Thema

UMR 8184

THéorie Économique, Modélisation et Applications

THEMA Working Paper n°2015-08
Université de Cergy-Pontoise, France

Technology, Skill, and Growth in a Global Economy

Jaewon Jung

Février 2015

Technology, Skill, and Growth in a Global Economy

Jaewon Jung*

This version: February, 2015†

Abstract

This paper develops an endogenous growth model based on a Roy-like assignment model in which heterogeneous workers endogenously sort into different technologies/tasks according to their comparative advantage. By modeling explicit distinction between worker skills and tasks, as well as incorporating task-specific technologies, worker skill distribution and heterogeneous firms, we analyze in depth the technology-skill-growth and offshoring-growth links that are absent in traditional models of endogenous growth. The model provides therefore richer predictions on the relationship between labor market changes and growth due to technology up- and downgrading mechanism at both individual worker and firm levels.

Keywords: Endogenous growth, Technology-augmented skill distribution, Worker/firm heterogeneity, Offshoring, Skill upgrading/polarization.

JEL codes: F43, F66, J24, O4.

*School of Business and Economics, RWTH Aachen University, Germany, and THEMA, Université de Cergy-Pontoise, France. Corresponding author at: RWTH Aachen University, School of Business and Economics, Templergraben 64, 52056 Aachen, Germany. Tel.: +49 241 80 93339; fax: +49 241 80 92393; e-mail: jung@wiwi.rwth-aachen.de.

†I am grateful to Jean Mercenier, Philippe Martin, Cristina Terra, Gerald Willmann, and Maurizio Zanardi for helpful comments and/or encouragements. I also thank Akihiko Yanase and seminar/conference participants at the IPN Research Seminar, the APTS 2014 Seoul, the International Workshop on Regions, Firms, and FDI in Ghent, the fifth International Conference on Economics of Global Interactions in Bari, the DEGIT XIX Conference in Nashville, and the LACEA-LAMES 2014 São Paulo for their helpful comments and discussions. Any remaining errors are, of course, my own.

1 Introduction

Economists have traditionally considered, among many other factors, technology and skill (or human capital) to be at the heart of economic growth. The emergence of endogenous growth theory in the mid-1980s, in particular, gave further strength to such a view by showing how investment in human capital and/or innovation can lead to a permanent economic growth. While many important technology-growth and/or skill-growth links were studied and revealed separately, however, much less attention has been paid to the interplay between technology and skill to explain growth. Workers choose tasks (or occupations) based on their comparative advantage; and since different tasks (or occupations) require different specific technologies, workers' productivity reflects not only their own skill level but also the task/occupation-specific technology they are employing. While such labor assignment and the induced implications on labor productivity and wage inequality due to the interplay between technology and skill have been at the center of concerns in labor economics since the seminal Roy (1951) model, it has been largely neglected in the endogenous growth literature. If technology would exhibit any increasing returns to skill, equilibrium matching between technology and skill itself would have considerable implications for economic growth.[1]

The technology/task-skill links are especially important in today's globalized economy. The nature of globalization is changing in that today it is occurring at a much finer level of disaggregation. Recent revolutionary advances in transportation and communication technologies are shifting the paradigm from trade in goods to trade in tasks, and production processes increasingly entail different countries to form a global supply chain (see e.g. Baldwin, 2006; Grossman and Rossi-Hansberg, 2008). Furthermore, institutional progresses in many cheap labor countries such as China and India provide increasingly firms in the North with strong new incentives to adopt offshoring strategies and transfer larger parts of their production activities to the South. Even though offshoring has been a focal point in political debates over the last decades (see e.g. Blinder, 2006; Mankiw and Swagel, 2006), the economic consequences are still largely

[1] See e.g. Hsieh, Hurst, Jones and Klenow (2013). They find that 15 to 20 percent of US growth in aggregate labor productivity over 1960 to 2008 can be explained by improved allocation of talent to occupations. See also Kambourov and Manovskii (2008) showing that occupational mobility in the US has increased significantly since the late 1960s.

unanswered. In particular, how offshoring some tasks leads to a task/technology-skill reassignment and thus affects economic growth should be a key question to be addressed, but not yet answered satisfactorily in the literature.

The aim of this paper is to highlight the technology-skill-growth links in a global economy within a unified theoretical framework. For this, we develop an endogenous growth model based on a Roy-like assignment model. A continuum of workers differentiated by their skill level produce different tasks (or intermediate inputs), which are then combined into final goods by firms. Since each task requires a task-specific technology and technologies exhibit increasing returns to skill, workers sort endogenously into different tasks according to their respective comparative advantage. Our multi-task/technology-based model incorporates several features that are absent in canonical models in the endogenous growth literature. First, modeling explicit distinction between worker skills and tasks allows for analyzing how different shocks lead to different reassignments of skills to tasks/technologies and how such task/technology-upgrading and/or -downgrading mechanisms affect economic growth.[2] Second, by explicitly incorporating task-specific technologies and worker skill distribution, we account for "technology-augmented skill distribution" which is fully tractable and endogenously determined by technology-skill matching in equilibrium. Finally, our model incorporates also heterogeneous firms employing different technologies. Two types of firms – high-tech multinational firms and low-tech domestic firms – coexist and compete on the final good market. Our elaborated model – both on the labor market and production side allowing for the interplay between technology and skill – therefore provides much richer predictions on the relationship between labor market and economic growth as well as the effects of globalization (offshoring), which are empirically testable and can not be captured by canonical models in the literature. As we shall show, our multi-task/technology-based heterogeneous worker framework allows for studying in depth the relationship between labor market changes – e.g., task/occupational mobility, la-

[2] Note that traditional models with homogeneous labor (one or two skill groups) are very limited to study the complex labor market changes – e.g. simultaneous sorting up and down of workers on the skill ladder. See e.g. Cortes (2014); testing rigorously Jung and Mercenier's (2014) theoretical model using US panel data, he provides clear evidence of a two-way task/occupational switching pattern of workers – i.e. workers of relatively high (low) skill within a task/occupation are more likely to switch to higher (lower) technology tasks/occupations.

bor productivity and wage inequality – and growth, thus enables also to provide richer predictions on the static and dynamic welfare impacts for different worker groups; our heterogeneous firm framework allows also for studying the technology-growth links on the firm side due to technology-upgrading and/or -downgrading of firms.

Given our setup, we first investigate the impact of increased offshoring due to a fall in offshoring costs. This induces pervasive task/technology-upgrading effects at both individual worker and firm levels, which leads to a pervasive increase in (between-group) income inequality. We identify then four offshoring-and-growth links: (i) redistribution effect, (ii) deindustrialization effect, (iii) technology-upgrading effect, and (iv) South-industrialization effect, of which the first two are anti-growth while the latter two are pro-growth. By pushing up the relative wage of the most skilled workers, offshoring increases also the relative replacement costs of capital (*redistribution effect*); offshoring leads to displacement of manufacturing activities to the South and a contraction of domestic firms (*deindustrialization effect*), which slow down growth. On the other hand, a fall in offshoring costs attracts more domestic firms to adopt high technology and turn to multinationals, thus assigning also more workers to higher tasks and technologies (*technology-upgrading effect*); finally, market size expansion from a rise of income in the South attracts in general more entry of firms so that forward-looking capitalists invest more (*South-industrialization effect*), which enhance growth. We highlight that the latter two pro-growth effects dominate the former two anti-growth effects.

We then investigate the impact of changes in skill distribution. Assuming a log-normal skill distribution, we study in particular two cases: (i) a monotonous rise in the average skill level and (ii) a rise of skill distribution at the two extremes, which we refer to as "skill upgrading" and "skill polarization", respectively. First, we show that skill upgrading induces both task-downgrading (at the lower skill level) and task-upgrading (at the higher skill level), leading to different welfare implications for each group of workers. In this case, if there would be any welfare gainers the least skilled workers would gain the most, while if there would be any welfare losers the middle skilled workers would lose the most. We show also that skill upgrading enhances growth, implying a possible tension between the static and dynamic welfare effects.

Second, differently from the case of skill upgrading we show that skill polarization yields an ambiguous result depending on the initial economy characteristics. Depending on the initial worker skill thresholds relative to the overall skill distribution, skill polarization leads either to (i) task-downgrading (at the lower skill level) and task-upgrading (at the higher skill level) or to (ii) task-upgrading (at the lower skill level) and task-downgrading (at the higher skill level), each of which induces totally different welfare implications. Given the same task/technology-skill matching in equilibrium, case (i) results in the same welfare implications as in the case of skill upgrading, while in case (ii) it would be the middle skilled workers who gain the most if there would be any welfare gainers. Finally, we also highlight the important role of worker skill heterogeneity in explaining the market concentration in a global economy. We show that higher levels of worker skill dispersion are likely to be associated with more multinationals relative to domestic firms – implying more offshoring – unless the initial economy is extremely concentrated on low technology. All of our theoretical discussions are then explored and confirmed by numerical simulations with a parameterized version of the model roughly calibrated on US data. In particular, we show that relatively small negative changes in skill distribution ("skill downgrading") are enough to outweigh the positive scale effects of growth due to population growth, which explains that what matters for economic growth is the population quality, and not the population size.

Our paper contributes to the endogenous growth literature. The main idea of endogenizing long-run growth (e.g. Romer, 1986, 1990; Lucas, 1988; Aghion and Howitt, 1992) has largely been adapted and explored in international trade context too (see e.g. Rivera-Batiz and Romer, 1991a,b; Grossman and Helpman, 1991a,b; Young, 1991). Though the main mechanisms are different, overall they recognize the pro-growth effects of openness.[3] The trade-and-growth links are also examined in North-South trade

[3] These pro-growth effects of openness become less confirmative in recent more sophisticated model setups. Peretto (2003) develops an endogenous growth model with global oligopolists performing in-house R&D, and analyzes the effects of economic integration among identical countries. He finds an ambiguous growth effects of an incremental tariff reduction due to a trade-off between *homogenization effect* – global number of firms falls so that the diversity of innovation paths falls – and *rationalization effect* – the surviving firms become larger and raise R&D spendings under tougher competition. Also, Baldwin and Robert-Nicoud (2008) incorporates heterogeneous firms à la Melitz in a series of endogenous growth models in the literature. He finds an ambiguous growth effects of trade due to a trade-off between $\overline{\kappa}$-*channel effect* – freer trade raises the expected knowledge sunk cost to operate driven by a selection effect à la Melitz – and p_K-*channel effect* – freer trade lowers the price of new knowledge

or foreign direct investment contexts. In this branch of literature, several authors studied the effects of technology transfer from the North and/or imitation from the South, and emphasize the importance of intellectual property rights in explaining growth (see e.g. Helpman, 1993; Dinopoulos and Segerstrom, 2010; Branstetter and Saggi, 2011). All of these works, however, do not address directly the core offshoring issue between North and South, and thus provide little guidance on how today's massive production relocation to cheap labor economies would affect the home country. In our paper, we highlight the offshoring-and-growth links by explicitly modeling technology adoption and market competition between domestic and multinational firms as well as their interaction with labor market. In particular, as mentioned before we highlight the technology-skill-growth links by explicitly modeling and examining the equilibrium matching between technologies and workers of heterogeneous skill.[4]

Our paper is also related to the recent literature on assignment and globalization with heterogeneous workers (see e.g. Grossman and Maggi, 2000; Grossman, 2004; Yeaple, 2005; Antràs, Garicano and Rossi-Hansberg, 2006; Costinot and Vogel, 2010; Helpman, Itskhoki and Redding, 2010; Blanchard and Willmann, 2013; Jung and Mercenier, 2014). Also closely related to the recent firm heterogeneity literature in international trade, this rapidly growing literature studies how globalization, in a general sense, affects equilibrium sorting of heterogeneous workers, and provides rich predictions on worker occupational choice and wage inequality – also, consistently with observations – that were absent in traditional models with homogeneous workers. In terms of labor market modeling approach, the most related to our paper is Yeaple's (2005) where he assumes firm-specific technologies and heterogeneous workers in skill level. In a world of two identical countries, he shows how trade liberalization affects skill premium by reallocation of workers across technologies. In our paper, we study the technology-skill links in an offshoring and endogenous growth context. Furthermore, by explicitly incorporating worker skill distribution, we are able to shed new light

(marginal cost of innovating). The balance of these two effects depends on the model specifications they consider. In this paper, we study the trade-off between two anti-growth effects (*redistribution* and *deindustrialization*) and two pro-growth effects (*technology-upgrading* and *South-industrialization*) in a North-South offshoring context, and show the dominance of the two pro-growth effects.

[4] Though the context is different, Murphy, Shleifer and Vishny (1991) show also the importance of talent allocation for growth when occupations exhibit increasing returns to ability.

on the interplay between technology and skill distribution, and its links to economic growth.

The rest of the paper is organized as follows. In Section 2, we present the basic setup of the model. In Sections 3 and 4, we study the effects of offshoring and changes in skill distribution (skill upgrading and polarization), respectively. Section 5 supplements our theoretical discussions by exploring numerically a parameterized version of the model roughly calibrated on US data. Section 6 concludes with some concluding remarks.

2 Setup of the model

2.1 Demand

The infinitely lived representative consumer in the North has intertemporal preferences:

$$U = \int_{t=0}^{\infty} e^{-\rho t} \ln C_t dt, \tag{1}$$

where $\rho > 0$ is the discount rate and C is the CES consumption aggregate:

$$C = \left[\int_{i \in N} x(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}, \tag{2}$$

where N represents the mass of available varieties and $\sigma > 1$ is the elasticity of substitution between varieties.[5]

Consumer's intertemporal optimization implies a transversality condition and the Euler equation:

$$\dot{E}/E = r - \rho, \tag{3}$$

where r is the nominal interest rate. Taking as given this optimal time path of expenditure and subject to budget constraint $E = \int_{i \in N} p(i)x(i)di$, consumer's optimization yields the instantaneous demand schedule for each variety:

$$x(i) = \left[\frac{P_C}{p(i)} \right]^{\sigma} C, \tag{4}$$

[5] To ease notation, we drop the time index when no confusion can arise.

associated with an aggregate price index:

$$P_C = \left[\int_{i \in N} p(i)^{1-\sigma} di \right]^{\frac{1}{1-\sigma}} . \quad (5)$$

2.2 Production

There is a continuum of firms in the manufacturing sector, each producing a different variety i. Production of any variety requires combining two inputs, $h(i)$ and $m(i)$, which we refer to as headquarter services and intermediate components, respectively. We assume a Leontief production function with units conveniently chosen so that:[6]

$$x(i) = h(i) = m(i). \quad (6)$$

While headquarter services $h(i)$ can be produced only in the North, intermediate components $m(i)$ can be produced in the North and in the South, both inputs produced using labor.

Firms are free to enter the market facing firm-level technological and organizational decisions. First, firms choose an overall managerial technology for headquarter services. There are two technologies for producing $h(i)$, a high-tech (H) and a low-tech (L); we distinguish $h_H(i)$ and $h_L(i)$. Entering the market by adopting either technology incurs technology-specific fixed costs f_H or f_L, where we assume $f_H > f_L$. Second, firms also choose where to produce their intermediate components $m(i)$, domestically in the North or offshored to the South. Domestically there is a single technology (M) for producing $m(i)$. There are no other fixed costs to produce $m(i)$ domestically, but adopting offshoring option bears additional fixed costs f_O including every organizational set-up cost for foreign production (e.g., for searching, monitoring, communication, etc.). The three fixed costs (f_L, f_H and f_O) involve units of knowledge capital developed in the innovation sector. There is now ample evidence that multinationals use more productive technologies than national firms. We assume that only firms using H-technology adopt offshoring strategy and become multinationals, whereas L-

[6] $h(i)$ and $m(i)$ can be viewed as managerial inputs by white-collar (non-production) workers – such as marketing, finance, accounting, etc. – and production of intermediate material inputs by blue-collar (production) workers, respectively, which are not substitutable.

technology firms produce all inputs only domestically. Thus, though born identical, firms will sort in equilibrium between these two types: low-tech non-multinationals (non-MNs) and high-tech multinationals (MNs), associated with f_L and $f_H + f_O$ units of knowledge capital, respectively.

