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ARTICLE

Vertical specialization, global expansion of supply chain, and convergence

Hamid Beladi[1], Sugata Marjit[2], Reza Oladi[3], and Sepideh Raei[4]

[1]University of Texas at San Antonio, San Antonio, TX, USA
[2]Indian Institute of Foreign Trade, CES-Ifo, Hong Kong Polytechnic University, Munich, Germany
[3]Department of Applied Economics, Utah State University, Logan, UT, USA
[4]Department of Economics and Finance, Utah State University, Logan, UT, USA
Corresponding author: Reza Oladi; Email: reza.oladi@usu.edu

Abstract

In this paper, we construct an elaborate general equilibrium model with a continuum of production fragments for an intermediate good, then incorporate it in a growth model to address the effects of global production fragmentation, vertical specialization, and trade on growth and inequality for a small developing country. Among other things, we show that a small developing economy grows faster than the rest of the world as a result of global fragmentation and trade in intermediates if it is skilled-labor scarce. We further address the effects of such a trade opening on wage inequality.

Keywords: vertical specialization; trade; growth; inequality

JEL Classification: F1

1. Introduction

Although numerous arguments have been made in the literature on positive role of trade on economic growth, disputes remain (see Lucas, 1990; Krueger, 1999; Frankel and Romer, 1999; Baldwin and Robert-Nicoud, 2008, among others). While the canonical (neoclassical) theory may seem to suggest that trade opening and reforms have a positive impact on economic growth, numerous trade theorists cast doubt on this proposition (see Rodrik, 1995; Krueger, 1999, among others). Extensive empirical literature also provides mixed evidence (see, Sachs et al., 1995; Rodriguez and Rodrik, 2000; Winters and Masters, 2013, among others).[1] On the other hand, the phenomenon of growth in international trade concurrent with widening income inequality in recent decades has brought an additional dimension to these debates (see Bound and Johnson, 1989; Katz and Murphy, 1992; Jones, 1996; Cline, 1997; Baldwin and Cain, 2000; Oladi and Beladi, 2008, among others). Despite the fact that these debates span about half a century, the subject matter is still unsettled both in academia and in policy circle. The recent populist waves of nationalism and protectionism have only intensified the public discourse both in developed and developing countries. The current paper is an attempt to go beyond the canonical models and present a theory of trade, growth, and inequality. It also contributes to a branch of literature that deals with global production fragmentation and offshoring (see Antras and Helpman, 2004; Grossman and Rossi-Hansberg, 2008, among others). In particular, our paper is closely related to Nakanishi and Long (2020) that address the impact of virtual mobility of labor and global task fragmentation on endogenous growth rate as well as the effects of R&D offshoring on skilled wages.[2]

The literature is rich and extensive. Nevertheless, a number of important issues including the impact of trade on economic growth, its differential effects on south visa-a-vie north, and its effect on inequality are still in dispute and remain to be fully addressed. The current paper takes a holistic view of these three aspects and in that it contributes to these related branches of literature. Although the literature on growth and trade theory is substantial (e.g., Grossman and Helpman, 1990 and Rivera-Batiz and Romer, 1991), this literature seldom provides a model that explains a direct relationship between trade and growth. In contrast, our paper provides such a direct link whereby trade by itself allows growth rate to increase. In other words, there is a subtle and significant difference between our model and those models of trade and endogenous growth. For instance, the key driving force in Rivera-Batiz and Romer (1991) is technological progress while product innovation and research R&D are the driving force in Grossman and Helpman (1990), and not trade as such. Trade is the facilitator of technical progress and R&D. Hence, trade plays an indirect role. There is no growth without innovations and just trade opening does not stimulate growth. On the other hand, the link between growth and trade is direct in our model as the driving force is just trade. We do not need innovation to grow faster. Notably, in terms of casual observations, the fastest growing countries in the world during the past few decades (i.e., China and India) are not global leaders in innovation. A direct link between trade and growth that our model provides is the access to the global supply chain. In fact, trade in final goods in our setup will not affect growth rate and only lead to gains from trade, but trade in intermediates and accessing global supply chain will lead to dynamic gains. It is a unique theoretical structure where the direct link between supply chain driven gains from trade and growth is very cleanly demonstrated. Well accepted stylized empirical facts are theoretically shown under the umbrella of a unified model.

In particular, we attempt to address the effects of vertical specialization, global production fragmentation and global expansion of supply chain on economic growth and income inequality. In doing so, we construct an elaborate dynamic general equilibrium model of trade with continuum of production fragments (or productive services) and supply chain. We first set up a model with three goods, two final goods and an intermediate. The intermediate good itself consists of a continuum of fragments in the spirit of Dornbusch et al. (1977), each produced with Ricardian production technology. We show that the level of capital is consequential in determining the skilled–unskilled wage gap in our setup with trade in fragments. Hence, it is paramount to cast our general equilibrium within a growth model.

As our main results, we first show that vertical specialization, global fragmentation, and global extension of supply chain induce economic growth. As elaborated in Section 2, our model assumes constant labor supplies for both skilled and unskilled workers. This raises the question: what drives growth in our framework? The answer lies in the relationship between the marginal product of capital and the price of the intermediate good. Opening up to trade and the expansion of the value chain will lead to a permanent reduction in the price of the intermediate good. This reduction is the principal catalyst for growth in our economic model. This is in contrast to the view held by those trade critics that question the validity of trade being pro development (see Rodrik, 1995; Rodriguez and Rodrik, 2000, among others). Our model provides yet another additional theoretical foundation that supports the old idea advocated by Krueger (1999) and Sachs et al. (1995), among others. In particular, we provide a theoretical channel for explaining the empirical evidence that vertical specialization and enhancement of global value chains have induced economic growth (see Hermida et al. 2022). This result has an intuitive explanation. Opening to the global supply chain and production fragmentation reduces the price of intermediate. In turn, more efficiently globally produced intermediate increases the marginal product of capital permanently. This latter effect will increase economic growth.

Second, we revisit the catch-up hypothesis, stating that developing countries grow faster and ultimately will catch up with developed countries. Here again, the debate has not yet been settled although it is a decades-old idea. The premise of the hypothesis is based on the basic principle of productivity. As economies grow, their growth rates converge in the long run (see Abramovitz, 1990; Baumol, 1986). Implied by the neoclassical assumption of diminishing marginal productivity of capital, there is a limit to the rate of capital accumulation in the long run (see Baily et al. 1990, for such evidence in the US data). Hence, it is argued that developing countries must experience a higher growth rate than the developed world. Lucas (1990) famously criticized this hypothesis by raising the question of why capital does not move to the south. We contribute to this old unsettled question by providing the conditions under which the hypothesis holds. Particularly, we show that a small developing economy grows faster than the rest of the world due to vertical specialization, production fragmentation and the global extension of supply chain if it is skilled-labor scarce both relative to capital and unskilled labor. Our intuitive explanation is that prior to opening in global supply chain, a developing country faces a higher price of intermediate, given that it faces scarcity of skilled labor. Hence, it will experience a greater reduction in the price of intermediate good due to the opening in global supply chain than a developed economy. Therefore, the gain in marginal productivity of capital will be larger, resulting in faster economic growth.

