Globalization and Divergence

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Abstract

This paper analyzes the effect of trade on growth, when technology adoption is endogenous and depends on factor prices. It shows that trade can lead to an increase in income disparities across countries, as the rich countries grow much faster than the poor countries. This is due to specialization of richer countries in skilled goods, which experience more technical change, while poor countries specialize in unskilled goods, which experience less technical change. Due to lack of sufficient labor mobility between the two sets of countries, wage gaps do not narrow.

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Globalization and Divergence

1. Introduction

This paper offers an additional explanation to the growing gap between rich and poor countries. In the last two centuries, since the beginning of the industrial revolution, the gaps in output per capita between countries increased significantly. As shown by Maddison (2001, 2005), GDP per capita in the developed countries (Western Europe, North America and Japan) increased 20 fold from 1820 to 2001, while in the rest of the world GDP per capita increased only 6 fold during the same period.[1] Thus, the income ratio between the two regions increased 3.5 fold. This phenomenon, which is sometimes called the great divergence, is one of the main puzzles in the area of economic growth. This paper claims that one of the possible explanations for this divergence can be the combined effect of globalization, namely increased international trade, and of technical change.

To show this, the paper constructs a theoretical model of technical change, skill acquisition and international trade. The model makes five main assumptions. First, technology is modeled as machines that replace labor in the production of the various goods. Hence, technical progress reduces labor costs but raises capital costs and is therefore adopted only if wages are sufficiently high. Second, there are two sectors, skilled and unskilled, which can also be thought of as manufacturing and raw materials, and technical change is sector specific. Third, there is international trade in goods, but no labor mobility. Fourth, there are two countries in the model, which differ only in the cost

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[1] This phenomenon is documented by many others. See for example Pritchett (1997). Bourguignon and Morrison (2000) show that the main rise in global inequality is due to rise in inequality between countries.

of education and in size. Fifth, demands to the skilled and non-skilled goods are non-homothetic, so that growth changes the terms of trade and through it relative incomes.

Using these assumptions the paper shows that the income ratio between developed and less developed countries can grow significantly along the path of economic growth. The mechanism operates as follows. Due to differences in cost of education one country specializes in producing the skilled good, while the other in the unskilled goods. Since wages in the country that specializes in the unskilled good are low it adopts technologies slower than the country that specializes in the skilled good. This amplifies the income gap between the two countries. Note, that due to lack of labor mobility the wage gap between skilled workers in one country and unskilled workers in another country can grow significantly. The paper also shows that in the presence of a friction to copying technologies from one country to the other, the income gap between the two countries can grow by even more.

This paper is part of the endogenous growth literature that began in the late 1980s. This literature has dealt thoroughly with the issues of convergence and divergence, both theoretically and empirically, where the empirical studies use mainly the tool of “growth regressions” developed by Barro (1991). Following is a very partial summary of this literature. According to the neoclassical production function approach to economic growth, output is determined by the inputs of labor and capital and by productivity. Hence, in open economies output per capita in a country could lag behind in two possible cases: first, if labor is less productive, namely with less human capital or less education, and second, if this country uses a different inferior technology. The first explanation, of differences in human capital, is very influential, since education has a strong effect on output. But this explanation is limited, as empirical "development accounting" studies have shown that differences in education can explain around 40% of the variation in income across countries.[2] This is significant, but still leaves much to other explanations.

Indeed, there are many more explanations to divergence in addition to human capital. One involves institutions, which affect property rights and through it technology adoption. This line of literature is summarized in Acemoglu et al (2005). Another line of literature claims that geography plays an important role in a country's growth success. Sachs (2001) is a good example of this line of research. Another line of literature builds on demographic trends and evolutionary dynamics and is surveyed in Galor (2005). Parente and Prescott (1995) and Zeira (1998) use costs of technology adoption of various types to explain differences in technology adoption across countries.

This paper follows the latter line of research, namely exploring the effect of adoption costs on technology adoption. The specific cost used in this paper is the cost of capital, as it is assumed that new technologies are in the form of machines that replace labor, which need to be purchased in order to adopt the new technology. The idea of labor saving and capital increasing innovations is not new and is mentioned earlier in the literature, but has lately been studied more widely. The idea appears in the famous book by Habbakuk (1962), who claims that technical progress in the US took over UK in the nineteenth century due to higher wages, which provided a stronger incentive to develop labor saving innovations. Champernowne (1963) developed a model of machines that replace workers, but focused mainly on how it affects the aggregate production function. Many years later Zeira (1998) used a similar model to show that the mechanism of machines that replace workers amplifies differences in productivity across countries

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[2] See Caselli (2005) for a survey of these studies and additional results.

through technology adoption. More recent works that follow this approach in various directions are Givon (2006), Peretto and Seater (2006), Zeira (2009), Zuleta (2006) and Alesina and Zeira (2009). Recently Acemoglu (2011) has expanded this approach to a more general theme of "innovations induced by labor costs."

The relationship between economic growth, technology and international trade has also been studied extensively. The early literature of endogenous growth has claimed that globalization should increase technical progress, since it increases the scale of global production and since scale has a positive effect on growth.[3] But recently the belief in the scale effect has declined following Jones (1995). A similar argument to the one in this paper, namely that trade might contribute to the large divergence, is raised by Galor and Mountford (2008), but the mechanism they use to analyze this relation is demographic, while this paper suggests instead a technological mechanism.

There is another line of the literature that focuses on non-homothetic preferences, which relates growth to deterioration of the terms of trade in poor countries. Concern over this issue has been raised already by Prebisch (1950) and Singer (1950). Models of this effect have been presented by Flam and Helpman (1987), Stokey (1991), and recently by Matsuyama (2000). This paper differs from these by departing from their static framework, and by extending it to long-run growth with endogenous technical change and by making technology dependent on the terms of trade.

The paper is organized as follows. Section 2 presents the main assumptions of the model. Section 3 outlines the equilibrium dynamics if each economy remains closed to international trade. Section 4 describes the patterns of trade and of specialization. Section

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[3] The literature on R&D based endogenous growth began with Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992). The connection to international trade was made mainly in Grossman and Helpman (1991).

5 analyzes the dynamics of technology and of divergence under full specialization. Section 6 examines the conditions to full specialization and divergence under less than full specialization. Section 7 supplies quantitative estimates for the degree of divergence explained by the model. Section 8 summarizes.

2. The Model

Consider a world with two countries and a single final good. The final good Y is produced by two intermediate goods, a skilled good S and an unskilled good N, using the following CES production function:

$$(1) \qquad Y = \left(S^a + N^a\right)^{\frac{1}{a}}.$$

The coefficient a satisfies $a < 1$. It is further assumed that a is positive, since the elasticity of substitution between skilled and unskilled goods is high.[4]

Each of the intermediate goods is produced prior to the industrial revolution by labor only, where S is produced by skilled labor and N by unskilled labor. Each is produced by many tasks, where production can be described by a Cobb-Douglas function in a continuum of tasks. Thus, production of the skilled good S prior to the industrial revolution is described by:

$$(2) \qquad \ln S = \int_0^1 \ln s(j)dj,$$

where $s(j)$ is the amount of labor in task j in production of the skilled good. Similarly the production of the unskilled good N prior to the industrial revolution is described by:

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[4] More accurate assumptions on a appear in the quantitative assessment in Section 7.

