The World Income Distribution: The Effects of International Unbundling of Production*

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Abstract

We build a dynamic trade model to study how international unbundling of production has affected the world income distribution. We consider a world where countries only differ in their productivity. The level of productivity determines the number of varieties a country produces. To manufacture each variety, a bundle of intermediates, which require capital and labor in different proportions, needs to be assembled. We characterize two trade regimes: *(i)* trade in varieties and *(ii)* trade in both varieties and intermediates (unbundling). We show that unbundling of production generates a fanning out of the world income distribution. First, it generates income divergence among ex-ante identical countries (symmetry breaking). Second, for heterogeneous countries, unbundling of production leads to non-monotonic changes of the world income distribution: top-bottom inequality increases and the income share of the most productive countries rises mostly at the expense of middle-productivity countries. Overall, the world income distribution becomes more unequal, as measured by the Lorenz curve. We also show that when southern countries participate in the unbundling of production and become part of the global supply chain, the income share of all northern and the most productive southern countries increase at the expense of the least productive southern countries. In addition, we study how the effect of a labor-saving technology (computerization) and technology diffusion depend on the trade regime.

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JEL Classification: F12, F43, O11, O19, O40.

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1 Introduction

One of the most remarkable facts in international trade in the last twenty-five years has been the “unbundling” of production (Baldwin, 2012). Before the 1990s, the production process was much less fragmented across the globe and most of the trade was in final goods. The unbundling of production has facilitated the emergence of “global supply chains,”whereby the production of a significant fraction of the intermediate inputs required to manufacture goods is located in several countries. As a result, unbundling has changed the composition of the type of goods being traded and countries now specialize in different stages of the global supply chain. A paradigmatic example of this fragmentation of production is the iPod, which is designed in the United States and assembled in China from several hundred components that are sourced from around the world (Dedrick et al., 2010).

Figure 1 provides new evidence consistent with this unbundling of production. Figure 1a shows the evolution of the value of world exports and how trade in intermediates has become more prominent relative to final goods over time. Figure 1b directly reports the ratio of the value of world exported intermediates to final goods. Before the 1990s this ratio was about .5, which means that for each dollar of intermediate exported there were two dollars of final goods exported. After the 1990s this ratio sharply increased and it has converged to around .8. Therefore, trade in intermediates has grown much more than trade in final goods.[1]

A vast and rich literature has studied the effects of trade on the income and economic growth of countries.[2] However, it has been mostly silent about the distinctive effects of trade in intermediates.[3] We develop a dynamic trade model to study how the unbundling of production has changed the world income distribution. The key novel aspect of our theory is the introduction of intermediates that are heterogeneous in their capital intensity. In our framework, the unbundling of production leads countries to sort in the production of intermediates according to their productivity levels. In equilibrium, high-productivity countries sort into the production of capital-intensive intermediates. This prediction is supported by the data (see Table 1) and consistent with previous empirical studies.[4]

[1]These findings are consistent with recent empirical work on global supply chains. For example, Antràs (2014) shows that the average upstreamness of world exports has increased, which suggests that trade in inputs has become more important over time. Similarly, Johnson (2014) documents that the ratio of value-added to gross-value of exports fell in early 1990s, which is mostly explained by increased offshoring within manufacturing. Hummels et al. (2001) also document the emergence of global supply chains, which they refer as vertical specialization, whereby countries specialize in the production of different sets of intermediate inputs. Hanson et al. (2005) show that a sizable part of this intermediate trade involves multinational firms.

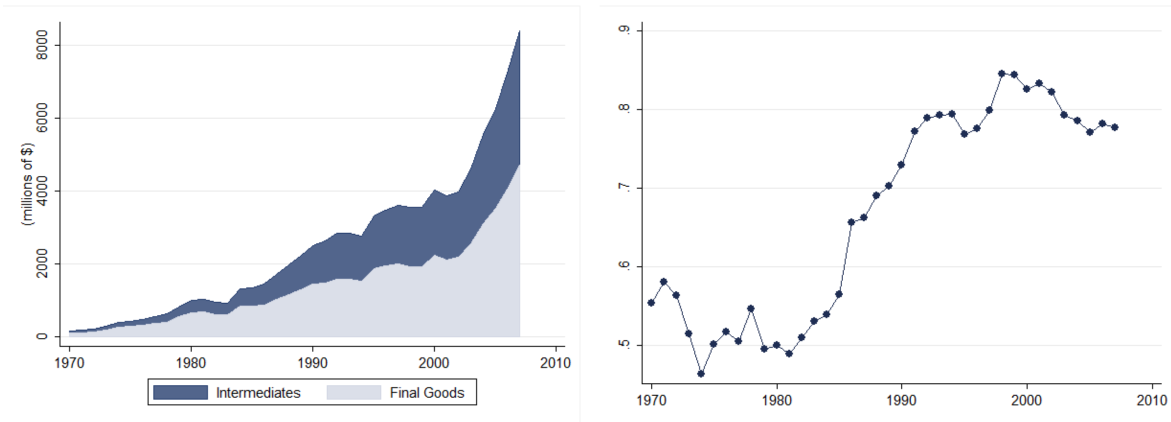
[2]See, for example, Grossman and Helpman (1993) and Ventura (2005) for an overview of the channels through which trade affects economic growth.

[3]One exception is Rodríguez-Clare (2010), who studies the effects of offshoring on the allocation of labor to innovation.

[4]It is also quantitatively important. We find that, if the productivity of a country moved from the 25th to the 75th percentile, the rise in the value of exports of intermediates in the 75th percentile of capital intensity would be 40% larger than the increase in the 25th percentile. Note also that this is consistent with the existing empirical literature, e.g., Schott, 2004, Baxter and Kouparitsas (2003), Hanson (2012) and Schott (2003a,b).

Figure 1: World Trade in Intermediates, 1970-2008

(a) Value of Exported Intermediates and Final Goods (b) Ratio of Exported Intermediates to Final Goods



Note: To classify goods as intermediates, we use the end-use classification of Feenstra and Jensen (2012). Final goods also include commodities.

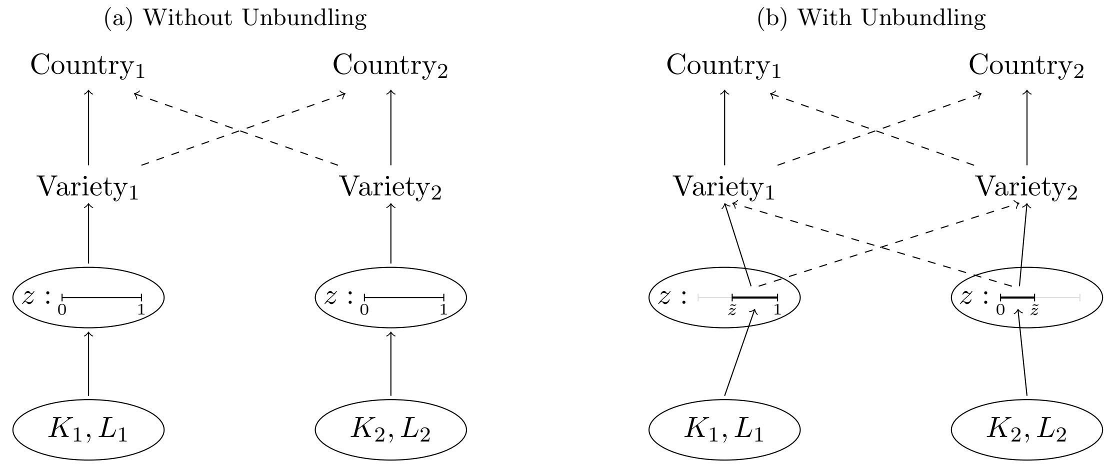
We show that unbundling of production generates a fanning out of the world income distribution. First, it amplifies income differences among very similar countries (symmetry breaking). Second, for heterogeneous countries, unbundling of production leads to non-monotonic changes of the world income distribution: top-bottom inequality increases and the income share of the most productive countries rises mostly at the expense of middle-productivity countries. Overall, the world income distribution becomes more unequal, as measured by the Lorenz curve. Within-country inequality between labor and capital income also increases in all countries. These predictions are broadly consistent with the evolution of the world income distribution over the last 25 years.

Our model features a large number of countries, which only differ in their productivity. Each country produces a number of varieties that is proportional to its productivity level.[5] These varieties are differentiated by origin (Armington assumption) and consumed by the representative agent of each country. In order to produce a variety, a bundle of intermediates needs to be assembled. Each of these intermediates requires capital and labor in different proportions. As it is standard in the trade literature, we assume that neither labor nor capital are internationally mobile.

Intermediates differ in their capital-intensity requirements, while all varieties are produced with the same technology. This assumption allows us to highlight the role of heterogeneity in capital intensity of intermediates. In fact, the dispersion in capital intensity is larger for more disaggregated goods. Using the direct requirements U.S. input-output table, we show in Figure 7 and Table A.1 that the dispersion in capital intensity at 6-digit NAICS level (which

[5] In the baseline model, we assume that the number of varieties is proportional to a country's productivity level. Online appendix C provides an exact microfoundation that delivers this result as an endogenous outcome.

Figure 2: Market Structure for the 2-country, 2-varieties case



Note: Figure represents the market structure for two countries and two varieties under the two different trade regimes. Dashed lines indicate trade flows, z indexes intermediates.

we interpret as intermediates) is larger than at 3-digit NAICS level (varieties). Therefore, our formulation is an extreme representation of this fact.

We start characterizing the steady-state equilibrium without unbundling. When only trade in varieties is possible, each country has to produce all intermediates domestically. Once the intermediates are manufactured, they are bundled into varieties, and these varieties are traded. The structure of this economy is summarized in Figure 2a for a two-country, two-variety case. We show that the share of world income of any country is determined by the share of varieties this country produces, which is proportional to its productivity. For example, if a country is twice as productive as another country, its share of world income is twice the share of the other country.

The world income distribution changes with unbundling. When intermediates can be offshored, the producer of a variety does not need to purchase all intermediates at home. Rather, it can import intermediates from the cheapest producer in the world. Therefore, the location of production of intermediates becomes endogenous. The structure of this economy is illustrated in Figure 2b. We show that the most productive countries have comparative advantage and specialize in capital-intensive intermediates. This endogenous selection of intermediates is important because it determines the relative income of each country in the new steady-state. We show that the world income share is determined by the mass of intermediates that a country produces and their relative capital intensity.

The first main result of the paper is that unbundling of production generates symmetry breaking of ex-ante identical countries. To gain intuition for this result, we first consider a two-country world. In the equilibrium without unbundling, the two countries have the same income share, as they produce the same number of varieties. With unbundling of production, this symmetric equilibrium becomes unstable to arbitrarily small perturbations to productivity. Let us assume that the first country is slightly more productive than the second one. This implies that the first country has a slight comparative advantage in capital-intensive intermediates and, thus, it specializes in more capital-intensive intermediates. By producing more capital-intensive intermediates, it accumulates more capital, thereby reinforcing the initial comparative advantage in capital-intensive intermediates. This process continues over time and the two countries end up with different stocks of capital in the new steady-state. We show that this argument extends to an arbitrary number of ex-ante identical countries and we provide a complete characterization of the equilibrium.[6]

Our second main result characterizes the long-run change in the world income distribution with heterogeneous countries. We show that top-bottom inequality rises with unbundling: the world income share increases in high-productivity countries, while it declines in the rest. Moreover, this change in the world income distribution is non-monotonic. The largest fall in income share is for middle-productivity countries and the largest rise is for the most productive countries. Without unbundling, the stock of capital is determined by the number of varieties that a country produces. In contrast, with unbundling, the stock of capital also depends on the intermediates in which the country specializes. The most productive countries increase their world income share because they specialize in the most capital-intensive intermediates. Middle-productivity countries reduce their world income shares because, in the equilibrium without unbundling, they accumulate a substantial amount of capital to produce varieties. However, with unbundling, they specialize in relatively low-capital-intensive intermediates and, thus, reduce the average capital intensity of the intermediates they produce. In other words, there is a large mismatch between the capital accumulated during the equilibrium without unbundling and the capital needed to produce the equilibrium mass of intermediates with unbundling. Finally, we also show that unbundling increases within-country inequality between capital and labor income. In particular, the cross-country change in inequality is U-shaped in the productivity of the country. Inequality increases the most at the top and bottom of the world income distribution because these countries experience the largest change in the relative demand of capital.

In addition to analyzing and comparing the equilibria with and without unbundling, our model is helpful to understand other substantial changes that have occurred in the process of unbundling. The role of emerging economies in international trade has substantially increased in the last twenty-five years. For example, the share of world trade of developing Asia has increased from less than 15% in the early 1990s to 35% in 2011. Baldwin (2012), among others, has argued that the unbundling of production is a main driver accounting for this increase in

[6]We also show that unbundling generates within-country inequality between capital and labor income. The reason is that unbundling of production leads countries to sort in the production of intermediates with different capital intensity, which makes them accumulate a different amount of capital and this changes the relative sources of income in the country.

the volume of trade of emerging economies. Figure 4 shows that most of the growth of world trade in intermediates has indeed come from emerging countries. Motivated by this evidence, we study how the world income distribution changes when the South joins the global supply chain. To be precise, we analyze the effect of southern countries starting to participate in trade in intermediates, in an equilibrium where previously only northern countries traded intermediates (and all countries traded in varieties). We show that the income share increases in all northern countries and the most productive southern countries, while it declines for the rest of southern countries. Northern countries increase their income share the most because they can specialize in more capital-intensive intermediates and sell them to a larger market. For southern countries, the income share only raises in those that are productive enough to "climb up the supply chain" and specialize in relatively capital-intensive intermediates.

