accounting for the observed cross-country income differences. 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, bilateral trade flows, and capital goods production in a model with trade frictions.

Hsieh (2000) provides evidence for the channels in our model by contrasting Argentina and India. India reduced barriers to capital goods imports in the 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 and a decline in the investment rate.

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

2. Model

We extend the framework of Alvarez and Lucas (2007), Eaton and Kortum (2002), and Waugh (2010) to two tradable sectors and embed it into a neoclassical growth framework (see also Mutreja, 2017).

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 *varieties* and a continuum of capital goods *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 *composite* good. The composite intermediate good is used with capital and labor to produce the consumption good, the investment goods, 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 initial capital stocks of producer durables and structures per worker, k^e_{0i} and k^s_{0i}, respectively.

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 $b \in \{e, m\}$.

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

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

where η is the elasticity of substitution between any two varieties, $q_{bi}(v_b)$ is the quantity of variety v_b used by country i to construct the sector b composite good, and q_{bi} 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:

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

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 $k^e_{bi}(v_b)$ and $k^s_{bi}(v_b)$ denote the quantities of producer durables capital and structures capital, and $\ell_{bi}(v_b)$

denotes the fraction of labor used. The parameter $\nu_b \in [0, 1]$ denotes the share of value added in total output in sector b and α denotes capital's share in value added. The parameter $\mu \in [0, 1]$ denotes the share of producer durables capital in the aggregate capital stock. These parameters are constant across countries.

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 θ and country-sector-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 $\gamma = \Gamma(1 + \frac{1}{\theta}(1-\eta))^{\frac{1}{1-\eta}}$ and $\Gamma(\cdot)$ is the gamma function, and T_{mi} 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 θ 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

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

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

Structures are produced similarly:

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

2.3. Trade

International trade is subject to frictions of 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. 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_{it}^e, and a stock of structures, k_{it}^s. Investment, x_{it}^e and x_{it}^s add to the respective stocks of capital, which depreciate at the rates δ_e and δ_s.

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

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_i^e and x_i^s, 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:

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

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

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

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 $p_{bi}(z_b) = \min_{j=1,\ldots,I}[p_{bjj}(z_b)\tau_{bij}]$. 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 in sector b in country i.

Next we define sectoral aggregates for inputs and output.

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

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 fraction 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, ℓ_{bi} is the fraction of country i's labor used in sector b. Similarly, m_{bi}, k_{bi}^e, and k_{bi}^s 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.

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

Trade flows. In sector b, the fraction of country i's expenditures allocated to varieties produced by country j is given by

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

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 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 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,

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

(see Appendix A for the derivation). In equation (3), T_{mi} and A_{fi} are exogenous. The remaining components on the right-hand side of (3), π_{mii} and k_i, are equilibrium objects. Measured TFP (up to a constant) is the term multiplying k_i^{α}, as in the neoclassical growth model.

The expression for income per worker can be written more conveniently as

$$y_i \propto \left(A_{fi} \left(\frac{T_{mi}}{\pi_{mii}} \right)^{\frac{1-\nu_f}{\theta \nu_m}} \right)^{\frac{1}{1-\alpha}} \left(\frac{k_i}{y_i} \right)^{\frac{\alpha}{1-\alpha}}. \tag{4}$$

In steady state, the capital–output ratios for equipment and structures are proportional to the respective investment rates: $\frac{k_i^b}{y_i} \propto \frac{x_i^b}{y_i}$ for $b \in \{e, s\}$. Moreover, the investment rate is proportional to the inverse of the relative price: $\frac{x_i^b}{y_i} \propto \frac{P_{fi}}{P_{bi}}$. Therefore, the (aggregate) capital–output ratio is given by

$$\begin{aligned} \frac{k_i}{y_i} &= \left(\frac{k_i^e}{y_i} \right)^{\mu} \left(\frac{k_i^s}{y_i} \right)^{1-\mu} \\ &\propto \left(\frac{x_i^e}{y_i} \right)^{\mu} \left(\frac{x_i^s}{y_i} \right)^{1-\mu} \\ &\propto \left(\frac{P_{fi}}{P_{ei}} \right)^{-\mu} \left(\frac{P_{fi}}{P_{si}} \right)^{\mu-1}. \end{aligned} \tag{5}$$

All else equal, any trade policy that affects the relative price of capital will affect economic development via the capital–output ratio.

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

$$\frac{P_{ei}}{P_{fi}} \propto \left(\frac{A_{fi}}{(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}} \right) \left(\frac{T_{mi}}{\pi_{mii}} \right)^{\frac{\nu_e - \nu_f}{\theta \nu_m}}. \tag{6}$$

The first term in equation (6) is the ratio of productivity in final goods, A_{fi}, to the measured productivity in capital goods, $(T_{ei}/\pi_{eii})^{\frac{1}{\theta}}$. A reduction in frictions to trade capital goods reduces the relative price of capital goods via a fall in the home trade share, π_{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.[4]

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 is 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, π_{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 α, a one percent increase in a country's measured TFP increases its income per worker by $\frac{1}{1-\alpha} = 1.5$ percent. (The TFP in rich countries is roughly 8 times that in poor countries.)

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.

Two remarks are in order regarding equations (4) and (5). (i) If $\pi_{eii} = \pi_{mii} = 1$, then our economy reduces to a closed economy. (ii) If $\nu_f = 1$, then changes in trade frictions have no effect on income per worker in Alvarez and Lucas (2007) or Waugh (2010) but will have an effect in our model via capital–output ratio.

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. Changes in the relative price affect the investment rate and, hence, 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 et al., 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. In Appendix B, we describe data sources, data construction, and how we map our model to the data.

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 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, α, is set to 1/3, as in Gollin (2002). Using data from the Bureau of Economic Analysis (BEA), Greenwood et al. (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, μ, at 0.56 in accordance with Greenwood et al. (1997).

We compute ν_m and ν_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 set $\nu_s = \nu_f$ in the model, which implies that the price of structures relative to final goods is A_{fi}/A_{si}. Computing ν_f is slightly more involved since there is no clear industry classification for consumption goods. We infer this share by

[4] Sposi (2015) discusses how trade barriers affect cross-country differences in the relative price primarily through the price of nontraded goods.

Table 1
Parameters common across countries.

