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. Namely, the rich countries grow much faster than the poor countries. This is due to specialization of richer countries in more 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 blocks of countries wage gaps do not narrow.

JEL: O11, O14, O30, O40.

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1. Introduction

This paper offers a possible explanation to the large gap in economic performance between rich and poor countries. In the last two hundred years, since the beginning of the industrial revolution, the gap in output per capita across countries increased significantly. As shown by Maddison (2001), GDP per capita in the developed countries (Western Europe, North America and Japan) increased 20 fold since 1820, while in the rest of the world GDP per capita increased only 5 fold during the same period.[1] This phenomenon, which is sometime called the great divergence, is one of the main puzzles in economic growth. This paper claims that globalization, namely increased international trade, could have been one of the possible explanations for the divergence in income across countries.

To show this the paper constructs a theoretical model of technical progress, technology adoption, and international trade. The model consists of the following main elements. 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 in the economy, skilled and unskilled. They can be also thought of as manufacturing and raw materials. Technical progress is sector specific, and as explained above the rates of technical progress depend on the wages in each sector. The wages themselves in each sector are affected by technical change in that sector, but are also moderated by labor mobility within the country. Third, international trade creates a global division of

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

production between the two sectors. Since there is no labor mobility between countries, the wage gap between skilled workers in one country and unskilled workers in another country can grow significantly. This is a two country model, where the only differences between the two countries are in access to education and in size. Another important assumption in the paper is non-homothetic demands to skilled and non-skilled goods, so that growth changes the terms of trade and through it relative incomes.

Using these working assumptions the paper shows that the income ratio between developed and less developed countries can grow significantly with economic growth. The difference is fueled by the difference in wages. Since wages in the country that specializes in unskilled good are low it adopts less technologies, and it reaches technical change much later than the country that specializes in skilled goods.

This paper is part of the endogenous growth literature that began in the late 1980s and has dealt significantly with the issues of convergence and divergence, both theoretically and empirically, where the empirical studies used 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 was less productive, namely with less human capital or less education, and second, if this country used a different inferior technology. The first explanation, of differences in human capital, gains much support, as education has a strong effect on economic growth in many empirical studies. But this explanation has its limitations as well, since empirical "development accounting" has shown that although

differences in education can explain a large part of the variation in income across countries, it is still a partial explanation, as it can explain only 40% of the variation.[2] This means that countries lagged behind not only due to less human capital, but also due to using inferior technologies.

There are a number of explanations to the large differences in countries' growth performance in addition to human capital. One is differences in institutions, mainly those that account to property rights and can affect 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) provides 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 various types of costs of technology adoption 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 here are the cost of capital, as it is assumed that new technologies are in the form of machines that replace labor. 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. Much later Zeira (1998) used a similar model to show that this mechanism of

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

machines that replace workers amplifies differences in productivity across countries through differences in technology adoption. More recent works that follow this approach in various directions are Givon (2006), Peretto and Seater (2006), Zeira (2006), Zuleta (2006) and Alesina and Zeira (2007). A recent discussion of the underlying assumptions of this line of research appears in Acemoglu (2009).

The relationship between economic growth, technology and international trade has also been studied recently. The early literature of endogenous growth has shown 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 in recent years 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 to relate growth to deterioration of the terms of trade in the poorer 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 papers by departing from the static framework, 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 outline the equilibrium dynamics if each economy remains closed to

[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).

international trade. Section 4 describes the patterns of trade and of specialization. Section 5 analyzes the dynamics of technology and shows how incomes in the two countries diverge over time. Section 6 examines specialization along the dynamic path and Section 7 tries to evaluate how much of the divergence is the contribution of trade. Section 8 summarizes.

2. The Model

Consider a world with two countries and a single final good. The final good Y is produced by use of two intermediate goods, a skilled one S and an unskilled one N, by use of the following CES production function, where $0 < a < 1$:

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

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

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

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

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

At some historical moment new technologies are developed that enable replacing labor in some tasks by machines. Once such a machine is invented a worker can be replaced by a machine of size k units of capital.[4] This machine must be invested one period ahead of production and it is assumed that a period of time is sufficiently long that the machine fully depreciates in that period, namely the depreciation rate is 1.