MNs and non-MNs compete on the output market. We assume monopolistic competition to prevail so that firms charge a constant mark-up over marginal production costs. Defining C_M, C_L and C_H as the unit cost of $m(i)$, $h_L(i)$ and $h_H(i)$, respectively, and C_M^* as the unit cost of $m(i)$ when produced in the South,[7] we have from the Leontief technology (6):

$$p_L = \frac{\sigma}{\sigma - 1}\left(C_L + C_M\right) \quad \text{and} \quad p_H = \frac{\sigma}{\sigma - 1}\left(C_H + C_M^*\right). \tag{7}$$

Labor is cheaper in the South:

$$C_M^* < C_M, \tag{8}$$

and further we assume:

$$\frac{C_M^*}{C_M} < \frac{C_H}{C_L}, \tag{9}$$

implying that price advantage of MNs over non-MNs, if any, results relatively more from employing cheap labors in the South.

2.3 Heterogeneous workers

Firms also differ in the types of workers they employ. There is a continuum of workers with unit mass, differentiated by their skill level z. The skill distribution in the population is given by $G(z)$ with density $g(z)$ on support $(0, \infty)$. The productivity of a worker depends not only on his/her own skill level z, but also on the technology he/she employs. Let $\varphi_j(z)$ denote the productivity of a worker with skill z when using technology $j \in \{M, L, H\}$. $\varphi_j(z)$ is continuous and increasing in z at a given technology j. In addition to this absolute advantage property of z, we assume a worker comparative

[7] In what follows, we use an asterisk to denote foreign (South) variables.

advantage in technologies: workers with higher z are relatively more productive when using higher technologies. Formally, we assume that

$$0 < \frac{\partial \varphi_M(z)}{\partial z}\frac{1}{\varphi_M(z)} < \frac{\partial \varphi_L(z)}{\partial z}\frac{1}{\varphi_L(z)} < \frac{\partial \varphi_H(z)}{\partial z}\frac{1}{\varphi_H(z)}, \tag{10}$$

with $\varphi_j(0) = 1$, $j \in \{M, L, H\}$. Note that economy-wide labor productivity is then determined not only by skill distribution but also by technologies. Following Figure 1 illustrates such "*Technology-Augmented Skill Distribution (TASD)*" for each given technology.[8] It should be clear from Eq. (10) that the total labor productivity is higher when all populations use higher technologies in the order of $H > L > M$.

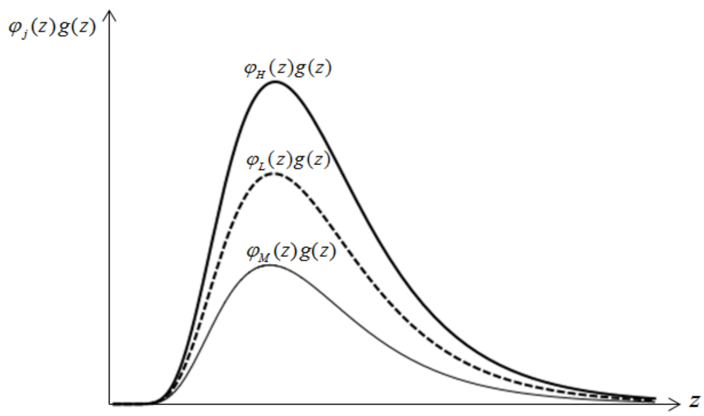


Figure 1: TASD for each given technology j

Assuming in what follows that all three types of technology are used in equilibrium, workers will sort based on their respective comparative advantage. Let z_1 and z_2 be equilibrium skill thresholds with $0 < z_1 < z_2 < \infty$. Then the least skilled workers with $z \in (0, z_1)$ will be employed to produce domestic intermediate components using M-tech, while the middle skilled with $z \in (z_1, z_2)$ and the most skilled with $z \in (z_2, \infty)$ will be hired for headquarter services, in L-tech national firms and H-tech multinationals, respectively. Workers are paid their marginal product so that:

[8] To avoid explosion of labor productivity, we assume, as usual, convergence of $\varphi_j(z)g(z)$ at the extremes: specifically, $\lim_{z\to 0} \varphi_j(z)g(z) = 0$ and $\lim_{z\to\infty} \varphi_j(z)g(z) = 0$, $j \in \{M, L, H\}$.

$$w(z)=\begin{cases} C_M\varphi_M(z), & z\in(0,z_1)\\ C_L\varphi_L(z), & z\in(z_1,z_2)\\ C_H\varphi_H(z), & z\in(z_2,\infty)\,. \end{cases} \tag{11}$$

Finally, note that the economy's TASD would be determined endogenously by skill-technology assignment in equilibrium. Following Figure 2 shows the equilibrium TASD in which the total labor productivity in efficiency units is determined by two skill thresholds z_1 and z_2 in equilibrium.

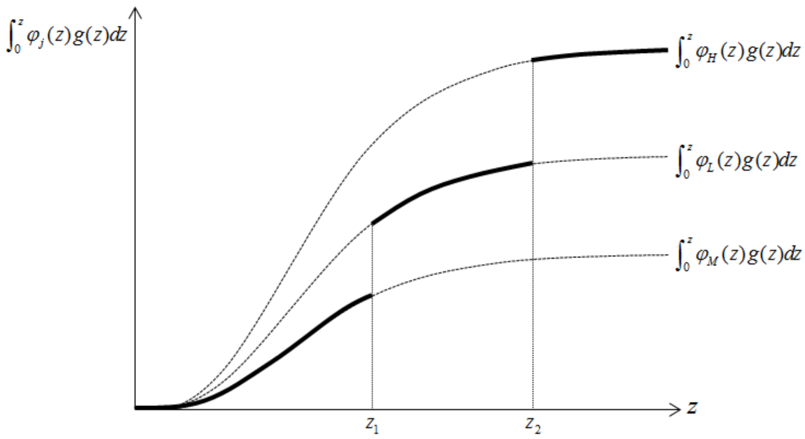


Figure 2: Equilibrium TASD

2.4 Innovation sector

Manufacturing firms bear fixed costs in the form of knowledge capital when entering the market, f_L and f_H+f_O for non-MNs and MNs, respectively. The total stock of knowledge capital K in the North is therefore:

$$K=f_LN_L+(f_H+f_O)N_H, \tag{12}$$

where N_L and N_H denote the number of each firm type. The knowledge capital is developed by a perfectly competitive innovation sector (I-sector) and one unit of K is produced with a_I effective units of labor. Given our heterogeneous worker framework, we now have to specify an I-sector technology. For simplicity, we assume that I-sector workers have access to the most efficient H-tech, rather than adding an additional technology with an additional skill threshold.[9] The unit production cost of K is therefore:

$$C_K = C_H a_I. \tag{13}$$

Further, we assume a sector-wide positive externality (Romer, 1990; Grossman and Helpman, 1991): a_I falls as the cumulative output of I-sector rises. Formally,

$$a_I = \frac{1}{\lambda K}, \tag{14}$$

with λ a parameter. Denoting I-sector's effective labor employment as L_I, the flow of new K is then:

$$Q_K = \frac{L_I}{a_I}. \tag{15}$$

2.5 Instantaneous equilibrium

We begin by working out the instantaneous equilibrium at a given growth rate. Free entry ensures zero profits for both firm types – non-MNs and MNs –, so that mark-up revenues exactly cover the fixed costs:

$$\frac{1}{\sigma} p_L x_L = \pi f_L \quad \text{and} \quad \frac{1}{\sigma} p_H x_H = \pi \left(f_H + f_O \right), \tag{16}$$

where π is the factor reward of K.

Non-MNs produce all inputs only domestically, whereas MNs offshore production of $m(i)$ to the South. From Eq. (6) and I-sector technology, it follows that:

$$\int_0^{z_1} \varphi_M(z) g(z) dz = \int_{z_1}^{z_2} \varphi_L(z) g(z) dz \qquad (non\text{-}MNs) \tag{17}$$

[9] Therefore, the most skilled workers with $z \in (z_2, \infty)$ in Eq. (11) include now MNs' headquarter service workers in the manufacturing sector and knowledge developing workers in the innovation sector.

$$\text{and} \quad \int_{z_2}^{\infty} \varphi_H(z)g(z)dz - L_I = L^* \quad (MNs), \tag{18}$$

where L^* denote the effective labor employment in the South by MNs.

Labor incomes in the North and in the South follow from employment:

$$\begin{aligned} &\widetilde{W} = C_M \int_0^{z_1} \varphi_M(z)g(z)dz + C_L \int_{z_1}^{z_2} \varphi_L(z)g(z)dz + C_H \int_{z_2}^{\infty} \varphi_H(z)g(z)dz, \\ &\widetilde{W}^* = C_M^* L^*. \end{aligned} \tag{19}$$

To avoid unnecessary balance of payment complication, we conveniently assume that labor costs in the South are paid in units of the consumption basket (2) produced only in the North:

$$P_C C = E + E^*. \tag{20}$$

Given our perfectly competitive I-sector making no pure profits, total consumption expenditures are:

$$E = \widetilde{W} + \pi K - C_H L_I \quad \text{and} \quad E^* = \widetilde{W}^*, \tag{21}$$

where $C_H L_I$ is nominal savings/investment.

Now we determine C_M, C_L and C_H, the unit production costs of each input (or technology-specific efficiency wage rates).[10] In a perfectly competitive labor market, no-arbitrage conditions for the threshold workers pin down C_M, C_L and C_H. From Eq. (11) and choosing C_M as our numeraire, we get:

$$\begin{aligned} &C_M = 1 \\ &C_L = C_M \frac{\varphi_M(z_1)}{\varphi_L(z_1)} \\ &C_H = C_L \frac{\varphi_L(z_2)}{\varphi_H(z_2)}. \end{aligned} \tag{22}$$

[10] For analytical tractability and also to focus on the home county (the North) effects, we abstract from labor market adjustments in the South assuming that there is a large enough cheap labor force in the South – i.e. exogenously given C_M^* with $C_M^* < C_M$ and endogenous L^*. Endogenizing C_M^* with fixed L^* would only mitigate the variations of skill thresholds z_1 and z_2 without affecting the main results of the paper as long as conditions (8) and (9) are satisfied (checked also by numerical simulations). C_M^* would also be interpreted to include any trade costs.

Note from Eq. (10) that $C_M > C_L > C_H$, and that C_L and C_H are decreasing respectively in z_1 and z_2. Also note that $p_L > p_H$ from Eqs. (7) and (8). We define for future use:

$$\begin{array}{ll} \alpha_1(z_1) \equiv \frac{\varphi_M(z_1)}{\varphi_L(z_1)}; & \alpha_2(z_2) \equiv \frac{\varphi_L(z_2)}{\varphi_H(z_2)} \\ \text{and} \quad \alpha_1'(z_1) \equiv \frac{\partial \alpha_1(z_1)}{\partial z_1} < 0; & \alpha_2'(z_2) \equiv \frac{\partial \alpha_2(z_2)}{\partial z_2} < 0, \end{array} \tag{23}$$

where a prime indicates a partial derivative: $\alpha_1'(z_1) < 0$ and $\alpha_2'(z_2) < 0$ from Eq. (10). Finally from Eqs. (10), (11) and (22), Figure 3 illustrates the equilibrium skill allocation to different technologies and the resulting equilibrium wage distribution.[11]

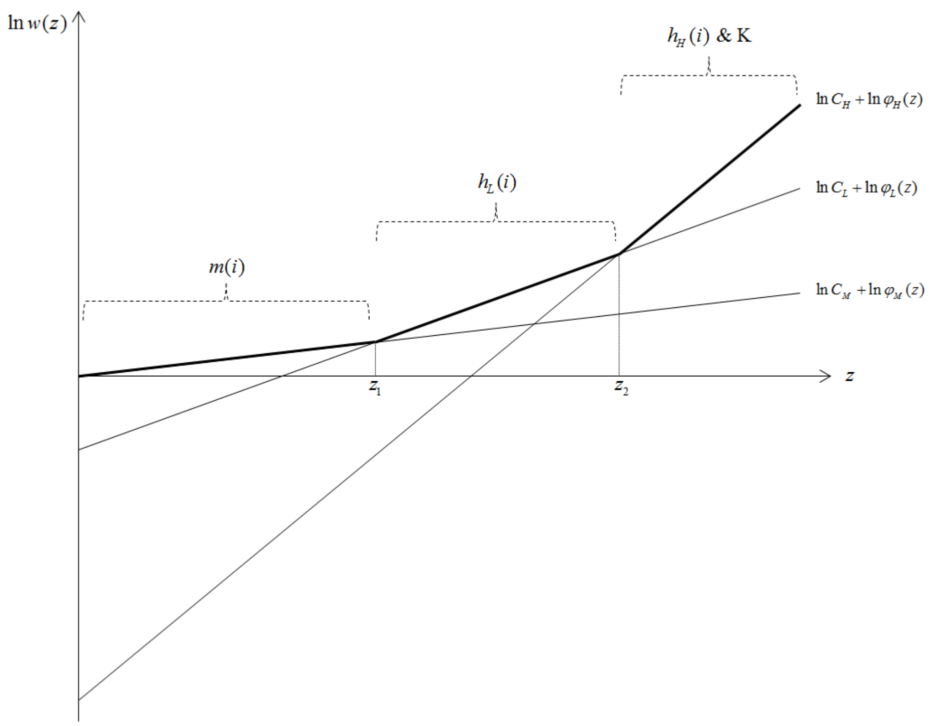


Figure 3: The equilibrium skill allocation and wage distribution

[11]For a graphical simplicity, here log-linear technologies are adopted. Any more general functional forms consistent with Eq. (10), however, could of course be adopted.

2.6 Steady-state growth

Now we solve for steady-state growth rate. Let g be the growth rate of K. From Eqs. (14) and (15), we get:

$$g \equiv \frac{\dot{K}}{K} = \frac{Q_K}{K} = \lambda L_I, \tag{24}$$

which implies from Eq. (12) that N_L and N_H grow at the rate g over time. From Eqs. (12), (16) and (20), K owners are paid firm's operating profit so that:

$$\pi = \frac{E + E^*}{\sigma K}. \tag{25}$$

It then follows from Eqs. (21) and (25) that:

$$E = \frac{\sigma(\widetilde{W} - C_H L_I) + \widetilde{W}^*}{\sigma - 1}. \tag{26}$$

In steady state where $\dot{z_1} = 0$, $\dot{z_2} = 0$ and $\dot{L_I} = 0$, and from Eqs. (17), (18), (19) and (22), Eq. (26) implies $\dot{E} = 0$ in steady state. It readily follows from Eq. (3) that in steady state $r = \rho$. Observe also that $\dot{L_I} = 0$ implies from Eq. (24) that g is time invariant in steady state.