(3) $$\ln N = \int_0^1 \ln n(j)dj.$$

At some historical moment new technologies appear that enable replacing labor in some tasks by machines. Once such a technology for task j is invented, a worker in task j can be replaced by a machine of size k units of capital.[5] This machine must be invested one period ahead of production. It is also assumed that a period of time is sufficiently long so that the rate of depreciation is equal to 1.

We next describe the invention of machines. First, machines are invented as long as there is demand for them, as described below. Second, tasks are ordered by invention of machines. This means that the set of skilled tasks for which machines have been invented until time t (not including t) is $[0, f_S(t)]$. Namely, the technology $f_S(t)$ is the frontier of the skilled sector. Third, invention of machines is gradual, even if they are demanded, due to difficulty of invention. In each period invention is costless up to some level and then becomes infinitely costly, until the next period. Formally, the amount of new skilled tasks for which machines are invented in period t, as long as there is demand for them, is:

(4) $$\Delta f_S(t) = f_S(t+1) - f_S(t) = b[1 - f_S(t)].$$

The dynamics of innovation in the unskilled sector are similar and the unskilled technology frontier, $f_N(t)$, changes according to:

(5) $$\Delta f_N(t) = f_N(t+1) - f_N(t) = b[1 - f_N(t)].$$

Individuals in this model live in overlapping generations, work in first period of life and consume in both periods. They can either work as unskilled or as skilled. If they

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[5] It is assumed that machines for all tasks, skilled and unskilled, have the same size. Removing this assumption complicates the analysis, but leaves the main results unchanged.

are unskilled, they supply one unit of labor each. If they become skilled, education requires time and thus reduces supply of labor by skilled by a factor h, which is country specific. Individuals are assumed to be risk neutral and their utility is:[6]

(6) $$U = c_{young} + \frac{c_{old}}{1+\rho}.$$

It is assumed that the two countries are identical except for size and for the cost of education: country A has lower cost of education and less population:

(7) $$L_A < L_B \text{, and } h_A < h_B.$$

Note that the higher cost of education for country B can reflect a shorter career horizon, due to bad health. Then, even if education requires the same time, it requires a larger share of a person's career time. For simplicity assume that there is no government, that there is full capital mobility and that markets are perfectly competitive. We begin our analysis in the case of no trade and later allow trade between the two countries, to study the effect of globalization. It is assumed that under trade the two intermediate goods, the skilled and the unskilled, are tradable but the final good is not. It is also assumed that even under trade, there is no labor mobility between the two countries.

3. Equilibrium in a Closed Economy

Assume first that the final good is the numeraire in the closed economy.[7] We begin our analysis with the decision of technology adoption, namely whether to produce with machines or with labor, or whether to industrialize or not. If a skilled task j is produced by labor, its unit cost of production is w_S, where w_S is the skilled wage. If a skilled task j

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[6] In most of the following discussion the time subscript is deleted whenever it is not confusing.

[7] Country subscripts are deleted in this section.

is produced by machines, its unit cost of production is Rk, where $R = 1 + r$ is the sum of the interest rate and the rate of depreciation. Hence, the machine technology is adopted for this skilled task if and only if:

(8) $$w_S \geq Rk.$$

In a similar way, if w_N is the wage of unskilled, the machine technology is adopted for the unskilled task if and only if:

(9) $$w_N \geq Rk.$$

Hence, technology adoption depends crucially on the prices of the factors of production, namely on R and the wage rates of skilled and unskilled. We next turn to describe how these factor prices are determined.

First note that due to risk neutral utility (6) the interest rate is constant over time and is equal to the subjective discount rate ρ. Hence, $R = 1 + \rho$. The determination of the skilled and unskilled wage rates requires analysis of the goods markets.

We begin with the demand for the skilled and unskilled goods. Competitive producers maximize profits and this leads to the following first order conditions:

$$P_S = \frac{\partial Y}{\partial S} = \left(\frac{Y}{S}\right)^{1-a}, \text{ and } P_N = \frac{\partial Y}{\partial N} = \left(\frac{Y}{N}\right)^{1-a}.$$

Substituting the derived S and N in the production function (1) we get a condition that relates the prices of the two intermediate goods:

(10) $$P_S^{-\frac{a}{1-a}} + P_N^{-\frac{a}{1-a}} = 1.$$

This condition describes the demand for the two goods.

The FOC in production of the skilled good, with respect to skilled tasks performed by labor, is given for each $j \in (f_S, 1]$ by:

(11) $$w_S = \frac{P_S \partial S}{\partial s(j)} = \frac{P_S S}{s(j)}.$$

Similarly the FOC for tasks performed by machines, $j \in [0, f_S]$, where *s*(*j*) is equal to the amount of machines, is:

(12) $$Rk = \frac{P_S \partial S}{\partial s(j)} = \frac{P_S S}{s(j)}.$$

Conditions (11) and (12) describe the supply side of the skilled good. Substituting them in the production function (2) leads to the following relationship between the price of the skilled good and the prices of the factors of production and the state of technology in the skilled sector:

(13) $$\ln P_S = f_S \ln(Rk) + (1 - f_S)\ln w_S = \ln(Rk) + (1 - f_S)\ln\frac{w_S}{Rk}.$$

In a similar way it can be shown that the price of the unskilled good satisfies:

(14) $$\ln P_N = f_N \ln(Rk) + (1 - f_N)\ln w_N = \ln(Rk) + (1 - f_N)\ln\frac{w_N}{Rk}.$$

Let us denote the variable $(1 - f_S)\ln(w_S / Rk)$ by e_S. It is going to be an important variable in the following dynamic analysis. The reason is that it indicates whether there is technical progress in the skilled sector or not, since f_S is increasing if e_S is non-negative, as indicated by (8), and f_S is stagnant if e_S is negative. The parallel variable in the unskilled sector is $e_N = (1 - f_N)\ln(w_N / Rk)$. From (13) and (14) we get: $e_S = \ln(P_S / Rk)$ and $e_N = \ln(P_N / Rk)$. Substituting in equation (10) leads to the following relation between e_S and e_N:

(15) $$\exp\left(-\frac{a}{1-a}e_S\right) + \exp\left(-\frac{a}{1-a}e_N\right) = (Rk)^{\frac{a}{1-a}}.$$

Equation (15) describes the equilibrium in the goods market, as it is derived from the supply and demand for the two intermediate goods, the skilled good and the unskilled good. This equilibrium condition is plotted in Figure 1 as a curve in the e_N and e_S plane, which is called the goods market equilibrium curve, GME. This is a downward sloping convex curve. It can be shown that the curve passes through the first quadrant, as in Figure 1, if the following condition is satisfied:

$$(16) \qquad Rk < 2^{\frac{1-a}{a}}.$$

In most of the following analysis we focus on the case that GME passes through the first quadrant, namely that condition (16) is satisfied. Note, that the GME curve in Figure 1 passes also through the second and fourth quadrant if $Rk > 1$.