Third, we address the effects of production fragmentation and global extension of supply chain on skilled–unskilled wage inequality. Hence, our paper also contributes to an important growing literature on international production and task fragmentation (e.g, see Nakanishi and Long, 2015).[3] Our results indicate that opening to the global supply chain raises skilled–unskilled wage gap. To see the intuition behind this result, one must note that as a result of opening to the global supply chain, the sector that uses such global production fragmentation will expand at the expense of the sector in our economy with two finished good sector. Now, if the former is more skilled labor intensive than the later (as it is in our setup), the sector will demand more (less) skilled (unskilled) labor than the latter contracting sector sheds. The consequence is a rising (economy-wide) skilled–unskilled wage gap.

To illustrate our theoretical results numerically, we calibrate our model and conduct a numerous computational experiments. These computational exercises are meant to provide qualitative insights and to facilitate visualizing our results.[4] Finally, we discuss alternative formulations of the economy and the effects of these model alterations on our main results.

The rest of our paper is organized as follows. Section 2 lays out our general equilibrium framework. Then, in Section 3, we cast our general equilibrium model within a dynamic growth model, where we also present our main results. Section 4 and 5 provide some numerical analysis, and Section 6 discusses alternative models. Section 7 concludes our paper.

2. A general equilibrium model of vertical specialization

Consider a small open economy that produces two final goods, denoted by X and Y. Good X uses capital and intermediate good M as inputs with Cobb–Douglas production technology $X = AK^{\alpha}M^{1-\alpha}$. Good Y uses unskilled labor and skilled labor as inputs with production technology $Y = S_Y^{\beta}L_Y^{1-\beta}$, where S_Y is the usage of skilled labor and L_Y denotes the unskilled labor employed by sector Y. Sector M uses a continuum of services or components $Z = [0, 1]$ to produce the intermediate good with costless assembly technology. Finally, let service z be produced both at home country and abroad using skilled labor with Ricardian production technology. In particular, let Ricardian unit labor demand be $a_S(z), \forall z \in Z$, where $a_S(1) = 1$. For any $z \in Z$, let $\delta(z) \equiv a_S^*(z)/a_S(z)$, where an asterisk denotes foreign variables in the remainder of the paper. We assume that $\delta'(z) < 0, \forall z \in Z$. Define $\tilde{z} \in Z$ such that $\delta(\tilde{z}) = w_S/w_S^*$, where w_S denotes skilled wage rate. Therefore, all $z \in [0, \tilde{z}]$ will be produces at home and all $z \in (\tilde{z}, 1]$ will be produced in the rest of the world. Then, given our setup, the total skilled labor whose service will be assembled in M, denoted by S_M, can be given by

$$S_M = M \int_0^{\tilde{z}} a_S(z)dz \tag{1}$$

We maintain full employment of labor, implying that $L_Y = \bar{L}$ and:

$$S_M + S_Y = \bar{S} \tag{2}$$

where $\bar{L}$ and $\bar{S}$ are constant endowments of unskilled and skilled labor, respectively. The equilibrium price of intermediate good M is given by

$$p_m(\tilde{z}) = B(\tilde{z})w_S + [1 - B(\tilde{z})]w_S^* \tag{3}$$

where $B(\tilde{z}) \equiv \int_0^{\tilde{z}} a(z)dz$ is the share of home-made components $z \in Z$ in M.[5] By our small open economy assumption, prices of X and Y, denoted by p_x and p_y, as well as w_s^* are all given. Hence, w_s and w will be determined with $p_x = p_y = w_s^* = 1$ by appropriate choice of units. Note also that, following the definition of δ and equation (3), we have $p_m(\tilde{z}) < 1$.[6]

Profit maximization implies the demand for intermediate as $M = [(1-\alpha)X/p_m(\tilde{z})$. Hence, equilibrium output of X for any amount of capital can be obtained as

$$X = \left(A(1-\alpha)^{1-\alpha}\right)^{\frac{1}{\alpha}} \left(\frac{1}{p_m(\tilde{z})}\right)^{\frac{1-\alpha}{\alpha}} K \tag{4}$$

Using the above derived demand for M and equation (4), we can obtain instantaneous equilibrium quantity of M for any given level of capital as

$$M = \tilde{A}K\tilde{p}_m^{-\frac{1}{\alpha}} \tag{5}$$

where $\tilde{A} \equiv [A(1-\alpha)]^{1/\alpha}$ and $\tilde{p}_m \equiv p_m(\tilde{z})$ for notational simplicity. Therefore, it follows from equations (1) and (5) that the equilibrium level of employment for skilled labor, used in production of domestic components $[0, \tilde{z}]$ for any given level of capital, can be given as

$$S_M(w_s) = \frac{\tilde{A}KB(\tilde{z})}{(B(\tilde{z})w_s + [1 - B(\tilde{z})])^{\frac{1}{\alpha}}} \tag{6}$$

Differentiating equation (6), it can be shown that:

$$\frac{\partial S_M}{\partial w_s} = \tilde{A}K \frac{B'(\tilde{z})\frac{d\tilde{z}}{dw_s} - \frac{1}{\alpha}[B(\tilde{z})]^2[\tilde{p}_m]^{-1}}{p_m^{\frac{1}{\alpha}}}$$

where we have used $\left(d[B(.)w_s + (1 - B^*(.))]/d\tilde{z}\right)\left(d\tilde{z}/dw_s\right) = 0$, since $d[B(.)w_s + (1 - B^*(.))/d\tilde{z} = 0$ due to the envelope theorem. Recall also that $B'(.) > 0$ and $d\tilde{z}/dw_s < 0$. Hence, we conclude that $\partial S_m/\partial w_s < 0$.

Next, consider sector Y. Equilibrium in this sector implies:

$$S_Y(w_s, \bar{L}) = \left(\frac{w_s}{\beta \bar{L}^{1-\beta}}\right)^{\frac{1}{\beta-1}} \tag{7}$$

where $\partial S_Y/\partial w_s < 0$. Therefore, the market clearing condition for skilled labor can be rewritten as

$$S_M(w_s) + S_Y(w_s, \bar{L}) = \bar{S} \tag{8}$$

which determines equilibrium w_s, for any given level of K, hence sectoral skilled-labor demand will be determined. Then, unskilled-labor market clearing condition determines unskilled wage, that is, $w = (1-\beta)[S_Y(w_s)]^\beta/\bar{L}^\beta$. Moreover, skilled–unskilled wage gap is given by

$$\frac{w_s}{w} = \frac{\beta \bar{L}}{(1-\beta)S_Y(w_s, .)} \tag{9}$$

implying that any change that leads to a decrease in demand for skilled labor in sector Y will increase the skilled–unskilled wage gap. Clearly, capital accumulation has consequences on skilled–unskilled wage gap and on inequality. Particularly, equations (6) and (8) imply that an increase in capital will increase (decrease) the demand for skilled labor whose services are used in sector M (Y). Hence, we have the following result.