Machines are invented as long as there is demand for them, as discussed below. The invention of machines is costless up to some amount of inventions and then becomes infinitely costly. Namely, invention of machines is bounded. Let $f_{s,t}$ denote the amount of skilled tasks for which machines have been invented until time t (not including t). This is the technology frontier in the skilled sector. Then the amount of new skilled tasks for which machines are invented in period t is:

(4) $$\Delta f_s = f_{s,t+1} - f_{s,t} = b(1 - f_{s,t}).$$

Hence the rate of innovation is decreasing with the technology frontier.[5] The dynamics of innovation in the unskilled sector, namely of the unskilled technology frontier f_n, are the same:

(5) $$\Delta f_n = f_{n,t+1} - f_{n,t} = b(1 - f_{n,t}).$$

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 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 h_j, which is country specific. Individuals are assumed to be risk neutral and their utility is:

[4] It is assumed for simplicity that the sizes of machines are equal for all tasks, skilled and unskilled. This is a simplifying assumption only. Removing it will complicate the analysis a bit, but will leave the main results unchanged.

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

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

We assume that the two countries are identical except for size and the cost of education. Assume that country A has lower cost of education and less population:

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

For simplicity assume that there is no government, that there is full capital mobility and that all markets are perfectly competitive. We begin our analysis in the case of no trade and then extend it to discuss the effect of trade and globalization. More specifically, trade is in the two intermediate goods, the skilled and the unskilled.

3. Equilibrium in a Closed Economy

Assume first that the final good is the numeraire in the closed economy.[6] We begin our analysis with the decision on technology adoption, or whether to produce with machine or with labor, in other words, 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 is produced by machines, its unit cost of production is Rk, where $R = 1 + r$ is the sum of the interest rate and the depreciation rate. 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 an unskilled task if and only if:

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

[6] Country subscripts are deleted in this section throughout.

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.

Note that the production function of the final good implies the following first order conditions:

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

Substituting the derived S and N in the production function (1) we get:

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

Note that this condition holds both with and without international trade. Note also that due to the risk neutral utility function (4) the interest rate is constant over time and equal to the subjective discount rate ρ. Hence, $R = 1 + \rho$.

Next note that the FOC of production of the skilled tasks performed by labor, for $j \in (f_s, 1]$ are:

(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, are:

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

Substituting (11) and (12) in (2) and leads to the following condition that the price of the skilled good satisfies:

(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 an important variable, since it indicates whether there is skilled technical progress and f_s is increasing, if e_s is non-negative. Similarly we denote: $e_n = (1-f_n)\ln(w_n/Rk)$ and if this variable is non-negative there is technical progress in the unskilled sector. Due to (13) and (14) we know that: $e_s = \ln(P_S/Rk)$ and $e_n = \ln(P_N/Rk)$. Substituting in equation (10) we get 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) is plotted in Figure 1 in a diagram where e_n and e_s are the two variables on the axis. Equation (15) is described by a downward sloping convex curve. It can be shown that the curve passes through the first, second and fourth quadrants, as in Figure 1, if:

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

We therefore assume from here on that Rk satisfies condition (16).

But equation (15) does not tell us yet the equilibrium values of the skilled and unskilled wages. For that we need to add one more condition. Note that if 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 must be equal, we get:

$$w_s(1-h) = w_n.$$

Hence, the ratio between the wage of skilled and of unskilled, which we denote by *I*, is equal to:

(17) $$I = \frac{w_s}{w_n} = \frac{1}{1-h} > 1.$$

After some algebraic manipulation we get from equation (17) the following relation between the two variables in Figure 1:

$$(1-f_s)\ln\frac{w_s}{Rk} = (1-f_s)\ln I + \frac{1-f_s}{1-f_n}(1-f_n)\ln\frac{w_n}{Rk},$$

or:

(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. 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 equilibrium is described diagrammatically in the intersection of the curves (15) and (18) in Figure 1.