In order to derive the equilibrium wages of the skilled and unskilled we need to add the labor market equilibrium condition. Note, that since education requires h units of time, the supply of a skilled worker is equal to $1 - h$. Since life-time income of skilled and unskilled should be equal, we get:

$$w_S(1-h) = w_N.$$

Hence, the ratio between the wage of skilled and of unskilled, denoted by I, is equal to:

$$(17) \qquad I = \frac{w_S}{w_N} = \frac{1}{1-h} > 1.$$

After some algebraic manipulation we get from equation (17) the following relation between the two wage rates:

$$(1-f_S)\ln\frac{w_S}{Rk} = (1-f_S)\ln I + \frac{1-f_S}{1-f_N}(1-f_N)\ln\frac{w_N}{Rk},$$

and translating it to the variables e_S and e_N we get:

(18) $$e_S = (1 - f_S)\ln I + \frac{1 - f_S}{1 - f_N} e_N .$$

Equation (18) is also plotted in Figure 1 and is a linear curve with a positive slope and a positive intercept. It describes the labor market equilibrium and is denoted LME. The two equations (15) and (18) together determine the equilibrium wage rates in the two sectors and thus determine the rates of technical progress for skilled and unskilled goods. This is shown diagrammatically in the intersection of GME and LME in Figure 1.

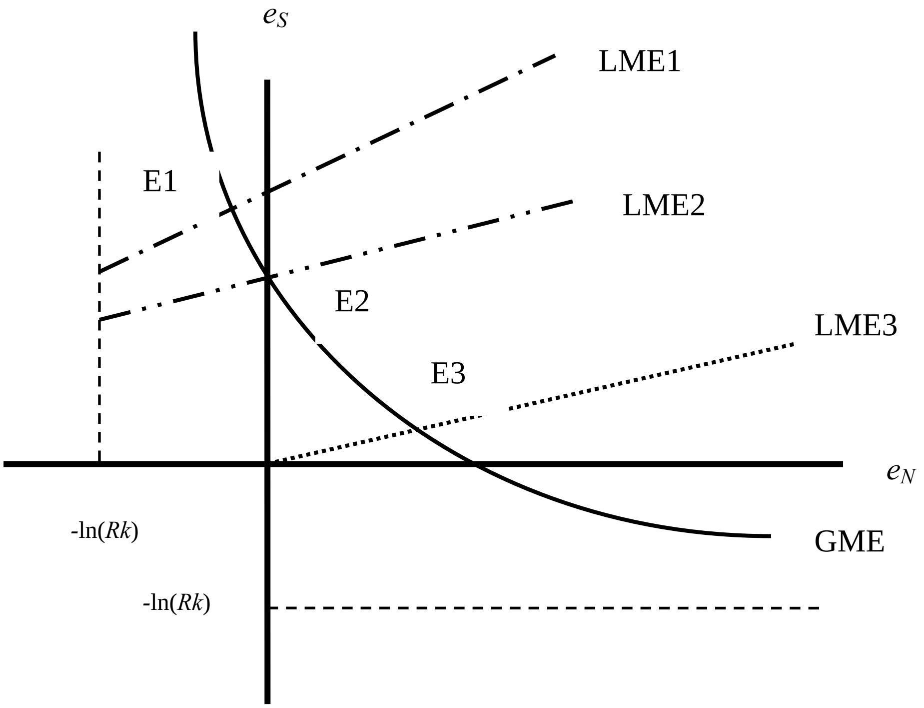

Figure 1: Dynamics in the Closed Economy

Note that since the curve LME has a positive intersect with the vertical curve and a positive slope, it can intersect the GME curve either in the second quadrant or in the first quadrant. We show below that the dynamics in the two cases are similar, since even if the initial intersection is in the second quadrant, the economy reaches the first quadrant after some time. Consider the case that the initial labor market equilibrium is described by LME1 so that the initial equilibrium E1 is at the second quadrant. Then (8) is satisfied, but (9) is not, so there is technical progress in the skilled sector, but not in the unskilled sector. As a result f_S increases and f_N remains unchanged, at 0. This shifts the LME curve downward and also reduces its slope, until it reaches the first quadrant at LME2.

At the equilibrium E2 the unskilled sector begins to adopt technologies and thus starts the process of technical progress. In the first quadrant both f_S and f_N grow according to (4) and (5) every period. Hence, $(1-f_S)/(1-f_N)$ remains unchanged since:

$$\frac{1-f_S(t+1)}{1-f_N(t+1)}=\frac{(1-b)[1-f_S(t)]}{(1-b)[1-f_N(t)]}=\frac{1-f_S(t)}{1-f_N(t)}.$$

As a result the curve LME does not change its slope, but keeps shifting downward until it converges in the long run to LME3, where industrialization is completed, as $f_S \to 1$. We therefore conclude that if Rk satisfies (16) the skilled sector experiences technical progress, and the unskilled sector joins in, sooner or later. Note that if (16) is not met and $Rk > 2^{\frac{1-a}{a}}$, so that the curve GME does not pass through the first quadrant, the economy experiences technical progress only in the skilled sector and even that stops after a finite time, when e_S becomes 0. Hence, long-run growth is possible only if the cost of machinery k is sufficiently low.

We next calculate the level of output and show that technical progress and economic growth indeed go together. Let L_S denote the number of workers in the skilled sector and L_N the number of workers in the unskilled sector. From equation (11) we get:

$$L_S(1-h) = \int_{f_S}^{1} s(j)dj = (1-f_S)\frac{P_S S}{w_S}.$$

Similarly:

$$L_N = \int_{f_N}^{1} n(j)dj = (1-f_N)\frac{P_N N}{w_N}.$$

Adding the two labor inputs together, so that $L_S + L_N = L$ leads to the following equation, which describes output per worker:

$$(19) \qquad y = \frac{Y}{L} = \frac{(Rk)^{\frac{1}{1-a}} \exp[e_N/(1-f_N)]}{(1-f_S)\exp[-e_S a/(1-a)] + (1-f_N)\exp[-e_N a/(1-a)]}.$$

This equation implies that output increases to infinity with technical progress. Hence, this model gives rise to continuing economic growth if condition (16) is met. If technical progress stops at some future period, output stops growing.

Finally, we can use equations (19), (15) and (18) to calculate output per worker in the closed economy before the beginning of technical progress and of industrialization:

$$(20) \qquad y = \frac{Y}{L} = \left(1 + I^{-\frac{a}{1-a}}\right)^{\frac{1-a}{a}}.$$

Hence, the higher the skill premium in the economy, the lower is output per worker.

4. International Trade and the Global Division of Labor

We now turn to the World of two countries, A and B. Since they differ in their cost of education, they differ in their autarkic skilled to unskilled wage ratios, so that: $I_A < I_B$. Figure 2 presents the equilibrium curves of the two countries together, before trade opens and before technical progress begins, namely before the industrial revolution, in a diagram similar to Figure 1. In Figure 2 the two countries share the same equilibrium condition in the goods market, GME, but differ in their LME curves. The slope of both LME curves are 1, since $f_S = f_N = 0$, but the curve LME_A is lower since its intersect is $\ln I_A$, while the intersect of LME_B is $\ln I_B$.