Proposition 1. *Any increase in capital raises the skilled–unskilled wage gap in this small open economy.*

Thus, it is crucial to study capital accumulation. We shall consider this in the next section.

3. Economic growth and Inequality

Our model and its analysis in the previous section is for any given capital level. We shall now allow capital to be endogenously determined and grow over time for any given initial value. Let the representative consumer's utility function be given by $u = u(c_t)$, where c_t denotes the consumption of Hicksian composite good at time t and all neoclassical assumptions are maintained. Moreover, we also assume throughout the rest of the paper that u exhibits constant inter-temporal elasticity of substitution. Our dynamic optimization problem can be written as

$$\max_{\{c_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \xi^t u(c_t)$$

$$s.t. \quad K_{t+1} - K_t = \frac{\tilde{A}K_t}{\phi(\bar{S}, K_t)} - c_t$$

$$K_0 = \bar{K}$$

where $\phi(\bar{S}, K_t) \equiv (1-\alpha)\tilde{p}_m^{(1-\alpha)/\alpha}$ and $\xi = 1/(1+\rho)$ is the discount factor and $\rho > 0$ is the discount rate. Recall that at a temporal equilibrium w_s depends on $\bar{S}$ and K_t, implying that $\tilde{p}_m$ also depends on $\bar{S}$ and K_t. Bellman equation for this dynamic programming problem can be written as

$$v(K_t) = \max_{c_t}\{u(c_t) + \xi v(K_{t+1})\} + \lambda_t \left[\frac{\tilde{A}K_t}{\phi(\bar{S}, K_t)} - c_t - (K_{t+1} - K_t)\right]. \tag{10}$$

The first-order conditions for this problem can then be obtained as

$$u'(c_t) = \lambda_t \tag{11}$$

$$\xi v'(K_{t+1}) = \lambda_t \tag{12}$$

$$v'(K_t) = \lambda_t \left(\frac{\tilde{A}}{\phi} - \frac{K_t}{\phi^2}\frac{\partial \phi}{\partial K_t} + 1\right) \tag{13}$$

Rewrite equation (13) for $t+1$, to get:

$$\xi v'(K_{t+1}) = \xi \lambda_{t+1} \left(\frac{\tilde{A}}{\phi}\left[1 - \frac{\varepsilon_{p_m k}(1-\alpha)}{\alpha}\right] + 1\right)$$

where $\varepsilon_{p_m k}$ is the elasticity of p_m with respect to capital. It directly follows from equation (5) that $\varepsilon_{p_m k} = \alpha$. Hence, by using equation (12), we can rewrite the above equation as

$$\frac{\alpha \tilde{A}}{(1-\alpha)\tilde{p}_m^{\frac{1-\alpha}{\alpha}}} + 1 = (1+\rho)\frac{\lambda_t}{\lambda_{t+1}} \tag{14}$$

Then, given the constant intertemporal elasticity of substitution, it follows from equations (11) and (14) that:

$$\frac{\alpha\tilde{A}}{(1-\alpha)\tilde{p}_m^{\frac{1-\alpha}{\alpha}}}+1=(1+\rho)(1+g)^{\sigma} \tag{15}$$

where $\sigma \equiv u''(.)/u'(.)$ is the (constant) inter-temporal elasticity of substitution and g is the growth rate. Recall that $u'(c^*(k_t))/u'(c^*(k_{t+1}))=[c^*(k_{t+1}/c*(k_t))]^{\sigma}=(1+g)^{\sigma}$, where k is capital-skilled labor ratio. By solving equation (15), we obtain:

$$g(t)=\Delta\left[1+\frac{\alpha\tilde{A}}{(1-\alpha)\tilde{p}_m^{\frac{1-\alpha}{\alpha}}}\right]^{\frac{1}{\sigma}}-1 \tag{16}$$

where $\Delta \equiv [1/(1+\rho)]^{1/\sigma}$. Recall that ϕ is monotonically increasing in p_m. Hence, we have the following result.

Proposition 2. *Vertical specialization and opening of international trade in components and global expansion of supply chain at time t will lead to an increase in temporal growth rate.*

To see this more clearly, let us consider an example where $u(c_t)=\ln c_t$, that is, $\sigma=1$. Then, it follows form equation (15) that approximately $g(t)\approx\alpha\tilde{A}/[(1-\alpha)\tilde{p}_m^{1-\alpha/\alpha}]-\rho$. Therefore, growth rate crucially depends on the price of intermediate. Vertical specialization and trade opening in components will lower this price, resulting in higher temporal growth rate.

Now, turning to the catch-up hypothesis, we need to establish whether our small open developing economy experiences a greater reduction in price of the intermediate good as a result of vertical specialization and trade in components. To do this, first we have to derive autarky equilibrium price of M, denoted by p_m^a. It is evident from (3) that $p_m^a=w_S$ since $B(1)=1$. Hence, we have to evaluate the change in skilled wage due to trade opening. Using $p_m^a=w$ and equations (6)–(8) as well as their equivalence in the rest of the world, we can show that at autarky we have:

$$\frac{\tilde{A}}{w_S^a}\bar{k}_S+\left(\frac{\beta}{w_S^a}\right)^{\frac{1}{1-\beta}}\bar{l}_S=1 \tag{17}$$

where $\bar{k}_s\equiv\bar{K}/\bar{S}$ and $\bar{l}_s\equiv\bar{L}/\bar{S}$. Using equation (17) and its equivalence for rest of the world, recalling that $w_s^*=1$, we obtain:

$$\frac{\tilde{A}}{w_S^a}\bar{k}_S+\left(\frac{\beta}{w_S^a}\right)^{\frac{1}{1-\beta}}\bar{l}_S=\tilde{A}\bar{k}_S^*+\beta^{\frac{1}{1-\beta}}\bar{l}_S^* \tag{18}$$

Thus, it follows from equation (18) that $w_S^a>w_S^*=1$ if $\bar{k}_S>\bar{k}_S^*$ and $\bar{l}_S>\bar{l}_S^*$. Hence, we have the following result.

Proposition 3. *Autarky skilled wage is higher at home economy if it is skilled labor scarce both relative to capital and unskilled labor.*

The condition of the above proposition is sufficient for skilled wage to be higher in the home economy. However, it is not a necessary condition. The necessary condition is that one of these skilled labor intensity conditions to be met. As it is evident from equation (18), for $w_S>w_S^*$ under autarky, it must be the case that $\bar{k}_S>\bar{k}_S^*$ or $\bar{l}_S>\bar{l}_S^*$. That is, killed labor must be scarce at home at least relative of the other primary production factors.

A crucial corollary to Proposition 3 follows from equation (3): $p_m^a>p_m^{a*}$ if home country is skilled labor scarce both relative to capital and unskilled labor. Suppose this sufficient condition is met. Then, home country will experience a bigger price drop for the intermediate good as a result of vertical specialization, global production fragmentation, and trade in fragments. That is, $dp_m = p_m^a - p_m(\tilde{z}) > p_m^{a*} - p_m(\tilde{z})$ if home country is skilled-labor scarce both relative to capital and unskilled labor. This, in turn, implies from equation (16) that $g(t) > g^*(t)$ if home country is skilled labor scarce both relative to capital and unskilled labor. Hence, we have the following formal result that addresses the catch-up hypothesis.