We now proceed to determine the steady-state level of real investment L_I. For this, we rely on Tobin's q method (Tobin, 1969).[12] Tobin's $q = 1$ condition implies that capital's market value equals its replacement cost. The market value of a unit of K is the present value of future income streams π_t. This income stream is discounted at ρ and π falls at the steady-state growth rate g from Eq. (25) so that:

$$V_0 \equiv \int_{t=0}^{\infty} e^{-rt} \pi_t dt = \frac{\pi_0}{\rho + g}. \tag{27}$$

The replacement cost of K is $C_H a_I$ from Eq. (13). Tobin's $q = 1$ condition is then

[12] Tobin's q has been widely used in finance as a proxy for firm performance and for investment opportunities. In our framework where investment is the key to endogenous growth, Tobin's q = 1 condition provides an intuitive and the simplest way to determine the steady-state level of real investment L_I. See Baldwin and Forslid (2000) using this approach to analyze the growth effects of trade liberalization between two symmetric countries, and Baldwin and Robert-Nicoud (2008) for an extension incorporating heterogeneous firms.

from Eqs. (13), (14), (21), (25), (26) and (27):[13]

$$q = \frac{\lambda\left(\widetilde{W} + \widetilde{W}^{*} - C_H L_I\right)}{(\sigma - 1)\,(\rho + g)\,C_H} = 1, \tag{28}$$

which solves for L_I using Eq. (24):

$$L_I = \frac{\widetilde{W} + \widetilde{W}^{*}}{\sigma C_H} - \frac{\rho}{\lambda}\left(\frac{\sigma - 1}{\sigma}\right). \tag{29}$$

Finally, from Eqs. (24) and (29), we solve for the steady-state growth rate:

$$g = \frac{\lambda(\widetilde{W} + \widetilde{W}^{*})}{\sigma C_H} - \frac{\rho(\sigma - 1)}{\sigma}. \tag{30}$$

Note from Eqs. (17), (18), (19), (22) and (30) that the steady-state growth rate is determined by two skill thresholds z_1 and z_2. In the following sessions, we analyze how these two skill thresholds are affected by offshoring decision of firms and changes in skill distribution, which in turn affect steady-state real investment and growth rate.[14]

3 Offshoring

In this section we investigate the impact of increased offshoring – due to a fall in the fixed costs of offshoring ($df_O < 0$) – on growth. Since the steady-state growth rate is determined by two skill thresholds z_1 and z_2 in this model, we start by showing how z_1 and z_2 are affected by a decline in f_O. First it can be shown easily by totally differentiating equilibrium condition (17) – taking account of any changes in f_O at a given skill distribution $G(z)$ – that:

[13] From Eqs. (13) and (27), Tobin's q – the ratio of capital's market value to its replacement cost – equals $\frac{\pi}{(\rho+g)C_H a_I}$. Using Eqs. (14) and (25), we get then $q = \frac{\lambda\left(E+E^{*}\right)}{\sigma(\rho+g)C_H}$. Finally, replacing E using Eq. (26) and E^{*} by $\widetilde{W}^{*}$ from Eq. (21) leads to $q = \frac{\lambda\left(\widetilde{W}+\widetilde{W}^{*}-C_H L_I\right)}{(\sigma-1)(\rho+g)C_H}$, which should be equal to one in steady state.

[14] Obviously, the model lacks transitional dynamics (jumps from one steady state to another) with our focus on the steady-state growth effects of policy and/or parameter changes. See Baldwin and Forslid (2000) proving, however, that there is a unique and interior steady-state value of L_I in this type of model, which assures that the model is always in steady state regardless of the transitional dynamics. The steady-state level of L_I is directly associated with steady-state thresholds z_1 and z_2 in our framework.

$$\frac{dz_1}{dz_2} = \frac{\varphi_L(z_2)g(z_2)}{\varphi_M(z_1)g(z_1) + \varphi_L(z_1)g(z_1)} > 0, \tag{31}$$

so that z_1 and z_2 move in the same direction. The reason behind is straightforward: an expansion of total employment in H-activities by any reason ($dz_2 < 0$) at a given $G(z)$ implies a contraction of aggregate activity by non-MNs, which leads to a decline in employment for domestic production of $m(i)$ ($dz_1 < 0$). Similarly, $dz_2 > 0$ implies $dz_1 > 0$. Consider next the revenue ratio between MNs and non-MNs. From Eq. (16) and combining Eqs. (4), (7) and (23), we get:

$$\frac{C_H + C_M^*}{C_L + C_M} \equiv \frac{\alpha_1(z_1)\,\alpha_2(z_2) + C_M^*}{\alpha_1(z_1) + C_M} = \left[\frac{f_H + f_O}{f_L}\right]^{\frac{1}{1-\sigma}}. \tag{32}$$

Note that the total marginal cost ratio is constant at the ratio of fixed costs.

We now consider a change in f_O. Totally differentiating Eqs. (17) and (32) leads immediately to following proposition.

Proposition 1 *A fall in f_O decreases two skill thresholds z_1 and z_2: $\frac{dz_1}{df_O} > 0$ and $\frac{dz_2}{df_O} > 0$.*

Proof. *See Appendix A.1.* ■

Then from Eqs. (22) and (23), following corollary is immediate.

Corollary 1 *A fall in f_O increases unit production costs so that: $\frac{dC_L}{df_O} < 0$, $\frac{dC_H}{df_O} < 0$ and $\frac{d\left(\frac{C_H}{C_L}\right)}{df_O} < 0$.*

Note from Eq. (32) that a fall in C_M^* – unit cost of $m(i)$ in the South including any trade costs – at given fixed costs ratio leads also to identical qualitative effects. Figure 4 illustrates the induced changes.

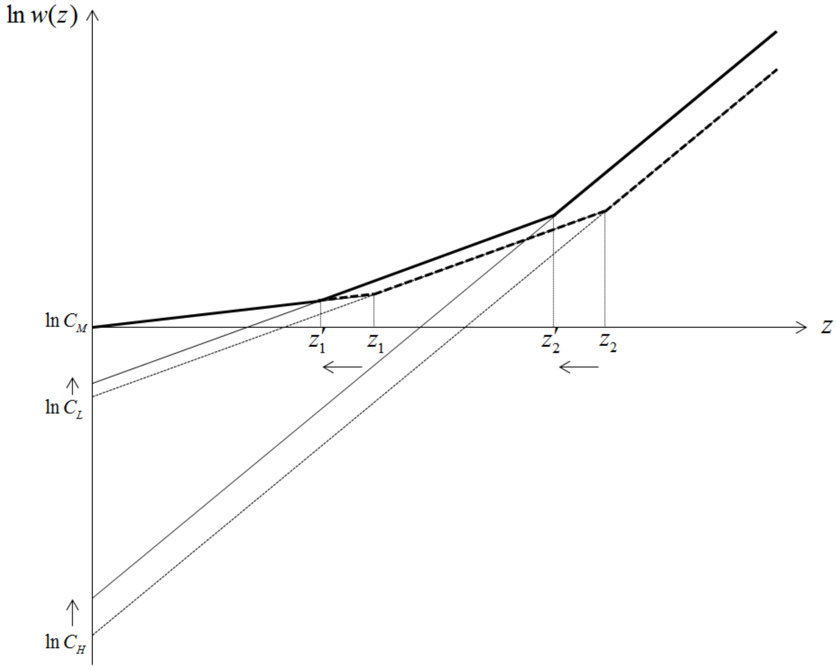


Figure 4: The effects of a fall in f_O on the equilibrium wage distribution

Observe that a fall in f_O generates technology-upgrading mechanisms at both individual worker and firm levels. First, workers with skill $z \in (z_1', z_1)$ – initially associated with M technology to produce intermediate components – are now matched with higher (L) technology within the same non-MNs. Similarly, workers with skill $z \in (z_2', z_2)$ – initially associated with L technology within non-MNs – are now matched with the highest (H) technology within MNs and/or I-sector. All these technology-upgrading mechanisms induce a monotonous rise in relative wages across workers of different skill (Corollary 1). Second, both decreases in z_1 and z_2 imply technology-upgrading of firms. A fall in f_O attracts more domestic firms to adopt high technology and turn to multinationals.

Now we consider growth effects of offshoring. For this, we focus again on the steady-state level of real investment L_I. From Eqs. (17), (18), (19) and (29), we have:

$$L_I = \frac{1}{\sigma}\left[\frac{C_L + C_M}{C_H}\int_0^{z_1}\varphi_M(z)g(z)dz + \int_{z_2}^{\infty}\varphi_H(z)g(z)dz + \frac{C_M^*}{C_H}L^*\right] - \frac{\rho}{\lambda}\left(\frac{\sigma-1}{\sigma}\right). \tag{33}$$

From Eq. (33) we can identify four offshoring-and-growth links: *(i) redistribution effect*; *(ii) deindustrialization effect*; *(iii) technology-upgrading effect; (iv) South-industrialization effect.*

(i) A redistribution effect is associated with the terms $\frac{C_L+C_M}{C_H}$ and $\frac{C_M^*}{C_H}$, where the first represents domestic redistribution and the second represents international redistribution with respect to the South, respectively. An increased offshoring raises the relative wage of the most skilled workers (Corollary 1) so that the relative replacement cost of capital increases from Eq. (13). By this channel, offshoring harms growth.

(ii) A deindustrialization effect is associated with the term $\int_0^{z_1}\varphi_M(z)g(z)dz$, representing the total domestic production of intermediate components. Offshoring leads to displacement of manufacturing activities to low-cost countries and a contraction of domestic firms (a fall in z_1). The induced decrease in capital demand affects negatively the real investment and growth rate.

(iii) A technology-upgrading effect is associated with the term $\int_{z_2}^{\infty}\varphi_H(z)g(z)dz$, representing the aggregate activity by H-tech firms. A fall in f_O makes offshoring option more attractive so that more domestic firms adopt high technology and turn to multinationals (a fall in z_2). More adoption of high-fixed-cost low-marginal-cost technology leads to higher demand for capital and hence boosts real investment and growth.

(iv) A South-industrialization effect is associated with L^*, representing the total production of intermediate components offshored to the South (and/or the total effective employment by MNs in the South). A rise in income in the South due to displacement of manufacturing activities attracts more entry of firms. This market size expansion and the induced increase in capital demand, in turn, contribute positively to growth.[15]

Proposition 2 *We identify four offshoring-and-growth effects: (i) redistribution, (ii) deindustrialization, (iii) technology-upgrading, and (iv) South-industrialization, of which the first two slow growth while the latter two stimulate it.*

[15] A formal derivation of $\frac{dL^*}{df_O} < 0$ can also be found in Appendix A.3.

The relative dominance of the two forces (pro- vs. anti-growth) can be analyzed given the variations of two skill thresholds: $\frac{dz_1}{df_O} > 0$ and $\frac{dz_2}{df_O} > 0$ (Proposition 1). From Eqs. (18) and (23), Eq. (33) can be rewritten:

$$
\begin{aligned}
L_I = \left[\tfrac{\alpha_1(z_1)+C_M}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right] \textstyle\int_0^{z_1} \varphi_M(z)g(z)dz \\
+ \left[\tfrac{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right] \textstyle\int_{z_2}^{\infty} \varphi_H(z)g(z)dz \\
- \tfrac{\rho(\sigma-1)\alpha_1(z_1)\alpha_2(z_2)}{\lambda\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]}.
\end{aligned}
\tag{34}
$$

Totally differentiating Eq. (34) and using Eq. (31), we find $\frac{dL_I}{dz_2} < 0$. From Proposition 1, the following proposition is then immediate.

Proposition 3 *A fall in f_O increases the steady-state level of real investment L_I, and thus enhances growth.*

Proof. *See Appendix A.2.* ■

Finally, we turn to welfare implications of offshoring. For this, we consider first the market concentration effects of a fall in f_O. From Eqs. (6), (17) and (18), we have:

$$
\begin{aligned}
&\textstyle\int_0^{z_1} \varphi_M(z)g(z)dz = x_L N_L, \\
&\textstyle\int_{z_2}^{\infty} \varphi_H(z)g(z)dz - L_I = x_H N_H,
\end{aligned}
\tag{35}
$$

and from Eqs. (7) and (16):

$$
x_L = \frac{(\sigma-1)\pi}{C_L + C_M} f_L \quad \text{and} \quad x_H = \frac{(\sigma-1)\pi}{C_H + C_M^*}(f_H + f_O). \tag{36}
$$

From Eqs. (35) and (36), the number of each firm type is then:

$$
\begin{aligned}
N_L &= \tfrac{C_L+C_M}{(\sigma-1)\pi f_L} \textstyle\int_0^{z_1} \varphi_M(z)g(z)dz, \\
N_H &= \tfrac{C_H+C_M^*}{(\sigma-1)\pi(f_H+f_O)} \left(\textstyle\int_{z_2}^{\infty} \varphi_H(z)g(z)dz - L_I\right),
\end{aligned}
\tag{37}
$$

from which and using Eq. (32), we get finally:

$$
\frac{N_H}{N_L} = \left(\frac{f_L}{f_H + f_O}\right)^{\frac{\sigma}{\sigma-1}} \frac{\int_{z_2}^{\infty} \varphi_H(z)g(z)dz - L_I}{\int_0^{z_1} \varphi_M(z)g(z)dz}. \tag{38}
$$

From Propositions 1 and 3, and Corollary 1, following proposition is then immediate:

Proposition 4 *A fall in f_O increases N_H and decreases N_L so that $\frac{N_H}{N_L}$ increases.*

Proof. *See Appendix A.3.* ■

Adopting high technology and turning to multinationals require higher fixed costs than remaining low-tech domestic firms. This implies from Eq. (12) a reduction in the total number of varieties at a given total capital stock K at the given moment of time, which has a negative impact on welfare. Given the two firm types and from Eq. (7), the aggregate consumption price index (5) can be written as:

$$P_C = \frac{\sigma}{\sigma - 1}\left[N_L\left(C_L + C_M\right)^{1-\sigma} + N_H\left(C_H + C_M^*\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{39}$$

We have shown that an increased offshoring raises unit production costs (Corollary 1) so that both p_L and p_H increase. Also, a reduction in the total number of varieties $(N_L + N_H)$ has a force to increase P_C. The only P_C-decreasing force comes from the technology-upgrading effects: a fall in f_O attracts more domestic firms to turn to high-tech multinationals and produce cheaper ($p_H < p_L$). Thus, it is likely that P_C increases, except only if there are large enough technology-upgrading effects so as to dominate all the other P_C-increasing forces. If P_C increases, this implies that the least skilled workers associated with M technology lose inevitably in terms of their real income. Such static welfare loss, if any, however, does not necessarily mean a dynamic welfare loss. As shown in Proposition 3, a rise in growth rate implies that there can be a tension between the dynamic and static welfare effects even if an increased offshoring might affect negatively some skill group workers in a static perspective. In Section 5, we address this question by exploring numerically a parameterized version of the model roughly calibrated on US data.

4 Skill distribution

Our analyses so far have been based on a given skill distribution $G(z)$. In this section we shift the focus to the role of worker heterogeneity, and explore the link between skill distribution and growth. For this, we assume a log-normal skill distribution:[16]

[16] Since Gibrat (1931), the most commonly used functional form in applied research to approximate the distribution of income has been the log-normal function: see e.g., Bourguignon (2003). Any other

$$g(z) = \frac{1}{z\sqrt{2\pi}\varepsilon} e^{-\frac{(\ln z - \mu)^2}{2\varepsilon^2}}, \qquad z \in (0, \infty) \tag{40}$$

with two parameters μ and ε characterizing the moments of distribution. Both parameters govern the mean $e^{\mu+\frac{\varepsilon^2}{2}}$ and variance $\left(e^{\varepsilon^2} - 1\right) e^{2\mu+\varepsilon^2}$ of skill distribution, while ε determines the skewness $\left(e^{\varepsilon^2} + 2\right) \sqrt{e^{\varepsilon^2} - 1}$ of the distribution. For any further analyses, we also need to specify our three technologies. We assume linear technologies consistent with Eq. (10):[17]

$$\varphi_j(z) = 1 + a_j z, \qquad j \in \{M, L, H\}. \tag{41}$$

Given our assumptions, we now investigate the impact of changes in skill distribution on growth – specifically, the impact of changes in the two parameters μ and ε. An increase in μ raises the dispersion of worker skill heterogeneity and the average skill level rises in a monotonous way: i.e., less least-skilled and more highest-skilled. On the other hand, an increase in ε not only raises both dispersion and mean, but also affects the skewness so that the distribution rises at the two extremes: i.e., more least-skilled and highest-skilled, and less middle-skilled. We refer to the former as "skill upgrading", and the latter as "skill polarization".[18] As one might guess, introducing skill distribution and working out TASD makes it much more complex to derive any analytical results. To make the subsequent analyses tractable and meaningful, we restrict our attention to the realistic cases. Specifically, we make the following assumptions on the skill distribution and the initial economy.

