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A THEORY OF DIGITAL DIVIDE: WHO GAINS AND LOSES FROM TECHNOLOGICAL CHANGES?

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This paper attempts to answer the question: How does the income gap between workers and capitalists evolve over time in the period of ITC and globalization increasing international technology creation and transfers? The model bases on a Romer's type of variety expansion of intermediate goods. We assume that there are two types of agents supplying two different types of factors. Workers supply specific skill weighted labor by accumulating their specific skills that depreciate with an introduction of new intermediate goods. The other type of agents, R&D agents, produce and sell new varieties of intermediate goods monopolistically after inventing them. The model yields: Depending on the elasticity of substitution between the two factors and on the value of the factor share, an increase in the efficiency of technology creation (or lowering the barriers on the imports of intermediate goods) affects the growth rates of workers' and R&D agents' average income *differently*. First, if the elasticity of substitution is greater than one, in a certain stage of development, an advance in ITC or 'globalization' increases the growth rate of R&D agents' average income, while it decreases that of workers'. Thus, the 'Digital Divide' happens. Conversely, if the elasticity of substitution is less than one, the result will be reversed. These results are intuitively obvious. Second, if an economy develops from a higher factor share of the workers to a sufficiently lower one, the growth rates of GNP, and the average incomes of both workers and R&D agents increase over time.

Keywords: Romer's Model, R&D, Specific Skill, Digital Divide
JEL classification: D33, J24, O30

1. INTRODUCTION

With the globalization, transfers of technology such as ITC happen among various different countries more freely. One of the important economic problems related to the New Economy is the so-called 'Digital Divide'.

In this context, this paper aims to theoretically identify how the income gap between workers and capitalists evolve over time in the period of ITC and globalization under what conditions. For this, we present a theoretical mechanism describing the dynamic interactions between workers' technology adoption and R&D agents' technology creation.[1]

We use a CES production function with two kinds of inputs; specific skills accumulated by investing time, and intermediated goods that are made of final goods and supplied by monopolistic competitors. Also there are two types of agents; workers with specific skills, and R&D agents who invent new kinds of intermediate goods by investing their time, also produce and sell them monopolistically.

An additional assumption is that the more rapid introduction of new intermediate goods makes the larger fraction of workers' specific skills obsolete.[2] Due to this mechanism, an exogenous increase in the variety of intermediate goods or opening up of the markets of intermediate goods can lower the economy's growth rate. This can happen more frequently when an economy's production depends more on workers' specific skills than on R&D agents' creation of new technologies (new intermediate goods). It is because if workers' specific skills exist more dominantly than intermediate goods, an exogenous increase in the variety of intermediate goods makes the effect of depreciating the dominant factor of specific skills to overshadow that of increasing the efficiency of producing intermediate goods, leading to the lower growth rate of income.

Also the income gap between workers and R&D agents can increase and decrease over time depending on the elasticity of substitution and factor shares. We also find that depending on the elasticity of substitution and the factor share, an exogenous increase in the variety of intermediate goods or lowering the barriers on the imports of intermediate goods affects the growth rates of workers' and R&D agents' average income differently.

More specifically, if the elasticity of substitution is greater than one, in a certain stage of development, an advance in ITC or 'globalization' increases the growth rate of R&D agents' average income, while it decreases that of workers'. Thus, 'Digital Divide' happens. Conversely, if the elasticity of substitution is less than one, the result will be reversed. Additionally, if an economy develops from a higher factor share of the workers to a sufficiently lower one, the growth rates of GNP, workers' and R&D agents' average income increases over time.

Several papers provide implications similar to ours. Caselli and Coleman (2000) find a negative cross-country correlation between the efficiency of unskilled labor and the efficiencies of skilled labor and capital. They interpret this finding as evidence of the existence of a World Technology Frontier. On this frontier, increases in the efficiency of

[1] Anand and Kanbur (1993) argue that the foremost important factor behind the Kuznets U curve process is the shift of population from traditional to modern activities.

[2] It is because a rapid introduction of new intermediate goods, implying a big change in business organizations, production systems and technologies, marketing channels, and so forth, depreciates workers' specific skills, lowering their income growth. This represents the mechanism of workers' adoption of new technologies. In other words, to form a different type of specific skills to operate new technologies, a certain fraction of the current specific skills will become obsolete.

unskilled labor are obtained at the cost of declines in the efficiency of skilled labor and capital. The optimal choice of technology depends on the country's endowment of skilled and unskilled labor. And they find that poor countries tend disproportionately to be inside the World Technology Frontier. This empirical finding supports our assumption stated above.

Using a specific data set of imports of computer equipment, Caselli and Coleman (2001) find strong evidence that computer adoption (imports of computer equipment) is associated with higher levels of human capital, and with manufacturing trade openness via-a-vis OECD countries. They also find evidence that computers adoption is enhanced by high investment rates, good property rights protection, and a small share of agriculture in GDP. They use data on imports of computer equipment for a large sample of countries between 1978 to 1990, to investigate the determinants of computer-technology adoption.

Borensztein *et al*. (1998) show that there is a strong complementary effect between FDI and human capital: FDI contributes to economic growth only when the host country has more than a minimum threshold stock of human capital. Lee (2001), and Caselli and Coleman (2001) show that adoption of computer technologies is strongly associated with higher levels of human capital. To relate these findings about human capital to the results of our model, we can assume that higher level of workers' human capital (education) lowers the depreciation rate of their specific skills with the arrival of new technology shocks. It is because human capital will increase agents' adaptability or flexibility. Then, the higher level of human capital agents own, with the higher probability new technologies can increase the growth rate of an economy, leading to more frequent adoption of new technologies.