Proposition 4. *With vertical specialization, trade opening for components and global expansion of supply chain, a small home economy grows faster than the rest of the world if the home country is skilled abor scarce both relative to capital and unskilled labor.*

This result is compatible with the observation of cross-country growth convergence (e.g., see Bal). A small developing country with skilled-labor scarcity grows faster than the developed world so that ultimately the cross-country per capita income converges.

We have already established in preceding section that a higher level of capital will increase the skilled–unskilled wage gap. Hence, this and Proposition 2 conclude the following important result on skill-unskilled wage inequality.

Proposition 5. *Vertical specialization, production fragmentation, trade opening, and global expansion of supply chain raise within country skilled–unskilled wage gap.*

Intuition of this result deserves attention. Following proposition 2, vertical specialization and trade in components will increase growth rate, hence raises the capital level. As K accumulates and S does not expand at that rate, w_s/w will go up in each group of countries. Again, this explains within country divergence that we observe from empirical evidence. This result contributes to the literature on rising inequality (e.g., Autor and Murnane, 2003; Acemoglu and Restrepo, 2018).

While the effect of global production fragmentation and vertical specialization on wage inequality is generally unambiguous, its extent differs between home country and the rest of the world. This follows from the implication of catch-up hypothesis in our setup. The following result highlights the differential effects of vertical specialization on inequality.

Proposition 6. *Skilled–unskilled wage inequality widens more in home country than the rest of the world if home country is skilled-labor scarce both relative to capital and unskilled labor.*

As a final note, it must be emphasized that the results of our paper are robust to many alterations of the simple model we develop in the paper. Everything hinges on the price of M, where a lower p_m via trade increases the marginal product of capital. As long as trade in intermediates leads to a decline in the world price of M, affecting the marginal product of capital, trade will lead to growth. One could bring in unskilled labor in production of M and define comparative advantage appropriately to generate this result.

4. Parametrization

In this section, we outline the calibration strategy for our general equilibrium model, discussed in previous sections. The primary aim of this calibration is to serve as a heuristic tool for visualizing theoretical outcomes and gaining intuitive insights into the relationships and phenomena under study.

It is important to note that our approach is more qualitative in nature and not geared toward precise parametric estimation. To guide our calibration, we adhere to established conventions in the literature, sourcing parameter choices from existing research to maintain consistency with mainstream approaches. The chosen parameters are consistent with "less developed" country relative to the rest of the world which resonates the theoritical framework that we are proposing.

The most crucial element of our model is the labor demand in both the home country and the rest of the world, which represents the trade partner in our model, for each unit of good M.

Table 1. Parameter values

Parameter	Value	Description
α	0.34	Capital intensity
A	1	TFP for good X, normalized
β	0.5	Skilled-labor intensity
σ	1	Intertemporal elasticity of substitution
ξ	0.96	Discount factor
T_h	1	Scale parameter for Frechet dist. for home
T_r	3	Scale parameter for Frechet dist. for rest of the world
θ	4	Shape parameter for Frechet dist. (common for both countries),
		(Simonovska and Waugh (2014))
$\bar{S}$	1	Skilled-labor supply, (normalized)
$\bar{L}$	2.3	Unskilled-labor supply, relative to skilled-labor supply,
		(avg. for low-income countries)

Note: This table summarizes values of parameters with brief descriptions.

To discipline $a_s(z)$ and $a_s^*(z)$, we follow Eaton and Kortum (2002). In a multicountry context, they formulated $Z_i(j)$ as the amount of good j that a bundle of inputs can produce in country i. In our framework, this corresponds to the inverse of labor demand for each unit of good M, expressed as $\frac{1}{a_s(z)}$. We posit that the productivity distribution for each good j in country i follows a Frechet distribution:

$$Pr(Z_i(j) \leq z) = F_i(z) = e^{-T_i z^{-\theta}}$$

with $T_i > 0$ governing the location of the distribution or the state of the technology in i, meaning that a higher T_i implies a higher efficiency draw for good j. We choose this parameter to capture the distinctions between the developed (rest of the world) and the developing country under focus. Specifically, we assign a smaller T for the home country and a larger T for the rest of the world. Parameter θ is responsible for dictating the variability in productivity; a higher θ leads to lower variability. Consistent with existing literature, we set a common θ for both locations. Consequently, we have two Frechet distributions that generate $a_s(z)$ and $a_s^*(z)$ for home country and the rest of the world, respectively.

Another set of parameters that we have in the model are $\bar{S}$ and $\bar{L}$ which represents the skilled-labor supply and unskilled-labor supply. The important aspect for our analysis is, in fact, the relative size of labor supply. therefore, we normalized the skilled-labor supply to 1 and set the unskilled-labor supply to 2.3 which is the average ratio of this ratio for low-income countries using world bank dataset.[7] Table 1 summarizes parameter choices employed in our model.

5. Exploratory experiments: from theory to visualization

We conducted a series of computational experiments to visualize the theoretical predictions made by our model. These experiments should be viewed as illustrative, providing qualitative insights into the effects of global production fragmentation, vertical specialization, and trade on economic growth and wage inequality.

The first result in Section 2 reveals that, within the context of our small open economy, an increase in capital correlates with a widening skilled–unskilled wage gap. To visualize this relationship, we conducted model simulations over varying levels of capital, capturing the respective values of skilled wage, ω_s, and unskilled wage, ω. Figure 1 depicts the ratio of skilled to unskilled

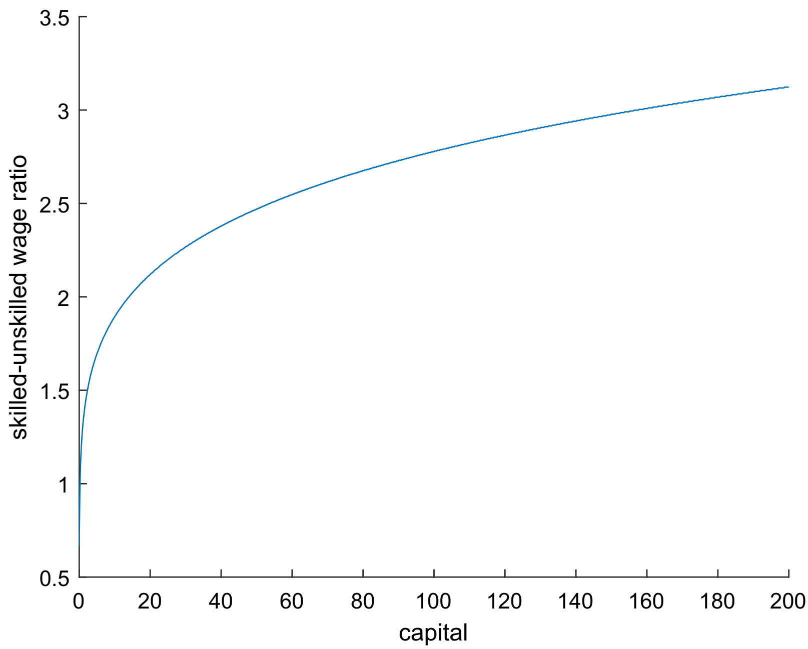

Figure 1. Skilled–unskilled wage gap.
Note: This figure illustrates an expanding wage gap between skilled and unskilled labor as the level of capital investment rises, which is consistent with the outcomes presented in Proposition 1.

wages across these capital levels. As illustrated, the wage gap—measured as the ratio of $\frac{\omega_s}{\omega}$ – expands as capital increases.