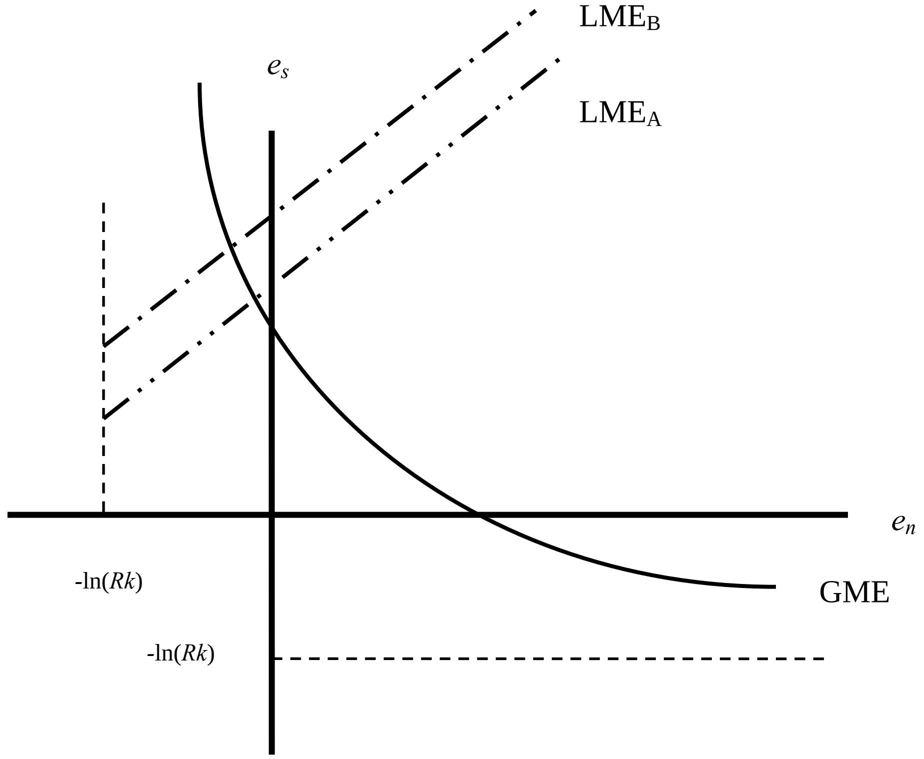

Figure 2: Countries A and B before Trade

The prices of the two goods are $\ln P_S = \ln(Rk) + e_S$ and $\ln P_N = \ln(Rk) + e_N$. Hence, Figure 2 implies that the price of the skilled good is higher in country B, while the price of the unskilled good is higher in country A. In other words, country A has a comparative advantage in production of the skilled good, while country B has a comparative advantage in production of the unskilled good. As a result, once trade opens between the two countries, country A specializes in the skilled good, while country B specializes in the unskilled good.

The prices of the two intermediate goods become equal in the two countries. As a result the prices of the final goods in the two countries are equal as well, whether they are traded or not, since it can be shown, in a similar way to the derivation of (10), that:

$$P_A^{-a/1-a} = P_B^{-a/1-a} = P_S^{-a/1-a} + P_N^{-a/1-a}.$$

We can therefore normalize the price of the final good in both countries to 1 and use it as a numeraire, as done in Section 3 on the closed economy.

Next assume that specialization in the world economy before technical change is full, and country A supplies all the global demand for the skilled good, while country B supplies all the unskilled good. To examine when such full specialization prevails, note that the prices of the skilled and the unskilled goods prior to technical change are: $P_S = w_{S,A}$ and $P_N = w_{N,B}$ respectively. The labor market conditions are therefore:

$$L_A(1-h_A) = \int_0^1 s(j)dj = \frac{P_S(S_A + S_B)}{w_{S,A}} = P_S^{-\frac{1}{1-a}}(Y_A + Y_B),$$

and:

$$L_B = \int_0^1 n(j)dj = \frac{P_N(N_A + N_B)}{w_{N,B}} = P_N^{-\frac{1}{1-a}}(Y_A + Y_B).$$

These two conditions yield the relative price of skilled to unskilled goods P_S / P_N and full specialization prevails as long as this relative price is lower than the potential relative wage in country B and higher than the potential relative wage in A. Hence, full specialization occurs prior to technical change if:

$$(21)\qquad I_A < \left(\frac{L_B}{L_A} I_A\right)^{1-a} < I_B .$$

Section 6 examines the conditions for full specialization along the complete dynamic path and also examines what happens when specialization is less than full.

5. Divergence under Full Specialization

This section describes the equilibrium and dynamics of the global economy under the assumption that specialization is full along the whole dynamic path. If the two goods are produced in separate countries, equation (15) becomes:

$$(22)\qquad \exp\left(-\frac{a}{1-a} e_{S,A}\right) + \exp\left(-\frac{a}{1-a} e_{N,B}\right) = (Rk)^{\frac{a}{1-a}} .$$

This is the Global Goods Market Equilibrium condition, GGME. This equation is very similar to (15), except that here it relates the wages of skilled in country A to the wages of unskilled in country B. Next, we ask how these wage rates are determined.

As long as production of all intermediate goods was in one country the wages of skilled and unskilled workers could not diverge, since labor mobility put an upper bound on the wage ratio between the two professions. But when the division of labor becomes global and labor mobility across countries is limited, or completely impossible as in this paper, the gap between wages of skilled and unskilled can grow significantly. This is even further amplified by technology divergence between the two countries. Country A adopts more and more technologies and becomes more industrialized, which raises income and wages, while country B does not adopt new technologies, remains under-industrialized and thus income and wages are stagnant.

Next the labor markets equilibrium conditions in the two countries are derived formally under full specialization. Using the first order conditions we get that the labor market equilibrium condition in country A is described by:

$$L_A(1-h_A)=\int_{f_S}^{1}s(j)dj=(1-f_S)\frac{P_S(S_A+S_B)}{w_{S,A}}=(1-f_S)\frac{P_S^{-a/1-a}(Y_A+Y_B)}{w_{S,A}}.$$

The labor market equilibrium condition in country B involves unskilled production only and is described by:

$$L_B=\int_{f_N}^{1}n(j)dj=(1-f_N)\frac{P_N(N_A+N_B)}{w_{N,B}}=(1-f_N)\frac{P_N^{-a/1-a}(Y_A+Y_B)}{w_{N,B}}.$$

From these two labor market equilibrium conditions we get:

$$\text{(23)}\qquad \frac{w_{S,A}P_S^{a/1-a}}{w_{N,B}P_N^{a/1-a}}=\frac{1-f_S}{1-f_N}\frac{L_B}{L_A}I_A.$$

Noting that wages and prices of the two goods are related through (13) and (14) we take the logarithm of equation (23) and derive from it a condition that relates together the variables e_S and e_N:

$$\text{(24)}\qquad e_{S,A}=\frac{\dfrac{a(1-f_S)}{1-a}+\dfrac{1-f_S}{1-f_N}}{\dfrac{a(1-f_S)}{1-a}+1}e_{N,B}+\frac{1}{\dfrac{a}{1-a}+\dfrac{1}{1-f_S}}\left(\ln I_A+\ln\frac{L_B}{L_A}+\ln\frac{1-f_S}{1-f_N}\right).$$

This is the Global Labor Market Equilibrium condition, GLME. It describes a positive linear relationship between $e_{N,B}$ and $e_{S,A}$. It can therefore be described by an upward sloping linear curve, as shown in Figures 3 and 4 below. Technical progress shifts this curve and changes its slope as well. Clearly, technical progress in country A, namely a rise in f_S, shifts the curve down and also reduces its slope. Technical progress in country B, namely a rise in f_N, shifts the curve upward and increases its slope. Note though that if there is technical progress in the two sectors and the two countries, then according to assumptions (4) and (5) the ratio $(1-f_S)/(1-f_N)$ remains unchanged. Hence, according to (24) the curve GLME shifts downward and its slope is reduced as well. Once we add to Figures 3 and 4 the downward sloping curve of the GGME, the intersection of the two curves determines the global equilibrium and with it the dynamics of technical change.