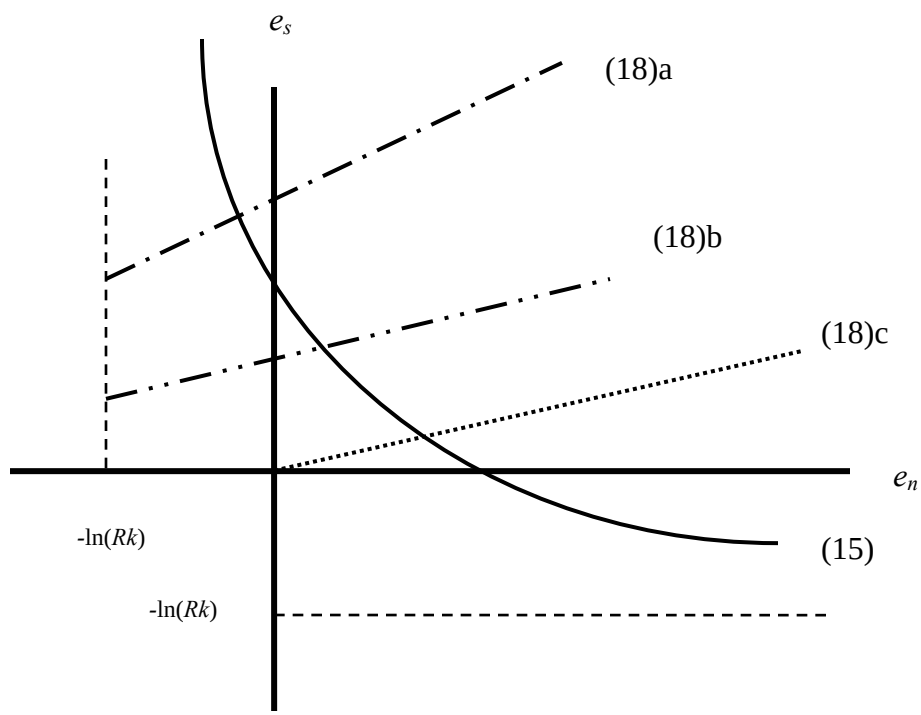

Figure 1: Dynamics of the Closed Economy

Note that since the curve (18) has a positive intersect with the vertical curve and a positive slope, there are only two cases, presented by (18)a and (18)b. In the first case (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 (18) curve downward, until it reaches the first quadrant, where the unskilled sector begins to adopt technologies and thus starts the process of technical progress. Once equilibrium is 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 (18) does not change its slope, but it keeps shifting downward until it converges in the long run to (18)c, as $f_s \to 1$. We therefore conclude that if *Rk* satisfies (16) the skilled sector experiences technical progress, and the unskilled sector joins, sooner or later. Note that if $Rk > 2^{\frac{1-a}{a}}$ and curve (15) does not pass through the first quadrant, the economy experiences technical progress only in the skilled sector and even there it stops after a finite time. Hence, long-run growth is possible only if the cost of machinery *k* is sufficiently low.[7]

We next calculate the level of output in the economy 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) $$y = \frac{Y}{L} = \frac{(Rk)^{1-\frac{a}{1-a}} \exp[e_n(1-f_n)]}{(1-f_s)\exp[-e_s a/(1-a)] + (1-f_n)\exp[-e_n a/(1-a)]}.$$

[7] This is not the main result and the main focus of this paper, but this result fits other papers which also apply the model of machines that replace workers, like Zeira (2008).

It follows that output increases to infinity with technical progress. Hence, this model leads to continuing economic growth. If technical progress stops at some future period, output stops growing.

Finally, we can use the output equation (19) and calculate the output per worker in the economy before technical progress begins. In this case we get:

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

Hence, the higher is wage inequality in the economy the lower is the output per worker.

4. International Trade and the Global Division of Labor

Assume next that the two countries in the world, A and B, differ in their cost of education h: $h_A < h_B$. The different cost of education implies that $I_A < I_B$, namely the wage gap between skilled and unskilled is larger in the less developed country than in the more developed country. Figure 2 presents the equilibrium curves of the two countries together, before opening to trade 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 (15) curve but differ in their (18) curve. The slope of both (18) curves are 1, since $f_s = f_n = 0$, but curve $(18)_A$ is lower since its intersect is $\ln I_A$, while the intersect of $(18)_B$ is $\ln I_B$.