Another key finding presented in Section 3 is that the vertical specialization and opening of international trade in components, along with the global expansion of supply chains, contribute to an increase in the temporal growth rate $g(t)$. This is mediated through their impact on the price of the intermediate good M. Specifically, vertical specialization and trade liberalization lead to a decline in the price $\tilde{p}_m$, which in turn boosts the temporal growth rate both at the time of opening and in subsequent periods, compared to a no-trade scenario. To illustrate this inverse relationship between $\tilde{p}_m$ and $g(t)$, we simulate our model across a range of $\tilde{p}_m$ values to calculate the corresponding growth rates. Figure 2 highlights this inverse relation, showing that an increase in the price of intermediate goods results in a reduced temporal growth rate. Consequently, any period in which the economy opens up to trade—and thus experiences a decrease in $\tilde{p}_m$—will see a surge in temporal growth rate.

A further set of findings elaborated in the previous section underscores the influence of skilled labor scarcity on a country's response to vertical specialization and trade. To illustrate these outcomes, we simulate our model for two countries with identical levels of capital, unskilled-labor supply, and technology, but divergent levels of skilled-labor supply. Specifically, one of those countries has a skilled-labor supply twice as large as the other. The country with the smaller skilled labor supply serves as a proxy for higher skilled labor scarcity, relative to its counterpart. In the accompanying graphs, this country is labeled as 'Low-Skilled Labor Supply' and is represented by a dashed blue line. Conversely, the country with the larger skilled labor supply signifies lower skilled labor scarcity and is labeled as "High-Skilled Labor Supply," depicted by a solid red line in the graphs.

Figure 3 displays the skilled-labor wages, ω_s in autarky—that is, in the absence of trade—across a range of capital levels for two countries, with a high-skilled labor supply and a low-skilled abor

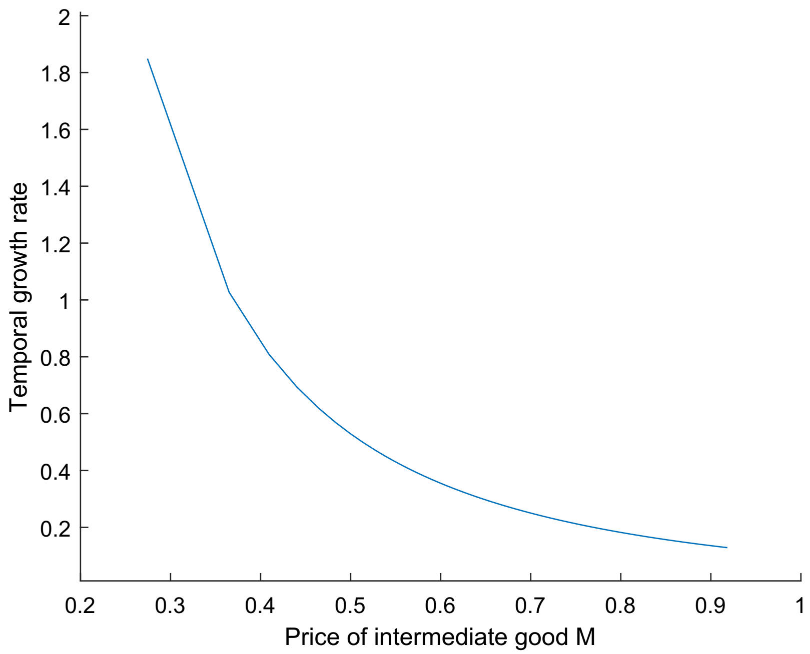

Figure 2. Temporal growth rate and price of intermediate good.
Note: The figure demonstrates the inverse correlation between the price of the intermediate good $\tilde{p}_m$, which declines as the country engage in vertical specialization and trade, and the temporal growth rate, $g(t)$.

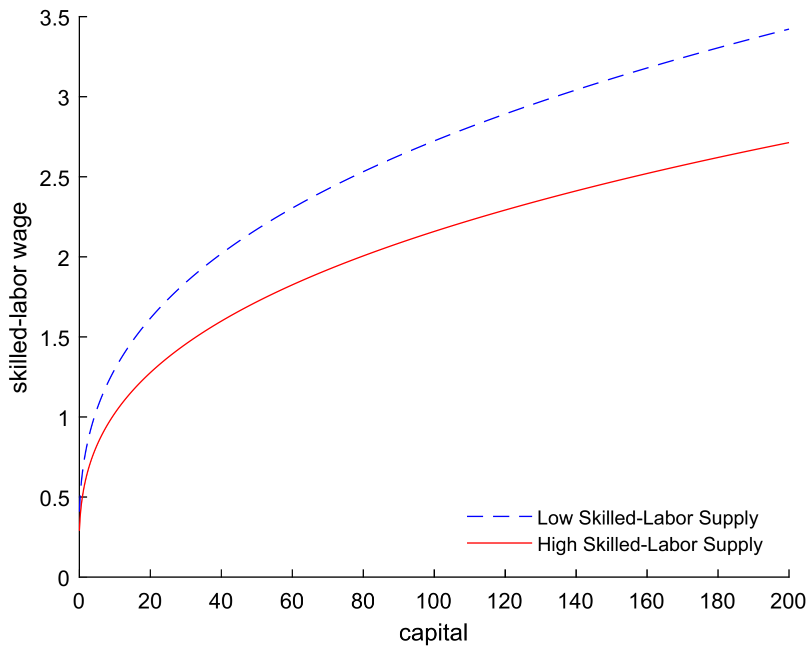

Figure 3. Autarky skilled-labor wage.
Note: The figure demonstrates that at autarky, the skilled labor wage is higher for the country which is more skilled-labor scare both relative to capital and unskilled labor.