Parameter	Description	Value
β	Discount factor	0.96
η	Elasticity of substitution in aggregator	2
α	k's Share	0.33
δ_e	Depreciation rate of producer durables	0.12
δ_s	Depreciation rate of structures	0.06
μ	Share of producer durables in composite capital	0.56
ν_m	k and ℓ's Share in intermediate goods	0.67
ν_e	k and ℓ's Share in capital goods	0.80
ν_f	k and ℓ's Share in final goods	0.58
ν_s	k and ℓ's Share in structures	0.58
θ	Variation in (sectoral) factor productivity	4

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

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

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 EX_{mi} and IM_{mi} are gross exports and imports of intermediates. Using a standard method of moments estimator, our estimate of ν_f is 0.58.

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

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 producer durables 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, τ_e and τ_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:

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

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 9.40, while it is 1.96 for rich countries. The intermediate goods sector displays a similar pattern: The trade-weighted export friction is 13.18 for poor countries and is 2.21 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:

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

Table 2
Model fit for targeted data.

Variable	Correlation
Income per worker, y	1.00
Price of capital goods, P_e	0.87
Price of final goods, P_f	0.95
Price of intermediate goods, P_m	0.99
Price of structures, P_s	0.99
Bilateral trade shares for capital goods, $\pi_{eij} (i \neq j)$	0.93
Bilateral trade shares for intermediate goods, $\pi_{mij} (i \neq j)$	0.91
Home trade shares for capital goods, π_{eii}	0.90
Home trade shares for intermediate goods, π_{eii}	0.93

Notes: Correlations for each variable (relative to the U.S.) are between the model and the data.

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

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

$$\begin{aligned}\frac{y_i}{y_U} &= \left(\frac{A_{fi}}{A_{fU}}\right)\left(\frac{T_{ei}/\pi_{eii}}{T_{eU}/\pi_{eUU}}\right)^{\frac{\mu\alpha}{\theta(1-\alpha)}}\left(\frac{A_{si}}{A_{sU}}\right)^{\frac{(1-\mu)\alpha}{1-\alpha}} \\ &\times \left(\frac{T_{mi}/\pi_{mii}}{T_{mU}/\pi_{mUU}}\right)^{\frac{1-\nu_f+\frac{\alpha}{1-\alpha}(1+\mu\nu_e+(1-\mu)\nu_s)}{\theta\nu_m}}.\end{aligned} \tag{11}$$

See Appendix A for derivations of the equations.

Our measure of income per worker for each country is *not* taken directly from PWT but is constructed as in the model: $\frac{GDP_i}{(1-\alpha)L_i P_{fi}}$, where GDP_i is the gross domestic product for country i in current U.S. dollars using market exchange rates. We normalize T_{eU}, T_{mU}, A_{sU}, and A_{fU} to 1 and solve for T_{ei}, T_{mi}, A_{si}, and A_{fi} for each country i using equations (8)–(11).

Table E.1 in Appendix E reports the calibrated productivity parameters. The average gap in productivity in the capital goods sector between rich and poor countries is 14.1. In the intermediate goods sector, the average productivity gap is 5.3.[5] 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

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.

Using the common parameters in Table 1 and country-specific values for labor force, productivities, and trade frictions, we solve for the model's steady state. Table 2 reports the correlations between model and data for each targeted variable.

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, 0.91, 0.99, and 0.90, respectively.

[5] 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, $T_e^{\nu_e/\theta}$, is 8.3 and that for the intermediate goods sector is 3.1.

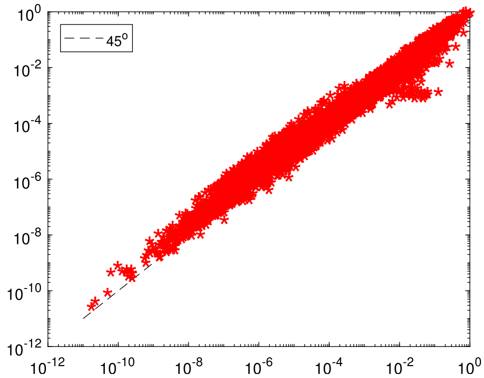

Fig. 1. Bilateral trade shares in capital goods. **Notes:** The vertical axis corresponds to the model and the horizontal axis corresponds to the data.

Table 3
Model fit for untargeted data.

	Data	Model
Contribution to log-variance in y: $\ln(Z^{\frac{1}{1-\alpha}})$	85.3%	83.3%
Contribution to log-variance in y: $\ln((k/y)^{\frac{\alpha}{1-\alpha}})$	2.9%	2.0%
Contribution to log-variance in y: covariance	11.8%	14.7%
Elasticity of x^e/y w.r.t. income per worker	39.7%	36.3%
Percent of capital goods production accounted for by		
top 10 countries	78.3%	79.5%
top 20 countries	92.0%	91.9%
top 50 countries	99.5%	99.8%

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

Income per worker. The model's fit for income per worker is perfect by construction since we can choose the final good sector productivity, A_f, to match the observed income per worker. This is because the value of A_f does not affect the home trade shares in our model, so equation (11) can be used to pin down the income per worker exactly.

Trade shares. Fig. 1 plots the bilateral trade shares in capital goods, π_{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 is 0.93 in the intermediate goods sector.

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 $y_i = Z_i^{\frac{1}{1-\alpha}} \left(\frac{k_i}{y_i}\right)^{\frac{\alpha}{1-\alpha}}$, where Z denotes measured TFP. Log variance in $(k/y)^{\frac{\alpha}{1-\alpha}}$ accounts for 2 percent of the log variance in y in the model, compared to 2.9 percent in the data. Log variance in $Z^{\frac{1}{1-\alpha}}$ counts for 83.3 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 14.7 percent of the log variance in y in the model, compared to 11.8 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. Fig. 2 illustrates the cdf for capital goods production. In the model and in the data, 10 countries

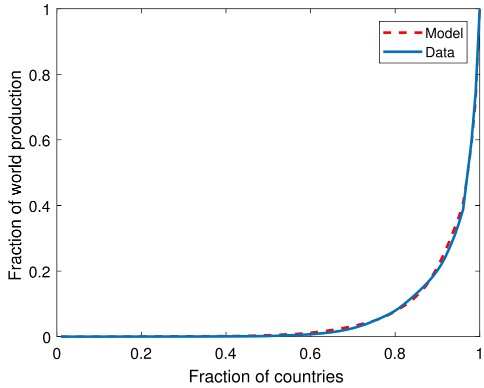

Fig. 2. Distribution of capital goods production.

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 is −0.30 in the data.