We also use our framework to study the effect of a labor-saving technology: computerization. Computerization (or, more broadly, the Information Technologies revolution) is one important factor behind the surge of the unbundling of production.[7] Autor et al. (2003) among others have also emphasized the effects of computerization on the relative demand for labor and on the income distribution within countries. We introduce computerization into the model as a technological shift that reduces the relative demand for labor-intensive intermediates. We show that the effect of computerization depends on the trade regime. Without unbundling, computerization does not change the world income distribution. In contrast, with unbundling, computerization raises inequality in the world income distribution. The intuition is that computerization changes the selection of intermediates in which countries specialize. All countries specialize in more capital-intensive intermediates, thus, the average intermediate produced in each country is more capital-intensive. However, this change in the trade pattern disproportionately favors the most productive countries, which exacerbates income inequality. We also show that computerization raises the capital income share in both trade regimes for all countries.

In our baseline model, we assume that productivity is exogenous and constant. However, in practice, technology diffuses over time and low-productivity countries learn about innovations done by the countries in the technological frontier. We analyze how the diffusion of technology changes the world income distribution. We show that technology diffusion always leads to convergence of income. However, the extent of convergence depends on the trade regime. For a given amount of technology diffusion, the mass of low-productivity countries increasing their income share is larger with unbundling.

Related Literature. This paper relates to different strands of the literature on growth, trade and offshoring. There exist a large number of models that study the interaction between economic growth and trade. Our model structure for production of varieties and final good is similar to Acemoglu and Ventura (2002). The most important difference is that we introduce the additional layer of intermediates in the production process. This allows us to study the

[7] See, for example, Basco and Mestieri (2013) and the references therein.

effect of unbundling on the world income distribution. In contrast to Acemoglu and Ventura (2002), we do not have long-run growth in our model because we have a collection of Cobb-Douglas countries instead of their AK countries. Other papers that study how trade in goods affect economic growth include Bajona and Kehoe (2010), Baxter (1992), Cunat and Maffezzoli (2004), Deardorff (2001b, 2013) and Ventura (1997). These papers make different assumptions on the number of goods and whether factor prices equalize. However, they do not consider trade in intermediates. Yi (2003) calibrates a two-country, two-stages Ricardian model to show that vertical specialization is needed to explain how small trade cost reductions resulted in the observed growth in exports.

There exists a growing literature analyzing the unbundling of production and its effects on the pattern of specialization and income levels in static frameworks. For example, Acemoglu et al. (2014), Baldwin and Robert-Nicoud (2014), Baldwin and Venables (2013) and Grossman and Rossi-Hansberg (2008) revisit the standard trade theorems in the presence of trade in intermediates. We model production as a sequential process in which intermediates are first produced and then used to assemble each variety. This is similar to, among others, Antràs and Chor (2013), Caliendo and Parro (2012), Costinot et al. (2013), Deardorff (1998, 2001a) and Kohler (2004). Differently from these papers, we build a dynamic trade model and derive our main results from the interaction between the sorting of countries across intermediates of different capital intensity and capital accumulation.

From a theoretical standpoint, as pointed out by Ethier (1984) and Costinot and Vogel (2010), general equilibrium models with an arbitrary number of countries and goods seldom provide tractable results. Our model provides a framework that accommodates a substantial amount of heterogeneity and still delivers sharp characterizations and comparative statics results. There are two main sources of heterogeneity in our model. First, countries differ in their aggregate productivity, a Ricardian feature. Second, intermediates are heterogeneous in their capital intensity, a Heckscher-Ohlin feature. We contribute to the dynamic Heckscher-Ohlin literature by showing how the presence of a continuum of traded goods with heterogeneous capital intensities generates a unique steady-state world income distribution (even when differences in productivity across countries are absent). This prediction is in contrast with the case of a finite number of traded goods (e.g., Bajona and Kehoe, 2010 and Caliendo, 2011). In terms of techniques, the characterization of the unbundling equilibrium relies in solving for the equilibrium assignment in a similar manner as in Matsuyama (2013).[8]

In our model, unbundling of production generates symmetry breaking of ex-ante identical countries. Krugman and Venables (1995) and Matsuyama (2004, 2013), among others, have also analyzed how trade can generate symmetry breaking. For example, Matsuyama (2013) emphasizes that the share of non-traded services is heterogeneous across varieties. With increasing

[8]Our solution differs from the Ricardo-Roy assignment models as Costinot and Vogel (2010) and Grossman and Helpman (2014) because our production functions are not linear and factors of production are homogeneous.

returns in the production of these non-traded services, this generates a two-way feedback loop that yields symmetry breaking. However, our mechanism is different because it does not rely on increasing returns or credit market imperfections. In our model, similar countries become different with unbundling of production because they specialize in different intermediates, which differ in capital intensity and this triggers different incentives to accumulate capital across countries. Our framework shows that the emergence of symmetry breaking is linked to the unbundling of production, rather than the fact that countries trade. Thus, in contrast to previous studies, we highlight the dynamic effects of countries specializing in the production of goods with heterogeneous capital intensities.[9]

The rest of the paper is organized as follows. Section 2 presents the model and characterizes the equilibria with and without unbundling. The main results of the paper comparing the world income distribution with and without unbundling are derived in Section 3. In Section 4.1, we analyze the empirically relevant case in which southern countries join the global supply chain. Section 4.2 analyzes the effects of a labor-saving technology, computerization. Section 4.3 analyzes technology diffusion under the two trade regimes and Section 5 concludes. All proofs can be found in the online appendix.

2 The Model

This section presents the baseline model and characterizes the steady-state equilibrium without unbundling (when only trade in varieties is possible) and the equilibrium with unbundling (when trade in both varieties and intermediates is possible).

We consider a world economy with J countries, indexed by $j = 1, \ldots, J$. Countries only differ in the level of productivity θ_j. Without loss of generality, we order countries such that $\theta_1 \geq \theta_2 \geq ... \geq \theta_J$. There is a mass of varieties indexed by $v \in [0, N]$. There is one final good used for consumption and investment. There is no trade in final goods or assets.

All countries admit a representative consumer with utility

$$\int_0^\infty e^{-\rho t} \ln c_j(t) dt, \tag{1}$$

where $c_j(t)$ is consumption in country j at time t. Each country j is endowed with an initial capital stock $k_j(0) > 0$ and a fixed stock of labor, normalized to one. The budget constraint of the representative household in country j is

$$p_j(t) \left[\dot{k}_j(t) + c_j(t) \right] = p_j(t) Y_j(t) = r_j(t) k_j(t) + w_j(t). \tag{2}$$

[9] In our model, symmetry breaking happens when any positive fraction of intermediates are traded (see online appendix D). In contrast to the symmetry breaking results in Krugman and Venables (1995) or Matsuyama (2013), which require a positive iceberg transportation cost or non-traded goods, our model also delivers symmetry breaking when all intermediates are traded (unbundling equilibrium).

We assume that varieties are differentiated by origin, and each country produces a measure μ_j of these differentiated varieties, so that

$$\sum_{j=1}^{J} \mu_j = N, \tag{3}$$

where N is the total number of varieties. In the baseline model we assume that the number of varieties is exogenously given by $\mu_j = \kappa\theta_j$, where $\kappa > 0$. This implies that more productive countries produce a larger number of varieties. Online appendix C provides an exact micro-foundation of this production function of varieties.

The final good is produced according to the constant returns to scale production function

$$Y_j(t) = \exp\left(\int_0^N \frac{1}{N} \ln x_j(v,t)dv\right), \tag{4}$$

where $x_j(v,t)$ denotes the amount of varieties used in final good production in country j. The production of varieties requires a bundle of intermediates, indexed by $z \in [0,1]$,

$$x_j(v,t) = \exp\left[\int_0^1 \beta(z) \ln a_j(z,v,t)dz\right], \tag{5}$$

where $a_j(z,v,t)$ denotes the amount of intermediate z used at time t to produce variety v in country j. $\beta(z)$ reflects the relative importance of intermediate z in the production of variety v. We assume, for simplicity, that $\beta(z) = 1$. In Section 4.2 we study the effects of computerization and make comparative statics on $\beta(z)$.

Intermediates are produced using labor l and capital k in different proportions,

$$a_j(z,t) = \theta_j \left(\frac{k_j(z,t)}{z}\right)^z \left(\frac{l_j(z,t)}{1-z}\right)^{1-z}, \qquad z \in [0,1], \tag{6}$$

where $a_j(z,t)$ denotes total production of intermediate z at time t in country j and θ_j denotes the productivity in country j.

2.1 Equilibrium Without Unbundling

This subsection analyzes the competitive equilibrium without unbundling. That is, when varieties are traded but intermediates cannot be traded between countries. We characterize the steady-state competitive equilibrium and show that the world income share of a country is determined by the share of varieties it produces.

Definition 1 *A competitive equilibrium without unbundling is defined by a sequence of prices* $\{w_j(t), r_j(t), p_j(t), p_j(v,t), p_j(z,t)\}$ *and allocations* $\{l_j(z,t), k_j(z,t), c_j(t), a_j(z,v,t), a_j(z,t),$

$x_j(v,t)\}$ for $t = 0,\ldots,\infty$ and $j = 1,\ldots,J$, such that for each country: (i) the representative agent maximizes utility subject to the budget constraint, (ii) final good producers maximize profits given prices, (iii) variety producers maximize profits given prices, (iv) intermediate producers maximize profits given prices, (v) labor and capital market clear and (vi) trade in varieties is balanced for each country.

The consumer utility maximization problem (1) subject to the budget constraint (2) yields

$$\frac{\dot{c}_j(t)}{c_j(t)} = \frac{r_j(t)}{p_j(t)} - \rho, \tag{7}$$

$$\lim_{t\to\infty} e^{-\rho t} c_j(t)^{-1} \left(\frac{r_j(t)}{p_j(t)} k_j(t)\right) = 0. \tag{8}$$

Equation (7) is the Euler Equation from a standard Ramsey model, with the price p_j made explicit, as it may differ across countries. Equation (8) is the transversality condition.

Omitting the time index t, the problem of the final good producer in country j is to

$$\max_{x_j(v)} p_j Y_j - \int_0^N p_j(v) x_j(v) dv,$$

where Y_j is given by (4). It follows that

$$\frac{p_j Y_j}{N} = p_j(v) x_j(v).$$

Thus, as varieties are traded, the total demand of variety v is

$$x(v) = \sum_{i=1}^{J} x_j(v) = \frac{1}{N} \frac{\sum_{i=1}^{J} p_j Y_j}{p_j(v)}. \tag{9}$$

The problem of variety-v producer in country j is

$$\max_{a_j(z,v)} p_j(v) x_j(v) - \int_0^1 p_j(z) a_j(z,v),$$

which implies that the demand of intermediate z to produce variety v is pinned down by

$$p_j(z) a_j(z,v) = p_j(v) x_j(v) = x_j(v) \exp\left(\int_0^1 \ln p_j(z) dz\right).$$

Since there is not trade in intermediates, the aggregate demand of intermediate z in country j comes only from the production of domestic varieties,

$$a_j(z) = \mu_j a_j(z,v),$$

where μ_j is the number of varieties produced in country j.