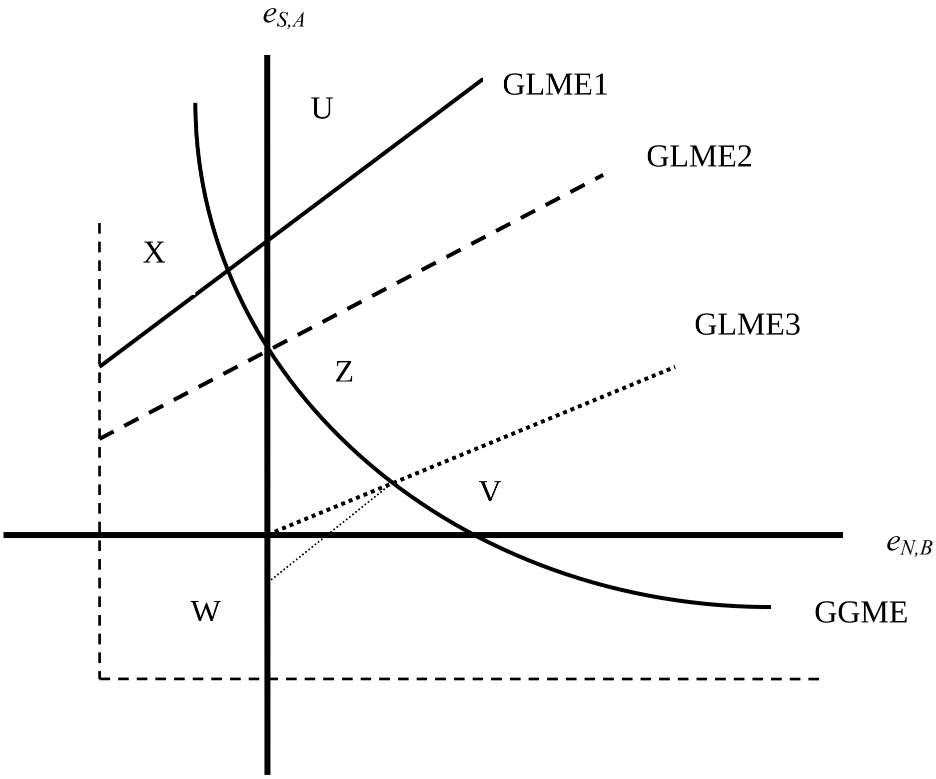

Figure 3: Equilibrium in the Global Economy – Case I

The analysis of the global dynamics of technical change begins with two cases, one where the initial equilibrium is at the second quadrant, described in Figure 3, and one where it is in the first quadrant, as described in Figure 4. Assume in both cases that dynamics begin at the eve of the industrial revolution, where both f_S and f_N are zero. At the initial equilibrium in Figure 3, where the intersection of GGME and GLME1 is at X, initial $e_{N,B}$ is negative and initial $e_{S,A}$ is positive. Technical progress begins only at the skilled sector in country A, so f_S increases and f_N remains 0. As a result the GLME curve shifts downward and its slope decreases, until it reaches GLME2 at Z and technical progress begins in the unskilled sector as well, in country B. Later on, the GLME curve shifts further downward, until it converges to GLME3 and the world economy converges to V.

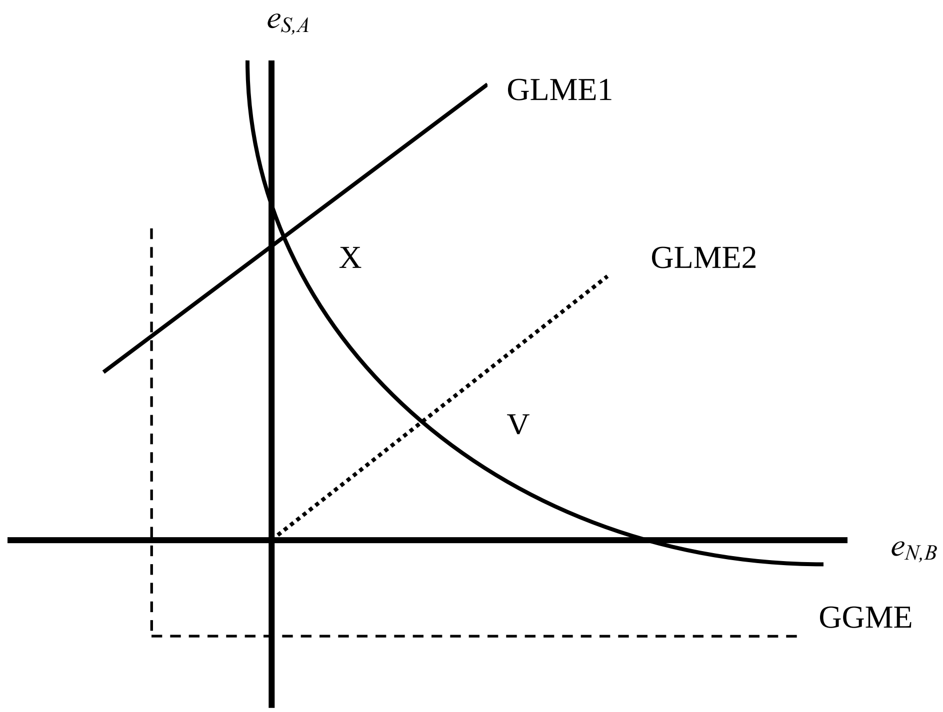

Figure 4: Equilibrium in the Global Economy – Case II

In the second case, where the initial equilibrium is at the first quadrant, as described in Figure 4, technical change begins in both sectors simultaneously. Since f_S and f_N grow at the same rate, the GLME curve shifts downward, keeping its slope constant at 1, until it reaches GLME2 in the long-run. The process of technical change moves the global equilibrium along the GGME curve until V in Figure 4. Note that in both cases the process of technical change shifts the global economy downward along the GGME curve, namely $e_{N,B}$ increases while $e_{S,A}$ is reduced.

We next show that this process increases the income gap between the two countries, not only at the stage when country B does not experience technical change, but also when technical change reaches country B after some time. To see this calculate the income ratio between the two countries, using the first order conditions of (1):

$$\frac{Y_A}{Y_B} = \frac{P_S(S_A + S_B)}{P_N(N_A + N_B)} = \frac{P_S^{-a/1-a}}{P_N^{-a/1-a}} = \left(\frac{P_N}{P_S}\right)^{a/1-a}.$$

Taking logarithms we get:

$$\ln\frac{Y_A}{Y_B} = \frac{a}{1-a}\left(\ln P_N - \ln P_S\right) = \frac{a}{1-a}\left(e_{N,B} - e_{S,A}\right). \tag{25}$$

As described above, the value of $e_{N,B}$ is increasing along the process, while the value of $e_{S,A}$ is decreasing. That means that the income ratio between country A and country B is increasing continuously. This is the divergence experienced between the two countries.