The observed negative correlation between the relative price of capital goods and income per worker 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 is 0.29 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 is 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 $\phi_b = \frac{\delta_b}{1/\beta-(1-\delta_b)}$ 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

$$P_{ei}x_i^e = \frac{\phi_e \mu w_i \alpha}{1-\alpha} \tag{12}$$

$$P_{si}x_i^s = \frac{\phi_s(1-\mu)w_i\alpha}{1-\alpha}. \tag{13}$$

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

$$\frac{P_{ei}x_i^e + P_{si}x_i^s}{w_i + r_i k_i} = \alpha[\mu\phi_e + (1-\mu)\phi_s], \tag{14}$$

which is a constant. In the data, the investment rate measured in domestic prices is uncorrelated with income per worker. The share of expenditures allocated to final consumption is 1 minus the investment rate.

Our model also captures the systematic variation in investment rates measured in purchasing power parity (PPP) prices. Rich countries have higher investment rates, $\frac{x^e}{y}$, 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 by setting $\tau_{eij} = 1$ for all country pairs. We leave all other parameters at their calibrated values; specifically, the intermediate goods trade frictions remain at the benchmark levels.

Table 4 reports the income gaps and the components therein. 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 1.23. If measured TFP were held fixed, the smaller gap in capital–output ratio by itself would reduce the income gap from 27.94 to 24.42, a reduction of 12 percent. However, measured TFP in poor countries increases following the removal of capital goods trade frictions since they can now import capital goods and specialize more in intermediate goods. The gap in measured TFP falls from 7.61 to 6.05. The combined effect of lower gaps

Table 4
Gap in income per worker and its components.

	Benchmark model	Frictionless trade in capital goods
y	27.94	16.70
$Z^{\frac{1}{1-\alpha}}$	20.47	14.56
$(k/y)^{\frac{\alpha}{1-\alpha}}$	1.27	1.11
Z	7.61	6.05
k/y	1.62	1.23
$(k^e/y)^{\mu}$	1.92	1.37
k^e/y	3.15	1.70

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: $k = \left(k^e\right)^{\mu} \left(k^s\right)^{1-\mu}$. The ratio, $\frac{k^s}{y}$, does not change in the counterfactual.

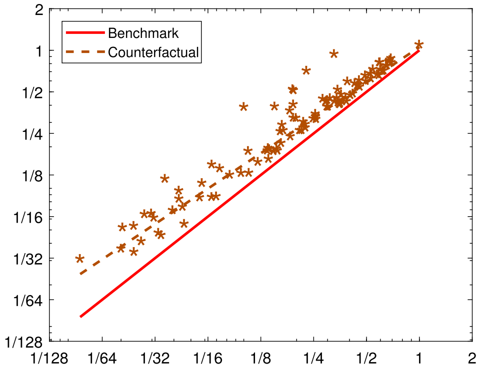

Fig. 3. Income per worker, U.S. = 1. **Notes:** The vertical axis corresponds to the model and the horizontal axis corresponds to the data. The dots indicate the counterfactual values for each country and the dashed line is the best linear fit for those dots. The solid line is the benchmark. Recall that our model matches the observed income per worker perfectly, so the benchmark is the 45° line.

in capital–output ratio and measured TFP is a 40 percent reduction in the income gap from 27.94 to 16.70. See Fig. 3 for the counterfactual cross-country distribution of income per worker. The log variance of income per worker declines from 1.08 to 0.83.

Comparative advantage and reallocation of resources. In our model, total labor in each country is held fixed when we go from the baseline to the counterfactual. Furthermore, (i) the fraction of labor allocated to final goods and structures is invariant to trade frictions and (ii) reallocation of factors takes place between tradable capital goods and intermediate goods. Feature (i) arises from that fact that, measured in domestic prices, the shares of expenditures that go toward final consumption, investment in capital goods, and investment in structures are invariant to the trade frictions (see equations (12), (13), and (14)). Since final consumption and structures are nontradable, the expenditure shares on those sectors are proportional to the share of labor in those sectors. Feature (ii) follows from the fact that capital goods and intermediate goods are tradable. This means that changes in net exports in those sectors, which depend on the trade frictions, break the link between expenditure shares and production shares. As a result, changes in trade frictions cause a reallocation between capital goods and intermediate goods sectors.

Trade liberalization increases the size of the pie in each country i.e., it changes the output in both intermediate goods and capital goods sectors. The change in the size of the sector by itself would imply different allocations of labor. To illustrate the comparative advantage forces and reallocation of resources across sectors, we compute the change in labor in each sector relative to the change in output of that sector. In poor countries, for instance, labor–output ratio in the capital goods sector is 0.31 in the counterfactual relative to its benchmark value and 0.39 in the intermediate goods sector. Put differently, more resources are allocated by poor countries to the sector of their comparative advantage. For rich countries, the corresponding ratios are 1.47 and 0.96 i.e., the rich countries allocate more resources to the sector of their comparative advantage.

The relative price channel. In the presence of capital goods trade frictions, poor countries transform 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

Table 5
Price elasticities with respect to income per worker.

	Benchmark model	Frictionless trade in capital goods
P_e	0.01	0.00
P_f	0.37	0.20
P_e/P_f	−0.36	−0.20

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. For every one percent decrease in the relative price, the ratio of producer durables capital to output increases by one percent and the aggregate capital to output ratio increases by $\mu = 0.56$ percent. 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 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.

Empirical evidence. Hsieh (2000) 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.

Alternative estimate of 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 they were calibrated to be consistent with prices and trade flows (equation (7)). In Appendix D we provide an alternative estimate of the trade frictions using gravity regressions that are standard in the trade literature.

We find that (i) the correlation between the two estimates of trade frictions is high, (ii) gravity-based trade frictions are higher than those in our benchmark calibration, (iii) the difference in the gravity-based trade frictions between rich and poor countries is larger than the difference in that in our benchmark frictions, and (iv) eliminating the gravity-based capital goods trade frictions reduces the income gap by more than 40 percent.

4.4. Technology vs. policy

Our calibrated trade frictions could include policy barriers as well as technological impediments (equation (7)). Thus, when we 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} is exports of capital goods from the U.S. to country i and X_{eU} is total 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., $\tau_{eij} = 1.81$). Fig. 4 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.

With the U.S. trade frictions, the income gap falls from 27.94 to 17.77, a reduction of 36 percent. Recall that in the counterfactual with frictionless capital goods trade the income gap declines from 27.94 to 16.70, 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.

4.5. Other trade liberalizations

The previous counterfactuals focused on the effects of removing frictions on capital goods trade. Trade liberalizations often involve reductions in frictions to trading non-capital goods as well. We consider two other counterfactual exercises in this subsection. First, we remove frictions to trading intermediate goods, while holding all other parameters, including capital goods trade frictions, at the calibrated values. Second, we remove frictions to trading both capital goods and intermediate goods.