Helpman and Rangel (1999) provides a theoretical model showing that under a wide set of circumstances a new technology shock that raises a long-run output can trigger a recession in the short run. It is mainly due to the fact that in their model, experienced workers' specific skill depreciates with the advent of a new technology, leading to a recession of the economy. This mechanism may explain the slowdown in productivity growth in US manufacturing at the beginning of the 20th century triggered by electrification, and the slowdown in productivity growth in the 1970's possibly triggered by computerization. One key aspect that differentiates ours from theirs is that our paper formally models the dynamic interactions between technology adoption and creation, and the consequent output growth and income distribution. However, they focus only on technology adoption, not on technology creation, and the consequent depreciation of workers' specific skills, given an exogenous advent of new technologies.

The structure of the paper goes as follows. Section 2 provides a theoretical model of the Romer's type of variety expansion of intermediate goods, and solve the model. Section 3 provides interesting implications that can possibly answer the question raised above. And Section 4 concludes.

2. THE MODEL

The model is a variant of the Romer's model of variety expansion of intermediate goods. We assume a continuum of agents having different abilities (a_i) on [0, 1] and a logarithmic preference. Higher abilities enable agents working with R&D firms (R&D agents) to make more inventions. There exist two types of agents endowed with one unit of time in each period. Workers invest their time to accumulate their specific skills, and provide the rest of the time to firms producing final goods at the competitive wage rates. We assume that they consume all their wage income and do not save at all to simplify the problem. And, the other type of agents are R&D agents who invest a certain fraction of their one unit of time to invent new types of intermediate goods, and the rest of the time to the labor market for producing intermediate goods. They also produce and sell these intermediate goods in monopolistic competitive markets as R&D firm owners. We assume that only this type of agents save a constant fraction of their income over time, and invest. We will call them as R&D agents in the below.

We assume that an R&D agent with ability $a_i = i$ owns $2i$ units of quality adjusted time. R&D agents devote a certain amount out of $2i$ units of quality adjusted time to produce intermediate goods, and the rest of the time to create new kinds of new intermediate goods during each period.[3] Here A represents the stock of socially accumulated knowledge. Thus, all R&D agents with the level of abilities above a certain threshold level (a^*) create new technologies together following

$$\frac{\dot{A}}{A} = \phi S_R = \phi(2\int_{a^*}^{1} i di - k) = \phi\{(1 - a^{*2}) - k\} \tag{1}$$

where the dot on the variable A represents the difference operator, ϕ the efficiency of creating new kinds of intermediate goods, S_R the quality-weighted aggregate labor input for R&D investment, and k the aggregate amount of time spent for the production of intermediate goods.[4]

Workers with abilities below the certain threshold level (a^*) invest time to accumulate specific skills (human capital) and the rest of the time will be supplied to labor markets to produce final goods. Here, we assume that an *i*-th worker with ability

[3] We can differently assume this feature that differentiates agents with different abilities from each other as: Assume that to join the R&D firms workers should be educated. For this education, workers should pay tuitions that decrease in the level of workers' ability. This different assumption gives identical implications with a little bit more complexity.

[4] Here, we regard the expansion of variety of intermediate goods implying various innovations of organizations, management systems, products, markets, manufacturing processes, and others.

$a_i = i \le a^*$ owns an identical level of specific skill of $h_t(i) = h_t(j) = h_t$ $(\frac{h_t(i)}{h_t(j)} = 1)$. In other words, we assume that all workers are identical.[5]

A certain fraction of the worker's specific skill will become obsolete with the advent of new technologies denoted by an increase in the variety of intermediate goods as[6]

$$\frac{\dot{h}}{h} = Bu_t - \delta \frac{\dot{A}}{A} = Bu_t - \delta\phi(1 - a^{*2} - k) , \tag{2}$$

where B represents the efficiency of accumulating specific skill. This obsolescence represents the cost for adopting new specific skills to operate new technologies.[7]

The rest of the time will be supplied to the labor market as

$$l_t = 1 - u_t . \tag{3}$$

Then the aggregate supply of the worker's labor adjusted by specific skills will be

$$H_t = \int_0^{a^*} h_t l_t di = a^* h_t l_t . \tag{4}$$

The economy's aggregate production function is described by[8]

[5] We can assume that more able workers own higher level of specific skills. However, this does not change the implications.

[6] This specification of specific skill obsolescence is similar to that in Galor and Moav (2000). And we can assume that higher level of workers' education level, not specific skills, lowers the depreciation rate (δ) of their specific skills with the arrival of new technology shocks. It is because human capital will increase agents' adaptability or flexibility. However, we do not consider an additional variable of worker's education, to focus on our issue.

[7] Lucas (1993), Parente (1994), Parente and Prescott (1994) formally considers the cost of adopting technologies in their model. The cost is represented by a constant rate of depreciation of specific skills with an adoption of new technologies.

[8] This specification is similar to Acemoglu (2000). This representation implies that the relation between specific skill and technology (or skilled labor; S_x) can be substitutes or complements while relation between S_x and technology is on the border line. We can regard Y as a composite good derived from two different kinds of goods. One type of the labor intensive good is produced from the production function of $Y(H) = H^{\gamma}$ with only one input of specific skills, while the other type of the capital intensive good from $Y(S_x, K) = S_x^{1-\alpha}(\{\int_0^A x(i)^{\beta} di\}^{\frac{1}{\beta}})^{\alpha}$ where S_x is defined as above. However, the BGP equilibrium is hard to exist with this formulation, unless $s_t(\cdot)$ stays constant, the factor share for each kind of good. This

$$Y = (\sigma H^{\gamma} + (1-\sigma)[S_x^{\,1-\alpha}(\int_0^A x(i)^{\beta} di)^{\frac{\alpha}{\beta}}]^{\gamma})^{\frac{1}{\gamma}} \text{, with } \gamma \le 1, \tag{5}$$

where $H_t = \int_0^{a^*} h_t(i) l_t(i) di = a^* h_t l_t$, $S_x = k$, and $x(i)$ represents an i-th intermediate good. To produce one unit of these intermediate goods, the firm needs one unit of final good. And each R&D firm also monopolistically produces and sells a different kind of each intermediate good.