Assumption 1 *The initial threshold skill level to be assigned for headquarter services is greater than the median of the skill distribution: i.e.,* $z_1 > e^{\mu}$.

Assumption 2 *The initial threshold skill level to be assigned for the highest (H) technology is high enough in the distribution. Specifically,* $z_2 - e^{\mu+\varepsilon^2} > \left| z_1 - e^{\mu+\varepsilon^2} \right|$.

functional forms, however, could of course be adopted, which leads to the same qualitative results.

[17] This simple functional form not only is consistent with Eq. (10), but also allows for integrability with log-normal skill distribution as well as satisfies convergence conditions at the extremes.

[18] In this paper we focus on how exogenous changes in skill distribution lead to a skill-technology reassignment (i.e. endogenous TASD), and not on the endogenous skill acquisition process. Such exogenous changes can be viewed as resulting from various policy changes (e.g., education, immigration, industry restructuring, trade, etc.).

These two reasonably mild assumptions are not essential for our results, but as will be shown prove sufficient to derive some clear-cut results.[19]

4.1 Skill upgrading

Here we study the impact of an increase in μ on growth. For this, again we begin by considering how two skill thresholds z_1 and z_2 are affected by such change. Taking account of any changes in the skill distribution $G(z)$ at given fixed costs, the relative changes of z_1 and z_2 can easily be shown by totally differentiating Eq. (32):

$$\frac{dz_1}{dz_2} = \frac{\alpha_1(z_1)\,\alpha_2'(z_2)\,[\alpha_1(z_1) + C_M]}{\alpha_1'(z_1)\left[C_M^* - \alpha_2(z_2)\,C_M\right]} < 0, \tag{42}$$

which is negative from Eqs. (9) and (23). Note that this bidirectional movement of z_1 and z_2 is different from what we had in the case of offshoring. At constant fixed costs – which was not the case for offshoring – if there would be any changes in the total marginal production cost of both competing firm types, z_1 and z_2 would move in opposite directions to recover the equilibrium total marginal cost ratio.

The impact of a rise in μ on respective z_1 and z_2 can be obtained again by totally differentiating Eqs. (17) and (32), where Eq. (17) is now specified from Eqs. (40) and (41):

$$\begin{aligned}&\left(1 + a_M e^{\mu+\frac{\varepsilon^2}{2}}\right) - \operatorname{erf}\left(\tfrac{\mu-\ln z_1}{\sqrt{2}\varepsilon}\right) - a_M e^{\mu+\frac{\varepsilon^2}{2}} \operatorname{erf}\left(\tfrac{\mu+\varepsilon^2-\ln z_1}{\sqrt{2}\varepsilon}\right)\\ &= \left[\operatorname{erf}\left(\tfrac{\mu-\ln z_1}{\sqrt{2}\varepsilon}\right) - \operatorname{erf}\left(\tfrac{\mu-\ln z_2}{\sqrt{2}\varepsilon}\right)\right] + a_L e^{\mu+\frac{\varepsilon^2}{2}} \left[\operatorname{erf}\left(\tfrac{\mu+\varepsilon^2-\ln z_1}{\sqrt{2}\varepsilon}\right) - \operatorname{erf}\left(\tfrac{\mu+\varepsilon^2-\ln z_2}{\sqrt{2}\varepsilon}\right)\right].\end{aligned} \tag{43}$$

The following proposition then follows.

Proposition 5 *A rise in μ increases z_1 and decreases z_2: $\frac{dz_1}{d\mu} > 0$ and $\frac{dz_2}{d\mu} < 0$.*
Proof. *See Appendix A.4.* ■

The intuition is fairly straightforward. For given z_2, a rise in μ induces relatively more L workers (relative to M workers), which results in a rightward shift of z_1. This induces a relative cost advantage of MNs over non-MNs from Eqs. (9), (22) and (23).

[19] In our calibrated model to US data in Section 5, we have: $e^{\mu} < e^{\mu+\varepsilon^2} < z_1 < z_2$.

This cost advantage then induces more entry of MNs (and/or technology upgrading of firms: N_L to N_H) – a leftward shift of z_2 (with z_1 therefore shifted back to the left) – until the equilibrium cost ratio, Eq. (32), is restored. From Eqs. (22), (23) and (32), following corollary is then immediate.

Corollary 2 *A rise in μ changes unit production costs so that:* $\frac{dC_L}{d\mu} < 0$, $\frac{dC_H}{d\mu} < 0$ *and* $\frac{d\left(\frac{C_H}{C_L}\right)}{d\mu} > 0$.

Figure 5 illustrates the induced changes.

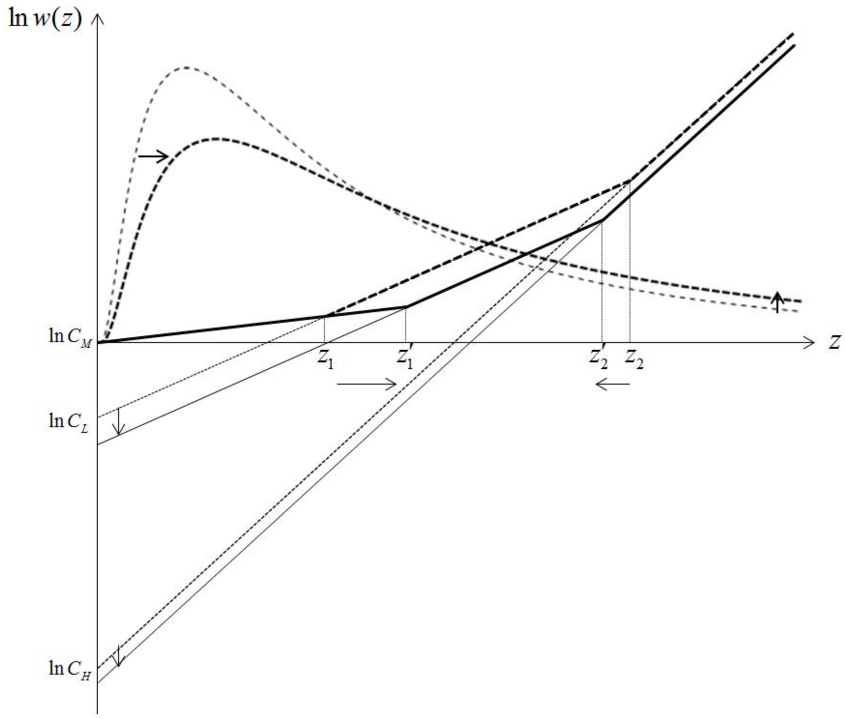


Figure 5: The effects of a rise in μ on the equilibrium wage distribution

Observe that differently from the case of offshoring, in this case we have both technology-upgrading and -downgrading of individual workers. Workers with skill $z \in (z_1, z_1')$ – initially associated with L technology supplying headquarter services – are now matched with lower (M) technology and produce intermediate components within the same non-MNs, whereas workers with skill $z \in (z_2', z_2)$ upgrade their technology and are employed by MNs and/or I-sector. A contraction of aggregate activity by non-MNs and an expansion of aggregate activity by MNs and/or I-sector due to a rise in μ imply again technology-upgrading of firms.

Given such changes, we now investigate growth effects of a rise in μ. The final growth effects can easily be conjectured in this case. We study again Eq. (34). From Proposition 5, Corollary 2, and Eq. (32), we know that all terms in Eq. (34) influence positively except only for the term $\int_0^{z_1} \varphi_M(z)g(z)dz$ possibly decreasing in μ.[20] This negative force, if any, should, however, be dominated by a positive force from $\int_{z_2}^{\infty} \varphi_H(z)g(z)dz$.[21] Finally we have the following proposition immediately.

Proposition 6 *A rise in μ increases the steady-state level of real investment L_I, and thus enhances growth.*

Skill upgrading at a given population should be isomorphic to labor-augmenting technological progress, as in the case of offshoring with access to cheap labor. Both contribute to an aggregate productivity increase, and thus enhance growth. The welfare implications of skill upgrading should, however, be quite different from those of offshoring. Let us study again the aggregate consumption price index (39). Differently from the case of offshoring, a rise in μ reduces unit production costs (Corollary 2) so that both p_L and p_H decrease. In this case, the only P_C-increasing force comes from a reduction in the total number of varieties.[22] Thus, it is likely that P_C decreases, except only if σ is small enough – i.e., except only if varieties are strongly differentiated – to dominate all the other P_C-decreasing forces. If P_C decreases, note from Corollary 2 that it is now the least skilled workers associated with M technology who gain the most. And it is the middle skilled workers associated with L technology who lose the

[20] Note from Eq. (32) that $dC_H < 0$ increases the first bracket, $\left[\frac{C_L+C_M}{\sigma C_H + C_M^*}\right]$, of Eq. (34). $dC_H < 0$ leads also to a rise in the second bracket, $\left[\frac{C_H+C_M^*}{\sigma C_H + C_M^*}\right]$, while the last term, $\frac{\rho(\sigma-1)C_H}{\lambda\left[\sigma C_H + C_M^*\right]}$, decreases. On the other hand, the impact on $\int_0^{z_1} \varphi_M(z)g(z)dz$ is analytically ambiguous, though it is more likely to decrease: see Appendix A.5.

[21] Note from Eq. (10) that $\frac{d\int_{z_2}^{\infty} \varphi_H(z)g(z)dz}{d\mu} > \left|\frac{d\int_0^{z_1} \varphi_M(z)g(z)dz}{d\mu}\right|$.

[22] As in the case of offshoring, technology upgrading of firms reduces the total number of firms since adopting high technology requires higher knowledge capital. From Eq. (12), $N_L + N_H$ decreases at a given total capital stock K at the given moment of time.

most (or gain the least). Though the middling workers might lose in a static sense, this does not necessarily mean from Proposition 6 that they lose in a dynamic sense too. We investigate this by numerical explorations in Section 5.

4.2 Skill polarization

In this subsection we briefly discuss the effects of an increase in ε. A rise in ε leads also to a more dispersed skill distribution with higher mean as in the case of a rise in μ. This, however, also affects the skewness so that the distribution rises at the two extremes. Thus, a rise in ε induces a skill polarization at a given population, with more least-skilled and highest-skilled workers, and less middle-skilled workers.[23] In this case, the effects on the two skill thresholds z_1 and z_2 are not as clear as in previous cases. The negative relationship between z_1 and z_2 from Eq. (42) still holds, but the impacts on respective z_1 and z_2 are ambiguous. They would depend on initial relative positions of z_1 and z_2. At given z_1 and z_2, if a rise in ε would induce relatively more L workers (relative to M workers), we would have $dz_1 > 0$ and $dz_2 < 0$. Contrarily, if a rise in ε would induce relatively more M workers (relative to L workers) at given z_1 and z_2, we would have inverse movements of z_1 and z_2: $dz_1 < 0$ and $dz_2 > 0$. This implies that depending on initial relative positions of z_1 and z_2, we might also have nonlinear movements of z_1 and z_2. Thus, in this case we may have two possible outcomes for changes in unit production costs. From Eqs. (22), (23) and (32), following proposition establishes.

Proposition 7 *A rise in ε leads to two possible outcomes depending on initial relative positions of z_1 and z_2: (i) $\frac{dz_1}{d\varepsilon} > 0$ and $\frac{dz_2}{d\varepsilon} < 0$; $\frac{dC_L}{d\varepsilon} < 0$, $\frac{dC_H}{d\varepsilon} < 0$ and $\frac{d\left(\frac{C_H}{C_L}\right)}{d\varepsilon} > 0$, or (ii) $\frac{dz_1}{d\varepsilon} < 0$ and $\frac{dz_2}{d\varepsilon} > 0$; $\frac{dC_L}{d\varepsilon} > 0$, $\frac{dC_H}{d\varepsilon} > 0$ and $\frac{d\left(\frac{C_H}{C_L}\right)}{d\varepsilon} < 0$.*

Figure 6 illustrates the two possible cases.

[23] Though most industrialized countries have been characterized by skill upgrading (increase of skilled labor supply) since World War II, there is now ample evidence that labor markets have been polarizing at the extremes of the skill distribution in most developed countries since the early 1990s, which is known as job polarization literature in labor economics. See Jung and Mercenier (2014) and references therein.

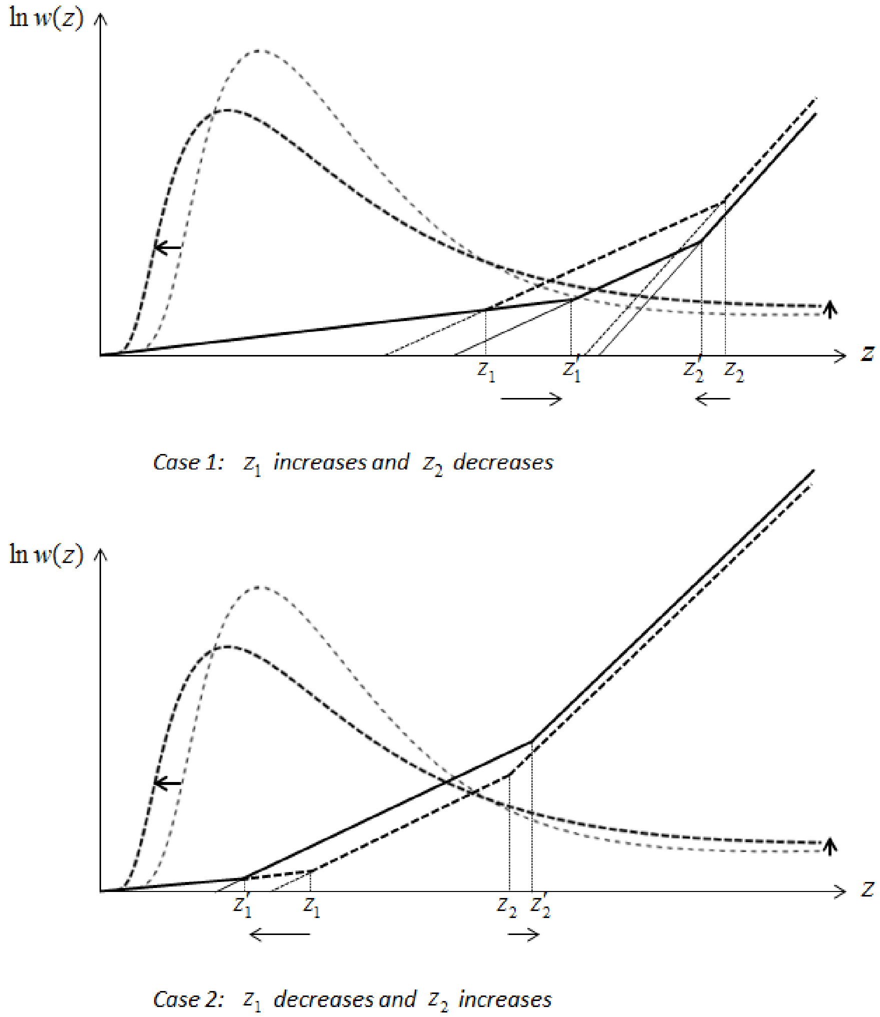


Figure 6: The effects of a rise in ε on the equilibrium wage distribution

In the Case 1, a rise in ε induces finally the same effects as a rise in μ. A rise in ε would increase the steady-state level of real investment and enhance growth for the same reasons as in the case of a rise in μ. And if there would be any welfare gainers the least skilled workers associated with M technology would be the main beneficiaries, while if there would be any welfare losers the middle skilled workers associated with L technology would be the main victims. In the Case 2, however, we have again completely different welfare implications. In this case, if there would be any welfare gainers the middle skilled workers associated with L technology would be the main beneficiaries, while if there would be any welfare losers the least skilled workers associated with M technology would be the main victims. In either case, however, even if some skill group workers might be affected negatively in terms of their real income, it does not necessarily mean that they lose in a dynamic perspective too. Since such full welfare implications are difficult to derive analytically, we address this question numerically in Section 5.