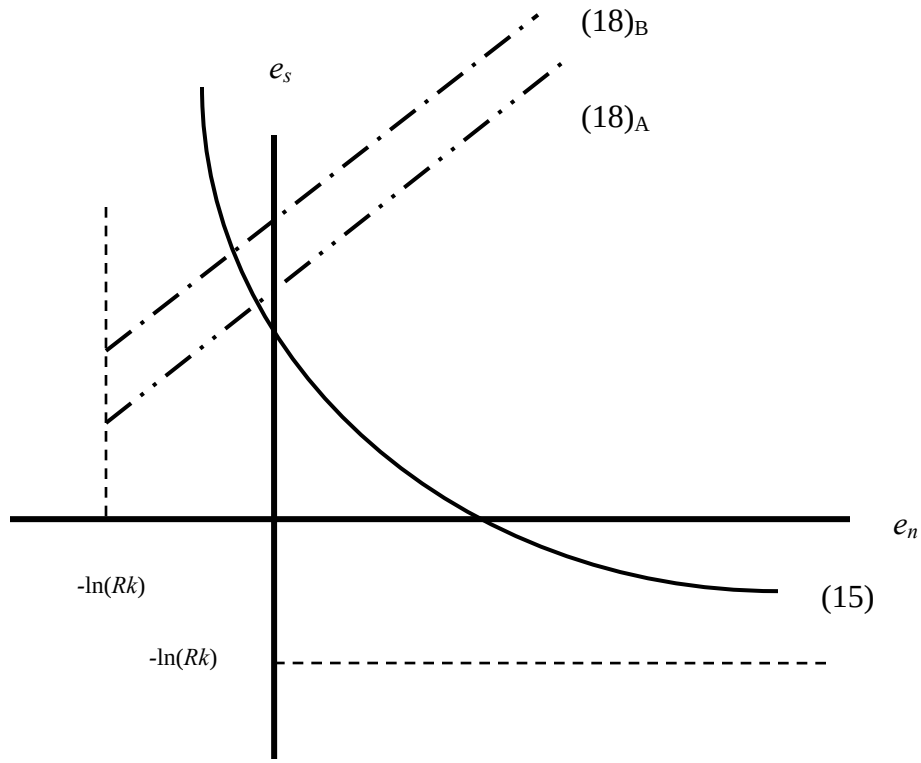

Figure 2: Countries A and B Before Trade

Note that the prices of the two goods are directly related to e_s and e_n, since: $\ln P_S = \ln(Rk) + e_s$ and $\ln P_N = \ln(Rk) + e_n$. As can be seen from Figure 2 the price of the skilled good is higher in country B, while the price of the unskilled good is higher in country A. Hence, if 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 and as a result so are the prices of the final goods in the two countries, 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 in the closed economy.

We next assume that specialization in the world economy is full, and country A produces all the skilled intermediate goods, while country B produces all the unskilled intermediate goods. In order to examine the condition for such full specialization note that it means that the prices of the skilled and the unskilled goods are: $P_S = w_{s,A}$ and $P_N = w_{n,B}$ respectively. The labor market conditions are:

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

and:

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

From these two conditions we can calculate the relative price of skilled to unskilled goods P_S / P_N. Full specialization prevails as long as this relative price is smaller than the potential relative wage in country B and higher than the relative wage in country A. Hence the condition for full specialization is:

(20) $$I_A \le \left(\frac{L_B}{L_A} I_A\right)^{1-a} \le I_B.$$

Next we apply condition (15) to the global division of labor. Remembering the two goods are produced in separate countries, equation (15) becomes:

(21) $$\exp\left(-\frac{a}{1-a} e_{s,A}\right) + \exp\left(-\frac{a}{1-a} e_{n,B}\right) = (Rk)^{\frac{a}{1-a}}.$$

This equation is very similar to (15), except that here it relates wages of skilled in country A with wages of unskilled in country B. In the next section we examine how these wage rates are determined and how that affects income differences across countries, namely global divergence.

