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Daron Acemoglu[†] **Fabrizio Zilibotti**[‡]

Abstract

We suggest a possible explanation for cross-country differences in total factor productivity. Many technologies used by LDCs are developed in OECD economies, and as such, are designed to make optimal use of the skills of these richer countries' workforces. Due to differences in the supply of skills, some of the tasks performed by skilled workers in richer economies will be carried out by unskilled workers in the LDCs. Since the technologies in these tasks are designed to be used by skilled workers, productivity in LDCs will be low. Even when all countries have equal access to new technologies, this mismatch between skills and technology can lead to sizable differences in total factor productivity, in the order of 40 to 70 percent of the variation we observe in the data. Our theory also suggests that the trade regime and the degree of intellectual property right enforcement in LDCs have an important effect on the type of technologies developed in richer economies and on productivity differences.

JEL Classification: F43, O14, O34, O47.
Keywords: Development, Directed Technical Change, Intellectual Property Rights, Skills, Technology, Total Factor Productivity.

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I. Introduction

Most economists view technological differences as an important part of the large disparities in per capita income across countries (e.g. Romer, 1993; Prescott, 1998). This view receives support from a number of recent studies, such as Klenow and Rodriguez (1997), Caselli et al. (1997), and Hall and Jones (1998), which find significant total factor productivity (TFP) differences across countries. Large cross-country differences in technology are difficult to understand, however. Ideas, perhaps the most important ingredient of technologies, can flow freely across countries, and machines, which embed better technologies, can be imported by less developed countries. This compelling argument has motivated papers such as Mankiw, Romer and Weil (1992), Chari, Kehoe and McGrattan (1997), Parente, Rogerson and Wright (1998) and Jovanovic and Rob (1998) to model cross-country income differences as purely driven by differences in factors rather than in technology.

In this paper, we offer an explanation for cross-country TFP differences which applies even when all countries have access to the same technology. The center-piece of our approach is that many technologies used by less developed countries (LDCs/the South) are imported from more advanced countries (the North) and, as such, are designed to make optimal use of the prevailing factors and conditions in these richer countries. The North, which is more abundant in skills, tends to develop relatively skill-complementary technologies, and these are only of limited use to the countries in the South.

The main result of our paper is that, due to the mismatch between technologies developed in the North and the skills of the South's labor force, there will be TFP differences between the North and the South, even in the absence of any barriers to technology transfer. The South must use unskilled workers in tasks performed by skilled workers in the North. Since the technology imported from the North is not suited to the needs of unskilled workers performing these tasks, the South will have low TFP, even after controlling for the contribution of human capital to output.

Figure 1 plots (the logarithm of) the level TFP in 1985 calculated by Klenow and Rodriguez (1997) and the ratio of college graduates to non-college graduates in a sample of 96 countries (data details in Section III), and points to a high positive correlation between the relative supply of skills and TFP.[1] Though not a test of our theory, this positive correlation is encouraging for an approach attempting to explain TFP differences with differences in the relative supply of skills.[2] It might be more important, however,

[1]The R^2 of the regression is 0.53. Excluding oil producing countries and Trinidad, an outlier, the R^2 increases to 0.59. One standard deviation increase in H/L is associated with an increase in the TFP level of 21%. Similar results are obtained using TFP measures from Hall and Jones (1998).

[2]The TFP measures control for the contribution of human capital to output, so there is no mechanical

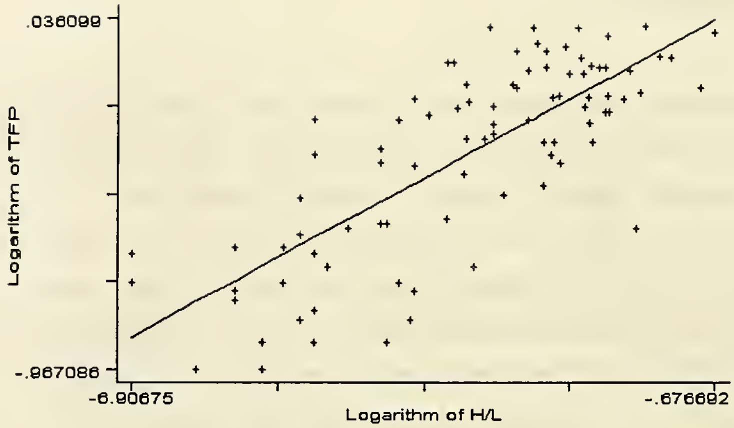

Figure 1: TFP vs. Ratio of College Graduates to Non-College Graduates.

to investigate whether the mechanism we propose can be quantitatively significant. Our model gives a simple expression for the TFP of a country relative to the U.S. as a function of its ratio of skilled to unskilled workers and the equilibrium skill-bias in U.S. technology. By choosing this equilibrium bias to match the U.S. skill premium, we perform a simple calibration. This exercise suggests that the differences predicted by our model are sizeable and can account for approximately between 40 and 70 percent of the TFP differences observed in the data.