4.3 Skill heterogeneity and offshoring

Before proceeding to numerical simulations, in this subsection we briefly discuss the role of worker skill heterogeneity in explaining the market concentration and the relationship with offshoring. Specifically, we consider how an increase in μ – i.e. higher skill dispersion at a given skewness – affects the relative market concentration ratio. Given our specification of technologies (41) and skill distribution (40), Eq. (38) can now be written as:

$$\frac{N_H}{N_L} = \left(\frac{f_L}{f_H + f_O}\right)^{\frac{\sigma}{\sigma-1}} \frac{F_2(a_M, a_H, \mu, \varepsilon, z_1, z_2)}{F_1(a_M, \mu, \varepsilon, z_1)}, \tag{44}$$

where the denominator is:

$$F_1(a_M, \mu, \varepsilon, z_1) = \frac{1}{2}\left[\left(1 + a_M e^{\mu+\frac{\varepsilon^2}{2}}\right) - \text{erf}\left(\frac{\mu - \ln z_1}{\sqrt{2}\varepsilon}\right) - a_M e^{\mu+\frac{\varepsilon^2}{2}} \text{erf}\left(\frac{\mu + \varepsilon^2 - \ln z_1}{\sqrt{2}\varepsilon}\right)\right],$$

and using Eq. (34) the numerator is:

$$\begin{aligned} F_2(a_M, a_H, \mu, \varepsilon, z_1, z_2) = \\ \left[\frac{(\sigma-1)\alpha_1(z_1)\alpha_2(z_2)}{2\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]}\right] \cdot \left[\left(1 + a_H e^{\mu+\frac{\varepsilon^2}{2}}\right) + \text{erf}\left(\frac{\mu-\ln z_2}{\sqrt{2}\varepsilon}\right) + a_H e^{\mu+\frac{\varepsilon^2}{2}} \text{erf}\left(\frac{\mu+\varepsilon^2-\ln z_2}{\sqrt{2}\varepsilon}\right)\right] \\ - \left[\frac{\alpha_1(z_1)+C_M}{2\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]}\right] \cdot \left[\left(1 + a_M e^{\mu+\frac{\varepsilon^2}{2}}\right) - \text{erf}\left(\frac{\mu-\ln z_1}{\sqrt{2}\varepsilon}\right) - a_M e^{\mu+\frac{\varepsilon^2}{2}} \text{erf}\left(\frac{\mu+\varepsilon^2-\ln z_1}{\sqrt{2}\varepsilon}\right)\right] \\ + \frac{\rho(\sigma-1)\alpha_1(z_1)\alpha_2(z_2)}{\lambda\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]}. \end{aligned}$$

Though it might be ex ante plausible that an increase in μ (skill upgrading) would increase relative market share of high-skill intensive MNs, it is analytically ambiguous which depends on the skill distribution as well as initial positions of z_1 and z_2 in the distribution. The possible outcomes are summarized in the following proposition.

Proposition 8 *A rise in μ – higher dispersion of skill heterogeneity – is likely to increase $\frac{N_H}{N_L}$; but if the initial economy would be highly concentrated on low technology (i.e. if initial z_1 and z_2 are located around the right tail of the distribution), $\frac{N_H}{N_L}$ might decrease.*

Proof. *See Appendix A.5.* ■

Intuitively, the higher the initial z_1 and z_2 are, the more the induced skill upgrading effects are absorbed in domestic firms. Furthermore, MNs are in competition with I-sector for the most skilled workers. Since a rise in μ increases L_I (Proposition 6), MNs may be squeezed between domestic firms and I-sector. How much realistic this extreme case is should, of course, be an empirical question. As discussed in Appendix A.5, we may plausibly conclude that a rise in μ is likely to increase N_H/N_L and leads to increased offshoring. The model's prediction on the link between skill heterogeneity and offshoring might, however, be potentially interesting to test empirically. Skill upgrading might not necessarily lead to a rise in the relative market share of high-tech firms depending on the initial relative technology intensity of the economy: the more the initial economy would be concentrated on low technology, the more any positive skill upgrading effects on high-tech firms would be dampened in favor of their low-tech competitors. On the other hand, note that in the case of an increase in ε (skill polarization), above possibility of high absorption of skill upgrading effects in non-MNs does not occur. Since a rise in ε increases the distribution at the two extremes, this leads to skill downgrading within non-MNs and skill upgrading within MNs, which would ensure a rise in N_H/N_L. To supplement our theoretical discussions, we now turn to numerical simulations in the next section.

5 A numerical appraisal

5.1 Calibration

In this section we illustrate our theoretical discussions with numerical simulations. To get a feeling of the quantitative effects involved, we roughly calibrate the model on US data. We set $\rho = 0.05$ for the discount rate and $\sigma = 4$ for the elasticity of substitution between varieties. Empirical evidence on the level of fixed costs is scarce but it seems reasonable that the ratio of fixed costs for a vertically fragmented firm to those for a domestic firm lies between 1 and 2 (Markusen, 2002); we choose the following relative fixed costs: $f_L = 1.00$, $f_H = 1.15$ and $f_O = 0.65$. ILO provides us with unit labor costs (relative to US) in manufacturing for a number of cheap labor countries. From which we choose $C_M^* = 0.8$, a value of Mexico in 1992 (the year that NAFTA was signed). Given these parameter values and functional forms from Eqs. (40) and (41), we calibrate other key parameter values – μ, ε, a_M, a_L, a_H and λ – by characterizing the initial equilibrium as follows.

(i) M-workers represent 70% of the population. US Economic Census reports that the ratio of production workers to total employees in manufacturing is about 70%. From the cumulative distribution function (CDF) of log-normal distribution, we set: $\frac{1}{2} + \frac{1}{2}\,\mathrm{erf}\left(\frac{\ln z_2 - \mu}{\sqrt{2}\varepsilon}\right) = 0.7$;

(ii) From the same source, we pick the non-production workers' wage share in total value added from labor as: $\frac{C_L \int_{z_1}^{z_2} \varphi_L(z) g(z) dz + C_H \int_{z_2}^{\infty} \varphi_H(z) g(z) dz}{\widetilde{W}} = 0.42$;

(iii) US Economic Census also reports industry statistics by employment size. We approximate MNs' total output value share as that of establishments with 2,500 or more employees: $\frac{p_H x_H N_H}{p_L x_L N_L + p_H x_H N_H} = 0.14$;

(iv) For productivity difference between MNs and non-MNs, we set: $\frac{a_H}{a_L} = 1.15$;[24]

(v) For initial income inequality level, we choose: Gini index $= 0.32$;[25]

(vi) Finally, for the initial growth rate we set $g = 0.03$, the average US real GDP

[24] In their estimation, Helpman, Melitz and Yeaple (2004) find that MNs have 15-percent productivity advantage over non-MN exporters.

[25] We calculate cumulative population share and income share at z_1 and z_2, respectively. We get then an approximate measure of Gini index by linear interpolations, and distributing capital incomes πK to H-workers. Since our appoximate measure obviously underestimates the actual inequality level, we pick the level of OECD average of recent years rather than that of US. For the late 2000s, US had the fourth highest Gini index among all OECD countries.

growth rate between 1980 and 2006.

Appendix B.1 and B.2 report the calibrated benchmark equilibrium values and the moments of calibrated log-normal skill distribution. Appendix B.3 displays the initial TASD from calibrated μ, ε and a_j.

5.2 Simulated results

Table 1 reports the effects of a fall in f_O and rises in μ and ε, respectively, which confirms our theoretical analyses. Results are percentage change from initial equilibrium. For a comparability of three different shocks, the size of these shocks has been arbitrarily chosen so that MNs' total output value share ($Sh^{MN} = \frac{p_H x_H N_H}{p_L x_L N_L + p_H x_H N_H}$; initially 0.14) would finally represent 70% of the economy.[26]

	f_O				μ				ε			
	0.6500	0.6437	0.6373	0.6310	-0.3963	-0.2562	-0.1160	0.0242	0.4210	0.6114	0.8017	0.9920
z_1	0.0000	-0.1022	-0.1956	-0.2768	0.0000	0.0491	0.0826	0.1059	0.0000	0.0020	-0.0076	-0.0197
z_2	0.0000	-0.1814	-0.3040	-0.3943	0.0000	-0.0432	-0.0693	-0.0861	0.0000	-0.0019	0.0073	0.0194
C_L	0.0000	0.0178	0.0375	0.0581	0.0000	-0.0075	-0.0122	-0.0154	0.0000	-0.0003	0.0012	0.0032
C_H	0.0000	0.0203	0.0424	0.0653	0.0000	-0.0070	-0.0114	-0.0144	0.0000	-0.0003	0.0011	0.0030
π	0.0000	0.1613	0.3267	0.4792	0.0000	0.2287	0.5342	0.9079	0.0000	0.2682	0.5734	0.9535
L^*	0.0000	2.1383	4.2962	6.2418	0.0000	2.0486	4.9616	8.5845	0.0000	2.7998	5.6002	8.7582
L_I	0.0000	0.3686	0.7274	1.0361	0.0000	0.6329	1.4718	2.4953	0.0000	0.7162	1.5242	2.5273
g	0.0000	0.3686	0.7274	1.0361	0.0000	0.6329	1.4718	2.4953	0.0000	0.7162	1.5242	2.5273
$Gini$	0.0000	0.1142	0.1577	0.1224	0.0000	0.1317	0.2079	0.1856	0.0000	0.6180	1.1945	1.7136
N_L	0.0000	-0.2800	-0.4961	-0.6512	0.0000	-0.2402	-0.4674	-0.6512	0.0000	-0.3249	-0.5204	-0.6512
N_H	0.0000	1.7298	3.0758	4.0532	0.0000	1.4754	2.8712	3.9998	0.0000	1.9958	3.1964	3.9998
$N_L + N_H$	0.0000	-0.1133	-0.1998	-0.2610	0.0000	-0.0979	-0.1905	-0.2654	0.0000	-0.1324	-0.2121	-0.2654
Sh^{MN}	0.1400	0.3808	0.5666	0.7000	0.1400	0.3466	0.5420	0.7000	0.1400	0.4194	0.5875	0.7000

Table 1: The effects of a fall in f_O and rises in μ and ε

[26] All along the simulations, the conditions (8) and (9) are satisfied.

The first f_O-column reports percentage changes of each variable as f_O declines from the benchmark value 0.65 to 0.631 where Sh^{MN} reaches 70%. As shown in Section 3, falling f_O decreases both skill thresholds z_1 and z_2 so that both C_L and C_H increase, with the latter being increased relatively more. Not surprisingly, a fall in f_O attracts more domestic firms to adopt high technology and turn to multinationals: N_L decreases and N_H increases. We have identified four offshoring-and-growth effects, of which two are anti-growth (redistribution and deindustrialization effects) whereas the other two are pro-growth (technology-upgrading and South-industrialization effects). As also shown analytically, the latter two are dominant enough to increase the steady-state level of investment L_I, and thus enhance growth. Table 1 reports also changes in the approximate measure of Gini index.[27] While $dC_L > 0$, $dC_H > 0$ and $d\left(C_H/C_L\right) > 0$ lead to an increased between-group income inequality, within-group composition effect due to technology-upgrading of individual workers may reduce the overall income inequality. In our numerical experiment, falling f_O yields a hump-shaped Gini index.

The second μ-column reports the case of a rise in μ: from benchmark value -0.3963 to 0.0242 where Sh^{MN} reaches 70%. As shown in Section 4.1, a rise in μ induces an increase in z_1 and a decrease in z_2 so that both C_L and C_H decrease while C_H/C_L increases. In our simulation of the model (calibrated to US data), skill upgrading of workers induces also technology-upgrading of firms with a decrease in N_L and an increase in N_H. Contrary to the case of offshoring, the changes in C_L and C_H (redistribution effect) also affect positively the steady-state real investment level, which leads finally to a much higher growth rate. On the other hand, we find a similar hump-shaped pattern of Gini index as in the case of offshoring due to the same possible tension between within- and between-group income inequality.

Finally, the third ε-column reports the case of a rise in ε: from benchmark value 0.421 to 0.992 where Sh^{MN} reaches 70%. As shown in Section 4.2, in this case we may have two possible movements of z_1 and z_2: $dz_1 > 0$ and $dz_2 < 0$, or $dz_1 < 0$ and $dz_2 > 0$, which is indeed the case in our numerical simulation. z_1 first increases and then decreases, while z_2 changes inversely. These nonlinear movements of z_1 and z_2

[27] Here we report an approximate measure of Gini index calculated only from labor incomes.

lead in turn to nonlinear changes in C_L and C_H.[28] On the other hand, since either case induces skill downgrading within non-MNs and skill upgrading within MNs, skill polarization leads to technology-upgrading of firms: $dN_L < 0$ and $dN_H > 0$, and enhances growth. Not surprisingly, skill polarization leads to an increased income inequality.

5.3 Welfare effects

We now turn to welfare implications of three respective shocks. Table 2 reports again percentage changes of welfare for each skill group.

	f_O				μ				ε			
	0.6500	0.6437	0.6373	0.6310	-0.3963	-0.2562	-0.1160	0.0242	0.4210	0.6114	0.8017	0.9920
P_C	0.0000	0.0054	0.0114	0.0177	0.0000	-0.0023	-0.0037	-0.0047	0.0000	-0.0001	0.0004	0.0010
$Welf_{Agg}$	0.0000	0.0054	0.0130	0.0226	0.0000	0.0927	0.2017	0.3299	0.0000	0.0756	0.1903	0.3582
$Welf_M$	0.0000	-0.0054	-0.0113	-0.0174	0.0000	0.0023	0.0037	0.0047	0.0000	0.0001	-0.0004	-0.0010
$Welf_L$	0.0000	0.0123	0.0258	0.0397	0.0000	-0.0052	-0.0085	-0.0108	0.0000	-0.0002	0.0008	0.0022
$Welf_H$	0.0000	0.0148	0.0306	0.0468	0.0000	-0.0047	-0.0077	-0.0097	0.0000	-0.0002	0.0008	0.0020
$ItWelf_{Agg}$	0.0000	0.1074	0.2381	0.3800	0.0000	0.2980	0.9012	2.5353	0.0000	0.3103	0.9231	2.6890
$ItWelf_M$	0.0000	0.0955	0.2084	0.3261	0.0000	0.1907	0.5881	1.6709	0.0000	0.2182	0.6150	1.7135
$ItWelf_L$	0.0000	0.1151	0.2538	0.4031	0.0000	0.1818	0.5686	1.6298	0.0000	0.2178	0.6170	1.7221
$ItWelf_H$	0.0000	0.1178	0.2596	0.4127	0.0000	0.1824	0.5699	1.6325	0.0000	0.2179	0.6169	1.7216
Sh^{MN}	0.1400	0.3808	0.5666	0.7000	0.1400	0.3466	0.5420	0.7000	0.1400	0.4194	0.5875	0.7000

Table 2: Welfare effects of a fall in f_O and rises in μ and ε

$Welf_{Agg}$, $Welf_M$, $Welf_L$ and $Welf_H$ measure real incomes $\frac{E}{P_C}$, $\frac{C_M}{P_C}$, $\frac{C_L}{P_C}$ and $\frac{C_H}{P_C}$, respectively. As shown in Section 3 and 4, respective shocks lead to quite different welfare implications. While in the case of a fall in f_O only M-workers lose in terms of their real income due to an increase of P_C, in the case of a rise in μ they are main

[28] The results are also graphed in Appendix B.4.

beneficiaries due to a decrease of P_C and it is the L-workers who lose the most. On the other hand, the nonlinear changes in z_1 and z_2 in the case of a rise in ε lead also to nonlinear welfare consequences. Since P_C first decreases and then increases, in this case M-workers' real income first slightly rises and then falls whereas those of L- and H-workers change inversely. In all of the three cases, the aggregate welfare rises monotonously.