We next try to get a more accurate estimate of the size of divergence. We define the degree of divergence to be the change in the income ratio from the beginning of the industrial revolution, when trade is already established, but industrialization is still at zero, to the long run. Formally, divergence measures the relative change in the output ratio between points X and V in Figures 3 and 4. Hence, a diagrammatic measure of divergence is the vertical distance between the intersection of the curve LME1 with the $e_{S,A}$ axis and between point W in Figure 3 or the origin in Figure 4, multiplied by $a/(1-a)$.

Proposition 1: Divergence is bounded below by:

$$\left(I_A \frac{L_B}{L_A} \right)^a .$$

In the case described in Figure 4 this is the exact measure of divergence. In the case described in Figure 3 exact divergence is given by:

$$\left(I_A \frac{L_B}{L_A} \right)^a \exp\left(\frac{a}{1-a} e^* f^* \right),$$

where f^* is the level of technology f_S when the economy reaches the point Z and e^* is equal to $e_{N,B}$ at the long-run equilibrium V.

Proof and calculations of f^* and e^* are in the Appendix.

Note that the case described in Figure 3 seems to be more realistic, as technical change begins first in the developed world, and begins only later at the poorer countries, and even then, only in the unskilled industries.

6. Specialization along the Dynamic Path

Condition (21) guarantees full specialization initially, before technical change takes off. But after it starts, wages of skilled workers increase continuously, while wages of unskilled, which are concentrated in the less developed country, rise by less. This creates an incentive for unskilled workers to become skilled and might lead to less than full specialization. In this section we examine the conditions for full specialization along the whole dynamic path and also examine the degree of divergence when there is less than full specialization.

Clearly the condition for full specialization is that the global skill premium will be smaller than the autarkic skill premium in country B, to deter the unskilled from acquiring skill, and higher than the autarkic skill premium in country A, to deter skilled from choosing to be unskilled. Let us denote the global skill premium by *GSP*, which is defined by $GSP = w_{S,A} / w_{N,B}$. Then the condition for full specialization is that along the dynamic path it should satisfy:

(26) $\ln I_A < \ln GSP < \ln I_B .$

Actually, we are interested here mainly in the right hand side inequality, which guarantees that the growing gap between the two countries does not lead to a shift to skill in country B. The following Proposition explores how the global skill premium GSP changes along the dynamic path and this helps in finding conditions for full specialization along technical change and industrialization.

Proposition 2: If the dynamics are described by Figure 4, the global skill premium rises throughout the whole process from X to V and the global skill premium at V is:

$$\ln GSP(V) = \ln I_A + \ln \frac{L_B}{L_A} .$$

If the dynamics are described by Figure 3, GSP rises from Z to V but not necessarily from X to Z. In this case the global skill premium at Z is equal to:

$$\ln GSP(\mathrm{Z}) = \frac{(1-a)\left[\ln I_A + \ln\frac{L_B}{L_A} + \ln(1-f^*)\right]}{a(1-f^*)+1-a},$$

where *f** is defined and calculated as in Proposition 1. The global skill premium at V is:

$$\ln GSP(\mathrm{V}) = \ln I_A + \ln\frac{L_B}{L_A} + \ln(1-f^*) + \frac{a}{1-a} f^* e^*,$$

where *e** is defined and calculated as in Proposition 1.

Proof: in the Appendix.

When technology changes in both countries, as they move from Z to V, the global skill premium rises, and the possibility of less than full specialization emerges, where country A specializes in the skilled good and country B produces both goods. Then, the global skill premium is equal to I_B and the new GLME curve is described by:

(27) $$e_S = (1-f_S)\ln I_B + (1-f^*)e_N.$$

Note that *f** is as defined in Proposition 1. It is easy to see that the global economy still converges to the same long-run equilibrium V and to the same long-run value $e_N = e^*$. We next turn to calculate the output ratio when there is less than full specialization.

Proposition 3: If specialization is not full, the limit of output ratio Y_A / Y_B as the global economy approaches V is:

$$\frac{I_B}{I_A}\frac{L_A}{L_B^* f^* + L_B(1-f^*)},$$

where L_B^* is the amount of skilled labor in country *B* at the long-run equilibrium V, which is equal to:

$$L_B* = \frac{L_B(1-f*)\exp\left(\frac{e*f*a}{1-a}\right) - \frac{I_B}{I_A}L_A}{1+(1-f*)\exp\left(\frac{e*f*a}{1-a}\right)}.$$

Proof: in the Appendix.

We next claim that it is possible to have full specialization all along the dynamic path of the economy, if we add to the model the assumption that technology adoption is not immediate but gradual. Note that our benchmark model assumes that whenever people from country B wish to become skilled, they can produce the skilled good with the most advanced available technology developed in country A. This is of course a strong assumption, while it is reasonable to assume that not only the process of inventing technologies is gradual, but their learning and adoption is gradual as well. A simple way to model it is to assume that country B can adopt technologies from country A at the following rate:

(28) $$\Delta f_S = f_{S,t+1} - f_{S,t} = d(1-f_{S,t}).$$

It is assumed that adoption is of course quicker than invention, namely that: $d > b$. We next show that under this assumption, if d is not too large, people in country B remain unskilled and specialization remains full.

Proposition 4: If technology adoption is gradual, as in (28), if initially the two countries fully specialize, namely if (21) holds, and if the speed of technology adoption d satisfies:

(29) $$d < \frac{\ln I_B - (1-a)\ln I_A - (1-a)\ln(L_B/L_A)}{\frac{1-a}{a}\ln\left[1+\left(\frac{L_B}{L_A}I_A\right)^{-a}\right] + \ln I_B - \ln(Rk)},$$

then the two countries experience full specialization along the dynamic path all the way from X to V.

Proof: in the Appendix.

7. Quantitative Assessment

This section supplies some numerical calculations of the size of divergence, which emerges in this model. These numerical estimates are based on some historical data, when country A in the model is interpreted as Western Europe, Japan and the Western Offshoots (as defined in Maddison 2001, 2005), while country B is interpreted as the rest of the world. The ratio between the populations of Western Europe, Japan and the Western Offshoots and the rest of the world in 1820 was 1/5 and it went down to 1/6 toward the end of the 20th century, according to Maddison (2005). Hence we assume that L_B/L_A is equal to 5. As for a value for I_A we assume that it is equal to 1.5, based on estimates by Van Zelden (2009) for the beginning of the 19th century.[8] We assume that I_B is equal to 3, also according to Van Zelden (2009). The other parameter which we need to consider is a, which is given by the size of the elasticity of substitution of skilled and unskilled goods. We do not have an estimate of this elasticity, but many studies have estimated the elasticity of substitution between skilled and unskilled labor. According to Caselli and Coleman (2006), which summarize these studies, this elasticity is between 1 and 2 and its best estimate is 1.4. For this elasticity we get that $(1\text{-}f)a$ is equal approximately to 0.3, and since we can assume that in the developed country the degree

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[8] Actually this was the skill premium in Western Europe, while in other areas of Europe, mostly East and Southern Europe it was a bit higher.

of mechanization is around half, we can deduce that *a* is around 0.6. In the calculations below we examine the degree of divergence for a few values of *a*, from 0.5 up. We also allow the cost of machinery *Rk* to vary, as long as (15) is satisfied.