5. International Trade and Divergence

As long as production of all intermediate goods has been concentrated 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, 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 un-industrialized and thus income and wages are stagnant.

To show it we need to examine how wages in both countries are determined. To do this we turn to the labor markets in the two countries under full specialization of production. 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 is related to unskilled workers 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:

(22) $$\frac{w_{s,A}P_S^{a/1-a}}{w_{n,B}P_N^{a/1-a}} = \frac{1-f_s}{1-f_n}\frac{L_B}{L_A}I_A.$$

Noting that wages and prices of the two goods are related through (13) and (14) we take the logarithm of equation (22) and derive from it a condition that relates together the variables e_s and e_n:

(23) $$e_{s,A} = \frac{\frac{a}{1-a}+\frac{1}{1-f_n}}{\frac{a}{1-a}+\frac{1}{1-f_s}}e_{n,B} + \frac{1}{\frac{a}{1-a}+\frac{1}{1-f_s}}\left[\ln I_A + \ln\frac{L_B}{L_A} + \ln\frac{1-f_s}{1-f_n}\right].$$

Equation (23) describes a positive linear relationship between $e_{n,B}$ and $e_{s,A}$. It can therefore be described by an upward sloping curve in the plane where these two variables are on the axis. This is shown in Figure 3 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 in such a case the curve (23) shifts downward and its slope is reduced as well. Once we add to Figure 3 the downward sloping curve of equation (21) we get two curves that their intersection determines the global equilibrium and therefore determines the dynamic path of technical progress.

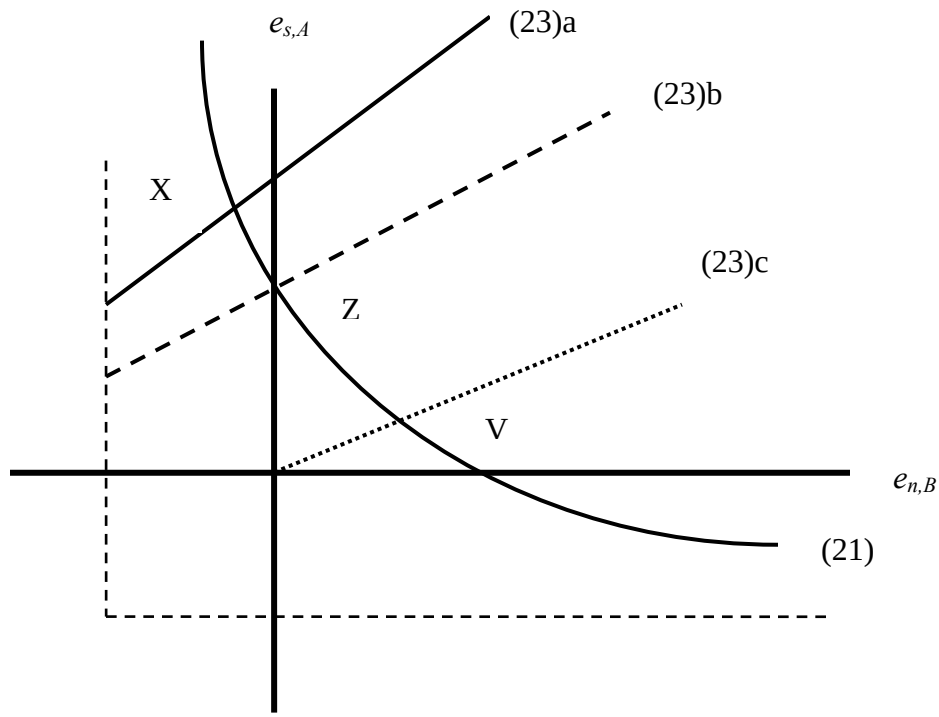

Figure 3: Equilibrium in the Global Economy

To analyze the process of technical progress using Figure 3 we begin at the eve of the industrial revolution, where both f_s and f_n are equal to zero. In this case condition (23) becomes equal to:

(24) $$e_{s,A} = e_{n,B} + (1-a)\left[\ln I_A + \ln\frac{L_B}{L_A}\right].$$

Note that since condition (20) of full specialization holds, we get that (24), which is described in Figure 3 by the curve (23)a, is located above condition (18) of a closed economy in country A. Hence, if was assume that country A begins technical progress initially only at the skilled sector, as is indicated in Figure 2, this holds even more so in

the case of trade and full specialization. Hence, (23)a intersects (21) at initial location X in Figure 3 with technical change in the skilled sector, but not in the unskilled. Thus f_s increases and f_n remains at 0. As a result the curve (23) shifts downward and its slope decreases as well, until it reaches (23)b and technical progress begins in the unskilled sector as well, namely in country B. This point is reached at point Z in Figure 3. Later on the curve (23) shifts further downward, as discussed above, until it converges to (23)c and the world economy converges to the equilibrium point V. Hence, country A experiences technical change from the beginning of the industrial revolution, while country B kicks in only after reaching point Z.

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

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

Taking logarithms we get:

$$\ln\frac{Y_A}{Y_B}=\frac{a}{1-a}\left(\ln P_N-\ln P_S\right)=\frac{a}{1-a}\left(e_N-e_S\right). \tag{25}$$

As can be seen from Figure 3, the value of e_n is increasing during the process, while the value of e_s is decreasing. That means that the income ratio between country A and country B is increasing continuously. This is the divergence experienced between these two countries. We next try to get a more quantitative assessment of the size of this divergence.

We first examine the income ratio of the two countries at the point just before the industrial revolution, namely at X. Substituting (24) in (25) we get:

$$\ln\frac{Y_A}{Y_B}=\frac{a}{1-a}\left(e_N-e_S\right)=-a\left(\ln I_A+\ln\frac{L_B}{L_A}\right).$$

Hence, the If we calculate the initial ratio of income per capita we get:

(26) $$\ln\frac{Y_A}{Y_B}-\ln\frac{L_A}{L_B}=(1-a)\ln\frac{L_B}{L_A}-a\ln I_A.$$

We next examine the value of f_s at which the equilibrium reaches Z, which we denote by f_s*. This value is important since it can be shown that at the long-run equilibrium point V equation (23) becomes:

(27) $$e_s=(1-f_s*)e_n.$$

This technology level f_s* is therefore the solution of equations (19) and (23) in point Z, where e_N is equal to zero. It can therefore be shown that f_s* is the solution of the following equation:

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

Once f_s* is known we can substitute it in (27) and then in (19) and get that at the long-run equilibrium V:

(29) $$\exp\left[-\frac{a}{1-a}e*_{N,B}(1-f_S*)\right]+\exp\left(-\frac{a}{1-a}e*_{N,B}\right)=(Rk)^{\frac{a}{1-a}}.$$

Finally, the long-run ratio of income per capita between the two countries is:

(30) $$\ln\frac{Y_A}{Y_B}-\ln\frac{L_A}{L_B}=\frac{a}{1-a}f_s*e*_{N,B}+\ln\frac{L_B}{L_A}.$$

We next simulate the model to get some quantitative results on the level of divergence. We assume first that the ratio of populations in the two countries is 5. The ratio between the populations of Western Europe, Japan and the Western Offshoots and the rest of the world in 1820 was 4 and it increased to 5 toward the end of the 20th centruy, according to Maddison (2001). We further assume that $I_A = 1.2$. Finally we assume that the coefficient *a* is equal to 0.6. Under these numerical specifications the ratio of income per capita between the two countries prior to the industrialization was equal, according to equation (26), to 1.7. This is not far from the ratio of 2, which is reported in Maddison (2001). Given these parameters it can be shown that the ratio of income between the two countries in the long run is larger by 4 to 4.9, depending on the size of *Rk*. Hence, this model is capable of explaining, under these parameters, a divergence of the order of 4 to 5 times. If we assume that the coefficient *a* is higher, the divergence can be even greater. Note that *a* can be as high as condition (20) allows. Thus for a = 0.8, the income ratio between the two countries can diverge by almost 8 times for some values of *Rk*.