The problem of the producer of intermediate z in country j is

$$\max_{l_j(z),k_j(z)} p_j(z)\theta_j\left(l_j(z)\right)^{1-z} k_j(z)^z - w_j l_j(z) - r_j k_j(z),$$

which implies the following labor and capital demands

$$(1-z)p_j(z)a_j(z) = w_j l_j(z), \tag{10}$$

$$z p_j(z)a_j(z) = r_j k_j(z). \tag{11}$$

Aggregating labor demand (10) across intermediates and noting that the labor supply is normalized to one, we obtain the labor market clearing condition

$$1 = \int_0^1 l_j(z) = \frac{1}{w_j}\int_0^1 (1-z)p_j(z)a_j(z)dz = \frac{1}{2}\mu_j \frac{\sum_i p_i Y_i}{N}\frac{1}{w_j}.$$

Likewise, using (11), the capital market clearing condition is given by

$$K_j = \frac{1}{r_j}\int_0^1 z p_j(z)a_j(z)dz = \frac{1}{2}\mu_j \frac{\sum_i p_i Y_i}{N}\frac{1}{r_j}.$$

To derive the trade balance equation, recall that without unbundling, only varieties are traded. Thus, the value of exported varieties $\mu_j p_j^x(v)x(v, \text{exported})$ (all varieties produced by one country are symmetric) has to be equal to the value of imported varieties,

$$\underbrace{\frac{\mu_j}{N}\left(\sum_{i=1}^{J} p_i Y_i - p_j Y_j\right)}_{\text{Exports of Varieties}} = \underbrace{\frac{N-\mu_j}{N} p_j Y_j}_{\text{Imports of Varieties}}. \tag{12}$$

All final goods are produced using the same varieties by competitive producers in all countries. Thus, the prices of final goods are the same across countries $p_i = p_j$. Rewriting (12), we obtain

$$\frac{\mu_j}{\sum_{i=1}^{J}\mu_i} = \frac{p_j Y_j}{\sum_{i=1}^{J} p_i Y_i} = \frac{Y_j}{\sum_{i=1}^{J} Y_i}. \tag{13}$$

From the factor market clearing conditions, we can write the labor and capital income in country j as

$$w_j = \frac{1}{2}\kappa\theta_j \frac{\sum_i p_i Y_i}{N}, \tag{14}$$

$$r_j k_j = \frac{1}{2}\kappa\theta_j \frac{\sum_i p_i Y_i}{N}.$$

Using the trade balance equation (13) and the fact that the number of varieties produced in country j is $\mu_j = \kappa\theta_j$, we can express the world income share of country j as a function of the exogenous levels of productivity[10]

$$s_j \equiv \frac{Y_j}{\sum_{i=1}^{J} Y_i} = \frac{\theta_j}{\sum_{i=1}^{J} \theta_i}. \tag{15}$$

This equation means that the relative income of country j is the relative productivity of the country.

Steady-state solution In the steady-state there is no growth, $\dot{k} = \dot{c} = 0$. The Euler condition implies that the interest rate is equalized across countries (i.e., $r_j = \rho$). The consumption level is determined by the budget constraint, $c_j = p_j Y_j = w_j + \rho k_j$. Finally, note that the country ranking in income shares coincides with the welfare ranking in steady-state.

2.2 Equilibrium With Unbundling

This subsection characterizes the equilibrium with unbundling. In this case, both varieties and intermediates can be costlessly traded. This implies that countries no longer need to produce all intermediates required to produce varieties. Rather, they can specialize in a subset of these intermediates and import the rest. We show that the world income share depends on the mass of intermediates in which the country specializes.

Definition 2 *A competitive equilibrium with unbundling is defined by a sequence of prices* $\{w_j(t), r_j(t), p_j(t), p_j(v,t), p_j(z,t)\}$ *and allocations* $\{l_j(z,t), k_j(z,t), c_j(t), a_j(z,v,t), a_j(z,t), x_j(v,t)\}$ *for* $t = 0, ..., \infty$, $j = 1, ..., J$, *such that for each country: (i) the representative agent maximizes utility subject to the budget constraint, (ii) final good producers maximize profits given prices, (iii) variety producers maximize profits given prices, (iv) intermediate producers maximize profits given prices, (v) labor and capital market clear and (vi) trade in varieties* ***and*** *intermediates is balanced for each country.*

To derive the equilibrium, we repeat the same steps as in Section 2.2. The demand of varieties is given by (9), as in the previous section. The key difference is that since intermediates are now costlessly traded, the producer of variety v purchases intermediates from the cheapest location. Thus, the price of variety v is given by

$$\ln p_j(v) = \int_0^1 \ln \left(\min_{j \in \{1,...,J\}} \{p_j(z)\} \right) dz.$$

[10] Note that in Eaton and Kortum (2002), the number of varieties is also proportional to the productivity of the country. In their framework, the income share is also proportional to a re-scaled productivity measure in the zero-gravity case.

This implies that the aggregate demand of intermediate z in country j, rather than coming from the domestic demand as in the equilibrium without unbundling, comes now from the entire world, provided that country j produces z at the cheapest world price.[11] Thus, the mass of intermediates that each country produces is endogenously determined. Denoting by Z_j the mass of intermediates that country j produces in the unbundling equilibrium, we have that

$$a_j(z) = \sum_{i=1}^{J} \mu_i a_j(z,v) = N a_j(z,v), \qquad \text{if } z \in Z_j,$$

and zero otherwise. Substituting the expression for $a_j(z,v)$ into equation (9) and using that $p_j(v)x(v) = p_j(z)a_j(z,v)$, we find the total value of intermediate z produced in country j,

$$p_j(z)a_j(z) = \sum_i p_i Y_i.$$

The expressions for the demand of labor and capital are as in the equilibrium without unbundling, (10) and (11), adjusting for the fact that each country only produces a subset Z_j of the intermediates,

$$\begin{aligned} 1 &= \int_{z\in Z_j} (1-z)dz \frac{1}{w_j} \sum_{i=1}^{J} p_i Y_i, \\ K_j &= \int_{z\in Z_j} z dz \frac{1}{r_j} \sum_{i=1}^{J} p_i Y_i. \end{aligned} \tag{16}$$

The trade balance changes with unbundling because now intermediates are also traded. Trade balance implies that the value of exported varieties plus the value of exported intermediates has to be equal to the value of imports of any country,[12]

$$\underbrace{\frac{\mu_j}{N}\left(\sum_{i=1}^{J} p_i Y_i - p_j Y_j\right)}_{\text{Exports of Varieties}} + \underbrace{Z_j \frac{N-\mu_j}{N} \sum_{i=1}^{J} p_i Y_i}_{\text{Exports of Intermediates}} = \underbrace{\frac{N-\mu_j}{N} p_j Y_j}_{\text{Imports of Varieties}} + \underbrace{(1-Z_j)\frac{\mu_j}{N} \sum_{i=1}^{J} p_i Y_i}_{\text{Imp. of Intermediates}}.$$

After rearranging terms, the above expression simplifies to

$$s_j = \frac{p_j Y_j}{\sum_i p_i Y_i} = Z_j. \tag{17}$$

[11] We are implicitly assuming that each intermediate is done only by one country, which is indeed true almost everywhere in equilibrium.

[12] To derive the value of exported intermediates, note that, for a given intermediate z, each variety producer demands $\frac{1}{N}\sum_i p_i Y_i$. Given that country j produces μ_j varieties, the value of a given intermediate z that goes into exporting is $\frac{N-\mu_j}{N}\sum_i p_i Y_i$. Finally, since country j produces the range Z_j of intermediates, the total value of exported intermediates is $Z_j \frac{N-\mu_j}{N}\sum_i p_i Y_i$. The value of imports can be computed in an analogous way.

This equation means that with unbundling the world income share of country j is only determined by the mass of intermediates that the country produces. Note that a country is a net exporter of intermediates when it specializes in a larger share of intermediates than the fraction of varieties it produces (i.e., $Z_j > \frac{\mu_j}{N}$). It implies that unless $Z_j = \frac{\mu_j}{N}$, there will be an imbalance in intermediates trade and the income share will change with unbundling.

The productivity level of a country θ_j affects the income share (17) only through the endogenous selection of intermediates Z_j. The reason is that we assume that all value added comes from the production of intermediates. We show in online appendix D that if some intermediates cannot be traded (which is equivalent to introduce capital and labor as direct inputs in the production of intermediates, equation 5), then the productivity of a country also enters directly in the income share equation (17).[13] We choose to focus on comparing the two extreme cases (intermediates are either traded or non-traded) rather than making comparative statics in the share of traded intermediates to better understand the distinctive effects of unbundling. However, this alternative model could be used to perform a quantitative analysis of the effects of unbundling, which we leave for future research.[14]

2.2.1 Steady-state solution

The final step is to derive the equilibrium share of intermediates that each country produces, Z_j. We proceed by focusing on the steady-state equilibrium.

From the Euler equation (7), the rental rates are equalized across countries in the steady-state, $r_j = \rho$. Therefore, the cost of producing intermediate z in country j is

$$c_j(z) = \theta_j^{-1} w_j^{1-z} \rho^z.$$

This implies that the most capital-intensive intermediate ($z = 1$) is produced by the most productive country, country 1, because $c_1(1) = \theta_1^{-1}\rho = \min_j\{c_j\}$.

Let $p(z) = \min_j\{c_j\}$. Consider an intermediate $\tilde{z} < 1$ with price $p(\tilde{z})$. Perfect competition implies that

$$p(\tilde{z}) - c_j(\tilde{z}) \leq 0.$$

[13]In particular, online appendix D shows that if only a fraction α of each intermediate z can be traded at no cost, and the reminder fraction $1 - \alpha$ has to be produced domestically, the income share of country j is given by $s_j = (1-\alpha)\frac{\theta_j}{\sum_j \theta_j} + \alpha_j \, Z_j$, where Z_j is the mass of traded intermediates produced in country j. Note that when $\alpha = 0$ this expression becomes the solution of the equilibrium without unbundling and when $\alpha = 1$ the equilibrium with unbundling.

[14]From a theoretical standpoint, our unbundling equilibrium has the following additional property. The income share (17) coincides with what we would obtain in a standard Heckscher-Ohlin model in which the final good is directly produced using intermediates, and only intermediates are traded. The trade balance would be $Z_j\left(\sum_i p_i Y_i - p_j Y_j\right) = (1 - Z_j) p_j Y_j$. Thus, our results for the unbundling equilibrium can be interpreted as solving this equivalent dynamic Heckscher-Ohlin model. It is in this sense that we claim to contribute to this literature in the introduction.

Then, if two countries produce the same intermediate it has to be the case that

$$c_j(\tilde{z}) = c_i(\tilde{z}) \quad \Longrightarrow \quad \theta_j^{-1} w_j^{1-\tilde{z}} = \theta_i^{-1} w_i^{1-\tilde{z}},$$

which implies that

$$\frac{w_i}{w_j} = \left(\frac{\theta_i}{\theta_j}\right)^{\frac{1}{1-\tilde{z}}}.$$

Suppose that $j > i$, so that $\theta_j < \theta_i$. As $\frac{1}{1-z}$ is an increasing function of z, this implies that country j will not produce any intermediate with $z > \tilde{z}$. Thus, we have a sequence of thresholds z_j that determines the pattern of specialization in intermediates,

$$\frac{w_j}{w_{j+1}} = \left(\frac{\theta_j}{\theta_{j+1}}\right)^{\frac{1}{1-z_j}} \text{ for all } j. \tag{18}$$

We have derived two equilibrium conditions relating the equilibrium wages and the equilibrium thresholds: labor market clearing (equation 16) and the definition of the threshold intermediate (equation 18). Using the ratio of both equations, we obtain the following equation determining the endogenous pattern of specialization in intermediates.

Remark The endogenous selection of intermediates is given by the second order difference equation,

$$\begin{aligned} \left(\frac{\theta_j}{\theta_{j+1}}\right)^{\frac{1}{1-z_j}} &= \frac{\Delta_j}{\Delta_{j+1}}, \qquad (19) \\ \text{where } \Delta_j &= \int_{z_j}^{z_{j-1}} (1-z)dz, \end{aligned}$$

with terminal conditions $z_0 = 1$ and $z_J = 0$.[15]

An implication of this endogenous selection of intermediates is that countries with relatively high productivity have comparative advantage in high z intermediates and export capital-intensive intermediates. This is in line with the findings in Schott (2004), who documents that rich countries specialize in capital-intensive goods. Baxter and Kouparitsas (2003), Hanson (2012) and Schott (2003a,b) also find similar results.[16] We also provide additional evidence consistent with this pattern of specialization. Consider the following equation

$$X_{ict} = \alpha + \beta \cdot \text{TFP}_c \cdot \text{Capital Intensity}_{it} + \delta_{it} + \delta_{ct} + \varepsilon_{ict}, \tag{20}$$

[15] Note that the left-hand side is continuous and increasing in z_j and the right-hand side is continuous and decreasing in z_j. Therefore, the solution is unique.

[16] Bernard et al. (2006) find that U.S. manufacturing reallocates away from labor-intensive towards capital-intensive plants within industries, as industry exposure to imports from low-wage countries rises. At a more aggregate level, Davis and Weinstein (2001) and Romalis (2004) also provide evidence consistent with this pattern of specialization.

where X_{ict} is the log of total exports of intermediates i of country c at time t, TFP_c is total factor productivity of country c, δ_{it}, δ_{ct} are intermediate-year and country-year fixed effects, respectively. Our data is for the period 1994-2008. The prediction of the model is $\beta > 0$. That is, relatively high-productivity countries have comparative advantage in capital-intensive industries.[17] Columns (1) to (4) in Table 1 report the coefficient β of the regression for different sets of fixed effects. Consistent with the model, the coefficient is positive and significant at a 1% level in all specifications. Standard errors are clustered at country level. Quantitatively, our most conservative estimate, the interaction term in column (1), implies that increasing TFP from the 25th percentile to the 75th, would increase exports in the 75th percentile capital-intensive sectors a 18%. For the 25th percentile capital-intensive intermediates, the increase would be a 13%.[18] Thus, if TFP were to move from the 25th to the 75th percentile, the increase in intermediate exports in the 75th percentile of capital intensity would be a 40% higher than the rise in those in the 25th percentile.