We first examine in Table 1 whether full specialization remains throughout the dynamic process or not. This table presents the skill premium in the crucial points along the dynamic path of the global economy. Note that full specialization is violated when the skill premium exceeds 3 and is below 1.5. As Table 1 shows, the two cases appear, depending mainly on the cost of machinery.

a	*Rk*	*GSP*(X)	*GSP*(Z)	*GSP*(V)
0.5	1.4	2.74	2.73	7.06
0.5	1.5	2.74	2.66	5.88
0.5	1.6	2.74	2.51	4.77
0.5	1.7	2.74	2.27	3.68
0.5	1.8	2.74	1.98	2.76
0.5	1.9	2.74	1.56	1.83
0.6	1.4	2.24	2.00	3.61
0.6	1.5	2.24	1.58	2.07
0.7	1.2	1.83	1.82	4.22
0.7	1.3	1.83	1.39	1.84

Table 1: The Global Skill Premium along the Dynamic Path

We next calculate the degree of divergence for different values of *a* and *Rk*, using the results of Table 1, which tell us whether specialization is full or not, and using Propositions 1 and 3. The results of these calculations are presented in Table 2. It shows that divergence can be quite significant and in many cases it exceeds 3.

a	0.5	0.6	0.7	0.8
Rk				
1.1		1.34	1.66	4.12
1.2		1.39	3.27	
1.3		1.97	4.57	
1.4	1.17	3.10		
1.5	1.41	3.71		
1.6	1.75			
1.7	2.38			
1.8	3.05			
1.9	2.91			

Table 2: Degree of Divergence for Various Values of *a* and *Rk*

Finally, consider the case that technology adoption is gradual, which is discussed at the end of Section 6, where technology adoption is given by (28). Assume that *d* satisfies (29) in Proposition 4, so that the two countries remain fully specialized along the complete dynamic path. Table 3 presents the degree of divergence under this assumption, namely under full specialization for all relevant values of *a* and of *Rk*. As Table 3 shows, under this assumption of gradual technology adoption, divergence is much stronger and in some cases it even exceeds the actual observed divergence of 3.5.

a	0.5	0.6	0.7	0.8
Rk				
1.1		3.35	4.14	6.41
1.2		3.42	5.01	
1.3	2.74	3.88	4.57	
1.4	2.83	3.93		
1.5	3.02	3.71		
1.6	3.11			
1.7	3.12			
1.8	3.05			
1.9	2.91			

Table 3: Degree of Divergence under Full Specialization

8. Summary and Conclusions

This paper presents a highly stylized model that highlights one possible mechanism that could have contributed significantly to the great divergence. This is the mechanism of technology and its interaction with wages and with the global division of labor.

International trade leads to a global division of labor, where some countries specialize in production by skilled workers and some countries in production by unskilled workers. This division of labor, with limits on labor mobility between the two countries, creates an income gap between the two types of countries, which is also the wage gap between skilled and unskilled. Since technology is stimulated by high cost of labor, it therefore mean that the countries that produce unskilled goods industrialize later and by less and as a result the income gap between the countries further increases. Our calculations show that the size of such divergence, as implied by the model, can be quite significant.

What are the policy implications of such a model? Does it mean that the anti-globalization activists were right and international trade should be stopped in order to reduce gaps between countries? This is clearly not the message of this model, in which the allocation of resources is optimal, as in many similar neoclassical models. But this model does point at three main measures, which can alleviate poverty in less developed countries and reduce wage gaps between countries. The first is to increase access to education in the less developed countries, by supporting their investment in public education, so that these countries can increase their share in the production of the skilled goods. The second is to increase access to new technologies in developing countries by reducing the cost of equipment and of technology adoption in general to these countries. The third policy is to encourage birth control in the less developed countries, to reduce the population ratio L_B/L_A. These are not easy measures to follow, but they are necessary to reduce the large income gaps in our world.

Appendix

Proof of Proposition 1:

At the beginning of technical change and industrialization, namely at X, the labor market equilibrium condition (24) is equal to:

$$e_{S,A} = e_{N,B} + (1-a)\left(\ln I_A + \ln \frac{L_B}{L_A}\right).$$

Hence, the income ratio at this initial equilibrium at X is given by (25):

$$\text{(A.1)} \qquad \ln \frac{Y_A}{Y_B} = \frac{a}{1-a}\left(e_{N,B} - e_{S,A}\right) = -a\left(\ln I_A + \ln \frac{L_B}{L_A}\right).$$

Consider next the first case in Figure 3. Output in Country A is larger than in country B at the long-run point V, since $e_{N,B} > e_{S,B}$. This enables us to find a lower bound to divergence:

$$\left(\frac{Y_A}{Y_B}\right)_V \Bigg/ \left(\frac{Y_A}{Y_B}\right)_X > \left(I_A \frac{L_B}{L_A}\right)^a.$$

In the second case described in Figure 4 the long-run equilibrium at V satisfies precisely $e_{N,B} = e_{S,B}$. Hence, in the second case we have:

$$\left(\frac{Y_A}{Y_B}\right)_V \Bigg/ \left(\frac{Y_A}{Y_B}\right)_X = \left(I_A \frac{L_B}{L_A}\right)^a.$$

Denote by f^* the level of technology f_S at which the economy reaches point Z in Figure 3. Then from this point on the ratio $(1-f_S)/(1-f_N)$ is constant and equal to $1-f^*$. It can be shown from (25) that the long-run slope of the GLME curve at V is equal to $1-f^*$. Hence the GLME curve at V is described by:

$$\text{(A.2)} \qquad e_{S,A} = (1-f_S{}^*)e_{N,B}.$$

Substituting (A.2) in (25) shows that the income ratio between the two countries in V is:

(A.3) $$\left(\frac{Y_A}{Y_B}\right)_V = \exp\left(\frac{a}{1-a}e^* f^*\right).$$

Hence, together with (A.1) we get:

$$\left(\frac{Y_A}{Y_B}\right)_V \Big/ \left(\frac{Y_A}{Y_B}\right)_X = \left(I_A \frac{L_B}{L_A}\right)^a \exp\left(\frac{a}{1-a}e^* f^*\right).$$

This proves the theorem. We next calculate f^* and e^*. At point Z we have $e_{N,B} = 0$ and $f_N = 0$. Substituting it in the GGME and the GLME yields the following equation:

(A.4) $$\left[\frac{a}{1-a} + (1-f^*)^{-1}\right]^{-1}\left[\ln I_A + \ln L_B/L_A + \ln(1-f^*)\right] = -\frac{1-a}{a}\ln\left[(Rk)^{\frac{a}{1-a}} - 1\right].$$

The unique solution to (A.4) is f^*.

Note that at V the GLME curve is given by (A.2). Substituting it in the GGME we get the following equation:

(A.5) $$\exp\left[-\frac{a}{1-a}e^*(1-f^*)\right] + \exp\left(-\frac{a}{1-a}e^*\right) = (Rk)^{\frac{a}{1-a}}.$$

The solution to this equation is e^*.