Hence, this analysis shows that in our simple model, technical progress begins in one country, which specializes in skilled goods and reaches the other country, which specializes in unskilled goods, only after some time. During this period the two countries experience divergence of incomes that can be significantly high. When the second country begins to adopt technologies and industrialize the income ratio between the two economies keeps growing. Thus, even when the lagging behind country begins to experience technical change, the two countries do not converge to one another.

6. Full Specialization Along the Dynamic Path

Condition (20) guarantees full specialization at the initial situation, before technical change takes off. But after it starts wages of skilled workers are increasing continuously, while wages of unskilled, which are concentrated in the less developed country, rise by much 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 dynamic path and not just at the initial situation.

Clearly the main condition for specialization is that the wage of skilled, which is implied by the global price of the skilled good, is lower than the required wage for unskilled workers in country B to start acquiring skill. This condition is:

(31) $$\ln w_{s,A} - \ln w_{n,B} \leq \ln I_B .$$

Translating this condition to our main working variables, $e_{s,A}$ and $e_{n,B}$, we get:

(32) $$\frac{e_{s,A}}{1-f_s} - \frac{e_{n,B}}{1-f_n} \leq \ln I_B .$$

We can use equation (23) to calculate the LHS of equation (32) and get:

(33) $$LHS_{(32)} = \frac{(1-a)\left(\ln I_A + \ln\frac{L_B}{L_A} + \ln\frac{1-f_s}{1-f_n}\right) + ae_{n,B}\left(1-\frac{1-f_s}{1-f_n}\right)}{a(1-f_s)+1-a}.$$

At the beginning of the dynamic process, when technical change begins and f_s and f_n are equal to 0, equation (33) yields that:

$$LHS_{(32)} = (1-a)\left(\ln I_A + \ln\frac{L_B}{L_A}\right),$$

so that condition (32) is equivalent to condition (20). Once technical change kicks off the dynamics of (33) are a bit hard to follow, but once the point Z is crossed, and $e_{n,B}$ becomes positive, equation (33) becomes:

$$LHS_{(32)} = \frac{(1-a)\left(\ln I_A + \ln\frac{L_B}{L_A} + \ln(1-f_s*)\right) + ae_{n,B}f_s*}{a(1-f_s)+1-a},$$

where f_s* is the skilled technology level at Z, which is defined by equation (28). Note that after the world economy passes Z technical change increases $e_{n,B}$ and f_s, which together increase $LHS_{(32)}$. This raises the question whether the condition for specialization might still hold. Interestingly $LHS_{(32)}$ increases but is bounded. As the economy converges to V it converges to:

(34) $$\ln I_A + \ln\frac{L_B}{L_A} + \ln(1-f_s*) + \frac{a}{1-a}f_s*e_{n,B}(\mathrm{V}).$$

Hence, if (34) is lower than ln I_B, we have full specialization along the entire dynamic path of the economy.

We next analyze a specific case, in order to get a feeling of how large I_B is in order to maintain full specialization along the dynamic path. Let us consider the simple case where a = ½, $Rk = 1.8$, $I_A = 1.5$, $I_B = 3$ and $L_B / L_A = 4$. In this case the initial wage gap in country B, which leads to specialization, according to condition (20), is equal to 2.45. Calculation of condition (34) yields in this case 2.48. Namely, if $I_B \geq 2.48$, full specialization is maintained throughout the whole dynamic process. Note that in this case the long-run income ratio between the two countries is much higher than this wage gap:

$$\left(\frac{y_A}{y_B}\right)_\infty = 4.39.$$

Finally, even if I_B is not so high, the model can still yield diverging incomes and full specialization under an additional reasonable assumption. The discussion above assumes that whenever people from country B wish to become skilled, they can produce the skilled good with the most advanced available technology, namely they share f_s developed in country A. This is of course a fairly strong assumption, as not only the process of inventing technologies is gradual, but their learning and adoption as well. One simple way to model it is to assume that when country B adopts technologies of the skilled good it is done gradually. Formally: $\Delta f_s = f_{s,t+1} - f_{s,t} = d(1 - f_{s,t})$, where clearly adoption is quicker than invention, namely: $d > b$. Under this assumption the chances that people might become skilled in B is small, since their productivity as skilled is fairly low, d at most, while their wage as unskilled is continuously increasing.