Utilizing the symmetry among intermediate good inputs, we can also describe the above production function by

$$Y = (\sigma H^{\gamma} + (1-\sigma) Z^{\gamma})^{\frac{1}{\gamma}}, \;\; where \;\; Z = S_x^{\,1-\alpha}\{\int_0^A x(i)^{\beta} di\}^{\frac{\alpha}{\beta}} = S_x^{\,1-\alpha}(A^{\frac{1-\beta}{\beta}} K)^{\alpha}, \tag{6}$$

with $K = Ax(i)$.[9]

Using (6), we calculate the inverse demand functions for specific skill and intermediate inputs as

$$w(H)_t = \frac{\partial Y_t}{\partial H_t} = \frac{\sigma H_t^{\gamma-1}}{\sigma H_t^{\gamma} + (1-\sigma) Z_t^{\gamma}} Y_t \equiv \frac{1}{H_t} s_t(H) Y_t, \tag{7}$$

$$p(x(i)) = \frac{\partial Y_t}{\partial K_t} = \frac{\alpha}{K_t} s_t(Z) Y_t, \tag{8}$$

where $s_t(H) = \dfrac{\sigma H_t^{\gamma}}{\sigma H_t^{\gamma} + (1-\sigma) Z_t^{\gamma}}$, and $s_t(Z) = \dfrac{(1-\sigma) Z_t^{\gamma}}{\sigma H_t^{\gamma} + (1-\sigma) Z_t^{\gamma}} = 1 - s_t(H)$, representing the factor share in income for each type of production factors, specific skilled workers and high ability R&D agents.

happens when γ is negative. And as γ approaches to zero, this function will become the Cobb-Douglas. As Caselli and Coleman (2002, 2000) noted, Cobb-Douglas functions can not have different efficiencies for different factors. And Duffy and Papageorgiou (2000) show that a CES specification fits the cross-country data better than a Cobb-Douglas. Specifically, they find that physical capital and human capital adjusted labor are more substitutable in the richest group of countries, and are less substitutable in the poorest group of countries.

[9] The elasticity of substitution between capital and human capital adjusted labor is $\dfrac{1}{1-\gamma}$.

Monopolistic competitive producers of intermediate goods set the price of intermediate goods with a constant markup over the marginal cost as[10]

$$p_t(x(i)) = \frac{r}{\beta} = \frac{1}{K_t}\alpha s_t(Z)Y_t . \tag{9}$$

From (7) and (9), we calculate the total income belonging to each type of agents, workers and R&D agents, to be

$$H_t w(H)_t = H_t \frac{\partial Y_t}{\partial H_t} = \frac{\sigma H_t^{\gamma}}{\sigma H_t^{\gamma} + (1-\sigma)Z_t^{\gamma}} Y_t = s_t(H)Y_t , \quad \text{and} \tag{10}$$

$$K_t p_t(x(i)) = K_t \frac{r}{\beta} = \alpha s_t(Z)Y_t . \tag{11}$$

Then, (9), (10) and (11) imply that the interest rate will stay constant over time, because R&D agents are assumed to save a constant fraction ($\frac{\alpha\beta}{r}$) of their aggregate income ($s(Z)Y$). Also (11) implies that a certain fraction of income of $(1-\alpha)s(Z)Y$ goes to the labor of $1-a^{*2}-k$ devoted to producing intermediate goods. Now, Appendix B derives how much fraction of the total labor of high ability agents will be used for R&D investments and for the production of intermediate goods.

From (10) and (11), the average incomes of workers and R&D agents are, respectively,

$$\overline{w}_t = s_t(H)Y_t \frac{1}{a^*} , \quad \text{and} \tag{12}$$

$$\overline{k}_t = s_t(Z)Y_t \frac{1}{1-a^*} . \tag{13}$$

Assuming a logarithmic utility preference for all agents, using (2) and the assumption of no depreciation of human capital, the first order conditions with respect to u_t and l_t will be

[10] For the detailed and standard derivation of this, refer to Appendix A.

$$\lambda_t = \frac{1}{mu_t(i)} \int_0^\infty mu_{t+j}(i)\overline{w}_{t+j} B \exp[(Bu(t+j) - \delta\phi + \delta\phi a^{*2} + \delta k) j] h_t l_{t+j} dj$$
$$= \frac{1}{mu_t(i)} \int_0^\infty mu_{t+j}(i)\overline{w}_{t+j} B h_{t+j} l_{t+j} dj$$
$$= w_t(i) B \int_0^\infty \exp(-\rho j) dj$$
$$= w_t(i) \frac{B}{\rho} \tag{14}$$

where λ_t denotes the shadow price of one unit of the endowed time at time t in the numeraire of output, ρ the instantaneous rate of time preference, $w_t(i) = w(H)_t h_t(i) l_t(i)$, and $mu_t(i) = \exp(-\rho t)\frac{1}{w_t(i)}$ an *i*-th agent's marginal utility at time t.

$$\lambda_t = w(H)_t h_t(i)$$
$$= w_t(i) \frac{1}{l_t(i)} \quad . \tag{15}$$

Simple algebra of these first order conditions with respect to u_t and l_t yield

$$l_t(i) \equiv \bar{l} = \frac{\rho}{B} . \tag{16}$$

Thus, each worker's time allocation between u_t and l_t will be[11]

$$u_t \equiv \bar{u} = \frac{B - \rho}{B} . \tag{17}$$

Using (2) and (4), we obtain

[11] We can assume that workers' specific skill increases due to learning by doing, not through education. Then, the assumption of a logarithmic preference is not necessary, and the analysis will remain identical, by assuming the exogenously given amount of labor is $l_t(i) \equiv \bar{l} = \frac{\rho}{B}$, and the learning by doing efficiency is $B\bar{u} = B - \rho$. Here, ρ can be any constant, because in this specification, we do not assume anything about the preference.

$$\frac{\dot{H}}{H} = \frac{\dot{h}}{h} + \frac{\dot{a}^*}{a^*} = B\overline{u} - \delta\phi + \delta\phi a^{*^2} + \delta\phi k + \frac{\dot{a}^*}{a^*}$$
$$= B - \rho - \delta\phi + \delta\phi a^{*^2} + \delta\phi k + \frac{\dot{a}^*}{a^*} \ . \tag{18}$$

(18) implies that level of the aggregate specific skill grows at a rate less than that of the individual $B - \rho - \delta\phi + \delta\phi a^{*^2} + \delta\phi k$, if a^* decreases.