Above welfare conclusion is of course incomplete since it does not take into account the dynamic gains to be reaped from growth. From Eqs. (12) and (24), a rise in growth rate implies an increase of total number of firms (varieties) at the same rate. This, in turn, implies from Eq. (5) that P_C falls over time at the rate of $\frac{g}{1-\sigma}$. To evaluate the intertemporal welfare consequences, we compute the equivalent variation index ϕ from the following utility indifference condition:

$$(1+\phi)\int_{t=0}^{\infty} e^{-(\rho-\frac{g_0}{\sigma-1})t}\frac{C_{j0}}{P_{C0}}dt = \int_{t=0}^{\infty} e^{-(\rho-\frac{g_1}{\sigma-1})t}\frac{C_{j1}}{P_{C1}}dt, \qquad j \in \{M, L, H\}, \qquad (45)$$

where subscripts 0 and 1 indicate before and after shocks, respectively.[29] In Table 2, $ItWelf$s report these computed values of ϕ. As can be seen, the dynamic welfare gains are large enough to dominate any static losses.[30]

5.4 Task-specific technological progress

In this subsection, we explore the impacts of task-specific technological progresses which also directly affect TASD as changes in μ and ε. Table 3 reports the effects of a rise in a_H and a_L by 0.2% respectively, and a rise in a_M by 3.45% which leads to the same growth rate as a 0.2% rise of a_L.

[29] Our calibrated parameter values satisfy $\rho - \frac{g}{\sigma-1} > 0$ all over the simulations.

[30] As usual in this type of model, the elasticity of substitution between varieties σ is crucial for welfare implications. Also note from Eqs. (29) and (30) that σ is closely related to the determinations of steady-state level of real investment and growth rate. See Appendix B.5 for welfare effects with alternative values of σ. The main results are robust qualitatively.

	z_1	z_2	C_L	C_H	π	L^*	$Gini$	N_L	N_H	Sh^{MN}	g
a_H (0.20%)	-0.0525	-0.1023	0.0087	0.0082	0.0796	1.0621	0.0650	-0.1490	0.9151	0.9151	0.1889
a_L (0.20%)	0.0479	0.1240	-0.0090	-0.0085	-0.0669	-0.8941	-0.0672	0.1444	-0.8868	-0.8868	-0.1573
a_M (3.45%)	0.0414	0.1206	0.0185	0.0173	-0.0427	-0.8646	-0.0538	0.1396	-0.8577	-0.8577	-0.1573

	P_C	$Welf_{Agg}$	$ItWelf_{Agg}$		$Wage(z)$	$Welf(z)$	$ItWelf(z)$
a_H (0.20%)	0.0027	0.0021	0.0518	(z_1^0)	0.0087	0.0061	0.0559
				(z_1^1)	0.0000	-0.0027	0.0468
				(z_2^0)	0.0100	0.0073	0.0573
				(z_2^1)	0.0087	0.0061	0.0559
a_L (0.20%)	-0.0028	-0.0012	-0.0390	(z_1^0)	0.0000	0.0028	-0.0352
				(z_1^1)	-0.0073	-0.0046	-0.0422
				(z_2^0)	-0.0073	-0.0045	-0.0422
				(z_2^1)	-0.0085	-0.0057	-0.0433
a_M (3.45%)	0.0056	0.0141	-0.0242	(z_1^0)	0.0247	0.0190	-0.0196
				(z_1^1)	0.0185	0.0128	-0.0255
				(z_2^0)	0.0185	0.0128	-0.0255
				(z_2^1)	0.0173	0.0116	-0.0267

Table 3: The effects of task-specific technological progress

Upper table of Table 3 reports percentage changes of each variable. Not surprisingly, a technological progress in H induces an overall technology-upgrading in the economy – both z_1 and z_2 decrease – leading to a rise in the growth rate, whereas a technological progress either in L or in M results in an overall technology-downgrading – both z_1 and z_2 increase – and slows growth. Lower table of Table 3 reports the induced welfare effects (in percentage change) of each shock. Given the same proportional changes within each task-group, here we focus on the four threshold workers: z_1^0, z_1^1, z_2^0 and z_2^1 where superscripts 0 and 1 indicate before and after shocks. Note that since each shock affects individual worker's marginal product in this case, previous simple welfare measures of $\frac{C_j}{P_C}$ should now be modified to $\frac{w(z)}{P_C}$. As we can now easily conjecture, in the case of a rise in a_H the most skilled workers ($z > z_2^0$) are the main beneficiaries, while in the case of a rise in a_L they ($z > z_2^1$) would be the main victims. On the other hand, in the case of a rise in a_M the lowest threshold worker ($z = z_1^0$) would be the main beneficiary of static welfare gains and the least victim of dynamic welfare losses.[31]

5.5 Scale effects and skill distribution

Finally, before concluding, we consider scale effects of growth and the role of skill distribution. Most models in endogenous growth literature where discovery of new (non-rivalous) ideas is the engine of growth predict positive relationship between the size of population and the growth rate, which is strongly at odds with empirical evidences.[32] Consequently, a series of subsequent endogenous growth models have attempted to eliminate such linear scale effects of growth (due to population size) and to coincide with empirical evidences.[33] Adding to this line of research, this paper may provide an alternative explanation. From Eqs. (29) and (30), we may also have scale effects. From our discussions so far, it should, however, be clear that what really matters for economic growth is the quality of the population – dependent on skill distribution and TASD –, and not the population size alone. To evaluate this, we now consider a case where μ decreases (skill downgrading) with an elasticity η following a rise in the population size: $\mu_1 = \mu_0(\frac{Pop_1}{Pop_0})^\eta$, where subscripts 0 and 1 indicate again before and after, respectively.[34] Figure 7 displays how the same 10% increase of population can lead to different growth rate depending on different η. Table 4 reports then percentage changes of mean and median of skill distribution for different η as population increases by 10%. As can be seen, relatively small decreases in mean and/or median of the distribution are enough to dampen and even outweigh the positive scale effects.

[31] For graphical illustrations, see Appendix B.6.
[32] See e.g. Backus, Kehoe and Kehoe (1992) and Jones (1995).
[33] See Jones (1999) for a review of such models.
[34] Note that in our calibration μ is negative initially.

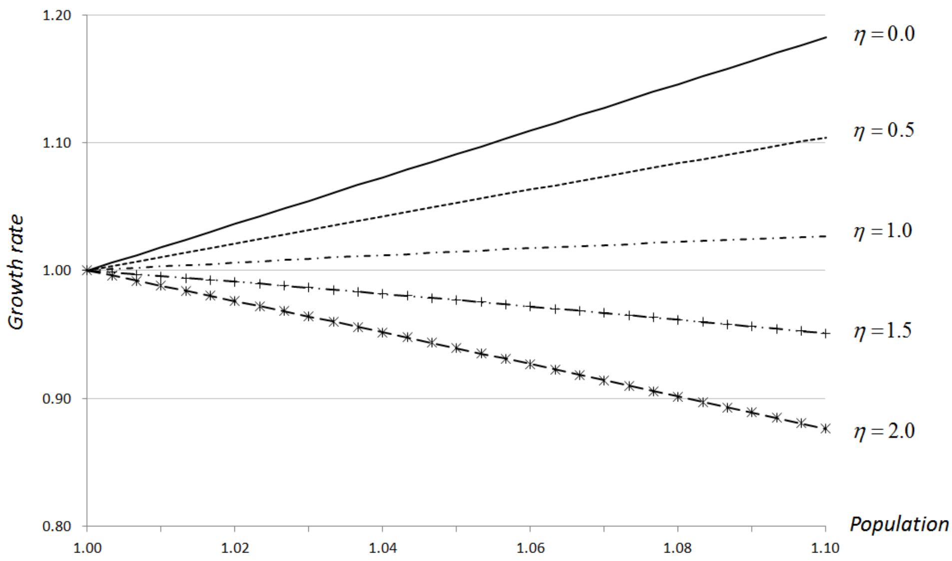


Figure 7: Scale effects of growth and skill distribution

η	0.000	0.500	1.000	1.500	2.000
Pop	0.100	0.100	0.100	0.100	0.100
g	0.182	0.104	0.027	-0.049	-0.124
$Mean$	0.000	-0.019	-0.039	-0.059	-0.080
$Median$	0.000	-0.019	-0.039	-0.059	-0.080

Table 4: Skill downgrading and scale effects of growth

6 Conclusion

Technology and skill (or human capital) have long been the central issue for economic growth. Though the development of endogenous growth theory since the mid-1980s has proven many important technology-growth and/or skill-growth links, it has, however, paid much less attention to the very interplay between technology and skill and its relationship to growth. In this paper, we developed an endogenous growth model in which heterogeneous workers in skill endogenously sort into different tasks requiring specific technologies, and analyzed the technology-skill-growth links. Since workers' productivity reflects not only their own skill level but also the technology they are using, the economy-wide technology-augmented skill distribution (TASD) is endogenously determined by technology-skill matching in equilibrium.

As we've shown, our multi-task/technology-based heterogeneous worker framework provides much richer – and empirically testable – predictions on the relationship between labor market changes and growth that could not be captured by traditional models with homogeneous workers and/or symmetric technologies. Due to the interplay between technology and skill, the same shock might even lead to different market equilibriums depending on the initial economy characteristics (e.g. initial technology concentration). Also, at least in our model's context it should be clear that what really matters for economic growth is the population quality, and not the population size. By incorporating heterogeneous firms and modeling explicitly their market competition in a global economy, we've also highlighted the offshoring-and-growth links and the role of worker skill heterogeneity in explaining the market structure. In terms of economic policy implications, the main message from this paper should be that any policy on either technology or population skill without considering the interplay between them might lead to different results not only quantitatively but also even qualitatively. Needless to say, more elaborating some of our simplified setup – e.g. endogenizing task-specific technologies and/or skill supply of workers, incorporating innovation competition between the North and the South, introducing labor market imperfection, etc. – might also lead to different results. I believe that this paper opens up new avenues for various promising extensions and for future research.

Appendix A

A.1 Proof of Proposition 1

Totally differentiating Eqs. (17) and (32), and using Eq. (23), we get:

$$\begin{bmatrix} j_{11} & j_{12} \\ j_{21} & j_{22} \end{bmatrix} \begin{bmatrix} dz_1 \\ dz_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} df_O,$$

where

$$\begin{aligned}
j_{11} &= \varphi_M(z_1)g(z_1) + \varphi_L(z_1)g(z_1), \\
j_{12} &= -\varphi_L(z_2)g(z_2), \\
j_{21} &= (\sigma-1)\, f_L \left(\tfrac{\alpha_1(z_1)+C_M}{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right)^{\sigma-2} \tfrac{\alpha_1'(z_1)\left[C_M^*-\alpha_2(z_2)C_M\right]}{\left[\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}, \\
j_{22} &= (\sigma-1)\, f_L \left(\tfrac{\alpha_1(z_1)+C_M}{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right)^{\sigma-2} \tfrac{-\alpha_1(z_1)\alpha_2'(z_2)[\alpha_1(z_1)+C_M]}{\left[\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}.
\end{aligned}$$

The Jacobian determinant is:

$$\begin{aligned}
|J| = [\varphi_M(z_1)g(z_1) + \varphi_L(z_1)g(z_1)] &\left[(\sigma-1)\, f_L \left(\tfrac{\alpha_1(z_1)+C_M}{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right)^{\sigma-2} \tfrac{-\alpha_1(z_1)\alpha_2'(z_2)[\alpha_1(z_1)+C_M]}{\left[\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}\right] \\
+ \varphi_L(z_2)g(z_2) &\left[(\sigma-1)\, f_L \left(\tfrac{\alpha_1(z_1)+C_M}{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right)^{\sigma-2} \tfrac{\alpha_1'(z_1)\left[C_M^*-\alpha_2(z_2)C_M\right]}{\left[\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}\right].
\end{aligned}$$

Note from Eqs. (9), (22) and (23),

$$C_M^* - \alpha_2\left(z_2\right) C_M < 0. \tag{46}$$

From Eqs. (23) and (46), it follows then that:

$$|J| > 0.$$

Using Cramer's rule, we now obtain:

$$\begin{aligned}
\tfrac{dz_1}{df_O} &= \tfrac{1}{|J|}\left[\varphi_L(z_2)g(z_2)\right] > 0, \\
\tfrac{dz_2}{df_O} &= \tfrac{1}{|J|}\left[\varphi_M(z_1)g(z_1) + \varphi_L(z_1)g(z_1)\right] > 0.
\end{aligned}$$

A.2 Proof of Proposition 3

Totally differentiating Eq. (34), we get:

$$\frac{dL_I}{dz_2} = \left[\begin{array}{l} \frac{\alpha_1'(z_1)\left[C_M^* - \sigma\alpha_2(z_2)C_M\right]}{\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2} \int_0^{z_1} \varphi_M(z)g(z)dz + \frac{(1-\sigma)\alpha_1'(z_1)\alpha_2(z_2)C_M^*}{\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2} \int_{z_2}^{\infty} \varphi_H(z)g(z)dz \\ -\frac{\rho(\sigma-1)\alpha_1'(z_1)\alpha_2(z_2)C_M^*}{\lambda^2\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2} + \frac{\alpha_1(z_1)+C_M}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\left[\varphi_M(z_1)g(z_1)\right] \end{array} \right] \frac{dz_1}{dz_2}$$
$$+ \left[\begin{array}{l} \frac{-\sigma\alpha_1(z_1)\alpha_2'(z_2)[\alpha_1(z_1)+C_M]}{\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2} \int_0^{z_1} \varphi_M(z)g(z)dz + \frac{(1-\sigma)\alpha_1(z_1)\alpha_2'(z_2)C_M^*}{\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2} \int_{z_2}^{\infty} \varphi_H(z)g(z)dz \\ -\frac{\rho(\sigma-1)\alpha_1(z_1)\alpha_2'(z_2)C_M^*}{\lambda^2\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2} - \frac{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\left[\varphi_H(z_2)g(z_2)\right] \end{array} \right]. \tag{47}$$

Given that all the other terms, however, are based on infinitesimal changes in $\alpha_1'(z_1)$ and $\alpha_2'(z_2)$, we compare the only two sizable terms: i.e. the last terms in each bracket. From Eqs. (22), (23) and (31), we obtain:

$$\frac{\alpha_1(z_1)+C_M}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\left[\varphi_M(z_1)g(z_1)\right] \frac{\varphi_L(z_2)g(z_2)}{\varphi_M(z_1)g(z_1)+\varphi_L(z_1)g(z_1)} - \frac{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\left[\varphi_H(z_2)g(z_2)\right]$$
$$= -\frac{C_M^*\varphi_H(z_2)g(z_2)}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*} < 0.$$

It can be thus believed that $\frac{dL_I}{dz_2} < 0$, implying $\frac{dL_I}{df_O} < 0$ from Proposition 1.