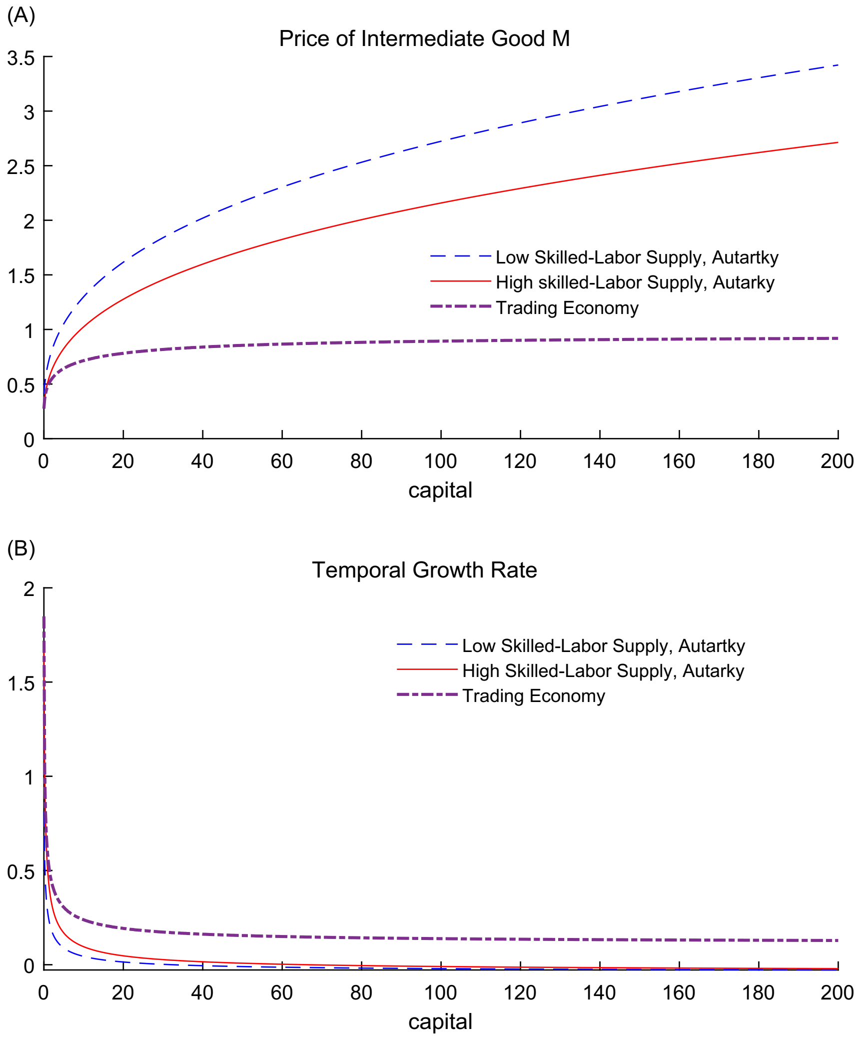

Figure 4. Influence of skilled-labor supply on trade openness.
Note: Panel A compares the price of the intermediate good *M* under autarky across a spectrum of capital levels for both high and low skilled-labor supply countries. The purple line illustrates how this price evolves when the country engages in trade. Panel B follows a similar structure, but focuses on representing the temporal growth rate across the same range of capital for both types of countries.

supply. As evident from the graph, the skilled labor wage is higher in the country with relative skilled labor scarcity. It is important to note that this scarcity is relative to both capital and unskilled labor by its setup.

Skilled-labor intensity is one of the significant factors when considering the impact of trade and vertical specialization on an economy. In the absence of trade, that is, autarky, higher skilled-labor scarcity results in a relatively higher price for intermediate goods. Consequently, when economies open up to trade, the country with lower skilled-labor supply experiences a more substantial decline in the price of intermediate goods compared to its higher skilled-labor supply counterpart. This is demonstrated in Panel A of Figure 4, which compares $\tilde{p}_m$ under autarky and post-trade conditions for both types of countries. The gap between autarky and trade-induced prices is wider for the country with skilled-labor scarcity. This suggests that upon opening up to

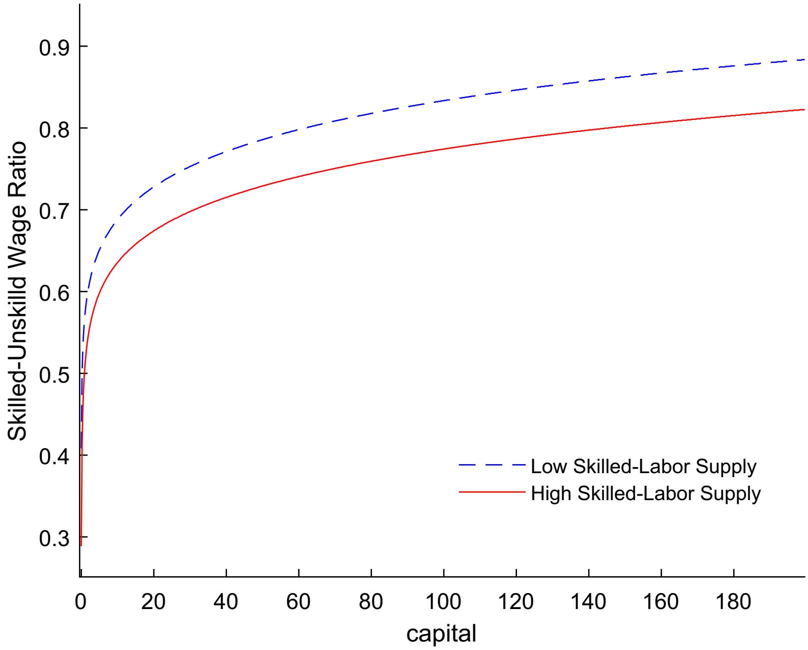

Figure 5. Influence of skilled-labor supply on skilled-unskilled wage inequality.
Note: This Figure illustrates the evolution of the skilled–unskilled wage gap as capital increases, contrasting cases with high and low skilled-labor supply.

trade, such a country will experience a more pronounced increase in its temporal growth rate, as illustrated in Panel B of Figure 4. In essence, with vertical specialization and the global expansion of supply chains, a small economy with skilled-labor scarcity—relative to both capital and unskilled labor—will grow faster than the rest of the world.

As previously outlined and illustrated in Figure 1, the skilled–unskilled wage gap expands as capital increases. Building on the discussion of the impact of skilled-labor scarcity, we show in section 3 that capital accumulation has a more pronounced effect on this wage gap, which is quantified as the ratio of skilled to unskilled-labor wages in a skilled-labor scarce country. Figure 5 contrasts the evolution of this wage gap as capital grows, comparing countries with high and low skilled-labor supply. The figure reveals that the skilled–unskilled wage inequality intensifies more significantly in the country experiencing skilled-labor scarcity as its capital stock expands.

6. Discussion

In this section, we explore a case where unskilled labor is also being uses in sector X or the intermediate M. One way to formulate this extension of our model is by assuming that production takes place in three stages, whereby in one stage skilled-labor services assembled in M and then in stage 2 and 3 unskilled labor is uses along with capital to complete this product. Let A be the share of home skilled labor used in production of M, where $A < 1$ implies that unskilled labor is indeed have been used in M. Let also $\gamma > 1$ be unit Ricardian unskilled-labor demand. Then, it is clearly conceivable that for a sufficiently high unskilled-labor requirement, unskilled labor would not be used at all in this sector, given a unskilled wage to unskilled wage ratio w/w_s. A necessary condition for such a corner solution would be $w/w_s > 1/\gamma$.