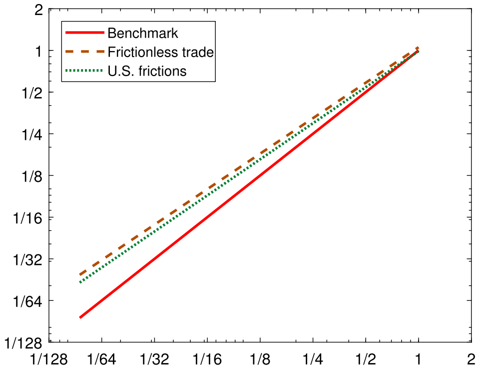

Fig. 4. Income per worker, US = 1. **Notes:** The vertical axis corresponds to the model and the horizontal axis corresponds to the data. The dashed line and the dotted line are the best linear fits for the respective counterfactual income per worker. The solid line is the benchmark. Recall that our model matches the observed income per worker perfectly, so the benchmark is the 45° line.

Table 6
Log-variance: Income, capital–output ratio, and relative price.

Log-variance	Benchmark model	Frictionless trade		
		in capital goods	in intermediates	in both
y	1.08	0.83	0.74	0.72
k/y	0.09	0.07	0.04	0.04
P_e/P_f	0.22	0.15	0.10	0.09

Table 6 summarizes the effects of the different frictionless trade scenarios on cross-country income differences. The key message from the table is the same as our message from the previous counterfactuals.

Empirical evidence. Starting in the 1960s Korea reduced the import restrictions (see Westphal, 1990; Yoo, 1993); the capital goods imports increased 11-fold subsequently. Over the next 30 years, the relative price of capital decreased by a factor of almost 2 and the investment rate increased by a factor of nearly 4 (Nam, 1995).

Wacziarg and Horn 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.

Rodriguez and Rodrik (2001) find evidence that trade barriers in part determine the cross-country difference in the relative price of capital that in turn affects the investment levels.

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) TFP. We embed a multicountry, multisector 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 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, 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 moving to frictionless trade in capital goods.

We studied the role of capital goods trade for economic development under the assumption of balanced trade. Trade imbalances can be incorporated into our model by: (i) Fixing trade imbalances as a share of world GDP as in Dekle et al. (2007), (ii) treating trade imbalances as net proceeds from a global portfolio as in Caliendo et al. (2014), or (iii) introducing one-period bonds as in Sposi (2012). In our model, with or without trade imbalances, the steady-state investment rate measured in domestic prices does not depend on the level of trade frictions. That is, the investment rate in domestic prices is the same in all countries under frictionless capital goods trade as well as under trade frictions. Trade imbalances could have a different effect on the investment rate in *PPP prices* and, hence, income per worker if the response of relative prices to changes in trade frictions is different. However, the quantitative effect of the relative price channel is likely to be similar to that in our model with balanced trade.

Appendix A. Derivations

A.1. Price indices and trade shares

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

Let $\gamma = \Gamma(1+\theta(1-\eta))^{\frac{1}{(1-\eta)}}$, where $\Gamma(\cdot)$ is the gamma function. Recall that $u_{mi} = \left(\frac{r_i}{\alpha\nu_m}\right)^{\alpha\nu_m}\left(\frac{w_i}{(1-\alpha)\nu_m}\right)^{(1-\alpha)\nu_m}\left(\frac{P_{mi}}{1-\nu_m}\right)^{1-\nu_m}$ is the unit cost for intermediates in country i. The price index for intermediates is

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

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

$$\pi_{mij} = \Pr\left\{p_{mij}(z_m) \le \min_l [p_{mil}(z_m)]\right\} = \frac{(u_{mj}\tau_{mij})^{-\theta}T_{mj}}{\sum_l (u_{ml}\tau_{mil})^{-\theta}T_{ml}}. \tag{A.2}$$

A.2. Relative prices

Here we derive expressions for the relative prices: P_{ei}/P_{fi}, P_{mi}/P_{fi}, and P_{si}/P_{fi}. Equations (A.1) and (A.2) imply that

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

Substituting for the unit cost, u_{mi}, and rearranging we get:

$$P_{mi} \propto \frac{\left(\frac{r_i}{w_i}\right)^{\alpha\nu_m}\left(\frac{w_i}{P_{mi}}\right)^{\nu_m}P_{mi}}{\left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta}}}, \tag{A.3}$$

Similarly,

$$P_{ei} \propto \frac{\left(\frac{r_i}{w_i}\right)^{\alpha\nu_e}\left(\frac{w_i}{P_{mi}}\right)^{\nu_e}P_{mi}}{\left(\frac{T_{ei}}{\pi_{eii}}\right)^{\frac{1}{\theta}}}, \tag{A.4}$$

$$P_{si} \propto \frac{\left(\frac{r_i}{w_i}\right)^{\alpha\nu_s}\left(\frac{w_i}{P_{mi}}\right)^{\nu_s}P_{mi}}{A_{si}}, \tag{A.5}$$

$$P_{fi} \propto \frac{\left(\frac{r_i}{w_i}\right)^{\alpha\nu_f}\left(\frac{w_i}{P_{mi}}\right)^{\nu_f}P_{mi}}{A_{fi}}. \tag{A.6}$$

Before proceeding, we use equation (A.3) to solve for w/P_m as it will be useful for the remainder of our derivations:

$$\frac{w_i}{P_{mi}} \propto \left(\frac{w_i}{r_i}\right)^{\alpha}\left(\frac{T_{mi}}{\pi_{mii}}\right)^{\frac{1}{\theta\nu_m}}. \tag{A.7}$$

Taking ratios of the equations (A.4) and (A.6), then substituting for w_i/P_{mi} using equation (A.7), we get

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

Other relative prices can be derived analogously.