Now, we calculate the threshold level of an agent's ability a^* assuming an interior solution. By utilizing the fact that the income at time t of the marginal agent with the ability of a^* will be identical between the two cases of investing one unit of time in accumulating workers' human capital and in R&D activities. Before going into further calculations, to simplify the problem, we further assume that agents believe that the income streams grow overtime with a constant growth rate of g.[12] For this, we first calculate the value of one unit of H_t and A_t at time t.

The Value of One Unit of Specific Skill at time t

$$= \int_t^\infty \exp(-rj + gj) w(H)_j \, dj = \frac{s_t(H)Y_t}{H_t} \frac{1}{r-g} \quad . \tag{19}$$

The Value of One Unit of A_t at time t

$$= \int_t^\infty \exp(-rj + gj)\pi_j \, dj = \frac{K_t}{A_t} \frac{r(1-\beta)}{\beta} \frac{1}{r-g}$$
$$= (1-\beta)\frac{\alpha s_t(Z)Y_t}{A_t} \frac{1}{r-g} \quad , \tag{20}$$

where π_t is the profit at time t for a firm producing one kind of $x(i)$ as

$$\pi_t = the \quad amount of \quad x(i) \quad times \quad profit \quad per \quad one \quad unit = \frac{K_t}{A_t}\frac{r(1-\beta)}{\beta} .$$

Using (19), we derive the value at time t that a worker with the ability a^* can obtain by investing one unit of time at time t as

[12] Because we are characterizing an equilibrium of the model including non-BGP equilibria of this model, and because agents are quite different from each other in their income streams, without this assumption, the analysis will be hardly solvable.

$$Value\ \ of\ \ One\ \ Unit\ \ of\ \ H_t\ \ at\ \ t\ \times\ h_t l_t$$
$$= \frac{s_t(H)Y_t}{H_t} h_t \bar{l} \frac{1}{r-g}$$
$$= \frac{s_t(H)Y_t}{a^*} \frac{1}{r-g}\ , \tag{21}$$

where $\frac{h_t l_t}{H_t} = \frac{1}{a^*}$.

(20) times $2a^*\phi A$ equals the value at time t that an R&D agent with the ability a^* can obtain by investing $2a^*$ units of time at time t as[13]

$$2a^*\phi(1-\beta)\alpha s_t(Z)Y_t \frac{1}{r-g}\ . \tag{22}$$

(21) and (22) imply that the income growth rates of the two types of agents grow at different rates, and thus the BGP equilibrium will not exist, unless the factor share in the total income of any type of agents remain constant over time.

Equating these two welfares represented by (21) and (22) yield

$$a^{*2} = \min\{\frac{1}{2\alpha\phi(1-\beta)} \frac{s_t(H)}{1-s_t(H)},\ 1\}\ . \tag{23}$$

We can obtain the following lemma from (23).

[13] The marginal agent's decision rule is myopic in the sense that she compares virtually only the current earning streams of each of the two capital investments in specific skill or that in R&D capital. And we are virtually assuming that when R&D agents move to workers' sector, they are automatically endowed with the current level of specific skill through spillover. Now, we will present a different specification of 'paying tuition model' that yields the same results. This specification assumes that to join the R&D firms workers should be educated. For this education, workers should spend a time of $1-a^*$, as the tuition for every point in time, that decreases in the level of workers' ability. We assume further that each R&D agent invents $2\phi A$ number of intermediate goods by investing one unit of time. Then the above specifications of (22) and (23) do not change, because their labor supply in the R&D sector will be a^*, after getting education. And the growth rates of consumption, income and saving of all R&D agents will be $2\phi(1-a^*)$ in this model, because (1) will be $\frac{\dot{A}}{A} = 2\phi S_R = \phi(2\int_{a^*}^{1} 1di - k) = \phi(2-2a^*-k)$.

Lemma 1: An increase in the efficiency (ϕ) of R&D investments induces more agents to join the R&D sector, leading to the higher growth rate of technology (A), even less able agents will join the group of R&D agents.

(Proof) (23) says that as an increase in the efficiency of creating technologies lowers the threshold level of ability (a^*), inducing more labor into R&D investment. Then from (1) it is obvious that the growth rate of technology (A) will increase.

3. IMPLICATIONS OF THE MODEL

Before deriving implications from the model, we will explain what we mean by 'an exogenous increase in the variety of intermediate goods'. It means an exogenous increase in $\frac{\dot{A}}{A}$ through rapid advances in ITC or through lowering import barriers on foreign intermediate goods.

(16) with the specifications of (1) and (2) implies the following lemma.

Lemma 2: An increase in the capital stock of the richer countries with the lower value of a^* (i.e., more labor force in the R&D sector) lowers their level of specific skill weighted labor by depreciating the larger fraction of the specific skill.

This lemma can be interpreted as "physical capital and human capital adjusted labor are more substitutable in the richest group of countries, and are less substitutable in the poorest group of countries", as Duffy and Papageorgiou (2000) find.