A number of other interesting results also follow from of our analysis. First, LDCs are predicted to have productivity levels comparable to advanced economies in very unskilled and very skilled sectors and tasks, but lower productivity in medium skilled tasks. In the most complex tasks, even very skill-scarce LDCs have to use skilled workers. These skilled workers can use the skill-complementary technologies developed in the North and achieve a high level of productivity. In contrast, there will be large productivity differences in sectors where workers are skilled in the North but unskilled in the South, since the technologies are not developed for the unskilled workers in these sectors. This pattern receives some support from the casual observation that there are pockets of efficient high-tech industries such as software programming in India.

Second, we show that international trade reduces TFP differences. In particular, if there is factor price equalization, TFP differences disappear because LDCs specialize in sectors where technology is appropriate to unskilled workers. Therefore, the commonly

relation between TFP and the ratio of college graduates. Nevertheless, part of the correlation may be due to the fact that the productivity of skilled workers is underestimated. Also countries with high productivity may choose to invest more in education, contributing to this correlation (e.g. Bils and Klenow, 1998, for a discussion of these issues).

held view that in a world with free access to new technologies there will be no TFP differences is correct if there is free trade and factor price equalization. Since factor price equalization is generally found not to hold, however, our model suggests that TFP differences should be widespread even when technology and ideas can flow freely from advanced to less developed countries. Interestingly, despite reducing TFP differences, international trade causes *GDP divergence*. Trade reduces the prices of unskilled goods in the North, and discourages investment in unskilled technologies, which were those most beneficial to the South. As a result, trade increases the relative productivity and pay of skilled workers, and widens the output gap between poor and rich countries.

Third, intellectual property rights are an important determinant of technological development. When such property rights are enforced internationally, firms in the North have more incentive to develop technologies suited to the skill requirements in the South. However, each less developed country individually benefits from not enforcing these rights, creating a potential for a classic Prisoner's Dilemma.

Finally, our theory suggests a stylized pattern of cross-country convergence in TFP and GDP. A less developed country diverges from the technological leader when it chooses to use local technologies for which there is no R&D, but this process necessarily stops at some point, and cross-country TFP and income differences tend to become stable as the LDCs start importing the leading technologies developed in the North. On the other hand, TFP (and income) convergence occurs when a country improves its skill base relative to the North, which concurs with the experiences of Korea and Japan (see for example, Rhee, Ross-Larson and Pursell, 1984; Lockwood, 1968).

The two building blocks of our approach, that most technologies are developed in the North and that these technologies are designed for the needs of these richer economies, appear plausible. For example, over 90% of the R&D expenditure in the world is carried on in OECD economies, and over 35% in the U.S..[3] Moreover, many of the technologies developed over the past twenty years in the U.S. and the OECD appear to be highly skill-complementary and substitute skilled workers for tasks previously performed by the unskilled (e.g. Katz and Murphy, 1992; Berman, Bound and Machin, 1998). So it should perhaps not be surprising that there are many examples of developing countries, abundant in unskilled workers, which adopt labor-saving technologies requiring specialized technical skills. This has led many development economists, like Frances Stewart (1977, p. xii), to conclude that "...the technology Third World countries gets from rich countries is inappropriate", which is consistent with the approach in this paper.

A number of other papers have emphasized the difficulties in adapting advanced tech-

[3] Authors' calculation from UNESCO (1997). UNESCO (1997) gives R&D expenditure as a percentage of GNP, and we calculated the OECD share using the Summers and Heston (1991) data on GNP.

nologies to the needs of LDCs. Evanson and Westphal (1995) suggest that new technologies require a large amount of tacit knowledge, and such knowledge cannot be transferred, thereby slowing down the process of technological convergence. The importance of "appropriateness" of technology has also received some attention, for example Salter (1966), Atkinson and Stiglitz (1969) and David (1974). Diwan and Rodrik (1991) use some of the insights of this literature to discuss the incentives of Southern countries to enforce intellectual property rights, as we do in Section V. An important recent contribution to the appropriate technology literature is Basu and Weil (1998), who adopt the formulation of Atkinson and Stiglitz whereby technological change takes the form of learning-by-doing and influences productivity at the capital labor ratio currently in use (see also Temple, 1998). Basu and Weil characterize the equilibrium in a two-country world where the less advanced economy receives productivity gains from the improvements in the more advanced economy. Our paper differs from Basu and Weil, in particular, and the rest of the appropriate technology literature, in general, in a number of ways. First, what matters in our theory is not capital-labor ratios (as in Atkinson and Stiglitz and Basu and Weil) or size of plants (as in Stewart), but relative supplies of skills, which we believe to be more important in practice. Second, our results do not follow because productivity depends on the exact capital-labor or skilled-unskilled labor ratios in use, but because skilled workers use different technologies than unskilled workers, and in the North skilled workers perform some of the tasks performed by unskilled workers in the South. Third, and perhaps most important, technological change is not an unintentional by-product of production, but a purposeful activity. In particular, R&D firms in the North direct their innovations towards different technologies depending on relative profitability. All our results originate from the fact that the relative abundance of skills in the North induces "skill-biased" innovations. In this respect, our model is closely related to Acemoglu (1998), which models directed technical change, but primarily focuses on its implications for wage inequality.