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

A.3. Income per worker

Income per worker in our model is defined as total factor compensation per worker deflated by the price of final goods: $y_i = \frac{w_i+r_ik_i}{P_{fi}}$. Using the fact that capital income is proportional to labor income, $r_ik_i = \frac{\alpha}{1-\alpha}w_i$, income per worker is equivalent to

$$\begin{aligned} y_i &= \frac{w_i}{(1-\alpha)P_{fi}} \\ &= \frac{1}{1-\alpha}\frac{w_i}{P_{mi}}\frac{P_{mi}}{P_{fi}}. \end{aligned}$$

Using expressions derived above for $\frac{w_i}{P_{mi}}$ and $\frac{P_{mi}}{P_{fi}}$, and using the fact that $\frac{w_i}{r_i} = \frac{1-\alpha}{\alpha}k_i$ we can solve out for income per worker as

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

A.4. Capital stock

Derivation of the expression for steady-state capital stock makes use of the two Euler equations for investment in producer durables and in structures:

$$r_{ei} = \left[\frac{1}{\beta} - (1-\delta_e)\right]P_{ei} \tag{A.8}$$

$$r_{si} = \left[\frac{1}{\beta} - (1-\delta_s)\right]P_{si} \tag{A.9}$$

Since $r_ik_i = \frac{\alpha}{1-\alpha}w_i$, aggregate stock of capital per worker $k_i \propto \frac{w_i}{r_i} = \frac{w_i}{r_{ei}^{\mu}r_{si}^{1-\mu}} \propto \left(\frac{w_i}{P_{ei}}\right)^{\mu}\left(\frac{w_i}{P_{si}}\right)^{1-\mu}$ (note, $r_{ei} \propto P_{ei}$ and $r_{si} \propto P_{si}$ in equations (A.8) and (A.9)). Using the expressions for relative prices we get:

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

Similarly,

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

Now, $k_i \propto \frac{w_i}{r_i}$, so

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

To derive an expression for the capital–output ratio, note that investment rates at domestic prices are identical across countries in our model: $\frac{P_{ei}x_i^e}{P_{fi}y_i}$ and $\frac{P_{si}x_i^s}{P_{fi}y_i}$ are constant. Therefore, $x_i^e/y_i \propto P_{fi}/P_{ei}$ and $x_i^s/y_i \propto P_{fi}/P_{si}$. Write $k_i = (k_i^e)^{\mu}(k_i^s)^{1-\mu}$ in terms of the relative price as follows: $k_i^e \propto x_i^e, k_i^s \propto x_i^s$, $x_i^e/y_i \propto P_{fi}/P_{ei}$, and $x_i^s/y_i \propto P_{fi}/P_{si}$. Finally, using the expressions for relative prices we get:

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

Appendix B. Data

This section 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. “Southeast 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. “Eastern Europe” includes Estonia, Latvia, Lithuania, Malta, Slovakia, and Slovenia. “Malaysia–Singapore” includes Malaysia and Singapore.

B.1. National accounts and prices

We construct sectoral price levels for each country using 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 foot wear”, and “Machinery and equipment”. Of these, capital goods in the model corresponds to “Machinery and equipment”, while structures correspond to “Construction”; 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 for each country. The PPP for each category equals the ratio of nominal expenditures to real expenditures. Aggregate expenditures at market prices, i.e., total GDP, is defined as the sum of all activities in the ICP. We compute real income in the data as the aggregate GDP divided by the price of consumption at PPP, i.e., we do not take income per worker directly from PWT.

Our measure of total employment is taken directly from version 8.1 of the Penn World Table.

B.2. Production and trade

Construction of trade shares requires data on both production and international trade flows. On the production side, we use two-digit International Standard Industrial Classification (ISIC) categories. Capital goods correspond to “Machinery and equipment” in the ICP; specifically, we use categories 29-35 in revision 3 of the ISIC. Intermediates correspond to the remaining ISIC manufacturing industries, 15-37, excluding 29-35.

We obtain production data from multiple sources. First, we utilize value added and gross output data from INDSTAT2, a database maintained by UNIDO (2013). This data is reported at the two-digit level using ISIC. This data extends no further than 2010 and not even to 2010 for many countries. We use data on value added output from United Nations National Accounts Main Aggregates Database for 2011. For countries that report both value added and gross output in INDSTAT, we apply the ratio from the year that is closest to 2011 to the value added from UNIDO in 2011 to recover gross output. Countries for which data on gross output is not available in INDSTAT for any of the years, we compute the average ratio of value added to gross output across all countries, and apply that ratio to the UNIDO figure 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 use the correspondence tables from Affendy et al. (2010) to map SITC into ISIC and construct bilateral trade flows for capital goods and intermediates. We omit petroleum-related products from the trade data.

Using the trade and production data, we construct bilateral trade shares for each country pair as in Bernard et al. (2003):

$$\pi_{ij} = \frac{X_{ij}}{ABS_{bi}},$$

where X_{ij} denotes manufacturing trade flows from j to i and ABS_i is country i’s absorption defined as gross output less net exports of manufactures.

Appendix C. Estimation of θ

Simonovska and Waugh (2014) build on the procedure in Eaton and Kortum (2002) to estimate θ. We refer to these papers as SW and EK henceforth. We ignore sector subscripts, as θ for each sector is estimated independently.

The EK methodology exploits cross-country data on disaggregate prices of goods within the sector. In the EK model, as well as ours,

$$\ln\left(\frac{\pi_{ij}}{\pi_{jj}}\right) = -\theta(\ln\tau_{ij} - \ln P_i + \ln P_j) \tag{C.1}$$

where P_i and P_j are the aggregate prices in countries i and j for the sector under consideration. If we knew τ_{ij}, estimating θ is straightforward. But τ_{ij} is unknown.

Let x denote a particular variety in the continuum. Each country i faces a price, $p_i(x)$, for that variety. Ignoring the source of the producer of variety x, a 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 varieties for which disaggregate prices are available. Thus, an estimate of the bilateral trade barrier is $\ln \hat{\tau}_{ij}(X) = \max_{x\in X}\{\ln p_i(x) - \ln p_j(x)\}$.

EK derive a method of moments estimator of θ:

$$\hat{\rho}_{EK} = -\frac{\sum_i \sum_j \ln\left(\frac{\pi_{ij}}{\pi_{jj}}\right)}{\sum_i \sum_j [\ln \hat{\tau}_{ij}(X) - \ln \hat{P}_i(X) + \ln \hat{P}_j(X)]}, \tag{C.2}$$

where $\ln \hat{P}_i(X) = \frac{1}{|X|}\sum_{x\in X} \ln p_i(x)$ is the average price of varieties in X in country i and $|X|$ is the number of varieties 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 $\hat{\rho}_{EK}$.