Finally, we show that the second order difference equation for the sequence of equilibrium thresholds z_j can also be expressed in terms of the equilibrium income shares $s_j = Z_j = z_{j-1} - z_j$. In this case, the recursion equation (19) becomes

$$\frac{\theta_j}{\theta_{j+1}} = \left(\frac{\sigma_j^2 - \sigma_{j-1}^2}{\sigma_{j+1}^2 - \sigma_j^2}\right)^{\sigma_j}, \tag{21}$$

where $\sigma_j = \sum_{i=1}^{j} s_i$. Note that the solution to this equation is directly related to the Lorenz curve, $L(j) = \sum_{i=J}^{j} s_i = 1 - \sigma_{j-1}$.[19] In this sense, this equation is similar to Matsuyama (2013), which also finds a second order difference equation in terms of the Lorenz curve.

Proposition 1 *The Lorenz curve generated as the solution of (21) is increasing and convex in j. For any productivity distribution with $J \leq 3$, if the productivity of country j, θ_j, increases, the equilibrium income share of country j rises, while it declines for the rest of countries.*

The intuition for this result is that when the productivity of a country increases, it gains comparative advantage in more capital-intensive intermediates. By producing these intermediates, it accumulates more capital and it ends up with a relatively higher income share in

[17] We classify goods as intermediates using the classification in Feenstra and Jensen (2012). Our data stops in 1994 because prior to this year we do not have the same level of disaggregation. Note that we are making the standard assumption that the ranking of capital-intensive industries is stable across countries, as our capital intensity data comes from the U.S. only. All data sources and definitions can be found in Table 1.

[18] The 25th percentile of TFP corresponds to Cameroon, with a measure of .274. The 75th percentile corresponds to Israel, with a measure of .817. Note that Hall and Jones (1999) report TFP relative to the U.S. TFP. For the sample period, the 25th percentile of capital intensity corresponds to NAICS 313312 (Textile and Fabric Finishing) with a measure of .271. The 75th percentile of capital intensity corresponds to NAICS 327125 (Nonclay Refractory Manufacturing) with a measure of .373.

[19] Recall that the ordering of countries is such that country 1 is the most productive. So, to plot the Lorenz curve, we would start with $L(J)$, then $L(J-1)$ and so on. Note also that for $L(1)$ to be well defined, we need to take the convention that $\sigma_0 = 0$.

the new steady-state. The rest of the countries experience a decline in their income share because they now compete with a more productive country and either specialize in relatively less capital-intensive intermediates than before or lose some capital-intensive intermediates to country j.[20]

3 Main Results

This section compares the equilibrium with and without unbundling. We first consider a world of ex-ante identical countries and show that unbundling of production generates symmetry breaking. We next study a world consisting of heterogeneous countries and show that unbundling raises top-bottom inequality and that middle-productivity countries experience the largest decline in income share. All omitted proofs are in the online appendix.

3.1 Symmetry Breaking of ex-ante Identical Countries

This section analyzes the case in which all countries have the same productivity. To build intuition, we start analyzing the two-country case. Then, we characterize the equilibrium for a world with an arbitrary number of countries.

3.1.1 The two-country case

Suppose that the world consists of two identical countries, $J = \{1, 2\}$ with $\theta_1 = \theta_2 = \theta$. In the equilibrium without unbundling, each country has half of the world income share,

$$\frac{s_1^{without}}{s_2^{without}} = \frac{\theta_1}{\theta_2} = 1.$$

In the equilibrium with unbundling, the endogenous selection of intermediates changes the world income shares. The difference equation (19) determining the specialization threshold becomes

$$1 = \frac{\frac{1}{2} - \left(z - \frac{z^2}{2}\right)}{\left(z - \frac{z^2}{2}\right)},$$

where we have used the terminal conditions $z_0 = 1$, $z_2 = 0$ and $\theta_1 = \theta_2 = \theta$. There exists a unique solution to this equation given by $z^* = 1 - \sqrt{1/2}$. That is, country 1 specializes in the production of intermediates $z \in (z^*, 1]$ and country 2 produces the rest of intermediates,

[20] The statement of the proposition is for three or less countries. However, our simulations suggest that the same result holds for an arbitrary number of countries. In fact, for an arbitrary number of countries, we can show that an increase in θ_j increases s_j and decreases all s_i with $i > j$.

$z \in [0, z^*)$. Thus, in the unbundling equilibrium, the relative income share of country 1 becomes

$$\frac{s_1^{with}}{s_2^{with}} = \frac{Z_1}{Z_2} = \frac{1 - z^*}{z^*} = \frac{1}{\sqrt{2} - 1} > 1. \tag{22}$$

We have established the following result.

Proposition 2 *Consider a world with two ex-ante identical countries. Without unbundling of production, the income share of the two countries is the same. With unbundling of production, the two countries end up with strictly different world income shares.*

Equation (22) shows that the country that specializes in more capital-intensive intermediates becomes richer in the steady-state with unbundling, even though the two countries have the same productivity. The intuition is that the country that specializes in more capital-intensive intermediates accumulates more capital, which gives this country additional comparative advantage in producing capital-intensive intermediates. There exists also a symmetric equilibrium, but it is unstable. Suppose that we start with a symmetric equilibrium in which both countries produce all intermediates in the same amount. Consider a small positive perturbation to the productivity of country 1. Country 1 gains comparative advantage in the production of capital-intensive intermediates. Once country 1 starts producing more capital-intensive intermediates, it accumulates more capital, which reinforces the pattern of comparative advantage. Thus, even if the initial perturbation vanishes, country 1 retains the comparative advantage in capital-intensive intermediates. Online appendix B contains a formal description of this perturbation argument. It also shows that the threshold equilibrium we characterize is unique once we allow for arbitrary small perturbations in productivity.[21]

Another way to understand this result is that unbundling of production changes the production function of countries. Without unbundling, all countries have the same aggregate production function because they have the same productivity and they produce the same intermediates. However, with unbundling, each country only produces a set of intermediates. Since these intermediates differ in capital intensity, the capital share of the aggregate production function is larger in country 1. This causes that, in the steady-state, country 1 has accumulated more capital. Therefore, both countries accumulate the same capital in the steady-state without unbundling, but country 1 accumulates more capital than country 2 in the equilibrium with unbundling.

Finally, we decompose the change in world income between changes in the relative labor and capital income. If we compare labor and capital income between countries in the equilibrium

[21] In online appendix D.2, we show that exactly the same thresholds solve the assignment when only a fraction α of intermediates are traded. Thus, symmetry breaking occurs as long as $\alpha > 0$.

with and without unbundling, we have that

$$\left(\frac{w_2}{w_1}\right)^{\text{with}} - \left(\frac{w_2}{w_1}\right)^{\text{without}} = \left(\frac{\theta_2}{\theta_1}\right)^{\frac{1}{1-z^*}} - \frac{\theta_2}{\theta_1} = 0,$$
$$\left(\frac{\rho k_2}{\rho k_1}\right)^{\text{with}} - \left(\frac{\rho k_2}{\rho k_1}\right)^{\text{without}} = \frac{z^{*2}}{1-z^{*2}} - \frac{\theta_2}{\theta_1} < 0,$$

where we have used the definition of z^* and that $\theta_1 = \theta_2$. In relative terms, the labor income remains unchanged between countries with unbundling. Country 2 relatively loses in capital income. The reason is that it specializes in relatively less capital-intensive intermediates, thereby accumulating less capital in the steady-state.

World Output and Steady-State Welfare Setting the final good as the numéraire, we show in the online appendix F.1 that the world output is the same with and without unbundling, $Y^{\text{World}} = \frac{4\theta^2}{\rho}$. The intuition for this result is that since the two countries have the same productivity, changing the allocation of intermediates does not change the aggregate production. Given that the income share strictly changes with unbundling, this implies that the income in the ex-post rich country increases, whereas the income in the ex-post poor country falls. It follows that welfare in the steady-state unbundling equilibrium is higher in the ex-post rich country and lower in the ex-post poor country.[22]

3.1.2 A world with a large number of ex-ante identical countries

The symmetry breaking result extends to a world with a large number of countries that are identical in terms of their productivity, $\theta(j) = \theta$. In this case, equation (19) reduces to

$$\Delta_j = \Delta_{j+1} \qquad \text{for all} \qquad j = 1, \dots, J-1.$$

Using the boundary conditions $z_0 = 1$ and $z_J = 0$, we obtain the following result.

Proposition 3 *Consider a world with J ex-ante identical countries in terms of their productivity level θ. Without unbundling of production, the world income share of each country is identical and equal to $1/J$. With unbundling of production, symmetry breaking occurs. Country j specializes in the set of intermediates $(z_j, z_{j-1}]$ with $z_j = 1 - \sqrt{\frac{j}{J}}$, and its world income share becomes $\sqrt{\frac{j}{J}} - \sqrt{\frac{j-1}{J}}$.*

Note that the equilibrium threshold z_j is a decreasing and convex function of j. Thus, while all countries have an equal share of the world income in the equilibrium without unbundling,

[22] In order to do a complete welfare assessment, we would need to compute the transition between the two steady-states. Thus, it could be that for very high discount factors, countries that reduce their steady-state consumption with unbundling are better off. We note that for sufficiently patient agents the steady-state income levels would be the only term pinning down the welfare gains of unbundling.

inequality emerges among ex-ante identical countries in the equilibrium with unbundling. The trade balance condition, equation (17), implies that the world income share of country j is $s_j = Z_j$, where Z_j is endogenously determined from the specialization in intermediates and differs across countries.

$$Z_j = z_{j-1} - z_j = \sqrt{\frac{j}{J}} - \sqrt{\frac{j-1}{J}}.$$

This term is decreasing and convex, which means that countries that specialize in capital-intensive intermediates have a higher income share.[23]

Lorenz Curve of World Output We can characterize the Lorenz curve of the world income distribution using the expression of the world income shares,

$$L(j) = \sum_{i=J}^{j} s_i = 1 - \sqrt{\frac{j-1}{J}}, \qquad j = 1, \ldots, J,$$

which is an increasing and convex function. Note that the ordering of countries for the Lorenz curve is descending in the country index j. It starts with $j = J$, with $L(J) = 1 - \sqrt{1 - 1/J}$, and it ends at $j = 1$, with $L(1) = 1$. These heterogeneous income shares are in contrast with the complete equality benchmark in the equilibrium without unbundling, which has a linear Lorenz curve, $L(j) = j/J$.

As in Matsuyama (2013), the model does not have a prediction as to which specific country will occupy rank-j in the world economy, but it shows that endogenous inequality will emerge. Notice that a symmetric equilibrium (all countries produce equal shares of all intermediates and, thus, have the same income) would also potentially be possible in this case. However, the intuition for the two-country case carries over to this general case. The symmetric equilibrium is not stable to small perturbations to productivity. As one country starts producing more capital-intensive intermediates, it accumulates more capital, which reinforces the initial comparative advantage in capital-intensive intermediates. Online appendix B formally introduces the equilibrium refinement concept of arbitrarily small perturbations to productivity. It shows that under this refinement, our threshold equilibrium is unique up to permutations in the country ordering.[24]

World Output and Steady-State Welfare Normalizing the price of the final good to one, we show in online appendix F.1 that the total output produced in the world in the steady-state

[23] The first derivative is proportional to $j^{-1/2} - (j-1)^{-1/2}$, which is negative for $j > 1$. The second derivative is proportional to $-j^{-3/2} + (j-1)^{-3/2}$, which is positive for $j > 1$.

[24] Note that the symmetry breaking result holds if we had assumed that varieties also differ on capital-intensity requirements, $\ln Y_j = \int_0^1 \beta_j(z) \ln a_j(z, v) dz$, provided that each country produced varieties with the same distribution of capital-intensity requirements. The reason is that we assume that varieties are differentiated by origin (Armington assumption). In this case, we would also have that ex-ante identical countries have the same world output share in the equilibrium without unbundling. Unbundling of production would generate symmetry breaking for the same logic as in the main text.

equilibria with and without unbundling coincide. The world output is

$$Y^{\text{World}} = \frac{2J\theta^2}{\rho}.$$

The intuition for the result is that, as all countries are technologically identical, the aggregate world output does not change. Therefore, the differences in income shares s_j generated with unbundling of production inform us on the changes in level of steady-state consumption and, thus, on steady-state welfare. It implies that the steady-state welfare rises in the countries in which the income share increases, while it falls in the rest of countries.

Within-country Inequality We also analyze the emergence of within-country inequality between the two sources of income for each country: capital and labor income. The change in the Theil index in country j is[25]

$$\Delta T_j = \left(1 - \frac{1}{2JZ_j}\right) \ln\left(2JZ_j - 1\right) - \ln\left(JZ_j\right).$$

The change in inequality has a U-shape in the country index j, with its minimum being equal to zero at

$$j = \frac{(1+J)^2}{4J}.$$

Thus, unbundling generically increases within-country inequality in all countries. The U-shape of ΔT_j implies that the rise in within-country inequality is the highest at the extremes of the support of the country indices.[26] The recurrence equation (19) implies that the wage bill is equalized across countries. Thus, all changes in inequality come through differences in capital accumulation. Since the steady-state level of capital is monotonically decreasing in the country index, this provides an intuition for the U-shape result in the change in within-country inequality. The difference in income obtained from capital and labor is maximized for the countries that accumulate the most and the least capital.