Finally, there is now a large literature on innovation, imitation and technology transfer, for example, Vernon (1966), Krugman (1979), Grossman and Helpman (1991), Rivera-Batiz and Romer (1991), Eaton and Kortum (1997) and Barro and Sala-i-Martin (1997). Some of these models, as well as more traditional models of trade and innovations, such as Krugman (1987), Feenstra (1991) and Young (1991), obtain the result that trade may reduce the growth rate of less developed countries, but the channel is very different. Moreover, in our model, trade affects TFP and GDP in opposite directions, and affects only relative GDP levels, not long-run growth. The most important difference from our work, however, is that these papers do not analyze an economy in which technological knowledge flows freely across countries, and they do not allow technical progress to be directed towards different levels of skills.

The plan of the paper is as follows. Section II introduces our basic model and characterizes the equilibrium in the North and the South in the absence of commodity trade and intellectual property rights in the South. Section III shows that TFP is higher in the North than the South and performs a simple calibration of our model to see to what extent the model can explain the TFP variations in the data. Section IV analyzes technical change, and TFP and income differences in a world with commodity trade. It shows that trade eliminates TFP differences but leads to further income divergence. Section V analyzes the impact of property rights enforcement in the South on technical change. Section VI endogenizes skill acquisition decisions and shows that improvements in the relative supply of skills in the LDCs lead to TFP convergence, and Section VII analyzes the choice between local and imported technologies in the South. Section VIII concludes, while Appendix A contains the main proofs. Appendix B, which contains some additional results, is available upon request.

II. The Basic Model

A. Countries, Agents and Preferences

We consider a world economy consisting of two groups of countries. There is one large advanced country which we call the North, and a set of small less developed countries which we refer to as the South. To simplify the analysis, we assume all Southern countries to be identical. What distinguishes the North and the South, other than their relative sizes, is the abundance of skills. The North has H^n skilled workers and L^n unskilled workers, whereas the South has H^s skilled workers and L^s unskilled workers. We assume that $H^n/L^n > H^s/L^s$, so the North is more abundant in skills.

New technologies are developed using final output. Due to the market size effect in the creation of new technologies, as we will see shortly, countries in the South will perform no R&D. All technological progress will therefore originate in the North. But the South can adopt these technologies *without any impediments or costs.* This is obviously an extreme assumption, but helps to clarify how TFP differences can occur without other factors emphasized in the previous literature.

All consumers have linear preferences given by $\int_0^\infty Ce^{-rt}dt$, where C is consumption and r is the discount rate, which is assumed to be equal to the interest rate. We suppress time indexes when this causes no confusion.

B. Technology

We first describe the production technology which is common across countries. The equations in this and the next subsection therefore apply both to the North and the South, and we omit the country indexes. Consumption and investment come out of an output aggregate,

$$C + I + X \leq Y \equiv \exp\left[\int_0^1 \ln y(i)di\right], \tag{1}$$

where I is investment in machines, and X is expenditure on R&D. We normalize the price of the consumption aggregate in each period to 1. Good i is produced as:

$$y(i) = \left[\int_0^{N_L} k_L(i,v)^{1-\beta}dv\right] \cdot [(1-i)\cdot l(i)]^\beta + \left[\int_0^{N_H} k_H(i,v)^{1-\beta}dv\right] \cdot [i \cdot Z \cdot h(i)]^\beta, \tag{2}$$

where $k_z(i,v)$ is the quantity of machines of type v used in sector i together with workers of skill level z (i.e. this is sector and skill-specific capital). There is a continuum of machines, denoted by $j \in [0, N_L]$, that can be used with unskilled workers, and a continuum of machines $j \in [0, N_H]$ used with skilled workers. Technical progress in this economy will take the form of increases in N_L and N_H, that is, technical change expands the range of machines that can be used with unskilled and skilled workers. This is similar to the expanding variety model of Romer (1990) (see also Grossman and Helpman, 1991), but allows for technical change to be skill-or labor-complementa y as in Acemoglu (1998). Equation (2) also implies that each good can be produced by skilled or unskilled workers, using the technologies suited to their needs. The terms $(1-i)$ and i imply, however, that unskilled labor has a comparative advantage in producing goods with low indexes. The parameter Z enables a positive skill premium. Feasibility requires that $\int_0^1 l(i)di \leq L$ and $\int_0^1 h(i)di \leq H$.