A.3 Proof of Proposition 4

From Eqs. (13) and (27), and Tobin's $q = 1$ condition, we have:

$$\pi = (\rho + g)\, C_H a_I.$$

N_L equation of (37) is then:

$$N_L = \frac{C_L + C_M}{(\sigma-1)(\rho+g)\, C_H a_I f_L} \int_0^{z_1} \varphi_M(z)g(z)dz.$$

From Proposition 1, Corollary 1, and Proposition 3, it is then straightforward that

$$\frac{dN_L}{df_O} > 0.$$

From Eq. (12), it is now immediate that

$$\frac{dN_H}{df_O} < 0,$$

at a given total capital stock at the given moment of time. From above, it is obvious that

$$\frac{d\left(\frac{N_H}{N_L}\right)}{df_O} < 0.$$

It can be also shown by directly investigating Eq. (38). From Eq. (18), the change in the numerator by a fall in f_O represents the South-industrialization effect.

South-industrialization effect of offshoring

Totally differentiating Eq. (18), and from Eq. (47), wet get:

$$\begin{aligned}
\frac{dL^*}{dz_2} &= -\left[\frac{dL_I}{dz_2} + \varphi_H(z_2)g(z_2)\right] \\
&= -\left[\begin{array}{l} \frac{\alpha_1'(z_1)\left[C_M^* - \sigma\alpha_2(z_2)C_M\right]}{\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}\int_0^{z_1}\varphi_M(z)g(z)dz + \frac{(1-\sigma)\alpha_1'(z_1)\alpha_2(z_2)C_M^*}{\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}\int_{z_2}^{\infty}\varphi_H(z)g(z)dz \\ -\frac{\rho(\sigma-1)\alpha_1'(z_1)\alpha_2(z_2)C_M^*}{\lambda^2\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2} + \frac{\alpha_1(z_1)+C_M}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\left[\varphi_M(z_1)g(z_1)\right] \end{array}\right]\frac{dz_1}{dz_2} \\
&\quad -\left[\begin{array}{l} \frac{-\sigma\alpha_1(z_1)\alpha_2'(z_2)[\alpha_1(z_1)+C_M]}{\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}\int_0^{z_1}\varphi_M(z)g(z)dz + \frac{(1-\sigma)\alpha_1(z_1)\alpha_2'(z_2)C_M^*}{\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}\int_{z_2}^{\infty}\varphi_H(z)g(z)dz \\ -\frac{\rho(\sigma-1)\alpha_1(z_1)\alpha_2'(z_2)C_M^*}{\lambda^2\left[\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2} - \frac{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\left[\varphi_H(z_2)g(z_2)\right] \end{array}\right] \\
&\quad - \varphi_H(z_2)g(z_2).
\end{aligned}$$

Given that all the other terms are based on infinitesimal changes in $\alpha_1'(z_1)$ and $\alpha_2'(z_2)$, we again compare the only three sizable terms: i.e. last two terms in the bracket and the last line. Using Eq. (31), we obtain:

$$-\left[\begin{array}{l}\frac{\alpha_1(z_1)+C_M}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\left[\varphi_M(z_1)g(z_1)\right]\frac{\varphi_L(z_2)g(z_2)}{\varphi_M(z_1)g(z_1)+\varphi_L(z_1)g(z_1)}\\-\frac{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\left[\varphi_H(z_2)g(z_2)\right]+\varphi_H(z_2)g(z_2)\end{array}\right]$$

$$=-\left[\frac{\sigma\alpha_1(z_1)\alpha_2(z_2)\varphi_H(z_2)g(z_2)}{\sigma\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right]<0.$$

It can be thus believed that $\frac{dL^*}{dz_2}<0$, implying $\frac{dL^*}{df_O}<0$ from Proposition 1.

From Proposition 1 and Eq. (38), it is then immediate that $\frac{d\left(\frac{N_H}{N_L}\right)}{df_O}<0$.

A.4 Proof of Proposition 5

Totally differentiating Eqs. (32) and (43), and using Eq. (23), we get:

$$\begin{bmatrix} j_{11} & j_{12} \\ j_{21} & j_{22}\end{bmatrix}\begin{bmatrix} dz_1 \\ dz_2\end{bmatrix}=\begin{bmatrix} A \\ 0\end{bmatrix}d\mu,$$

where

$$\begin{aligned}
j_{11} &= 2\frac{2e^{-\frac{(\mu-\ln z_1)^2}{2\varepsilon^2}}}{\sqrt{2\pi}\varepsilon z_1}+(a_M+a_L)\,e^{\mu+\frac{\varepsilon^2}{2}}\,\frac{2e^{-\frac{\left(\mu+\varepsilon^2-\ln z_1\right)^2}{2\varepsilon^2}}}{\sqrt{2\pi}\varepsilon z_1},\\
j_{12} &= -\frac{2e^{-\frac{(\mu-\ln z_2)^2}{2\varepsilon^2}}}{\sqrt{2\pi}\varepsilon z_2}-a_Le^{\mu+\frac{\varepsilon^2}{2}}\,\frac{2e^{-\frac{\left(\mu+\varepsilon^2-\ln z_2\right)^2}{2\varepsilon^2}}}{\sqrt{2\pi}\varepsilon z_2},\\
j_{21} &= (\sigma-1)\,f_L\left(\frac{\alpha_1(z_1)+C_M}{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right)^{\sigma-2}\frac{\alpha_1'(z_1)\left[C_M^*-\alpha_2(z_2)C_M\right]}{\left[\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2},\\
j_{22} &= (\sigma-1)\,f_L\left(\frac{\alpha_1(z_1)+C_M}{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right)^{\sigma-2}\frac{-\alpha_1(z_1)\alpha_2'(z_2)[\alpha_1(z_1)+C_M]}{\left[\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2},
\end{aligned}$$

and

$$A=\left[\begin{array}{l}a_Me^{\mu+\frac{\varepsilon^2}{2}}\left[\operatorname{erf}\left(\frac{\mu+\varepsilon^2-\ln z_1}{\sqrt{2}\varepsilon}\right)-1\right]\\+a_Le^{\mu+\frac{\varepsilon^2}{2}}\left[\operatorname{erf}\left(\frac{\mu+\varepsilon^2-\ln z_1}{\sqrt{2}\varepsilon}\right)-\operatorname{erf}\left(\frac{\mu+\varepsilon^2-\ln z_2}{\sqrt{2}\varepsilon}\right)\right]\\+\frac{2}{\sqrt{2\pi}\varepsilon}\left[2e^{-\frac{(\mu-\ln z_1)^2}{2\varepsilon^2}}-e^{-\frac{(\mu-\ln z_2)^2}{2\varepsilon^2}}\right]\\+\frac{2e^{\mu+\frac{\varepsilon^2}{2}}}{\sqrt{2\pi}\varepsilon}\left[a_Me^{-\frac{\left(\mu+\varepsilon^2-\ln z_1\right)^2}{2\varepsilon^2}}+a_L\left(e^{-\frac{\left(\mu+\varepsilon^2-\ln z_1\right)^2}{2\varepsilon^2}}-e^{-\frac{\left(\mu+\varepsilon^2-\ln z_2\right)^2}{2\varepsilon^2}}\right)\right]\end{array}\right].\quad(48)$$

From Eq. (43), the first and second line of Eq. (48) can be written:

$$-2\,\mathrm{erf}\left(\frac{\mu-\ln z_1}{\sqrt{2}\varepsilon}\right)+\left[1+\mathrm{erf}\left(\frac{\mu-\ln z_2}{\sqrt{2}\varepsilon}\right)\right],$$

which is positive from Assumption 1; the third line is also positive since $z_1 < z_2$. The fourth line is positive from Assumption 2. Thus, we have $A > 0$.

From Eqs. (23) and (46), the Jacobian determinant is

$$|J| = (j_{11}j_{22} - j_{12}j_{21}) > 0.$$

Using Cramer's rule, and from Eqs. (23) and (46), we finally obtain:

$$\begin{aligned} \frac{dz_1}{d\mu} &= \frac{1}{|J|}\left[A(\sigma-1)f_L\left(\frac{\alpha_1(z_1)+C_M}{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right)^{\sigma-2}\frac{-\alpha_1(z_1)\alpha_2'(z_2)[\alpha_1(z_1)+C_M]}{\left[\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}\right] > 0, \\ \frac{dz_2}{d\mu} &= \frac{1}{|J|}\left[-A(\sigma-1)f_L\left(\frac{\alpha_1(z_1)+C_M}{\alpha_1(z_1)\alpha_2(z_2)+C_M^*}\right)^{\sigma-2}\frac{\alpha_1'(z_1)\left[C_M^*-\alpha_2(z_2)C_M\right]}{\left[\alpha_1(z_1)\alpha_2(z_2)+C_M^*\right]^2}\right] < 0. \end{aligned} \tag{49}$$

A.5 Proof of Proposition 8

The total derivatives of F_1 and F_2 with respect to μ are: $\frac{dF_1}{d\mu} = \frac{\partial F_1}{\partial\mu} + \frac{\partial F_1}{\partial z_1}\frac{dz_1}{d\mu}$, and $\frac{dF_2}{d\mu} = \frac{\partial F_2}{\partial\mu} + \frac{\partial F_2}{\partial z_1}\frac{dz_1}{d\mu} + \frac{\partial F_2}{\partial z_2}\frac{dz_2}{d\mu}$. Since $\frac{\partial F_1}{\partial z_1}\frac{dz_1}{d\mu}$ and $\frac{\partial F_2}{\partial z_1}\frac{dz_1}{d\mu} + \frac{\partial F_2}{\partial z_2}\frac{dz_2}{d\mu}$ are based on infinitesimal changes in $\alpha_1'(z_1)$ and $\alpha_2'(z_2)$ from Eq. (49), we focus on the first direct impacts. We get:

$$\frac{\partial F_1}{\partial\mu} = \frac{1}{2}\left[\begin{array}{l} a_M e^{\mu+\frac{\varepsilon^2}{2}} - a_M e^{\mu+\frac{\varepsilon^2}{2}}\,\mathrm{erf}\left(\frac{\mu+\varepsilon^2-\ln z_1}{\sqrt{2}\varepsilon}\right) \\ -\frac{2}{\sqrt{2\pi}\varepsilon}e^{-\frac{(\mu-\ln z_1)^2}{2\varepsilon^2}} - a_M e^{\mu+\frac{\varepsilon^2}{2}}\frac{2}{\sqrt{2\pi}\varepsilon}e^{-\frac{\left(\mu+\varepsilon^2-\ln z_1\right)^2}{2\varepsilon^2}} \end{array}\right],$$

and $\frac{\partial F_2}{\partial\mu} = A + B$, where

$$A = \frac{1}{2}\left[\frac{(\sigma-1)\,\alpha_1(z_1)\,\alpha_2(z_2)}{\sigma\alpha_1(z_1)\,\alpha_2(z_2)+C_M^*}\right]\left[\begin{array}{l} a_H e^{\mu+\frac{\varepsilon^2}{2}} + a_H e^{\mu+\frac{\varepsilon^2}{2}}\,\mathrm{erf}\left(\frac{\mu+\varepsilon^2-\ln z_2}{\sqrt{2}\varepsilon}\right) \\ +\frac{2}{\sqrt{2\pi}\varepsilon}e^{-\frac{(\mu-\ln z_2)^2}{2\varepsilon^2}} + a_H e^{\mu+\frac{\varepsilon^2}{2}}\frac{2}{\sqrt{2\pi}\varepsilon}e^{-\frac{\left(\mu+\varepsilon^2-\ln z_2\right)^2}{2\varepsilon^2}} \end{array}\right],$$

$$\text{and} \qquad B = -\left[\frac{\alpha_1(z_1)+C_M}{\sigma\alpha_1(z_1)\,\alpha_2(z_2)+C_M^*}\right]\frac{\partial F_1}{\partial\mu}.$$

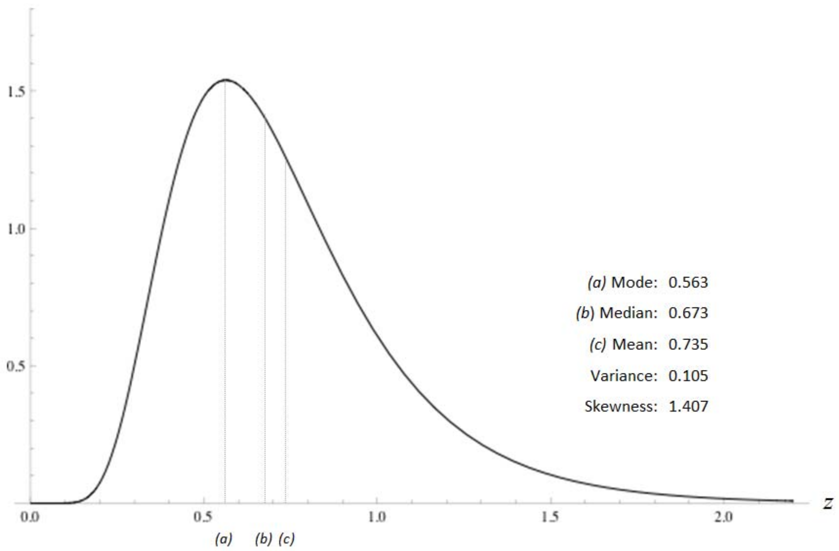
Note that $\frac{\partial F_1}{\partial \mu}$ converges *(i)* to zero when z_1 approaches zero and *(ii)* to $a_M e^{\mu+\frac{\varepsilon^2}{2}}$ when z_1 approaches ∞, and has a minus minimum between them. Note also that $A > 0$: second bracket of A converges *(i)* to $2a_H e^{\mu+\frac{\varepsilon^2}{2}}$ when z_2 approaches zero and *(ii)* to zero when z_2 approaches ∞, and has a maximum between them. Thus, it can be generally said that $d(\frac{N_H}{N_L})/d\mu > 0$, if and only if initial z_1 and z_2 are not extremely high; the *sufficient condition* for $d(\frac{N_H}{N_L})/d\mu > 0$ is $\frac{\partial F_1}{\partial \mu} < 0$, which would be the case if z_1 is low enough. How much is then low enough? Given the analytical difficulty, we address this issue numerically. In Section 5, we roughly calibrate the model on US data and explore numerically. In our benchmark case, the turning point value of z_1 (from $\frac{\partial F_1}{\partial \mu} < 0$ to $\frac{\partial F_1}{\partial \mu} > 0$) is $z_1 \approx 1.171$, which implies an economy where about 91% of the population are matched to the lowest (M) technology and produce $m(i)$ while only the other 9% of the population perform all the other activities. Note from Eq. (17) that z_2 should be then much more higher to ensure the balance of inputs. We may, therefore, plausibly conclude that $\frac{\partial F_1}{\partial \mu} < 0$ and $d(\frac{N_H}{N_L})/d\mu > 0$.