SW propose a simulated method of moments estimator to correct for the bias. Start with an arbitrary value of θ. Simulate marginal costs for all countries for a large number of varieties 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 structural equation:

$$\ln \frac{\pi_{ij}}{\pi_{ii}} = F_j - F_i - \theta \ln(\tau_{ij}), \tag{C.3}$$

where $F_i \equiv \ln u_i^{-\theta} T_i$. In order to estimate the F_i, SW use a parsimonious gravity specification for trade barriers:

$$\ln \tau_{ij} = dist_k + brdr_{ij} + exj + \varepsilon_{ij}. \tag{C.4}$$

The coefficient $dist_k$ is the effect of distance between countries i and j lying in the kth distance interval. The distance intervals are measured in miles using the great circle method: $[0, 375)$; $[375, 750)$; $[750, 1500)$; $[1500, 3000)$; $[3000, 6000)$; and $[6000, \max)$. 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 an orthogonal residual. Combining the gravity specification with equation (C.3), 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 variety in the "continuum" in every country. Recall that $p_{ij}(x) = \tau_{ij}\frac{u_j}{z_j(x)}$, where z_j is country j's productivity. Instead of simulating these productivities, SW simulate the inverse marginal costs, $imc_j = z_j(x)/u_j$. They show that the inverse marginal cost has the following distribution: $F(imc_i) = \exp(-\tilde{F}_i imc_i^{-\theta})$, where $\tilde{F}_i = \exp(F_i)$. Combining the simulated inverse marginal costs with the estimated trade barriers, they find the least-cost supplier for every country and every variety 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 simulated prices such that X contains the same number of disaggregate prices as in the data. Call that estimate $\rho_s(\theta)$. Then perform S 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, $\frac{1}{S}\sum_{s=1}^{S} \rho_s(\theta) = \hat{\rho}_{EK}$.

One issue in implementing this method for the capital goods sector is that the number of disaggregate price categories that fall under producer durables is small. To circumvent this, we increase the sample size by including consumer durables along with producer durables.

Appendix D. Gravity-based trade frictions

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 $b \in \{e, m\}$,

$$\frac{\pi_{bij}}{\pi_{bii}} = \left(\frac{u_{bj}}{u_{bi}}\right)^{-\theta}\left(\frac{T_{bj}}{T_{bi}}\right)(\tau_{bij})^{-\theta}, \tag{D.1}$$

where u_{bi} denotes the unit cost in sector b in country i.

We specify trade frictions as follows:

$$\log(\tau_{bij}) = ex_{bj} + \gamma_{b,dis}\log(dis_{ij}) + \gamma_{b,brd} brd_{ij} + \gamma_{b,lang} lang_{ij} + \varepsilon_{bij}, \tag{D.2}$$

where $ex_{b,j}$ is an exporter fixed effect dummy as in Waugh (2010), dis is the distance between two countries measured in miles using the great circle method, brd is a dummy for common border, $lang$ is a dummy for common language, and ε

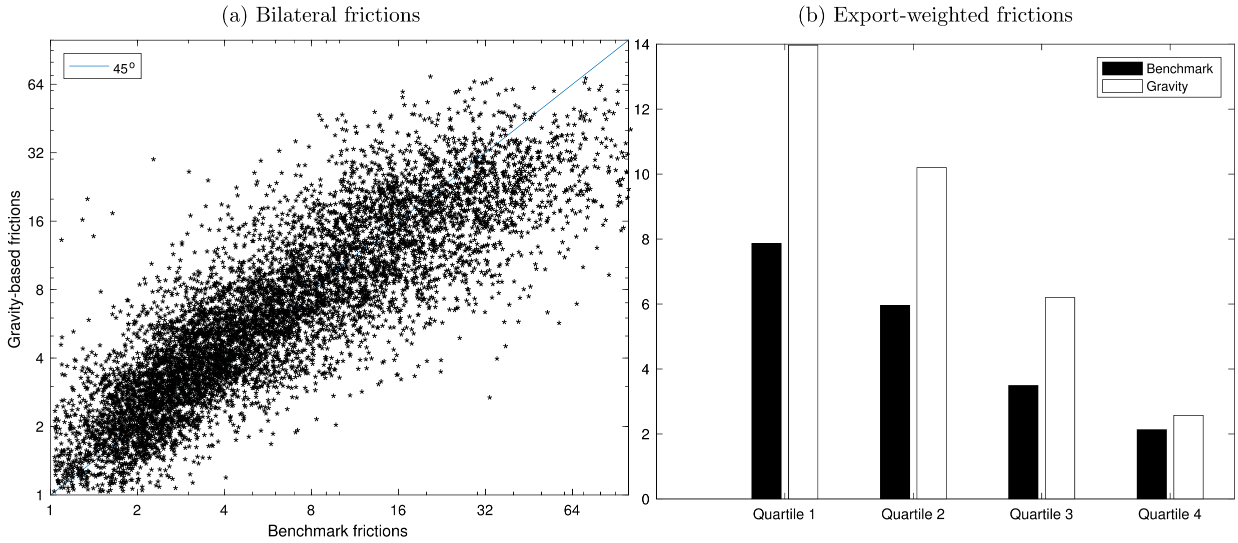

Fig. D.1. Capital goods trade frictions: benchmark calibration and gravity estimation.

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 (D.2) and taking logs of both sides of (D.1) we get

$$\ln\left(\frac{\pi_{bij}}{\pi_{bii}}\right) = \underbrace{\ln\left(u_{bj}^{-\theta}T_{bj}\right)}_{F_{bj}} - \underbrace{\ln\left(u_{bi}^{-\theta}T_{bi}\right)}_{F_{bi}} - \theta\left[ex_{bj} + \gamma_b^{dis}\ln(dis_{ij}) + \gamma_b^{brd}brd_{ij} + \gamma_b^{lang}lang_{ij} + \varepsilon_{bij}\right].$$

We use OLS to estimate the bilateral trade friction in each sector.

The data for this specification, except for trade flows, are taken from the Gravity Data set available at http://www.cepii.fr. 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

$$u_{bi} = \left(\frac{r_{ei}}{\alpha\nu_b\mu}\right)^{\alpha\nu_b\mu}\left(\frac{r_{si}}{\alpha\nu_b(1-\mu)}\right)^{\alpha\nu_b(1-\mu)}\left(\frac{w_i}{(1-\alpha)\nu_b}\right)^{(1-\alpha)\nu_b}\left(\frac{P_{mi}}{1-\nu_b}\right)^{1-\nu_b}.$$

We use data on prices of capital goods and structures together with the Euler equations (A.8) and (A.9) to measure the rental rates for each type of capital. We measure wages: $w_i = (1-\alpha)\frac{GDP_i}{L_i}$. 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).

Fig. D.1D plots the gravity-based estimates of the bilateral trade frictions in the capital goods sector against those in our calibration in Section 3. While the correlation is high—0.72—there are two important differences between the two sets of frictions.