[25] Suppose we have N measures of income x_i, $i = 1, \ldots, N$, with arithmetic mean $\bar{x}$. The Theil index is

$$T = \frac{1}{N} \sum_{i=1}^{N} \frac{x_i}{\bar{x}} \ln\left(\frac{x_i}{\bar{x}}\right).$$

[26] For the particular case of $J = 2$, the Theil index for country j becomes $\Delta T_j = \left(1 - \frac{1}{4Z_j}\right) \ln\left(4Z_j - 1\right) - \ln(2Z_j)$, which is .049 for country 1 and .275 for country 2. Note that if the production function of varieties were a bundle of intermediates of z aggregated with weight $\beta(z)$, such that the aggregate demand of capital and labor does not satisfy $\int_0^1 z\beta(z)dz = \int_0^1 (1-z)\beta(z)dz$, inequality could decrease for some countries. However, the U-shape result would still hold, and inequality would be maximized for the countries with the highest and the lowest productivity.

3.2 Heterogeneous Countries

In this section we study how the world income distribution changes when countries are heterogeneous and differ in their productivity level. We first consider a world that consists of two countries and show that inequality increases with unbundling. Then, we show that this result extends to a large number of countries and provide the additional result that middle-productivity countries are the most likely to lose with unbundling of production.

3.2.1 The two-country case

Consider a world that consists of two countries with different productivity levels. Let us assume that $\theta_1 > \theta_2$ and, without loss of generality, $\theta_1 + \theta_2 = 1$. The threshold z^* that divides the intermediates produced by each country is given by

$$\left(\frac{\theta_1}{\theta_2}\right)^{\frac{1}{1-z}} = \frac{(1-z)^2}{z(2-z)}.$$

The solution to this equation z^* is unique. Moreover, z^* is continuous and monotonically decreasing with θ_1/θ_2. The reason is that the larger the productivity difference between the two countries is, the larger the share of intermediates that country 1 produces. Note that this implies that inequality in the unbundling equilibrium is greater with heterogeneous countries than with countries with the same productivity.

Proposition 4 *Inequality between countries increases with unbundling of production.*

We can write the change in the relative income of country 2 between the two equilibria as

$$s_2^{\text{with}} - s_2^{\text{without}} = z^* - \theta_2.$$

The difference in relative income share is negative, which means that unbundling of production leads to more inequality between the two countries. The reason is that the rich country specializes in more capital-intensive intermediates, thereby accumulating more capital and increasing the income gap between the two countries.

To better understand this result, we decompose the change in world income between changes in the relative labor and capital income,

$$\begin{aligned}
\left(\frac{w_2}{w_1}\right)^{\text{with}} - \left(\frac{w_2}{w_1}\right)^{\text{without}} &= \left(\frac{\theta_2}{\theta_1}\right)^{\frac{1}{1-z^*}} - \frac{\theta_2}{\theta_1} < 0, \\
\left(\frac{\rho k_2}{\rho k_1}\right)^{\text{with}} - \left(\frac{\rho k_2}{\rho k_1}\right)^{\text{without}} &= \frac{z^{*2}}{1-z^{*2}} - \frac{\theta_2}{\theta_1} < 0.
\end{aligned}$$

Country 2 relatively loses in both sources of income with unbundling. For relative wages, note that unless the two countries have the same productivity (which is the case we analyzed in the previous section), the new relative wage will be lower in country 2 (because $z^* > 0$). For capital income, country 1 specializes in more capital-intensive intermediates, thereby accumulating more capital in the steady-state. Therefore, unbundling of production exacerbates the inequality between the two countries both in capital and labor income.

World Output and Steady-State Welfare We can also compute the steady-state levels of world output for the case of two heterogeneous countries (see online appendix F.2 for the detailed derivations). The expressions for world output in both steady-states are

$$\begin{aligned} Y^{\text{World, without}} &= \frac{2}{\rho}\theta_1^{\theta_1}\theta_2^{\theta 2}, \\ Y^{\text{World, with}} &= \frac{1}{\rho z^*(2-z^*)}\theta_1^{1-z^*}\theta_2^{1+z^*}. \end{aligned}$$

It is straightforward to see that $Y^{\text{World, with}} > Y^{\text{World, without}}$. Thus, world output increases with unbundling. The reason is that in the unbundling equilibrium the more productive country produces a larger set of intermediates, which is a more efficient use of resources and this results in a higher level of world output. Welfare in the more productive country increases with unbundling. Its income share of world output increases and world output also increases. For the less productive country there are two opposite effects. On the one hand, the world output increases with unbundling. On the other hand, its income share declines. In online appendix F.2 we show that the latter effect always dominates and country 2 has a lower level of output and welfare in the steady state with unbundling.

3.2.2 A world with a large number of countries

Equation (19) characterizes the assignment of countries to the production of intermediates. Unfortunately, equation (19) is not analytically solvable in general. To make progress, we take the same approach as in Matsuyama (2013). We approximate the solution to the case in which the number of countries is very large, $J \to \infty$. In this case, equation (19) converges to a second-order differential equation. Then, we make realistic parametric assumptions on the distribution of θ_j, which allows us to analytically characterize the assignment problem.

Define a new country index $\omega = j\varepsilon$ for $\varepsilon > 0$ and $j = 1, 2, \ldots, J$. We proceed by taking the limit $\varepsilon \to 0$ and $J \to \infty$ such that $\lim_{\varepsilon\to 0, J\to\infty} \varepsilon J = \bar{\omega} \leq \infty$. Equation (19) becomes

$$\left(\frac{\theta_{\omega+\varepsilon}}{\theta_\omega}\right)^{\frac{1}{1-z_\omega}} = \frac{\Delta_{\omega+\varepsilon}}{\Delta_\omega}. \tag{23}$$

Taking Taylor series expansions around $\varepsilon = 0$ for the left-hand side of equation (23) we obtain

$$\left(\frac{\theta_{\omega+\varepsilon}}{\theta_\omega}\right)^{\frac{1}{1-z_\omega}} = 1 + \frac{1}{1-z(\omega)}\frac{\theta'(\omega)}{\theta(\omega)}\varepsilon + o(\varepsilon)^2.$$

Note that we are assuming that, as countries become arbitrarily close ($\varepsilon \to 0$), so do their productivities. In other words, we assume that $\theta(\omega)$ is a smooth function with a well defined derivative in its domain. For the right-hand side, we find that

$$\frac{\Delta_{\omega+\varepsilon}}{\Delta_\omega} = 1 + \left(\frac{z''(\omega)}{z'(\omega)} - \frac{z'(\omega)}{1 - z(\omega)} \right) \varepsilon + o(\varepsilon)^2.$$

Taking the limit as $J \to \infty$, so that all terms of order higher than ε are negligible, we find that $z(j)$ has to satisfy the following second-order differential equation

$$(1 - z(\omega)) \frac{z''(\omega)}{z'(\omega)} - z'(\omega) = \frac{\theta'(\omega)}{\theta(\omega)}, \tag{24}$$

with terminal conditions $z(0) = 1$ and $z(\bar{\omega}) = 0$.

We know from the equilibrium assignment that more productive countries specialize in capital intensive (higher index z) intermediates, $z'(\omega) < 0$. Thus, $\theta'(\omega) z'(\omega) > 0$. Rearranging (24), we find that $z(\omega)$ is convex, as $z''(\omega) = (1 - z(\omega))^{-1} (\theta'(\omega) z'(\omega)/\theta(\omega) + z'^2(\omega)) > 0$.

Notation change In what follows, we abuse notation and use j to denote the continuous country index ω.

The differential equation governing the assignment process (24) is a non-linear differential equation, which cannot be characterized in analytical form without making parametric assumptions on $\theta(j)$. To make further progress in the analysis, we specialize $\theta(j)$ to be a distribution that approximates well the data. Our theory suggests that θ_j can be obtained by looking at the distribution of TFP across countries or, alternatively, at the world income distribution without unbundling, equation (15), which is also proportional to θ_j. Figure 8 shows the distribution of TFP and income per capita shares in 1988 and its exponential fit.[27] We find that the exponential fit is remarkably good. The R^2 of TFP on the country ranking is .97, and .99 for income shares.[28] Thus, we proceed making the following assumption.

Assumption 1 *Countries' productivity θ is exponentially distributed,*

$$\theta(j) = \lambda \exp(-\lambda j), \qquad j \in [0, \infty).$$

Note that the most productive country, $j = 0$, has productivity level $\theta(0) = \lambda$ and productivity is decreasing in j. Given this particular functional form, the differential equation (24) becomes

$$(1 - z(j)) \frac{z''(j)}{z'(j)} - z'(j) = -\lambda,$$

[27] The election of 1988 is given by our data source, Hall and Jones (1999), which report TFP data for this year. Note that it coincides with the change in trade regime documented in Figure 1b.

[28] This fit is better than a Pareto, which yields an R^2 of .8 and .69, respectively. We can also compute the solution of the differential equation for the Pareto distribution.

with terminal conditions $z(0) = 1$ and $z(\infty) = 0$. Making the change of variables

$$v(1 - z(j)) = \frac{d(1 - z(j))}{dj} = -z'(j),$$

equation (24) can be written as

$$v(1 - z)\left(\lambda + (1 - z)v'(1 - z) + v(1 - z)\right) = 0,$$

where we have used that $-z''(j) = v(1 - z)v'(1 - z)$. There are two solutions to this equation. The relevant solution is given by the terms inside the brackets (the other solution is to have $z(j)$ being constant, so that $v(1 - z) = 0$). Integrating the terms inside the brackets and applying the boundary conditions, we can characterize the inverse of the assignment function,

$$j(z) = \frac{z + \ln z^{-1} - 1}{\lambda}, \tag{25}$$

which is monotonically decreasing in z. It is possible to invert this function and obtain $z(j)$, although the expression involves a transcendental function,

$$z(j) = -W(-\exp(-1 - \lambda j)), \tag{26}$$

where $W(z)$ is the Lambert $W-$function defined as the real solution of $z = xe^x$ for x.

Proposition 5 *The assignment function $z(j; \lambda)$ is continuously decreasing and convex in j and λ. The cross-partial derivative $z_{j,\lambda}$ is negative for all $j < \bar{\jmath}(\lambda)$ and positive for $j > \bar{\jmath}(\lambda)$.*

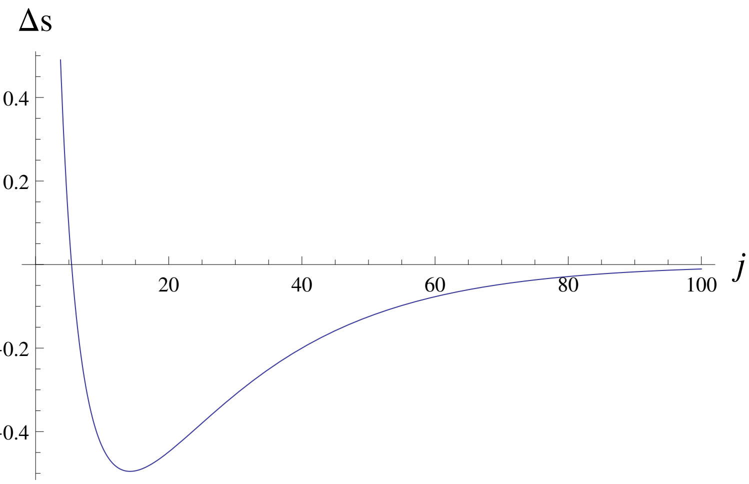
Lorenz Curve of World Output With a continuum of countries, the income share of country j becomes $\mu(j)/\int \mu(j)dj$ in the equilibrium without unbundling and $-z'(j)$ in the equilibrium with unbundling. Integrating these shares, we obtain the Lorenz curves in the equilibrium with and without unbundling

$$L(j)^{\text{without}} = \int_j^\infty \lambda e^{-\lambda j} dj = e^{-\lambda j},$$
$$L(j)^{\text{with}} = \int_j^\infty -z'(j)dj = z(j),$$

where $z(j)$ is given by (26). Note that the ordering of countries in the Lorenz curve is descending in the country index j. That is, the Lorenz curve is zero for $j = \infty$ and one for $j = 0$. Comparing the two Lorenz curves, we find that $L(j)^{\text{without}} > L(j)^{\text{with}}$ for all $j \in (0, 1)$.[29] Thus, the world distribution is more unequal with unbundling, as measured by the Lorenz curve.

[29]To see this, rewrite the Lorenz curves in terms of the assignment j(z), (25), so that $L(z)^{\text{without}} = ze^{1-z}$ and $L(z)^{\text{with}} = z$, and the result follows.