If unskilled labor cost is sufficiently high, it will not be used and we will have a corner solution. This can be viewed as a scenario that we maintained so far in the paper. Now what if this is not the case and that we have an interior solution whereby unskilled labor is used? Then, we must modify equation 3 to incorporate the unskilled-labor cost:

$$p_m(\tilde{z}) = w + B(\tilde{z})w_s + [1 - B(\tilde{z})]w_s^* \tag{19}$$

It is evident from equation (19) that our results on growth will hold even when unskilled labor is used in M. Under this scenario, using unskilled labor reduces the unit cost of home components, compared with when unskilled is not used. This is due to what we call internal specialization. These cost savings is in addition to home-foreign external specialization due to the global expansion of supply chain. Hence, as in the previous sections, p_m falls due to expansion of the global supply chain. In a sense, this extended model works exactly like the sector specific technical progress in sector X. As before, a fall in p_m raises the marginal product of capital, which will bring about faster growth.

Moreover, given that unskilled labor is indeed used in M and hence in X, assuming that unit requirement of M in X is unity, we also have:

$$ra_{KX} + p_m = 1 \tag{20}$$

In addition, equilibrium condition in sector Y requires:

$$wa_{LY} + w_s a_{UY} = p_Y \tag{21}$$

We can solve this general equilibrium system to re-derive our results on wages following the same steps as we did in preceding sections. Our conjecture is that the impacts on skilled and unskilled wages and their gap is no longer unambiguous since services of both skilled and unskilled labor are now embedded in X. Hence, the impacts on wages should depend on skilled–unskilled labor intensity rankings. The intuition is rather clear. As p_m falls and, as a result, the marginal product of capital rises (see equation (4)), sector X expands and sector Y contracts by sector X drawing both skilled and unskilled labor from sector Y at the initial wages. If sector X is more skilled-labor intensive (i.e., $S_X/L_X > S_Y/L_Y$), then sector X will demand more (less) skilled (unskilled) labor that sector Y sheds at initial wages. Hence, skilled (unskilled) wage must rise (fall) across the economy given this factor intensity ranking. It then follows that skilled–unskilled wage gap rises if X is more skilled-labor intensive. Notably, this factor intensity ranking condition trivially holds if no unskilled labor is used in M (hence, in X) as in our results of preceding sections. In conclusion, our results of preceding sections hold even if M uses both skilled and unskilled labor so long as the global value chain sector is skilled-labor intensive.

Alternatively, one can formulate the inclusion of unskilled labor in the following way.[8] Suppose GVC is also possible in utilization of the services of unskilled labor in intermediate sector M, also with Ricardian technologies. In particular, as in skilled-labor services, we assume that sector M uses a continuum of unskilled labor services, indexed on $T = [0, 1]$. Let $a_L(\tau)$ and $a_L^*(\tau)$, respectively, be the home and foreign Ricardian unit unskilled-labor requirements for service $\tau \in T$. Then, $\sigma(\tau) \equiv a_L^*(\tau)/a_L(\tau)$, with $\sigma' < 0$, is our measure of comparative advantage ranking for any $\tau \in T$. That is, we formulate fragments produces by unskilled labor exactly as we did for fragments produced by skilled labor globally. Define $\tilde{\tau} \in T$ such that $\sigma(\tilde{\tau}) = w/w^*$, that is, any unskilled fragment $\tau \in [0, \tilde{\tau}]$ will be procured at home while the rest will be imported.

Having modified our sector M in this way, we have to also introduce an equation similar to equation (1) that identifies demand for unskilled labor by sector M:

$$U_M = M \int_0^{\tilde{\tau}} a_L(\tau) d\tau \tag{22}$$

Unskilled-labor market clearing condition will also be similar to equation (2):

$$L_M + L_Y = \bar{L} \tag{23}$$

Next, the equilibrium price of M must also be modified to incorporate costs of both skilled and unskilled labor as

$$p_m(\tilde{z}, \tilde{t}au) = B_S(\tilde{z})w_s + [1 - B_S(\tilde{z})]w_s^* + B_L(\tilde{\tau})w + [1 - B_L(\tilde{\tau})]w^* \quad (24)$$

where $B_S(\tilde{z}) \equiv \int_0^{\tilde{z}} a_S(z)dz$ and $B_L(\tilde{\tau}) \equiv \int_0^{\tilde{\tau}} a_L(\tau)d\tau$. It follows that equations (4) and (5) only need to be modified such that $p_m(\tilde{z}, \tilde{\tau})$ must replace $p_m(\tilde{z})$ in their denominators. A reader easily sees that the rest of our model can easily be modified by adoption of unskilled labor in our model. By now, it is also evident that incorporation of an additional channel for GVC shall reduce the price of M further. Cost saving will be exploited via global fragmentation of unskilled-labor services in addition to those of skilled labor. Our results on growth rates hold. However, the impacts of an opening in GVC on skilled–unskilled wage gap is again ambiguous as in our other alternative formulation that we presented earlier in this section.

Despite ambiguity of effects of GVC opening on wage gap, it is also evident form our first extension which we presented earlier in this section that the impacts on wages would depend on skilled–unskilled labor intensity of the two finished good sectors. Specifically, so long as X is skilled-labor intensive, skilled–unskilled wage gap increases. Therefore, a sufficient condition for our results on wage gap to hold is $B_S(\tilde{z})/B_L(\tilde{\tau}) > a_{SY}/a_{LY}$.

7. Conclusion

We constructed an elaborate general equilibrium model of trade with vertical specialization, whereby two final goods and intermediate, with potential global production fragmentation, are produced. Our objective is to employ this general equilibrium model to study the within country as well as the cross-country consequences of vertical specialization, global production fragmentation on inequality and economic growth. In order to analyze growth consequences, we also cast our general equilibrium model in a growth theoretic framework. We derive a number of interesting results on the within-country divergence and the cross-country convergence (i.e., catch-up hypothesis).

We showed that changes in capital level is consequential for skilled–unskilled wage gap, hence inequality. Our results indicate that global production fragmentation, vertical specialization and trade in fragments will have positive effect on growth. Depending on the endowment differences in skilled labor, catch-up hypothesis may hold true. Hence, our paper contributes to a controversial issue on cross-country convergence by providing a mechanism through which the hypothesis hold, given the conditions of our results. We also showed that global production fragmentation, vertical specialization and trade in fragments cause widening skilled–unskilled wage gap. We also calibrated our model to present numerical analyses that are consistent with our theoretical results.

Our paper can be extended in a number ways. One can include unskilled labor as a factor in production of M and redefine comparative advantage. Moreover, one can endogenize the relative commodity prices with identical and homothetic demand structure. As long as elasticity of substitution in demand is not too low, small country type results should prevail. Yet as another possible extension, non-traded fragments can be introduced as in Beladi and Oladi (2011).

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Notes

1 For extensive review of literature see Krueger and Berg (2003) and Irwin (2019).

2 See also Bandyopadhyay et al. (2020) that consider the impacts of international task fragmentation and offshoring on wages in developed and developing economies.