First, the gravity-based frictions are *larger* than the ones in our calibration. This can be seen in Fig. D.1D, which illustrates the export-weighted trade frictions for different income quartiles. Second, the difference in the gravity-based trade frictions between rich and poor countries is larger than the difference in our calibrated trade frictions. Thus, if we were to repeat the counterfactual in Section 4.3 starting from the gravity-based trade frictions, 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 price of final goods than our benchmark; see Table D.1. Although the gravity approach captures the pattern in the price of capital goods as well as our benchmark does, it overstates the cross-country differences in the relative price of capital goods.

Table D.1
Price elasticities with respect to income per worker.

	Data	Benchmark model	Gravity-based model
P_e	−0.01	0.01	−0.01
P_f	0.31	0.37	0.50
P_e/P_f	−0.32	−0.36	−0.51

Appendix E. Calibrated productivity parameters

Table E.1
Productivity parameters.

Country	Isocode	A_{fi}	A_{si}	$T_{ei}^{\frac{1}{\theta}}$	$T_{mi}^{\frac{1}{\theta}}$
Armenia	ARM	0.58	0.41	0.20	0.50
Australia	AUS	0.97	0.82	0.76	0.73
Austria	AUT	0.76	0.95	0.44	0.72
Bahamas	BHS	0.64	1.40	0.24	0.30
Bangladesh	BGD	0.44	0.88	0.11	0.29
Barbados	BRB	0.58	1.14	0.26	0.30
BeNeLux	BNL	0.80	1.06	0.40	0.34
Belarus	BLR	0.61	0.47	0.21	0.66
Belize	BLZ	0.39	0.41	0.18	0.56
Benin	BEN	0.44	0.50	0.07	0.15
Bhutan	BTN	0.73	1.02	0.11	0.28
Bolivia (Plurinational State of)	BOL	0.51	0.64	0.05	0.28
Botswana	BWA	0.62	1.80	0.16	0.19
Brazil	BRA	0.50	1.26	0.27	0.53
Bulgaria	BGR	0.52	0.91	0.12	0.49
Burkina Faso	BFA	0.33	0.46	0.06	0.08
Burundi	BDI	0.23	0.32	0.04	0.12
Cambodia	KHM	0.39	0.88	0.03	0.07
Cameroon	CMR	0.38	0.48	0.06	0.32
Canada	CAN	0.84	0.99	0.60	0.54
Central African Rep.	CAF	0.28	0.43	0.07	0.14
Chile	CHL	0.74	1.09	0.14	0.28
China, Hong Kong, Macao	CHM	0.46	0.93	0.21	0.41
Colombia	COL	0.51	0.78	0.19	0.64
Costa Rica	CRI	0.54	0.98	0.13	0.58
Cyprus	CYP	0.85	1.33	0.24	0.66
Czech Rep.	CZE	0.71	1.02	0.09	0.53
Côte d'Ivoire	CIV	0.37	0.66	0.10	0.17
Denmark	DNK	0.72	1.06	0.40	0.47
Dominican Rep.	DOM	0.63	1.00	0.25	0.60
Eastern Europe	FSB	0.64	1.03	0.18	0.57
Egypt	EGY	0.68	1.04	0.16	0.55
Ethiopia	ETH	0.46	0.71	0.02	0.12
Fiji	FJI	0.64	1.20	0.09	0.28
Finland	FIN	0.76	1.12	0.77	0.69
France	FRA	0.86	1.04	0.78	0.76
Gambia	GMB	0.46	0.65	0.05	0.10
Georgia	GEO	0.49	0.36	0.08	0.56
Germany	DEU	0.80	0.91	0.75	0.73
Greece	GRC	0.84	1.10	0.43	0.69
Guatemala	GTM	0.53	0.94	0.22	0.49
Honduras	HND	0.41	0.71	0.14	0.37
Hungary	HUN	0.61	0.98	0.22	0.50
Iceland	ISL	0.63	0.68	0.22	0.39
India	IND	0.41	0.73	0.12	0.46
Indonesia	IDN	0.52	1.23	0.19	0.38
Ireland	IRL	0.63	1.61	0.76	0.47
Israel	ISR	0.73	1.08	0.46	0.61
Italy	ITA	0.76	1.31	0.74	0.80
Jamaica	JAM	0.55	1.04	0.24	0.43
Japan	JPN	0.82	0.95	0.86	0.66
Jordan	JOR	0.70	1.03	0.13	0.66
Kazakhstan	KAZ	0.71	0.56	0.27	0.28
Kyrgyzstan	KGZ	0.44	0.24	0.08	0.33
Lesotho	LSO	0.45	0.68	0.08	0.16
Madagascar	MDG	0.35	0.49	0.03	0.19

Table E.1 (*continued*)

Country	Isocode	A_{fi}	A_{si}	$T_{ei}^{\frac{1}{\theta}}$	$T_{mi}^{\frac{1}{\theta}}$
Malawi	MWI	0.26	0.45	0.03	0.20
Malaysia–Singapore	SGM	0.62	1.31	0.21	0.40
Maldives	MDV	1.19	1.61	0.27	0.25
Mali	MLI	0.37	0.53	0.07	0.08
Mauritius	MUS	0.66	1.39	0.14	0.51
Mexico	MEX	0.73	1.03	0.17	0.55
Morocco	MAR	0.44	1.37	0.09	0.44
Mozambique	MOZ	0.26	0.37	0.05	0.13
Namibia	NAM	0.57	1.44	0.16	0.18
Nepal	NPL	0.44	0.61	0.04	0.19
New Zealand	NZL	0.78	0.78	0.47	0.59
Niger	NER	0.33	0.41	0.06	0.17
Pakistan	PAK	0.53	0.94	0.12	0.42
Panama	PAN	0.75	0.88	0.08	0.34
Paraguay	PRY	0.49	0.86	0.08	0.38
Peru	PER	0.60	0.96	0.16	0.59
Philippines	PHL	0.47	1.04	0.17	0.41
Poland	POL	0.69	0.82	0.19	0.71
Portugal	PRT	0.67	1.35	0.33	0.68
Rep. of Korea	KOR	0.65	1.02	0.51	0.73
Rep. of Moldova	MDA	0.55	0.36	0.11	0.42
Romania	ROU	0.70	1.40	0.26	0.47
Russian Federation	RUS	0.61	0.54	0.33	0.77
Rwanda	RWA	0.31	0.37	0.06	0.21
Saint Vincent and the Grenadines	VCT	0.64	1.16	0.18	0.36
Sao Tome and Principe	STP	0.58	1.49	0.12	0.22
Senegal	SEN	0.37	0.61	0.07	0.25
South Africa	ZAF	0.55	1.17	0.27	0.52
SoutheastEurope	SEE	0.65	1.19	0.24	0.60
Spain	ESP	0.74	1.28	0.63	0.80
Sri Lanka	LKA	0.66	1.15	0.12	0.45
Sweden	SWE	0.69	0.75	0.74	0.72
Switzerland	CHE	0.84	1.04	0.35	0.68
TFYR of Macedonia	MKD	0.73	1.20	0.14	0.32
Thailand	THA	0.50	1.16	0.19	0.47
Togo	TGO	0.38	0.54	0.05	0.04
Tunisia	TUN	0.59	1.85	0.07	0.40
Turkey	TUR	0.69	1.34	0.43	0.72
USA	USA	1.00	1.00	1.00	1.00
Uganda	UGA	0.36	0.92	0.06	0.20
Ukraine	UKR	0.51	0.34	0.06	0.46
United Kingdom	GBR	0.87	1.10	0.61	0.55
United Rep. of Tanzania	TZA	0.39	0.97	0.02	0.15
Uruguay	URY	0.60	1.11	0.17	0.59
Viet Nam	VNM	0.45	0.88	0.07	0.19
Yemen	YEM	0.48	0.62	0.07	0.27