Appendix B

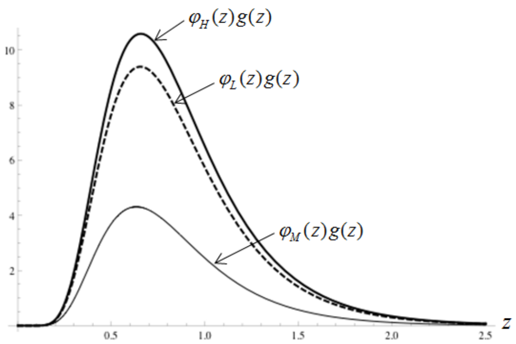
B.1 Calibrated benchmark equilibrium

σ	ρ	f_L	f_H	f_O	a_M	a_L	a_H
4.00	0.05	1.00	1.15	0.65	3.02	8.40	9.66
μ	ε	λ	z_1	z_2	C_M	C_L	C_H
-0.40	0.42	0.03	0.84	1.17	1.00	0.44	0.39
C_M^*	p_L	p_H	x_L	x_H	N_L	N_H	P_C
0.80	1.92	1.58	16.06	35.17	0.12	0.01	3.72
L^*	$\widetilde{W}$	$\widetilde{W}^*$	π	K	L_I	g	
0.38	3.28	0.30	7.70	0.14	1.03	0.03	

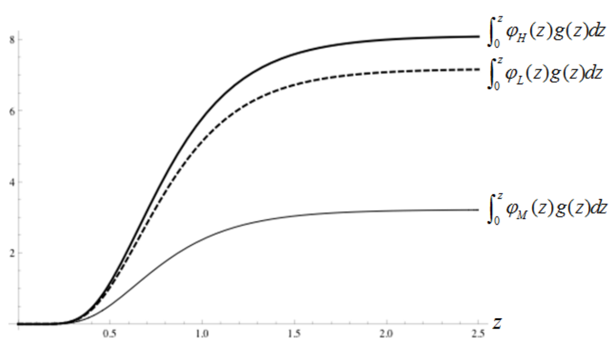
B.2 Moments of calibrated log-normal skill distribution



B.3 Calibrated technology-augmented skill distribution (TASD)

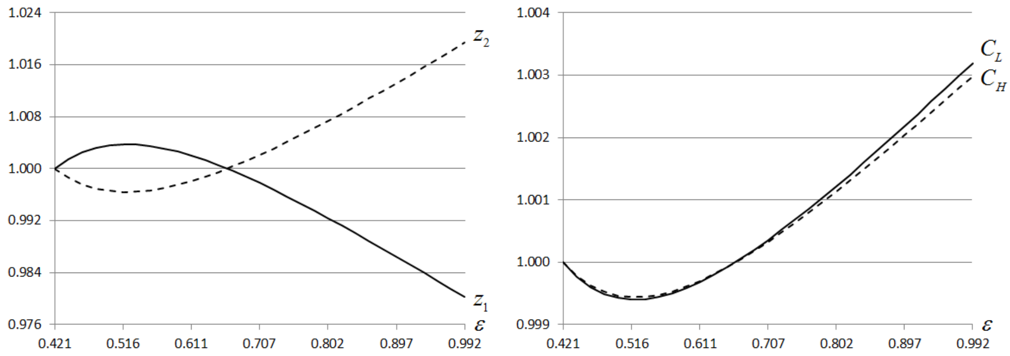


$(a)\quad \varphi_j(z)g(z)$



$(b)\quad \int_0^z \varphi_j(z)g(z)dz$

B.4 The effects of a rise in ε on z_1, z_2, C_L and C_H

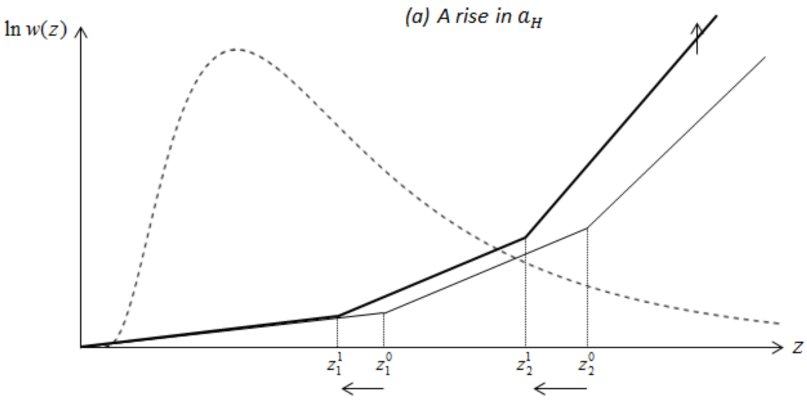


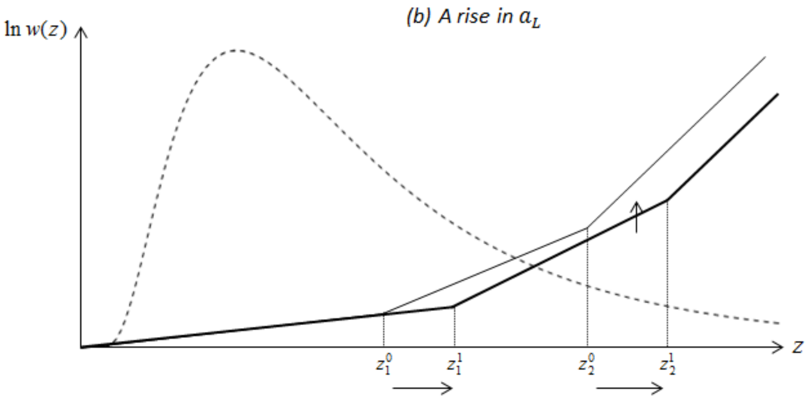
B.5 Welfare effects with alternative values of σ (% changes)[35]

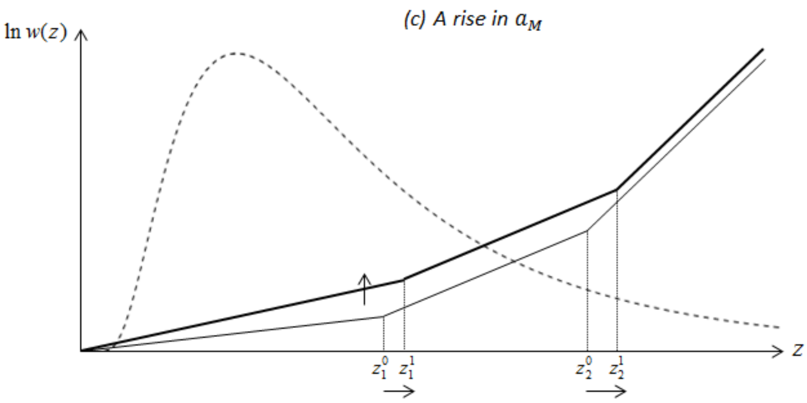
	1% fall in f_O			25% rise in μ			30% rise in ε		
	$\sigma = 3.5$	$\sigma = 4.0$	$\sigma = 4.5$	$\sigma = 3.5$	$\sigma = 4.0$	$\sigma = 4.5$	$\sigma = 3.5$	$\sigma = 4.0$	$\sigma = 4.5$
P_C	0.0077	0.0056	0.0028	-0.0007	-0.0017	-0.0028	0.0001	-0.0002	-0.0010
$Welf_{Agg}$	0.0111	0.0055	0.0023	0.0686	0.0639	0.0591	0.0492	0.0463	0.0428
$Welf_M$	-0.0077	-0.0056	-0.0028	0.0007	0.0017	0.0028	-0.0001	0.0002	0.0010
$Welf_L$	0.0243	0.0127	0.0049	-0.0023	-0.0039	-0.0049	0.0002	-0.0004	-0.0018
$Welf_H$	0.0265	0.0152	0.0074	-0.0020	-0.0036	-0.0046	0.0002	-0.0004	-0.0017
$ItWelf_{Agg}$	0.8157	0.1105	0.0271	0.8637	0.1906	0.0977	0.7527	0.1853	0.0946
$ItWelf_M$	0.7819	0.0982	0.0219	0.7453	0.1210	0.0393	0.6704	0.1330	0.0507
$ItWelf_L$	0.8393	0.1183	0.0298	0.7401	0.1147	0.0314	0.6709	0.1323	0.0478
$ItWelf_H$	0.8433	0.1211	0.0323	0.7406	0.1151	0.0317	0.6708	0.1324	0.0479

[35] Changing the values of σ obviously implies recalibrating the model. Six parameters – ε, a_L, a_H, ρ, λ and C_M^* – were recalibrated by maintaining the six calibration conditions *(i)* to *(vi)* in Section 5.1. To $\sigma \in [3.5, 4.0, 4.5]$ are associated $\varepsilon \in [0.41, 0.42, 0.43]$, $a_L \in [12.16, 8.40, 6.20]$, $a_H \in [13.98, 9.66, 7.13]$, $\rho \in [0.02, 0.05, 0.24]$, $\lambda \in [0.01, 0.03, 0.14]$, and $C_M^* \in [0.76, 0.80, 0.83]$, respectively. The results are identical qualitatively, except only for the case of a rise in ε which is due to the nonlinear changes in z_1 and z_2 as shown in B.4: z_1 (z_2) first increases (decreases), and then decreases (increases). 30% rise in ε induces increased z_1 and decreased z_2 with $\sigma \in [4.0, 4.5]$, while with $\sigma = 3.5$ we are already in the phase where z_1 decreased and z_2 increased compared to the initial levels.

B.6 Task-specific technological progress[36]







[36] Here log-linear technologies are again adopted just for a graphical simplicity.

References

[1] Aghion, P., and P. Howitt. 1992. "A Model of Growth Through Creative Destruction." *Econometrica,* 60(2), 323–51.

[2] Antràs, P., L. Garicano, and E. Rossi-Hansberg. 2006. "Offshoring in a Knowledge Economy." *Quarterly Journal of Economics,* 121(1), 31–77.

[3] Backus, D. K., P. J. Kehoe, and T. J. Kehoe. 1992. "In Search of Scale Effects in Trade and Growth." *Journal of Economic Theory,* 58(2), 377–409.

[4] Baldwin, R. E., and R. Forslid. 2000. "Trade Liberalisation and Endogenous Growth: A q-theory Approach." *Journal of International Economics,* 50(2), 497–517.

[5] Baldwin, R. 2006. "Globalisation: The Great Unbundling(s)." Paper for the Economic Council of Finland.

[6] Baldwin, R. E., and F. Robert-Nicoud. 2008. "Trade and Growth with Heterogeneous Firms." *Journal of International Economics,* 74(1), 21–34.

[7] Blanchard, E., and G. Willmann. 2013. "Trade, Education, and the Shrinking Middle Class." Working Paper, Universität Bielefeld.

[8] Blinder, A. S. 2006. "Offshoring: The Next Industrial Revolution?" *Foreign Affairs,* 85(2), 113–28.

[9] Bourguignon, F. 2003. "The Growth Elasticity of Poverty Reduction: Explaining Heterogeneity across Countries and Time Periods," in *Inequality and Growth: Theory and Policy Implications*, edited by Eicher, T. S., and S. J. Turnovsky. Cambridge: MIT Press.

[10] Branstetter, L., and K. Saggi. 2011. "Intellectual Property Rights, Foreign Direct Investment and Industrial Development." *Economic Journal,* 121(555), 1161–91.

[11] Cortes, G. M. 2014. "Where Have the Middle-Wage Workers Gone? A Study of Polarization Using Panel Data." Working Paper, University of Manchester.

[12] Costinot, A., and J. Vogel. 2010. "Matching and Inequality in the World Economy." *Journal of Political Economy,* 118(4), 747–86.

[13] Dinopoulos, E., and P. Segerstrom. 2010. "Intellectual Property Rights, Multinational Firms and Economic Growth." *Journal of Development Economics,* 92(1), 13-27.

[14] Gibrat, R. 1931. "Les Inégalité Economiques." Paris: Recueil Sirey.

[15] Grossman, G. M. 2004. "The Distribution of Talent and the Pattern and Consequences of International Trade." *Journal of Political Economy,* 112(1), 209–39.

[16] Grossman, G. M., and E. Helpman. 1991. "Quality Ladders in the Theory of Growth." *Review of Economic Studies,* 58(1), 43–61.

[17] Grossman, G. M., and E. Helpman. 1991. "Innovation and Growth in the Global Economy." Cambridge: MIT Press.

[18] Grossman, G. M., and E. Rossi-Hansberg. 2008. "Trading Tasks: A Simple Theory of Offshoring." *American Economic Review,* 98(5), 1978–97.

[19] Grossman, G. M., and G. Maggi. 2000. "Diversity and Trade." *American Economic Review,* 90(5), 1255–75.

[20] Helpman, E. 1993. "Innovation, Imitation, and Intellectual Property Rights." *Econometrica,* 61(6), 1247–80.

[21] Helpman, E., M. J. Melitz, and S. R. Yeaple. 2004. "Export versus FDI with Heterogeneous Firms." *American Economic Review,* 94(1), 300–16.

[22] Helpman, E., O. Itskhoki, and S. Redding. 2010. "Inequality and Unemployment in a Global Economy." *Econometrica,* 78(4), 1239–83.

[23] Hsieh, C.-T., E. Hurst, C. I. Jones, and P. J. Klenow. 2013. "The Allocation of Talent and U.S. Economic Growth." NBER Working Paper 18693, National Bureau of Economic Research.

[24] Jones, C. I. 1995. "Time Series Tests of Endogenous Growth Models." *Quarterly Journal of Economics,* 110(2), 495–525.

[25] Jones, C. I. 1999. "Growth: With or Without Scale Effects?" *American Economic Review: Papers & Proceedings,* 89(2), 139–44.

[26] Jung, J., and J. Mercenier. 2014. "Routinization-Biased Technical Change and Globalization: Understanding Labor Market Polarization." *Economic Inquiry,* forthcoming (DOI: 10.1111/ecin.12108).

[27] Kambourov, G., and I. Manovskii. 2008. "Rising Occupational and Industry Mobility in the United States: 1968–97." *International Economic Review,* 49(1), 41–79.

[28] Lucas, R. E. 1988. "On the Mechanics of Economic Development." *Journal of Monetary Economics,* 22(1), 3–42.

[29] Mankiw, N. G., and P. Swagel. 2006. "The Politics and Economics of Offshore Outsourcing." *Journal of Monetary Economics,* 53(5), 1027–56.

[30] Markusen, J. 2002. "Multinational Firms and the Theory of International Trade." Cambridge: MIT Press.

[31] Murphy, K. M., A. Shleifer, and R. W. Vishny. 1991. "The Allocation of Talent: Implications for Growth." *Quarterly Journal of Economics,* 106(2), 503–30.

[32] Peretto, P. F. 2003. "Endogenous Market Structure and the Growth and Welfare Effects of Economic Integration." *Journal of International Economics,* 60(1), 177–201.

[33] Rivera-Batiz, L. A., and P. M. Romer. 1991a. "Economic Integration and Endogenous Growth." *Quarterly Journal of Economics,* 106(2), 531–55.

[34] Rivera-Batiz, L. A., and P. M. Romer. 1991b. "International Trade with Endogenous Technological Change." *European Economic Review,* 35(4), 971–1001.

[35] Romer, P. M. 1990. "Endogenous Technological Change." *Journal of Political Economy,* 98(5), 71–102.

[36] Romer, P. M. 1986. "Increasing Returns and Long-Run Growth." *Journal of Political Economy,* 94(5), 1002–37.

[37] Roy, A. D. 1951. "Some Thoughts on the Distribution of Earnings." *Oxford Economic Papers,* 3(2), 135–46.

[38] Tobin, J. 1969. "A General Equilibrium Approach to Monetary Theory." *Journal of Money, Credit and Banking,* 1(1), 15–29.

[39] Yeaple, S. R. 2005. "A Simple Model of Firm Heterogeneity, International Trade, and Wages." *Journal of International Economics,* 65(1), 1–20.

[40] Young, A. 1991. "Learning by Doing and the Dynamic Effects of International Trade." *Quarterly Journal of Economics,* 106(2), 369–405.