Proof of Proposition 2:

Translating the required condition (26) to our main variables, $e_{S,A}$ and $e_{N,B}$, we get that the global skill premium which we denote by *GSP*, namely $\ln GSP = w_{S,A} - w_{N,B}$, is equal to:

$$\ln GSP = \frac{e_{S,A}}{1-f_S} - \frac{e_{N,B}}{1-f_N}.$$

We can use the GLME condition (24) to calculate the global skill premium and get:

(A.6) $$\ln GSP = \frac{(1-a)\left(\ln I_A + \ln\frac{L_B}{L_A} + \ln\frac{1-f_S}{1-f_N}\right) + ae_{N,B}\left(1-\frac{1-f_S}{1-f_N}\right)}{a(1-f_S)+1-a}.$$

We first consider the dynamics in the case of Figure 4. In this case there is technical progress at the two sectors and $(1-f_S)/(1-f_N)=1$. Substituting in (A.6) we get:

(A.7) $$\ln GSP = \frac{(1-a)\left(\ln I_A + \ln\frac{L_B}{L_A}\right)}{a(1-f_S)+1-a}.$$

Clearly the skill premium rises with technical change. Hence full specialization holds throughout the full dynamic path if:

(A.8) $$\ln GSP(V) = \ln I_A + \ln\frac{L_B}{L_A} < I_B.$$

This proves the first part of the proposition.

The dynamics of the skill premium in the case of Figure 3 are a bit more complicated. These dynamics should be divided to two stages, the first one, as the economy moves from X to Z and there is technical change only in country A, and the second one as the economy moves from Z to V, and there is technical change in both sectors. Initially the skill premium is:

(A.9) $$\ln GSP(\mathrm{X}) = (1-a)\left(\ln I_A + \ln\frac{L_B}{L_A}\right).$$

Between X and Z the skill premium is:

(A.10) $$\ln GSP = \frac{(1-a)\left[\ln I_A + \ln\frac{L_B}{L_A} + \ln(1-f_S)\right] + ae_{N,B}f_S}{a(1-f_S)+1-a}.$$

Note that the effect of f_S on *GSP* is not clear. At point Z, when technical change begins in country B, the global skill premium is:

(A.11)
$$\ln GSP(\mathrm{Z}) = \frac{(1-a)\left[\ln I_A + \ln \frac{L_B}{L_A} + \ln(1-f^*)\right]}{a(1-f^*)+1-a}.$$

Between Z and V technical change satisfies $(1-f_S)/(1-f_N) = 1-f^*$, so (A.6) becomes:

(A.12)
$$\ln GSP = \frac{(1-a)\left[\ln I_A + \ln \frac{L_B}{L_A} + \ln(1-f^*)\right] + ae_{N,B}f^*}{a(1-f_S)+1-a},$$

Hence, between Z and V *GSP* is increasing, both because f_S rises and because $e_{N,B}$ is increasing with f_S as well. If we assume, which is a reasonable assumption, that GSP is rising between X and Z as well, then full specialization holds along the whole dynamic path if it holds at V. At the long run the skill premium is equal to:

(A.13)
$$\ln GSP(\mathrm{V}) = \ln I_A + \ln \frac{L_B}{L_A} + \ln(1-f^*) + \frac{a}{1-a} f^* e^*.$$

This proves the proposition.

Proof of Proposition 3:

Denote the number of workers in B who work as skilled by L_B^S. Then the labor market equilibrium conditions are

$$L_A(1-h_A) + L_B^S(1-h_B) = (1-f_S)\frac{P_S^{-\frac{a}{1-a}}(Y_A+Y_B)}{w_S},$$

in the skilled sector, and in the unskilled sector:

$$L_B - L_B^S = (1-f_N)\frac{P_N^{-\frac{a}{1-a}}(Y_A+Y_B)}{w_N}.$$

Noting that in less than full specialization the global skill premium is I_B, so that: $P_S = (Rk)^{f_S} w_N^{1-f_S} I_B^{1-f_S}$ and $P_N = (Rk)^{f_N} w_N^{1-f_N}$. Also after Z: $1-f_S = (1-f_N)(1-f^*)$. We therefore get from the two labor market conditions:

$$\text{(A.14)} \qquad \frac{L_A(1-h_A)+L_B^S(1-h_B)}{L_B-L_B^S} = (1-f^*)I_B^{-(1-f_S)a/(1-a)-1}\exp\left(\frac{e_N f^* a}{1-a}\right).$$

As the global economy approaches V we get from (A.14):

$$\text{(A.15)} \qquad \frac{L_A(1-h_A)+L_B^S(1-h_B)}{L_B-L_B^S} = (1-f^*)I_B^{-1}\exp\left(\frac{e^* f^* a}{1-a}\right).$$

Denote the number of skilled workers at B in V by $L_B{}^*$, then (A.15) implies:

$$L_B{}^* = \frac{L_B(1-f^*)\exp\left(\frac{e^* f^* a}{1-a}\right) - \frac{I_B}{I_A}L_A}{1+(1-f^*)\exp\left(\frac{e^* f^* a}{1-a}\right)}.$$

We next calculate the output ratio between the two countries at the stage that equilibrium has already passed Z and is at less than full specialization. Skilled output in country B is described by:

$$\frac{L_B^S}{I_B} = \int_{f_S}^{1} s_B(j)\,dj = (1-f_S)\frac{P_S S_B}{w_S}.$$

Hence:

$$P_S S_B = \frac{L_B^S}{I_B}\frac{w_S}{1-f_S}.$$

Similarly value of unskilled production in B is:

$$P_N N = (L_B - L_B^S)\frac{w_N}{1-f_N}.$$

Value of output in country A is:

$$P_S S_A = \frac{L_A}{I_A}\frac{w_S}{1-f_S}.$$

Hence, the output ratio between the two countries is:

(A.16) $$\frac{Y_A}{Y_B} = \frac{P_S S_A}{P_S S_B + P_N N} = \frac{I_B}{I_A}\frac{L_A}{L_B(1-f^*) + L_B^S f^*}.$$

This proves the proposition.

QED.

Proof of Proposition 4:

Note that under the assumption of gradual adoption of technology the level of skilled technology in country B in the first period of adoption of the skilled technology is $f_S = d$. Hence the wage of skilled in country B can be:

(A.17) $$\ln w_S = \ln Rk + \frac{\ln P_S - \ln Rk}{1-d}.$$

The alternative income, namely wage of unskilled plus the cost of learning is:

(A.18) $$\ln Rk + \frac{\ln P_N - \ln Rk}{1-f_N} + \ln I_B.$$

We know that initially there is full specialization, namely:

(A.19) $$\ln P_N + \ln I_B > \ln P_S = \ln Rk + (\ln P_S - \ln Rk).$$

Note that the left hand side of (A.19) is equal to the initial (A.18). Using (10) and (21) to calculate the initial P_N and P_S we get that if condition (29) is satisfied then:

$$\ln P_N + \ln I_B > \ln Rk + \frac{\ln P_S - \ln Rk}{1-d}.$$

Namely, initially (A.18) exceeds (A.17).

Then, along the dynamic path P_S declines, while P_N and f_N rise. Hence, (A.18) exceeds (A.17) all along the dynamic path. As a result it does not increase income to become skilled in country B and specialization remains full throughout the dynamic path.

Q.E.D.

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