References

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

Alvarez, Fernando, Lucas, Robert E., 2007. General equilibrium analysis of the Eaton–Kortum model of international trade. Journal of Monetary Economics 54 (6), 1726–1768.

Armenter, Roc, Lahiri, Amartya, 2012. Accounting for development through investment prices. Journal of Monetary Economics 59 (6), 550–564.

Bernard, Andrew B., Eaton, Jonathan, Jensen, J. Bradford, Kortum, Samuel, 2003. Plants and productivity in international trade. The American Economic Review 93 (4), 1268–1290.

Buera, Francisco J., Kaboski, Joseph P., Shin, Yongseok, 2011. Finance and development: a tale of two sectors. The American Economic Review 101 (5), 1964–2002.

Caliendo, Lorenzo, Parro, Fernando, Rossi-Hansberg, Esteban, Sarte, Pierre-Daniel, 2014. The Impact of Regional and Sectoral Productivity Changes on the U.S. Economy. Working Paper 20168. National Bureau of Economic Research.

Caselli, Francesco, 2005. Accounting for cross-country income differences. In: Aghion, Philippe, Durlauf, Steven (Eds.), Handbook of Economic Growth. Elsevier, pp. 679–741, chap. 9.

Dekle, Robert, Eaton, Jonathan, Kortum, Samuel, 2007. Unbalanced trade. The American Economic Review 97 (2), 351–355.

Eaton, Jonathan, Kortum, Samuel, 2001. Trade in capital goods. European Economic Review 45, 1195–1235.

Eaton, Jonathan, Kortum, Samuel, 2002. Technology, geography, and trade. Econometrica 70 (5), 1741–1779.

Feenstra, Robert C., Inklaar, Robert, Timmer, Marcel, 2015. The next generation of the Penn world table. The American Economic Review 105 (10), 3150–3182.

Gollin, Douglas, 2002. Getting income shares right. Journal of Political Economy 110 (2), 458–474.

Greenwood, Jeremy, Hercowitz, Zvi, Krusell, Per, 1997. Long-run implications of investment-specific technological change. The American Economic Review 87 (3), 342–362.

Greenwood, Jeremy, Sanchez, Juan M., Wang, Cheng, 2013. Quantifying the impact of financial development on economic development. Review of Economic Dynamics 16 (1), 194–215.
Hall, Robert E., Jones, Charles I., 1999. Why do some countries produce so much more output per worker than others? The Quarterly Journal of Economics 114 (1), 83–116.
Hsieh, Chang-Tai, 2000. Trade policy and economic growth: a skeptic's guide to the cross-national evidence: comment. In: NBER Macroeconomics Annual 2000, NBER Chapters, vol. 15. National Bureau of Economic Research, Inc, pp. 325–330.
Hsieh, Chang-Tai, Klenow, Peter J., 2007. Relative prices and relative prosperity. The American Economic Review 97 (3), 562–585.
King, Robert G., Levine, Ross, 1994. Capital fundamentalism, economic development, and economic growth. Carnegie-Rochester Conference Series on Public Policy 40, 259–292.
Klenow, Peter, Rodríguez-Clare, Andrés, 1997. The neoclassical revival in growth economics: has it gone too far? In: NBER Macroeconomics Annual 1997, Vol. 12, NBER Chapters. National Bureau of Economic Research, pp. 73–114.
Mutreja, Piyusha, 2017. Composition of Capital and Gains from Trade in Equipment. Working paper. Syracuse University.
Mutreja, Piyusha, Ravikumar, B., Riezman, Raymond, Sposi, Michael, 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., pp. 153–179.
Restuccia, Diego, Urrutia, Carlos, 2001. Relative prices and investment rates. Journal of Monetary Economics 47 (1), 93–121.
Rodriguez, Francisco, Rodrik, Dani, 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, pp. 261–325.
Simonovska, Ina, Waugh, Michael E., 2014. The elasticity of trade: estimates and evidence. Journal of International Economics 92 (1), 34–50.
Sposi, Michael, 2012. Evolving comparative advantage, structural change, and the composition of trade. Mimeo, University of Iowa.
Sposi, Michael, 2015. Trade barriers and the relative price of tradables. Journal of International Economics 96 (2), 398–411.
Timmer, Marcel P., Dietzenbacher, Erik, Los, Bart, de Vries, Gaaitzen J., 2015. An illustrated guide to the world input–output database: the case of global automotive production. Review of International Economics 23 (3), 575–605.
UNIDO, 2013. International Yearbook of Industrial Statistics 2013. Edward Elgar Publishing.
Wacziarg, Romain, 2001. Measuring the dynamic gains from trade. World Bank Economic Review 15 (3), 393–429.
Wacziarg, Romain, Horn Welch, Karen, 2008. Trade liberalization and growth: new evidence. World Bank Economic Review 22 (2), 187–231.
Waugh, Michael E., 2010. International trade and income differences. The American Economic Review 100 (5), 2093–2124.
Westphal, Larry E., 1990. Industrial policy in an export-propelled economy: lessons from south Korea's experience. The 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., pp. 153–179.