Figure 3: Change in World Income Shares



To better understand how the world income distribution changes throughout its support, we next analyze the change in income shares country by country. Rewriting the change in income shares as a function of the equilibrium assignment of intermediates $j(z)$, (25), we obtain [30]

$$\Delta s(z) = z\lambda \left(\frac{1}{1-z} - e^{1-z} \right).$$

The change in income share is negative for $z \in (0, \bar{z})$ and positive for $z \in (\bar{z}, 1]$.[31] Thus, the income share declines in the countries assigned to the intermediates $z < \bar{z}$ and it increases in the rest. The next proposition characterizes the change in the world income distribution as a function of fundamentals, rather than the endogenous variable z.

Proposition 6 *The change in the income share from the equilibrium without unbundling to the equilibrium with unbundling, $\Delta s(j)$, (i) is continuous in j, (ii) it is decreasing in j for $j < j_-$ and increasing thereafter, with $j_- = \lambda^{-1}\left(-3W(3) - \ln\left(1 - 3W(3)\right)\right)$, (iii) it is convex for $j < j_c$ and concave thereafter, with $j_c < j_-$, (iv) $\Delta s(0) = \infty$, $\Delta s(\infty) = 0$ and $\Delta s(\lambda^{-1}\left(-W(1) - \ln\left(1 - W(1)\right)\right)) = 0$.*

This proposition implies that *(i)* top-bottom inequality increases with unbundling and *(ii)* the income share falls relatively more in middle-productivity countries. Figure 3 illustrates a generic case. Without unbundling of production, the demand of capital is determined by the number of varieties a country produces. In contrast, with unbundling, the demand of capital

[30] To derive this expression note that $s^{\text{without}}(z) = \lambda e^{-\lambda\left(-\frac{1+\ln\left(ze^{-z}\right)}{\lambda}\right)} = \lambda z e^{1-z}$. In addition, to express the income share with unbundling, note that $s^{\text{with}}(j) = -\frac{dz}{dj} \iff s^{\text{with}}(z) = -\frac{1}{\frac{dj}{dz}}$. Using that $\frac{dj}{dz} = -\frac{1-z}{\lambda z}$,we have that $s^{\text{with}}(z) = \frac{\lambda z}{1-z}$. The change in income share in terms of j is $\Delta s_j = \frac{\lambda W(-\exp(-1-\lambda j))}{1+W(-\exp(-1-\lambda j))} - \lambda \exp(-\lambda j)$.

[31] To see this, note that $\Delta s(z)$ is continuous, increasing for $z \in (1 - 3W(1/3), 1]$ and decreasing otherwise. Moreover, $\Delta s(0) = 0$, $\frac{d\Delta s}{dz}(0) < 0$, $\frac{d\Delta s}{dz}(1) = \infty$ and the result follows. Note also that $\Delta s(z)$ is convex for all z.

is determined by the intermediates in which the country specializes. The most productive country gains the most because it specializes in the most capital-intensive intermediates. Low productive countries specialize in low-capital-intensive intermediates but they do not lose much because they accumulated a small amount of capital in the equilibrium without unbundling. The main losers are middle-productivity countries. These countries accumulated a sizable amount of capital in the equilibrium without unbundling. However, they now compete against more productive countries and end up specializing in relatively low-capital-intensive intermediates and, thus, accumulate less capital and have a lower income share. In other words, there is a large mismatch between the capital they accumulated in the equilibrium without unbundling and the needed to produce the equilibrium intermediates with unbundling.

Some of these predictions are in line with the observed changes in the world income distribution between 1990 and 2008.[32] Consistent with our model, top-bottom income inequality increased during this period. For instance, the 90th percentile to 10th ratio of income per capita rose from 24 to 28 and the 95th-5th ratio went from 38 to 42. To test the prediction that the income shares of most productive countries increases while they declined for the rest, we have regressed income per capita growth between 1990-2008 on the country's TFP ranking in 1988 from Hall and Jones (1999). We find that the coefficient of this regression is negative, which is supportive of our prediction. However, the coefficient is not precisely estimated and it is not significant at conventional levels.[33] Indeed, many other factors have affected the world income distribution during this period and empirically disentangling the effects of unbundling on the world income distribution is beyond the scope of this paper.

World Output and Steady-State Welfare We can also compute the steady state levels of world output. To do so, we normalize the price of the final good to one and integrate the price index substituting in the equilibrium prices (see online appendix F.2 for the detailed derivations). We find that the expressions for world output in both steady-states are

$$\begin{aligned} Y^{\text{World, without}} &= \frac{2}{e}\frac{\lambda}{\rho}, \\ Y^{\text{World, with}} &= \sqrt{e}\frac{\lambda}{\rho}, \end{aligned}$$

where e is the base of the natural logarithm, $e = 2.718\dots$ Thus, we have that $Y^{\text{World, with}} > Y^{\text{World, without}}$. This result is not surprising. Unbundling allows a more efficient usage of technologies in the world. Thus, world output increases with unbundling. This implies that there exists some countries whose share of the world income decreases with unbundling that enjoy higher steady-state welfare in the unbundling equilibrium. More precisely, we find that coun-

[32]We choose to finish at 2008 to exclude the effects of the Great Recession.

[33]Figure I.1 in the online appendix reports the distribution of the income per capita growth in this period over the TFP ranking of the countries.

tries with $j \in [0, j_+)$ increase their steady-state welfare in the unbundling equilibrium, while all countries with $j > j_+$ decrease their steady state welfare. The threshold country has an index $j_+ = \lambda^{-1}\left(-W(e^{3/2}/2) - \ln\left(1 - W(e^{3/2}/2)\right)\right)$, which is strictly greater than the threshold country that increases its world income share $\lambda^{-1}\left(-W(1) - \ln\left(1 - W(1)\right)\right)$.

Within-country Inequality Finally, we analyze the changes in within-country inequality between capital and labor income. The change in the Theil index in country j is[34]

$$\Delta T_j = (1-z)\ln(1-z) + z\ln z + \ln 2. \tag{27}$$

It implies that the change in inequality has a U-shape in the country index, with a minimum of zero at $j_0 = \lambda^{-1}(\ln 2 - 1/2)$. Thus, within-country inequality generically increases with unbundling. The U-shape of ΔT_j implies that within-country inequality increases as the country index distances itself from j_0. In other words, the most and the least productive countries are the ones experiencing the highest increases in income inequality with unbundling. Indeed, it can be readily verified that ΔT_j is maximized for $j = \{0, \infty\}$. Finally, we note that the same U-shape result emerges when computing the Gini coefficient of each economy. The Gini coefficient is zero for country j_0, and it increases monotonically with $|j - j_0|$.[35]

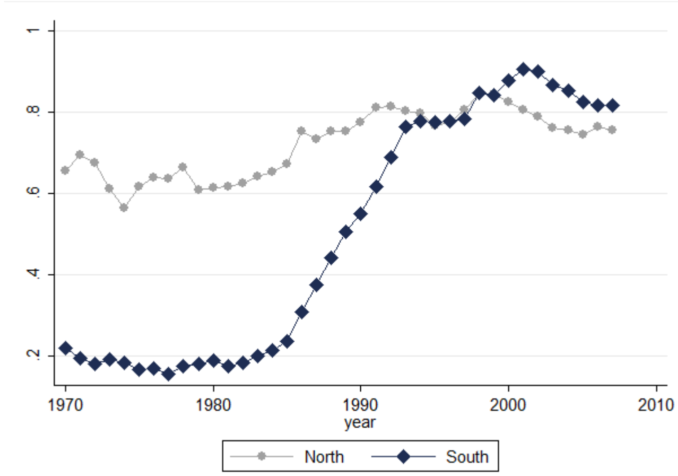
The U-shape prediction in the evolution of within-country inequality seems consistent with the data. We find that for developing countries, the change in the Gini coefficient between 1988 and 2008 is increasing in the TFP ranking of the country.[36] The coefficient is .09% and statistically significant at a 5% level, which means that moving from the 50th to the 100th position in the ranking, increases the Gini coefficient in 4.5% points. Figure I.2a in the online appendix shows the scatter plot. For developed countries, we find that the relationship is reversed and, consistent with the prediction of the model, changes in the Gini coefficient are decreasing in the TFP ranking. However, the coefficient is not statistically different from zero at conventional levels. Figure I.2b in the online appendix shows graphically this relationship. One perhaps surprising feature of the TFP ranking by Hall and Jones is that Spain, Italy and France are more productive than the U.S., Canada, Germany or the Netherlands. Indeed, as figure I.2b shows, these three countries are outliers in the regression. If we remove them, we

[34]To compute the Theil index, note that the wage bill paid in country j in the equilibrium with unbundling is $-z'(j)(1-z(j))Y$, total payments to capital are $-z'(j)z(j)Y$ and the average between the two is $-z'(j)Y/2$. The Theil index for the equilibrium with unbundling is thus $\frac{1}{2}\left(2(1-z)\ln\left(2(1-z)\right) + 2z\ln(2z)\right)$.

[35]The change in Theil index for the particular case of two heterogeneous countries (which we omitted in the main text) is $\Delta T_1 = \frac{1}{2}\left((1+z^*)\ln(1+z^*) + (1-z^*)\ln(1-z^*)\right)$ and $\Delta T_2 = \frac{1}{2}\left(z^*\ln z^* + (2-z^*)\ln(2-z^*)\right)$. Note that within-country inequality increases in both countries. ΔT_1 increases with z and $\Delta T_1(z=0) = 0$, thus, although the exact increase depends on the values of productivities θ_1 and θ_2, $\Delta T_1(z^*) > 0$. Similarly, ΔT_2 decreases with z and $\Delta T_2(z=1) = 0$, thus, $\Delta T_2(z^*) > 0$.

[36]For data comparability, we need to distinguish between developing and developed countries. Gini coefficients for developing countries are obtained from the World Development Indicators (World Bank), which does not report time series for developed countries. For developed countries, we use Luxembourg Incomes Studies data. The threshold between developing and developed countries is the 50% of the U.S. per capita income in 1990. We use the TFP ranking from Hall and Jones (1999).

Figure 4: Ratio of Value of Exported Intermediates to Final Goods.



Source: Feenstra World Trade Database. To classify goods as intermediates, we use the end-use classification of Feenstra and Jensen (2012). Southern countries are defined as countries with GDP per capita (PPP) lower than 50 percent of the United States in 2000.

obtain a negative and significant coefficient at a 5% level. Finally, we want to stress that many other factors such as taxation, technological change, etc. affect the income distribution of a country. While this evidence paints a picture consistent with our theoretical prediction, we do not attempt to identify the contribution of each different channel in this paper.

4 Extensions

In this section, we discuss three extensions of the baseline model. The first extension studies the effects of southern countries joining the global supply chain. The second extension analyzes the effects of a labor saving technology, computerization, on inequality. In the last extension, we characterize how the diffusion of technology changes the world income distribution.

4.1 South Joins the Global Supply Chain

One interpretation of the increasing importance of trade in intermediates is that southern countries have joined the global supply chain (e.g., Baldwin, 2012). Figure 4 reports evidence supporting this view. It decomposes the ratio of exported intermediates to final goods between northern and southern countries. Note that trade in intermediates increased in both northern and southern countries after late 1980s, but most of the aggregate increase comes from southern countries. For southern countries, the ratio was roughly constant around .2 before the 1990s, when it sharply increased and it has converged to around .8 in the late 2000s.

Motivated by this evidence, we analyze the effect on the world income distribution of southern countries joining the global supply chain. We consider a world of J countries and define as South the set of countries with a productivity level θ below $\underline{\theta}$. We compare two equilibria. *(i) Before* the South joins the global supply chain: all countries trade in varieties but only countries with productivity θ above $\underline{\theta}$ can trade intermediates. *(ii) After* the South joins the global supply chain: all countries trade both in varieties and intermediates.

The equilibrium *after* southern countries join the global supply chain is the same as in the baseline model (subsection 3.2.2). The income share of each country j is given by $s_j^{after} = -dz^{after}/dj$, where the assignment of intermediates to countries is given by equation (26).

The equilibrium income share *before* the South joins the global supply chain is a piecewise function that specifies the income share for northern and southern countries separately. Southern countries are those with low productivity levels, that is, countries $j > \underline{j}$, where $\underline{j} = \frac{1}{\lambda}\ln\left(\frac{\lambda}{\underline{\theta}}\right)$. As southern countries only trade varieties, their income shares, implied by the trade balance condition, are

$$s_j^{before} = \theta(j) = \lambda \exp(-\lambda j), \qquad \text{for } j > \underline{j}.$$

Northern countries trade both varieties and intermediates. The trade balance of each northern country $j < \underline{j}$ implies that[37]

$$s_j^{before} = -\frac{dz^{before}}{dj}\left(1 - \frac{\int_{\underline{j}}^{\infty}\mu_j dj}{\int_0^{\infty}\mu_j dj}\right), \qquad \text{for } j < \underline{j}, \tag{28}$$

where z^{before} is the equilibrium assignment of intermediates when only northern countries trade intermediates.