3 Our paper is related to Feenstra and Hanson (1996) that consider the impacts of global production fragmentation on wage inequality in the USA. They *empirically* studied the impacts of imports of fragments by the United States on wages in the USA. Our paper is first and foremost is a theoretical attempt. Moreover, a central feature of our model is a case of reciprocal outsourcing as in Oladi et al. (2014), but within a dynamic and growth theoretic setup. Home country imports foreign fragments while foreign country imports home fragments. That is, both countries participate in the global value chain. Second, there is a one-shot gain from trade in standard outsourcing models, where outsourcing increases the real income (i.e., the level effect) and there does not exists the growth effects. In contrast, the mechanism is altered in such a way in our setup that outsourcing raises marginal productivity of capital permanently that activates a process of endogenous growth. Put differently, level effect is what trade theory has been focused on. We demonstrate how level effect also leads to growth effect.
4 We are grateful to an anonymous referee for suggesting this.
5 Note that the share of any component $z \in Z$ in M is trivially $a(z)M/M = a(z)$.
6 See Sanyal (1983) and Marjit (1987).
7 To proxy skill for the labor force, we use the secondary education attainment reported by world bank.
8 We are grateful to an anonymous referee for suggesting this extension.

References

Abramovitz, M. (1990) The catch-up factor in postwar economic growth. *Economic Inquiry* 28(1), 1–18.

Acemoglu, D. and P. Restrepo. (June 2018) The race between man and machine: Implications of technology for growth, factor shares, and employment. *American Economic Review* 108(6), 1488–1542. DOI: 10.1257/aer.20160696, https://www.aeaweb.org/articles?id=10.1257/aer.20160696

Antras, P. and E. Helpman. (2004) Global sourcing. *Journal of Political Economy* 112(3), 552–580.

Autor, L. F., H. D. and R. J. Murnane. (2003) The skill content of recent technological change: An empirical exploration. *Quarterly Journal of Economics* 118(4), 1279–1333.

Baily, M. N., C. L. Schultze, D. W. Jorgenson and R. E. Hall. (1990) The productivity of capital in a period of slower growth. *Brookings Papers on Economic Activity. Microeconomics* 1990, 369–420.

Baldwin, R. E. and F. Robert-Nicoud. (2008) Trade and growth with heterogeneous firms. *Journal of International Economics* 74(1), 21–34.

Baldwin, R. E. and G. G. Cain. (2000) Shifts in relative us wages: The role of trade, technology, and factor endowments. *Review of Economics and Statistics* 82(4), 580–895.

Bandyopadhyay, S., A. K. Basu, N. H. Chau and D. Mitra. (2020) Consequences of offshoring to developing nations: Labor-market outcomes, welfare, and corrective interventions. *Economic Inquiry* 58(1), 209–224.

Baumol, W. J. (1986) Productivity growth, convergence, and welfare: What the long-run data show. *The American Economic Review* 76, 1072–1085.

Beladi, H. and R. Oladi. (2011) An elementary proposition on technical progress and non- traded goods. *Journal of Mathematical Economics* 47(1), 68–71.

Bound, J. and G. Johnson. (1989) Changes in the structure of wages in the 1980s: An evaluation of alternative explanations. *NBER* 2983.

Cline, W. R. (1997) *Trade and Income Distribution*. Washington, D.C.: Peterson Institute For International Economics.

Dornbusch, R., S. Fischer and P. A. Samuelson. (1977) Comparative advantage, trade, and payments in a ricardian model with a continuum of goods. *American Economic Review* 67, 823–839.

Eaton, J. and S. Kortum. (2002) Technology, geography, and trade. *Econometrica, ISSN* 70(5), 1741–1779, URL, http://www.jstor.org/stable/3082019

Feenstra, R. and G. Hanson. (1996). Globalization, outsourcing, and wage inequality. *American Economic Review*, 86..

Frankel, J. A. and D. H. Romer. (1999) Does trade cause growth? *American Economic Review* 89(3), 379–399.

Grossman, G. M. and E. Helpman. (1990) Trade, innovation, and growth. *The American Economic Review* 80(2), 86–91.

Grossman, G. M. and E. Rossi-Hansberg. (2008) Trading tasks: A simple theory of offshoring. *American Economic Review* 98(5), 1978–1997.

Hermida, C. C., A. M. A. Santos and M. V. L. Bittencourt. (2022) Do international fragmentation of production and global value chains participation affect the long-run economic growth? *Foreign Trade Review* 57(4), 367–389.

Irwin, D. A. (2019). Does trade reform promote economic growth? A review of recent evidence, National Bureau of Economic Research, Working Paper Series w25927.

Jones, R. W. (1996) International trade, real wages, and technical progress: The specific-factors model. *International Review of Economics and Finance* 5(2), 113–124.

Katz, L. F. and K. M. Murphy. (1992) Changes in relative wages, 1963-1987: Supply and demand factors. *Quarterly Journal of Economics* 107(1), 35–78.

Krueger, A. O. (1999) Trade policy as an input to development. *American Economic Review* 89, 379–399.

Krueger, A. O. and A. Berg. (2003) *Trade, Growth, and Poverty: A Selective Survey.* Washington, D.C.: International Monetary Fund.

Lucas, R. E. (1990) Why doesn't capital flow from rich to poor countries? *American Economic Review* 80, 92–96.

Marjit, S. (1987) Trade in intermediates and the colonial pattern of trade. *Economica* 54(214), 173–184.

Nakanishi, N. and N. V. Long. (2015) The distributional and allocative impacts of virtual labor mobility across time zones through communication networks. *Review of International Economics* 23(3), 638–662.

Nakanishi, N. and N. V. Long. (2020) A new impetus for endogenous growth: R&d offshoring via virtual labor mobility. *Review of International Economics* 28(3), 846–883.

Oladi, R. and H. Beladi. (2008) Non-traded goods, technical progress and wages. *Open Economies Review* 19(4), 507–515.

Oladi, R., H. Beladi and J. Gilbert. (2014) A strategic approach to offshoring. *Economics & Politics* 26(1), 1–12.

Rivera-Batiz, L. A. and P. M. Romer. (1991) Economic integration and endogenous growth. *The Quarterly Journal of Economics* 106(2), 531–555.

Rodriguez, F. and D. Rodrik. (2000) Trade policy and economic growth: A skeptic's guide to the cross-national evidence. *NBER Macroeconomics Annual* 15, 261–325.

Rodrik, D. (1995) Trade and industrial policy reform, *Handbook of Development Economics*, vol. 3, pp. pages 2925–2982.

Sachs, J. D., A. Warner, A.Aslundand S. Fischer. (1995) Economic reform and the process of global integration. *Brookings Papers on Economic Activity* 1(1), 1–118.

Sanyal, K. K. (1983) Vertical specialization in a ricardian model with a continuum of stages of production. *Economica* 50(197), 71–78.

Simonovska, I. and M. E. Waugh. (2014) The elasticity of trade: Estimates and evidence. *Journal of international Economics* 92(1), 34–50.

Winters, L. A. and A. Masters. (2013) Openness and growth: Still an open question? *Journal of International Development* 25(8), 1061–1070.

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