Considering $\frac{\dot{H}}{H}=\frac{\dot{h}}{h}+\frac{\dot{a}^*}{a^*}=\frac{2}{2-\gamma}\frac{\dot{h}}{h}-\frac{\gamma}{2-\gamma}\frac{\dot{Z}}{Z}$, using $H_t=a^*h_tl_t$ and (23), the aggregate income grows as[14]

$$\frac{\dot{Y}}{Y}=s_t(H)\frac{\dot{H}}{H}+(1-s_t(H))\frac{\dot{Z}}{Z}=\frac{2s(H)}{2-\gamma}\frac{\dot{h}}{h}+(1-\frac{2s(H)}{2-\gamma})\frac{\dot{Z}}{Z}. \tag{24}$$

Then, using $\frac{\dot{Z}}{Z}=\frac{\alpha(2-\gamma)}{2-\gamma(1+2\alpha s(H))}(\frac{1-\beta}{\beta}\frac{\dot{A}}{A}-\frac{2\gamma s(H)}{2-\gamma}\frac{\dot{h}}{h}+\frac{\dot{Y}}{Y})$ from (C4) in

[14] We are assuming that time proceeds continuously.

Appendix C,[15] we obtain

$$\frac{\dot{Y}}{Y}=\frac{1}{(2-\gamma)(1-\alpha)+2\alpha(1-\gamma)s(H)}[2(1-\alpha\gamma)s(H)B\overline{u}$$
$$+\frac{\dot{A}}{A}\frac{1}{\beta}\{\alpha(1-\beta)(2-\gamma)-2(\alpha(1-\beta)+\delta\beta(1-\alpha\gamma))s(H)\}]. \tag{25}$$

Before pursuing further implications of the model, note the following lemma, assuming $\frac{1}{\phi}(s_A+k)<1$. This is obvious from (1) and (25).

Lemma 3: If $\frac{\dot{A}}{A}>\frac{\beta(1-\alpha)Bu}{\alpha(1-\alpha\beta)}\equiv s_A \Rightarrow a^{*2}<1-\frac{1}{\phi}(s_A+k)$, and γ >0, (or if $\frac{\dot{A}}{A}<s_A$ $\Rightarrow a^{*2}>1-\frac{1}{\phi}(s_A+k)$, and γ <0) $s_t(H)$ and a^* decrease continuously over time. Conversely, if $\frac{\dot{A}}{A}<s_A$ and γ >0, (or if $\frac{\dot{A}}{A}>s_A$ and γ <0) $s_t(H)$ and a^* increase continuously over time.

(Proof) Using the expressions for $\frac{\dot{Y}}{Y}$ and $\frac{\dot{Z}}{Z}$ in (25), we obtain

$$\frac{\dot{s}(H)}{s(H)}=\frac{2\gamma}{2-\gamma}s(Z)(\frac{\dot{h}}{h}-\frac{\dot{Z}}{Z})$$
$$=\frac{2\gamma s(Z)}{(2-\gamma)(1-\alpha)+2\alpha(1-\gamma)s(H)}\{(1-\alpha)Bu-\frac{\dot{A}}{A}\frac{1}{\beta}(\alpha(1-\beta)+\alpha\beta(1-\alpha))\}$$

where $s_t(H)=\frac{\alpha H_t^{\gamma}}{\alpha H_t^{\gamma}+(1-\alpha)Z_t^{\gamma}}$. Using this result and the relationship of $\frac{\dot{a}^*}{a^*}=\frac{1}{2s(Z)}\frac{\dot{s}(H)}{s(H)}$, the statement is obvious.

Lemma 3 yields the following result of the existence of multiple equilibria.

[15] For the derivation of $\frac{\dot{Z}}{Z}$, refer to Appendix C.

Proposition 1: If γ >0, there exist two long run equilibria and one unstable equilibrium. If $a^{*2} < 1-\frac{1}{\phi}(s_A + k)$, $s_t(H)$ and a^* decrease continuously over time to zero, while if $a^{*2} > 1-\frac{1}{\phi}(s_A + k)$, $s_t(H)$ and a^* increase continuously over time to one. And if $a^{*2} = 1-\frac{1}{\phi}(s_A + k)$, factor shares, growth rates of GNP, workers' average income and R&D agents' average income stay constant over time, and the equilibrium is unstable. Conversely, if γ <0, then there exist one stable equilibrium with $a^{*2} = 1-\frac{1}{\phi}(s_A + k)$, where factor shares, growth rates of GNP, workers' average income and R&D agents' average income stay constant over time.[16]

Lemma 3 and Proposition 1 imply that depending on the elasticity of substitution between two factors and on the relative magnitudes of the efficiency of capital investment in specific skill and in R&D capital, factor shares or labor force allocation increase or decrease continuously over time. It also provides surprising results that even though the efficiency of capital investment in specific skill is higher than that in R&D capital, if the elasticity of substitution is less than one (as the poorest countries show), the factor share and the labor force of the workers' sector can decrease to the unique equilibrium, depending on the initial values of factor shares. And if $\gamma > 0$, an economy diverges to one of the two different steady states, only workers' sector or only R&D agents' sector. However, if $\gamma < 0$, there exist only one stable equilibria of BGP.

Considering the fact that an exogenous increase in the variety of intermediate goods make the larger fraction of workers' specific skills ($h_t(i)$) obsolete, interesting implications follow in the below. In other words, because R&D agents invest their time without considering the negative externalities of technology creation on worker's specific skills, market mechanism does not automatically lead to the growth and welfare maximization. Thus the next lemma follows.

Lemma 4: Market mechanism does not automatically guarantee the growth and welfare maximization. The market mechanism alone leads R&D investments and technological progress to excessively depreciate workers' specific skill.

3.1. Growth Rate of GNP

(25) implies that for a certain range of parameters, an exogenous increase in $\frac{\dot{A}}{A}$ can

[16] The result of Proposition 1 is basically identical to that in Acemoglu (2000).

decrease the growth rate of income, if $s(H)$ or δ is large enough. More precise statement is

Lemma 5: If $s_t(H) > \dfrac{\alpha(1-\beta)(2-\gamma)}{2(\alpha(1-\beta)+\delta\beta(1-\alpha\gamma))} \equiv s_y$ ($s_t(H) < s_y$), then an exogenous increase in $\dfrac{\dot{A}}{A}$ decreases (increases) the growth rate of income, and vice versa. However, in the long run it increases the growth rate of income, if $\dfrac{\dot{A}}{A} > \dfrac{\beta(1-\alpha)Bu}{(\alpha(1-\beta)+\alpha\beta(1-\alpha))}$ and $\gamma > 0$, (or if $\dfrac{\dot{A}}{A} < \dfrac{\beta(1-\alpha)Bu}{(\alpha(1-\beta)+\alpha\beta(1-\alpha))}$ and $\gamma < 0$).