7. The Role of Trade

As shown in Section 5, the income ratio between the two countries increases along their growth paths, namely the two countries get further apart as their output levels grow. But there is some divergence between the two countries even without trade, as can be deduced from the analysis in Section 3. In both countries there is technical progress in the skilled sector all the time, but in country B, which lags behind, technical progress in the unskilled sector starts later. This section tries to examine how much of the divergence is affected by trade and by the global division of labor.

To show that, let us simplify by assuming that a = ½. In that case the ratio of output if there is no trade, before technical change begins is:

$$\left(\frac{y_A}{y_B}\right)_0 = \frac{1+I_A^{-1}}{1+I_B^{-1}}.$$

If there is no trade, the economy reaches the point of $e_n = 0$ at technology level given by:

$$(1-f_s)\ln I = -\ln(Rk-1).$$

The long-run level of e_n is determined by the following condition:

$$\exp[-(1-f_s)e_n] + \exp(-e_n) = Rk.$$

Calculating these levels of f_s and e_n for the two countries, we can use equation (19) to calculate the long-run ratio of income, which is:

$$\left(\frac{y_A}{y_B}\right)_\infty = \frac{(1-f_{s,B})\exp[-(1-f_{s,B}]e_{n,B}) + \exp(-e_{n,B})}{(1-f_{s,A})\exp[-(1-f_{s,A}]e_{n,A}) + \exp(-e_{n,A})}\frac{1-f_{s,A}}{1-f_{s,B}}.$$

Let us calculate these ratios for the following values: $Rk = 1.8, I_A = 1.5, I_B = 3$. We therefore get that the initial ratio of income, prior to technical change is equal to:

$$\left(\frac{y_A}{y_B}\right)_0 = 1.25.$$

Under this specification of parameters the long-run ratio of incomes is given by:

$$\left(\frac{y_A}{y_B}\right)_\infty = 2.03.$$

Hence, the two countries diverge, but they do not diverge by far.

Interestingly if the two countries do not engage in trade but they can share technologies developed in one another, the picture is very different. In this case the two countries share not only skilled technologies, which they do above as well, but once country B crosses the line of positive e_n it can copy all the unskilled technologies already developed in A and the two countries share the same technologies. In this case the

income ratio between the two countries converges to 1, since in the long-run the difference in I becomes insignificant, as shown in equation (18).

We next calculate the ratios of income in the two countries if they trade and specialize, assuming that they fully specialize. Clearly, if $L_B / L_A = 4$, condition (20) is satisfied and the two countries specialize in the skilled and unskilled good respectively. The ratio of output before technical change begins is equal to:

$$\left(\frac{y_A}{y_B}\right)_0 = \left(\frac{L_B}{L_A}\right)^{1/2} I_A^{-1/2} = 1.63.$$

Hence, already before technical progress begins, trade increases the income gap between the two countries. At the long-run, the income ratio between the two countries converges to 4.39, as shown for these parameters in Section 6. Hence, incomes of the two countries diverge much more than in the case of no trade, either with or without technology sharing between the two countries. Hence, the divergence in this model can be accounted to a large extent to trade and to the global division of production.

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. Globalization through trade enables 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, as it comes with limits on labor mobility between the two countries, creates a situation that the wage gap between skilled and unskilled workers is

not reduced by labor mobility. Since technology is stimulated by high cost of labor, it therefore mean that the countries that produce unskilled goods do not industrialize and as a result the income gap between them and the developed countries further increases. This continues until at some point the demand for unskilled goods by the developed countries rises sufficiently to jumpstart technical progress and industrialization in the less developed countries as well. In the meantime incomes can diverge significantly and the gap can remain quite high.

What are the policy implications of such a model? Does it mean that the anti-globalization pundits 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 steps, 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 investing 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 subsidizing R&D and cost of equipment to these countries. The third policy is to encourage birth control in the less developed countries, thus reducing 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.

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