Therefore, we need to derive the equilibrium assignment of intermediates to compute the income share of northern countries before the South joins the global supply chain. To derive the assignment, we proceed in an analogous way as in Section 3.2.2 and solve equation (24) with the terminal condition $z(\underline{j}) = 0$. That is, the South (countries with $j > \underline{j}$) does not participate in intermediates trade. The equilibrium assignment is given by

$$j = -\frac{1 - z^{before}}{\lambda} - \frac{C_1^*(\underline{j})}{\lambda^2}\ln\left(1 - \frac{\lambda(1 - z^{before})}{C_1^*(\underline{j})}\right),$$

where $C_1^*(\underline{j})$ is an integrating constant. We show in online appendix G.1 that $z^{before}(j;\underline{j})$ is decreasing in $\underline{j}$. This is illustrated in Figure 5a for two different $\underline{j}$. It means that if there are more countries participating in intermediates trade ($\underline{j}$ larger), each northern country specializes in

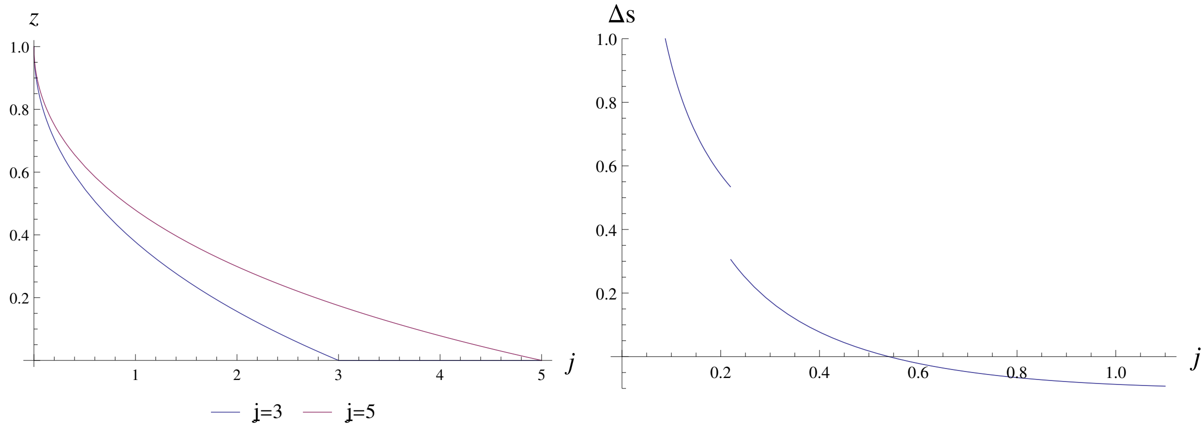
[37] Denoting by $\xi_{\underline{j}}$ the amount of varieties produced by southern countries (i.e., $\xi_{\underline{j}} = \sum_{j=\underline{j}}^{J}\mu_j$), the trade balance of northern countries j becomes

$$\frac{\mu_j}{N}\left(\sum_{i=1}^{J} p_i Y_i - p_j Y_j\right) + Z_j \frac{N - \xi_{\underline{j}} - \mu_j}{N}\sum_{i=1}^{J} p_i Y_i = \frac{N - \mu_j}{N} p_j Y_j + (1 - Z_j)\frac{\mu_j}{N}\sum_{i=1}^{J} p_i Y_i.$$

Rearranging, $s_j^{before} = Z_j^{before}\left(1 - \frac{\xi_{\underline{j}}}{N}\right)$ and taking the limit to a continuum of countries becomes (28).

Figure 5: South joins the Gobal Supply Chain

(a) Change in Equilibrium Assignment with $\underline{j}$ (b) Change in the World Income Distribution



more capital-intensive intermediates (higher z). Finally, note that, by definition, $z^{before}(j; \underline{j} = \infty) = z^{after}(j)$.

We can write the change in the world income distribution when the South joins the global supply chain as

$$\Delta s_j = \begin{cases} -z'(j) - \lambda e^{-\lambda j} & \text{if } j > \underline{j} \text{ (Southern country)}, \\ -z'(j) + z'(j; \underline{j})(1 - e^{-\lambda \underline{j}}) & \text{if } j < \underline{j} \text{ (Northern country)}. \end{cases}$$

Proposition 7 *When the South joins the global supply chain, all northern countries increase their income shares. If $\underline{j} < j^*$, southern countries with $j \in [\underline{j}, j^*]$ increase their income share and the rest decrease their share, where $j^* = -\lambda^{-1}(W(1) + \ln(1 - W(1))$. If $\underline{j} > j^*$, the income share of all southern countries declines.*

The reason for these results is as follows. For southern countries, we have the same comparison as in Section 3.2.2. Their income shares increase if they specialize in intermediates yielding to more capital accumulation than in the unbundling equilibrium. Therefore, if the country is productive enough, it produces enough intermediates and accumulates more capital participating in the global supply chain, thereby increasing its income share. For northern countries, there are two effects. *(i)* Selection effect: they produce less intermediates but they are more capital-intensive and *(ii)* market size effect: northern countries sell intermediates to all the countries, not only in the North. The overall effect is positive because northern countries specialize in more capital-intensive intermediates and sell them to a bigger market. Figure 5b illustrates the change in the world income distribution.

In this section, we have assumed, for simplicity, that southern countries either fully participated or did not participate in intermediates trade. In Section H of the online appendix we relax this assumption and we assume that a fraction $\alpha(j)$ of a country participates in intermediates trade, where $\alpha(j)$ is a decreasing function of j. We show numerically that the same qualitative results hold. As $\alpha(j)$ increases, the income share increases in countries with $j < j^*$ and it decreases in the rest.

4.2 Computerization

The adoption of Information Technologies has been pointed out as one important reason behind the unbundling of production (see, for example, Basco and Mestieri, 2013). Moreover, Autor et al. (2003), among others, have argued that computerization, by eliminating labor-intensive tasks, has also changed the income distribution within countries. In this extension, we analyze how the effects of computerization on the income distribution depend on the trade regime.

As discussed in equation (5), a bundle of intermediates of different labor-intensity must be assembled to produce a variety v,

$$x_j(v) = \exp\left[\int_0^1 \beta(z) \ln a_j(z, v) dz\right],$$

where $\beta(z)$ is a weight on intermediate z, with $\int_0^1 \beta(z)dz = 1$. We model computerization as a shift in the weighting function $\beta(z)$ that reduces the weight of labor-intensive (low z) intermediates.

More precisely, we assume that the distribution $\beta(z)$ has a monotonically decreasing probability ratio (MPR), where the probability ratio is defined as

$$\mathcal{I}(z) = \frac{\beta(z)}{B(z)},$$

and $B(z)$ denotes the cumulative distribution of z.[38] We assume that computerization induces a shift in $\beta(z)$ that can be ranked in terms of the probability ratio. Supposing that γ indexes computerization, we assume that $\mathcal{I}(z;\gamma)$ is monotonically increasing in γ. Eeckhoudt and Gollier (1995) show that a monotone increase in the probability ratio implies a first-order stochastic dominant shift.[39] Accordingly, we define computerization as an increase in γ. That is, an increase in γ implies that, ceteris paribus, relatively less labor-intensive intermediates are needed to produce each variety.

[38] This condition has been applied in other economic contexts, see Hopkins and Kornienko (2004) and the references therein. The normal, uniform and exponential distribution among other distributions satisfy this condition.

[39] Moreover, they also show that a Monotone Likelihood Ratio (MLRP) order implies MPR. Thus, MPR is more stringent than first-order stochastic dominance but less stringent than MLRP.

For example, one family of distributions satisfying the MPR ordering is given by

$$\beta(z) = \begin{cases} 0 & \text{if } z < \gamma, \\ \frac{1}{1-\gamma} & \text{if } z \in [\gamma, 1], \end{cases} \tag{29}$$

where γ is the index of computerization. When $\gamma = 0$, there is no computerization and $\beta(z) = 1$, as we assumed in the baseline model. For $\gamma > 0$, the most labor-intensive intermediates $z < \gamma$ are no longer required to produce varieties.

In the equilibrium without unbundling, the income share of each country depends only on the number of varieties and it is given by $s_j = \mu_j / \int_{j \in \mathcal{J}} \mu_j dj$, which is independent on the weighting function $\beta(z)$. However, computerization decreases the demand of labor, which in equilibrium increases the capital income share.

To analyze the equilibrium with unbundling, note that computerization changes the equilibrium assignment. Proceeding as in section 3.2.2, the assignment function is characterized by the following differential equation

$$(1 - z(j)) \left(\frac{z''(j)}{z'(j)} + z'(j) \frac{\beta'(z(j))}{\beta(z(j))} \right) - z'(j) = \frac{\theta'(j)}{\theta(j)} = -\lambda.$$

Note that $\beta(z)$ enters into the assignment function through its semi-elasticity, $z'(j)\beta'(z)/\beta(z)$.

The solution to this differential equation with boundary conditions $z(0) = 1$ and $z(\infty) = 0$ is given by[40]

$$j(z) = \frac{1}{\lambda} \int_z^1 \mathcal{I}(x, \gamma)(1 - x) dx.$$

The income share in terms of z is

$$s(z) = \frac{\lambda}{\mathcal{I}(z, \gamma)(1 - z)}. \tag{30}$$

With unbundling, computerization changes the world income distribution. From equation (30), we see that γ affects the income shares through the inverse probability ratio, $\mathcal{I}(z, \gamma)$, and the equilibrium assignment $z(j(\gamma))$. On the one hand, by assumption, $\mathcal{I}(z, \gamma)$ is increasing in γ, which reduces the income share. On the other hand, $z(j(\gamma))$ increases with γ, each country j is now assigned to a higher z intermediate, which raises the income share.[41] Therefore, the overall effect on the income share (30) is ambiguous. The next Proposition shows that it depends on the country ranking.

Proposition 8 *In the equilibrium without unbundling, computerization does not affect inequality between countries. In the equilibrium with unbundling, computerization increases the income*

[40]Note that if $\beta(z) = 1$, we obtain that $j(z) = \lambda^{-1}(z - \ln z - 1)$ as in the baseline model. Also, note that, for simplicity, we are reporting the case in which the support of intermediates remains $[0, 1]$. Online appendix G.2 discusses the case when $\beta(z)$ takes the form of (29), in which the support changes with computerization.

[41]Note from equation (4.2) that $j(z, \gamma)$ increases monotonically with an increase in $\mathcal{I}(z, \gamma)$.

share for countries with $j \in [0, j_1)$ and decreases it for countries with $j > j_2$. If $\beta(z)$ is given by equation (29), an increase in γ increases the income share of countries $j < j^*$, while it decreases in the rest. Computerization raises the capital income share in all countries and both trade regimes.

Proposition 8 implies that top-bottom inequality unambiguously increases. The reason is that all countries specialize in more capital-intensive intermediates. However, this shift in the pattern of specializing disproportionately favors the most productive countries, which can now specialize in even more capital-intensive intermediates. This is the reason why the income share raises at the top. The least productive countries do not benefit from computerization because $\beta(z)$ does not change much at the extreme of the distribution. Moreover, computerization always raises the capital income share, as the relative demand for capital increases. This empirical prediction is consistent with the finding of Karabarbounis and Neiman (2013) that the labor-share has declined in most countries.

To sum up, in this section we have shown that the effects of computerization on the world income distribution depend on the trade regime. Without unbundling, computerization does not change the relative income of countries. In contrast, with unbundling, computerization leads all countries to specialize in more capital-intensive intermediates, which exacerbates the income differences between countries and leads to an increase of the capital income share in all countries.

4.3 Diffusion of technology

The source of comparative advantage in our model is technology. In the baseline model, we assumed that technology is exogenous and constant. However, technology diffuses over time and low-productivity countries eventually learn the innovations that the countries in the technological frontier make. In this section we analyze how the diffusion of technology changes the world income distribution with and without unbundling.

We assumed, consistent with the data, that productivity follows an exponential distribution

$$\theta(j) = \lambda \exp(-\lambda j).$$

We model technological catch-up of low-productivity countries as a decline in the parameter λ from λ_1 to $\lambda_2 < \lambda_1$. This implies a first-order stochastic shift in the distribution of productivities in the world.[42]

[42] Note that this formulation implies a counterfactual decline in the TFP level of the most productive countries. We choose this formulation for notational convenience. It can be verified that the same results on income shares apply if we define technological catch-up as a change only in the slope of the original exponential function, ξ, so that productivity is given by $\theta(j) = \lambda \exp(-(\lambda - \xi)j)$ with $\xi > 0$. This formulation would avoid reducing TFP in absolute levels for the most productive countries. However, the same results go through in terms of income shares because, in relative terms, we still have a decline in TFP for the most productive countries and the assignment function would remains unaltered as $\theta'(j)/\theta(j) = -\lambda + \xi$.

Proposition 9 *Diffusion of technology leads to convergence in income with and without unbundling. Moreover, the income share increases in more low-productivity countries when there is unbundling of production.*

These results are illustrated in Figure 6. Without unbundling of production, the income share of country j is $s_j^{without} = \theta(j)$. Note that changes in productivity directly affect the income share. It is then straightforward to see that the income share increases in low-productivity countries ($j > \bar{j}$) and declines in the rest ($j < \bar{j}$).[43] Therefore, diffusion of technology leads to convergence in income shares.