(Proof) From (25) the first result is obvious. The second result is also obvious from the first result and Lemma 3 that $s_t(H) < \dfrac{\alpha(1-\beta)(2-\gamma)}{2(\alpha(1-\beta)+\delta\beta(1-\alpha\gamma))}$ will hold some time in the future, because $s_t(H)$ decreases continuously over time to zero, if $\dfrac{\dot{A}}{A} > \dfrac{\beta(1-\alpha)Bu}{(\alpha(1-\beta)+\alpha\beta(1-\alpha))}$ and $\gamma > 0$, (or if $\dfrac{\dot{A}}{A} < \dfrac{\beta(1-\alpha)Bu}{(\alpha(1-\beta)+\alpha\beta(1-\alpha))}$ and $\gamma < 0$).

This lemma implies that if the obsolescence of specific skill (δ) is very high, a rapid expansion of intermediate input variety can lower the growth rate of income. It is because an expansion of intermediate good variety implies various innovations in organization, management system, products, markets, and others, which make a large fraction of workers' specific skills obsolete. This in turn lowers the growth rate of income. This mechanism is identical to that in Helpman and Rangel (1999). And this can more easily happen in an economy where worker's specific skill is dominant than technology creation in the production process.

Due to the reason similar to that of Lemma 4, advances in ITC or globalization of markets of intermediate goods (i.e., removal of barriers on imports of foreign intermediate goods) can lower the income growth rate and the welfare of domestic agents. More formal discussion will follow in the below.

(1) changes into[17]

[17] Different specifications of the model give identical implications. First, if we assume that workers with ability (a_i) must spend a constant fraction of time ($1-a_i$) in education continuously, and that the ability does not affect the efficiency in producing new intermediate goods. Then, this assumption does not affect the marginal conditions of (14) and (15). Second, if we assume that $\dfrac{\dot{A}}{A} = \phi(1-a^{*2}-k) - \delta_A \dfrac{\dot{A}}{A}$

$$\frac{\dot{A}}{A}=\phi(2\int_{a^*}^{1} idi-k)+n^* =\phi(1-a^{*^2}-k)+n^* , \tag{26}$$

where n^* represents the additional spectrum of new foreign intermediate goods imported including intermediate goods related to ITC from foreign countries in each period.[18]

(25) yields the following proposition.

Lemma 6: If $s_t(H)>s_y$ ($s_t(H)<s_y$), then opening up the market of intermediate goods will decreases (increases) the growth rate of income.

Lemma 6 yields a surprising result that if one country's economy depends more on worker's specific skills than technology creation, then opening up the intermediate good market can decrease this country's growth rate. And the higher value of depreciation (δ) of specific skills is, the more likely this happens. In a similar context, Caselli and Coleman (2000) find that the optimal choice of technology depends on the country's endowment of skilled and unskilled labor. Also Caselli and Coleman (2001) find that computer adoption is enhanced by a small share of agriculture.

3.2. Growth Rate of Workers' Average Income

We can calculate the growth rate of workers' income as

$$\begin{aligned} g_W &= \frac{d\log(\frac{s(H)Y}{a^*})}{dt}=\frac{\dot{s}(H)}{s(H)}-\frac{\dot{a}^*}{a^*}+\frac{\dot{Y}}{Y} \\ &=\frac{2\gamma}{2-\gamma}s(Z)(\frac{\dot{h}}{h}-\frac{\dot{Z}}{Z})-\frac{\gamma}{2-\gamma}(\frac{\dot{h}}{h}-\frac{\dot{Z}}{Z})+\frac{\dot{Y}}{Y} \end{aligned} \tag{27}$$

$\Rightarrow \frac{\dot{A}}{A}=\frac{\phi}{(1+\delta_A)}(1-a^{*2}-k)$, instead of (1), then we will also have identical results by substituting $\frac{\phi}{1+\delta_A}$ instead of ϕ. This assumption implies that the stock of current technology also depreciates faster with a rapid growth rate of technology level.

[18] We can assume that there exist two identical countries that produce different spectra of intermediate goods.

$$= \frac{1}{(2-\gamma)(1-\alpha)+2\alpha(1-\gamma)s(H)}[\{\gamma(1-\alpha)+2(1-\gamma)s(H)\}B\overline{u}$$

$$+\frac{\dot{A}}{A}\frac{1}{\beta}\{2\alpha(1-\beta)(1-\gamma)-\gamma\alpha\beta(1-\alpha)-2(\alpha(1-\beta)(1-\gamma)+\delta\beta(1-\alpha\gamma)-\gamma\alpha\beta(1-\alpha))s(H)\}].$$

Lemma 7: If $s(H) >$ (<) $\frac{2\alpha(1-\beta)(1-\gamma)-\gamma\alpha\beta(1-\alpha)}{2(\alpha(1-\beta)(1-\gamma)+\delta\beta(1-\alpha\gamma)-\gamma\alpha\beta(1-\alpha))} \equiv s_w$ and if $2\alpha(1-\beta)(1-\gamma)-\gamma\alpha\beta(1-\alpha)>0$, an exogenous increase in $\frac{\dot{A}}{A}$ decreases (increases) workers' average income. And the higher value of depreciation (δ) of specific skills is, the more likely the condition of $s(H) > s_w$ holds.

Lemmas 5, 6 and 7 yield the following proposition.

Proposition 2: Assume that $\gamma < 0$. Then if $s(H) > s_w$, an exogenous increase in $\frac{\dot{A}}{A}$ decreases the growth rates of GNP and of workers' average income. If $s_y < s(H) < s_w$, it decreases the growth rate of GNP, while it increases that of workers' average income. And if $s_y > s(H)$, it decreases the growth rates of GNP and workers' average income.

(Proof) If $\gamma < 0$, then $s_y < s_w$. Then the results are obvious from Lemmas 5, 6 and 7.

Similarly, we derive the following proposition.

Proposition 3: Assume that $\gamma > 0$. Then if $s(H) > s_y$, an exogenous increase in $\frac{\dot{A}}{A}$ decreases the growth rates of GNP and of workers' average income. If $s_w < s(H) < s_y$, it increases the growth rate of GNP, while it decreases that of workers' average income. And if $s_w > s(H)$, it decreases the growth rates of GNP and workers' average income.

(Proof) If $\gamma > 0$, then $s_w < s_y$. Then the results are obvious from Lemmas 5, 6 and 7.

3.3. Growth Rate of R&D Agents' Average Income

We can calculate the growth rate of R&D agents' average income as

$$
\begin{aligned}
g_R &= \frac{d\log(\frac{s(Z)Y}{1-a^*})}{dt} = \frac{\dot{s}(Z)}{s(Z)} + \frac{\dot{a}^*}{a^*}\frac{a^*}{1-a^*} + \frac{\dot{Y}}{Y} \\
&= -\frac{2\gamma}{2-\gamma}s(H)(\frac{\dot{h}}{h}-\frac{\dot{Z}}{Z}) + \frac{\gamma}{2-\gamma}(\frac{\dot{h}}{h}-\frac{\dot{Z}}{Z})\frac{a^*}{1-a^*} + \frac{\dot{Y}}{Y} \\
&= \frac{1}{(2-\gamma)(1-\alpha)+2\alpha(1-\gamma)s(H)}[\{-\gamma(1-\alpha)\frac{a^*}{1-a^*} + 2(1-\gamma)s(H)\}B\overline{u} \\
&\quad + \frac{\dot{A}}{A}\frac{1}{\beta}\{2\alpha(1-\beta) + \frac{2a^*-1}{1-a^*}\alpha\gamma + \alpha\beta\gamma - \frac{a^*}{1-a^*}\alpha^2\beta\gamma \\
&\quad - 2(\alpha(1-\beta)(1-\gamma) + \delta\beta(1-\alpha\gamma) - \gamma\alpha\beta(1-\alpha))s(H)\}]\,. \qquad (28)
\end{aligned}
$$

Lemma 8: If $s(H) > \dfrac{2\alpha(1-\beta) + \frac{2a^*-1}{1-a^*}\alpha\gamma + \alpha\beta\gamma - \frac{a^*}{1-a^*}\alpha^2\beta\gamma}{2(\alpha(1-\beta)(1-\gamma) + \delta\beta(1-\alpha\gamma) - \gamma\alpha\beta(1-\alpha))} \equiv s_R$ ($s(H) < s_R$), and if $2\alpha(1-\beta)(1-\gamma) - \gamma\alpha\beta(1-\alpha) > 0$, an exogenous increase in $\frac{\dot{A}}{A}$ decreases (increases) R&D agents' average income.

Propositions 2 and 3, and Lemma 8 yield the following propositions.

Proposition 4: Assume that γ >0. Then if $s(H) > s_R$, an exogenous increase in $\frac{\dot{A}}{A}$ decreases the growth rates of workers' and of R&D agents' average income. If $s_w < s(H) < s_R$, it decreases the growth rate of workers' average income, while it increases that of R&D agents' average income. And if $s_w > s(H)$, it increases the growth rates of workers' and R&D agents' average income.

(Proof) If γ >0, then $s_R > s_w$. Then the results are obvious from Proposition 2 and Lemma 8.

The above case of $s_w < s(H) < s_R$ with $\gamma > 0$ will show the phenomena of 'Digital Divide'. However, even in this case, the income growth rates of both types of agents will increase with respect to an exogenous increase in $\frac{\dot{A}}{A}$ in the long run if $\frac{\dot{A}}{A} > \frac{\beta(1-\alpha)Bu}{(\alpha(1-\beta)+\alpha\beta(1-\alpha))}$, as Lemma 3 shows.

Similarly, we derive the following proposition.

Proposition 5: Assume that $\gamma < 0$. Then if $s(H) > s_w$, an exogenous increase in $\frac{\dot{A}}{A}$ decreases the growth rates of workers' and of R&D agents' average income. If $s_R < s(H) < s_w$, it increases the growth rate of workers' average income, while it decreases that of R&D agents' average income. And if $s_R > s(H)$, it increases the growth rates of workers' and R&D agents' average income.

(Proof) If $\gamma < 0$, then $s_w > s_R$. Then the results are also obvious from Proposition 2 and Lemma 8.

The above propositions imply the following. First, depending on the elasticity of substitution and the factor share, an increase in the efficiency of technology creation or in lowering the barriers on the imports of intermediate goods affects the growth rates of workers' and R&D agents' average income differently. For example, if $\gamma > 0$ (in other words, if the elasticity of substitution is greater than one), in some region of $s(H)$, an advance in information and computer technology or 'globalization' increases the growth rate of R&D agents' average income, while it decreases that of workers'. And, if $\gamma < 0$ (in other words, if the elasticity of substitution is less than one), the result can be reversed.[19] Second, if an economy develops from a higher value of $s(H)$ to a sufficiently lower value, the growth rates of GNP, workers' and R&D agents' average income increases over time, as Lemma 3 implies.

4. CONCLUSION

This paper attempts to answer the question: Who gain and lose in the period of 'New Economy' and the 'globalization' that increases the level of international technology transfers and spillovers especially?

The model is basically a Romer's type of variety expansion of intermediate goods. We also assume that there are two types of agents supplying two different types of factors. Workers supply specific skill weighted labor by accumulating their specific skills that depreciate with an introduction of new intermediate goods. The other type of agents, R&D agents, produce and sell new varieties of intermediate goods monopolistically after inventing them.