With unbundling of production, the income share of country j is $s_j^{with} = -z'(j)$. It means that productivity affects the income share through the endogenous assignment of intermediates. To understand the effect of technology diffusion on the income share, first notice how the assignment function changes,

$$\Delta j = \left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)(z - \ln z - 1) > 0.$$

This change in the assignment function implies that low-productivity countries are climbing up the ladder of global supply chains by producing higher z intermediates. This new selection of intermediates results in an increase in the income share of low-productivity countries ($j > j^\dagger$) and a decline in the rest ($j < j^\dagger$). The reason is that, due to the diffusion of technology, low-productivity countries can now produce more intermediates, thereby increasing their income share. This result implies that diffusion of technology leads to income convergence.

Finally, we compare the changes in the world income distribution under the two trade regimes. It can be checked that[44]

$$\frac{\partial s_j^{with}}{\partial \lambda}\bigg|_{j=\bar{j}} < 0.$$

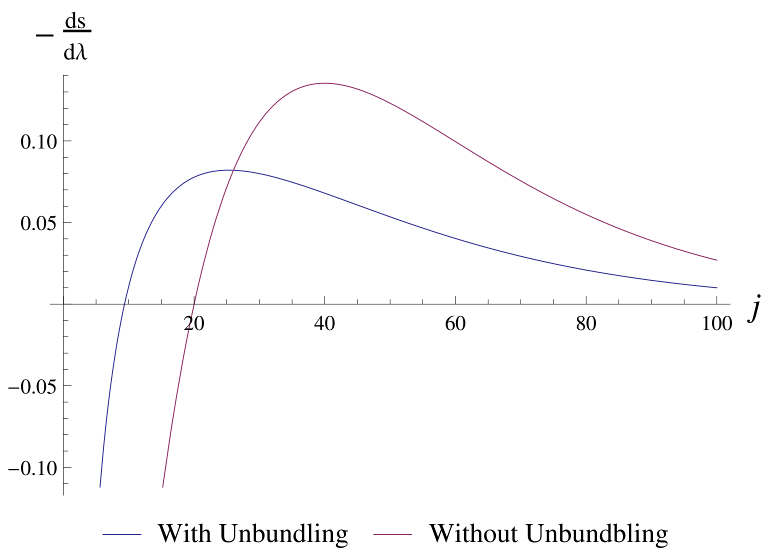
This inequality implies that $\bar{j} > j^\dagger$, which means that in the equilibrium with unbundling the income share increases for a larger mass of low-productivity countries. In particular, the income share of countries with $j \in \left(j^\dagger, \bar{j}\right)$ raises with unbundling but falls without unbundling. The intuition is that, in the equilibrium with unbundling, the relative productivity (not the absolute level) determines the assignment of intermediates. The slope of the distribution of productivities flattens with the diffusion of technology, which results in countries with productivity $j \in \left(j^\dagger, \bar{j}\right)$ gaining comparative advantage against nearby more-productive countries, which allows them to climb the supply chain ladder and produce relatively more capital-intensive intermediates.

To sum up, in this section we have shown that diffusion of technology leads to convergence in income under the two trade regimes. However, the mass of low-productivity countries benefiting

[43] Using that $\theta(j)$ follows an exponential distribution, the threshold $\bar{j}$ is $\bar{j} = \frac{\ln\left(\frac{\lambda_1}{\lambda_2}\right)}{\lambda_1 - \lambda_2}$.

[44] See online appendix G.3 for a derivation and further characterization of the shape in the change of the world income distribution.

Figure 6: Change in the World Income Distribution with a change in λ



from technological catch-up is larger in the trade equilibrium with unbundling.

5 Concluding Remarks

In this paper we have developed a framework to study how the international unbundling of production changes the world income distribution. In our setup, countries only differ in their productivity level, which determines the number of varieties they produce. To manufacture each variety, a bundle of intermediates heterogeneous in capital intensity needs to be assembled.

We showed that in the steady-state equilibrium without unbundling (only varieties are traded), the world income share is determined by the fraction of varieties that each country produces. Unbundling (intermediates can also be traded) changes this world income distribution. The share of world income depends on the intermediates in which each country specializes.

Our first main result is that unbundling of production generates symmetry breaking. That is, countries with the same productivity have the same income in the equilibrium without unbundling. In contrast, unbundling of production leads to divergence in income levels. The intuition is that arbitrarily small differences in productivity translate into comparative advantage differences in capital-intensive intermediates. Specialization in capital-intensive intermediates induces capital accumulation, thereby reinforcing the initial comparative advantage. As a result, specialization in capital-intensive intermediates increases the capital-labor ratio of a country, which translates into a higher income share.

Our second main result is to show that unbundling of production raises top-bottom inequality and it generates non-monotonic changes in the world income distribution. The largest fall in income share is in middle-productivity countries. The reason is that the most productive countries specialize in capital-intensive intermediates and, thus, accumulate more capital and become relatively richer. Middle-productivity countries lose relatively more because they produce a sizable amount of varieties and, thus, they accumulated a considerable amount of capital in the equilibrium without unbundling. However, with unbundling, the stock of capital only depends on the intermediates in which the country specializes. Since the country has intermediate productivity, it specializes in relatively low-capital-intensive intermediates. Thus, it accumulates relatively less capital and it ends with a lower income share. We also show that within-country inequality also increases in our set-up.

We extended the baseline model to show that when southern countries join the global supply chain (participate in trade in intermediates), the income shares of all northern and the most productive southern countries increase, while they decrease for the rest of southern countries. The reason is that northern countries specialize in more capital-intensive intermediates and sell them to a larger market. However, only productive enough southern countries are able to climb up the ladder of global supply chains to specialize in sufficiently capital-intensive intermediates.

We also analyzed how the effect of a labor-saving technology, computerization, depends on the trade regime. Without unbundling, computerization has no effect on the world income distribution. In contrast, with unbundling, computerization exacerbates inequality between countries. The reason is that with computerization all countries specialize in more capital-intensive intermediates, which disproportionately favors the most productive countries. Finally, our model predicts that diffusion of technology leads to income convergence and that the mass of countries benefiting from technological catch-up is larger in the trade equilibrium with unbundling of production.

The unbundling of production is exogenous in the model. Nonetheless, in practice, firms adopt technologies (for example, computers and the internet) to be able to offshore part of the production process. We plan on extending our framework to analyze the interdependence between technology adoption and trade. We have only considered two factors of production: capital and labor. Although we think of capital in broad terms, which could also include human capital (along the lines of Matsuyama, 2004), a more careful investigation of the distinctive effects of human capital accumulation would be another interesting extension of the model. Lastly, in our baseline model, we assume that intermediates are either costlessly traded or non-traded. Online appendix D shows that our framework can be extended to have an arbitrary fraction of intermediates being traded. In future work, we intend to quantitatively investigate the effects of changes in the fraction of intermediates traded on different long-run and short-run trade elasticities.

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A Tables and Figures

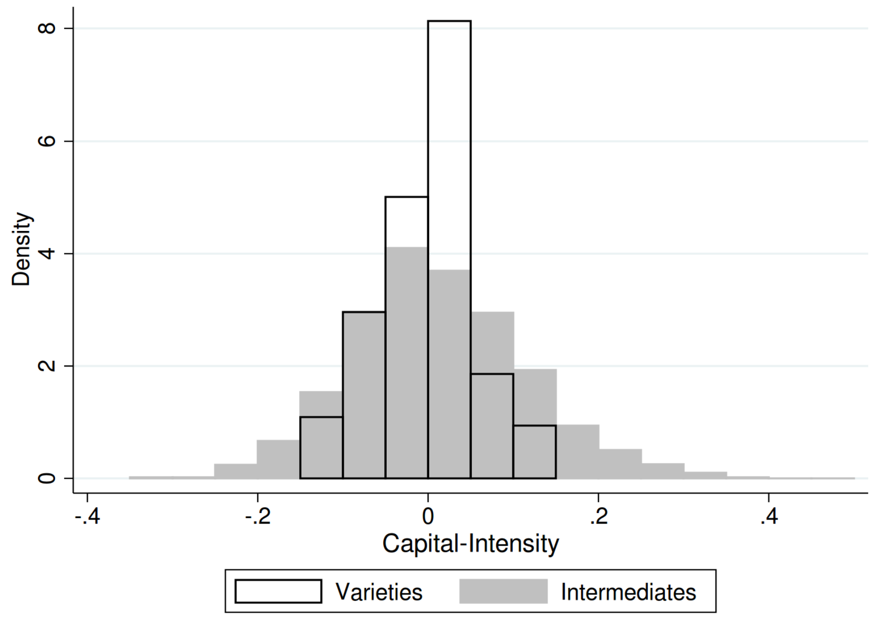
Table 1: TFP and Exports in Labor-Intensive Industries

$$X_{ict} = \alpha + \beta \cdot \text{TFP}_c \cdot \text{Capital Intensity}_{it} + \delta_{ct} + \delta_{it} + \varepsilon_{ict}$$

	(1)	(2)	(3)	(4)	(5)
$\text{TFP}_c \cdot \text{Capital-Intensity}_i$	0.88	1.82	1.82	2.77	2.75
	(0.26)	(0.41)	(0.41)	(0.62)	(0.62)
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
NAICS3 Fixed Effects	Yes	No	No	No	No
NAICS6 Fixed Effects	No	Yes	Yes	Yes	Yes
Year*Country FE	No	No	Yes	No	Yes
Year*NAICS6 FE	No	No	No	Yes	Yes
Observations	207,320	207,320	207,320	207,320	207,320

Notes: Standard errors are clustered at country level. X_{ict} is the log of world exports of intermediates i of country c in year t from 1994 to 2008. Our data is disaggregated at 6-digit NAICS. We classify intermediates using Feenstra and Jensen (2012) classification. TFP is from Hall and Jones (1999) in 1988. Capital intensity is measured as capital shares, which are computed from the NBER CES manufacturing industry database following their definition: $\alpha_k = 1 - \sum_{i \in \mathcal{I}} \alpha_i$, where $\mathcal{I}$ denotes production workers, non-production workers, energy and materials. Our data stops in 1994 because prior to this year we do not have the same level of disaggregation.

Figure 7: Distribution of Capital Intensity for Intermediates and Varieties

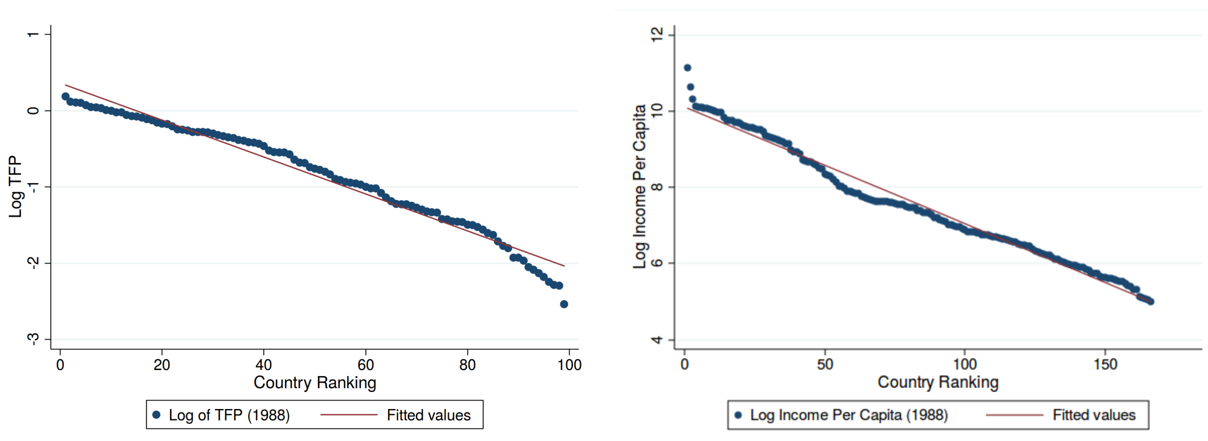


Notes: We define variety as a 3-digit NAICS and intermediate as a 6-digit NAICS (the highest level of disaggregation available). To construct the histograms we compute demeaned measures of capital intensity. Capital intensity of a variety is the difference between the weighted average of the capital shares of the intermediates used to produce the variety (according to input-output tables) and the capital share of the average variety. Similarly, capital intensity of an intermediate is the difference between the capital share of the intermediate and the capital share of the variety that uses the intermediate. Capital shares of intermediates are computed from the NBER CES manufacturing industry database following their definition. We use the 1997 direct requirement U.S. Input-Output tables from the BEA to impute the weight of each intermediate in the production of each variety. We report the results for year 1990 (the year around which we assume the unbundling of production started). We obtain the same qualitative results for year 2000. Table A.1 in the online appendix provides additional measures of capital intensity dispersion (standard deviation, interquartile range and range).

Figure 8: Distribution of TFP and World Income Share

(a) TFP

(b) World Income Shares



Notes: TFP and Income per capita (PPP adjusted) are from Hall and Jones (1999) and the World Bank.