The model produces the result that an increase in the efficiency of technology

[19] The case of $\gamma > 0$ represents richer countries, and that of $\gamma < 0$ poorer countries, following the results of Duffy and Papageorgious.

creation (or lowering the barriers on the imports of intermediate goods) affects the growth rates of workers' and R&D agents' average income differently, depending on the elasticity of substitution between the two factors and on the value of the factor share. More specifically, if the elasticity of substitution is greater than one, in a certain stage of development, an advance in ITC or 'globalization' increases the growth rate of R&D agents' average income, while it decreases that of workers'. Thus, 'Digital Divide' happens. Conversely, if the elasticity of substitution is less than one, the result will be reversed. Additionally, if an economy develops from a higher factor share of the workers to a sufficiently lower one, the growth rates of GNP, workers' and R&D agents' average income increases over time.

Even though we can describe the transitory movements more accurately, the main implications will not be much different from ours. We can make the model more flexible by allowing workers to save, or agents to have more general types of preferences. Also it will be very interesting to explore what causes countries to have different values of the elasticity of substitution. Finally calibration work can make the model more persuasive.

APPENDIX A

Derivation of the Price of Intermediate Goods

From (8), we can see that final good producers spend a constant fraction of output for buying intermediate goods as $p(x(i)) = \frac{1}{K_t}\alpha s_t(Z)Y_t \Rightarrow p(x(i))K_t = \alpha s_t(Z)Y_t$. Thus, given this constraint, we can derive the producer's demand function for intermediate goods by maximizing the following problem.

$$\max_{\{x(i)\}} \ \{\int_{i=0}^{A} x(i)^{\beta}\}^{\frac{1}{\beta}} di$$

$$s.t. \ \int_{i=0}^{A} p(x(i))x(i) = \alpha s(Z)Y \ .$$

With a Lagrangian multiplier λ on the constraint, the FOC with respect to $x(i)$ is

$$x(i)^{\beta-1} = \lambda p(x(i)) \, .$$

With this FOC, $MC = (1 + \frac{dp(x(i))}{dx(i)}\frac{x(i)}{p(x(i))})p(x(i))$ and $MC = r$, we obtain the desired result as $p(x(i)) = \frac{r}{\beta}$.

APPENDIX B

Derivation of the Fraction of High Ability Labor for R&D Invention

With the given level of the total labor force of high ability agents, and a constant interest rate, we will derive the following marginal conditions that the two wage rates of working for production of intermediate goods and for R&D investments should be equalized.

Using (22), the wage rate per one unit of time in the R&D invention sector is

$$w(A) = P_A \phi A = \phi(1-\beta)\alpha s(Z)Y \frac{1}{r-g}. \tag{B1}$$

And using (10) and (11), the wage rate in the production sector of intermediate goods is

$$w(S_x) = \frac{\partial Y}{\partial S_x} = \frac{(1-\alpha)s(Z)Y}{S_x}. \tag{B2}$$

(B1) and (B2) yield

$$S_x = \frac{(1-\alpha)}{\alpha}\frac{r-g}{(1-\beta)\phi} \equiv k \text{, and} \tag{B3}$$

$$S_R = 1 - a^{*2} - S_x = 1 - a^{*2} - \frac{(1-\alpha)}{\alpha}\frac{r-g}{(1-\beta)\phi}. \tag{B4}$$

APPENDIX C

Calculation of $\frac{\dot{Z}}{Z}$

For this we utilize the following three relationships

$$\frac{\dot{Z}}{Z} = \frac{1-\beta}{\beta}\frac{\dot{A}}{A} + \frac{\dot{s}(Z)}{s(Z)} + \frac{\dot{Y}}{Y}, \text{ where } Z = S_x^{1-\alpha}(A^{\frac{1-\beta}{\beta}}K)^{\alpha} \text{ and } K = \frac{\alpha\beta}{1+r}s(Z)Y, \tag{C1}$$

$$\frac{\dot{s}(H)}{s(H)} = \gamma(1 - s(H))\frac{\dot{H}}{H} - \gamma s(Z)\frac{\dot{Z}}{Z}, \text{ where } s(H) = \frac{\alpha H^{\gamma}}{\alpha H^{\gamma} + (1-\alpha)Z^{\gamma}}, \text{ and} \tag{C2}$$

$$\frac{\dot{H}}{H} = \frac{\dot{h}}{h} + \frac{\dot{a}^*}{a^*} = \frac{2}{2-\gamma}\frac{\dot{h}}{h} - \frac{\gamma}{2-\gamma}\frac{\dot{Z}}{Z}, \text{ where } H = ha^*\bar{l} \text{ and } \frac{\dot{a}^*}{a^*} = \frac{\gamma}{2}(\frac{\dot{H}}{H} - \frac{\dot{Z}}{Z}). \tag{C3}$$

Using (C1), (C2) and (C3), we derive

$$\frac{\dot{Z}}{Z} = \alpha(\frac{1-\beta}{\beta}\frac{\dot{A}}{A} + \frac{\dot{s}(Z)}{s(Z)} + \frac{\dot{Y}}{Y})$$
$$= \alpha(\frac{1-\beta}{\beta}\frac{\dot{A}}{A} - s(H)\frac{2\gamma}{2-\gamma}\frac{\dot{h}}{h} + s(H)\frac{2\gamma}{2-\gamma}\frac{\dot{Z}}{Z} + \frac{\dot{Y}}{Y}) \Rightarrow$$

$$\frac{\dot{Z}}{Z} = \frac{\alpha(2-\gamma)}{2-\gamma(1+2\alpha s(H))}(\frac{1-\beta}{\beta}\frac{\dot{A}}{A} - \frac{2\gamma s(H)}{2-\gamma}\frac{\dot{h}}{h} + \frac{\dot{Y}}{Y}) \tag{C4}$$

where $\frac{\dot{s}(H)}{s(H)} = -\frac{\dot{s}(Z)}{s(Z)}\frac{s(Z)}{s(H)}$.

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