Producers of good $i \in [0,1]$ take the prices of their products, $p(i)$, wages, w_L and w_H, and the rental prices of all machines, $\chi_L(v)$ and $\chi_H(v)$, as given, and maximize profits. This gives the following sectoral demands for machines:

$$\begin{aligned} k_L(i,v) &= \left[(1-\beta)\cdot p(i)\cdot((1-i)\cdot l(i))^\beta / \chi_L(v)\right]^{1/\beta} \\ k_H(i,v) &= \left[(1-\beta)\cdot p(i)\cdot(i\cdot Z\cdot h(i))^\beta / \chi_H(v)\right]^{1/\beta}. \end{aligned} \tag{3}$$

A (technology) monopolist owns the patent for each type of machine. We assume that it also owns machines and rents them out to users at the rental rates $\chi_z(v)$. Machines depreciate at the rate δ and investments in machines are reversible. Consider the monopolist owning the patent to a machine ν for skill class z, invented at time 0. Define the total demand for machine ν for skill type z as $K_z(\nu) = \int_0^1 k(i,\nu)di$. The monopolist chooses an investment plan and a sequence of capital stocks so as to maximize the present discounted value of profits, as given by $V_z(\nu) = \int_0^\infty e^{-rt}\left[\chi_z(\nu)K_z(\nu) - \theta I_z(\nu)\right] dt - \theta K_z^0(\nu)$, subject to $\dot{K}_z(\nu) = I_z(\nu) - \delta K_z(\nu)$ and to the set of demand constraints given by (3), where we have suppressed time indexes. θ denotes the marginal cost of machine production, assumed to be constant; $K_z^0(\nu)$ is the quantity of machines produced by the monopolist at the time when the variety ν is invented (in this case, at time 0); and $I_z(\nu)$ denotes gross investment. Since (3) defines isoelastic demands, the solution to this program involves $\chi_z(\nu) = \theta(r+\delta)/(1-\beta)$, that is, all monopolists charge a constant rental rate, equal to a mark-up over the marginal cost times the interest rate plus the depreciation rate. We assume $\theta \equiv (1-\beta)^2/(r+\delta)$, so that $\chi = (1-\beta)$. Profit-maximization also implies $K_z^0(\nu) = K_z(\nu) = K_z$ and $I_z(\nu) = \delta K_z(\nu) = \delta K_z$, that is, each monopolist rents out the same quantity of machines in every period. Notice also that $V_z(\nu) = V_z$ for all ν, that is all machines produced for skill type z are equally profitable (though this profitability can change over time).

Substituting (3) and the machine prices into (2), we obtain

$$y(i) = p(i)^{(1-\beta)/\beta} \cdot N_L \cdot (1-i) \cdot l(i) + p(i)^{(1-\beta)/\beta} \cdot N_H \cdot i \cdot Z \cdot h(i).$$

Therefore, increases in N_H (N_L) improve the productivity of skilled (unskilled) workers in all sectors. N_H and N_L are the only state variables of this economy.

R&D (in the North) leads to increases in the range of machines. We assume that technical change is *directed*, in the sense that the degree to which new technologies are skill-complementary is determined endogenously (see Acemoglu, 1998). Some firms improve technologies complementing unskilled workers, while others work to invent skill-complementary machines. In particular, $\dot{N}_z = \phi(X_z/N_z) \cdot X_z$ where X_z denotes total resources (final output) devoted to improve the technology of skill class z. We assume that there is a large number of small firms which can enter to perform R&D for either sector, and each firm ignores the effect of its expenditure on the productivity of others. More formally, each R&D firm takes $\phi(X_z/N_z)$ as given when it decides its research expenditure. A firm which discovers a new machine becomes the monopolist producer of that machine. We assume $\phi(x) = \Gamma x^{-\gamma}$, where $x_z \equiv X_z/N_z$ and $0 \le \gamma < 1$. This parameterization of the ϕ function simplifies the analysis of transitory dynamics. If $\gamma > 0$, then there are decreasing returns to research investment within a period.[4] We can write the law of motion of technologies as follows:

$$\dot{N}_z = \Gamma \cdot x_z^{1-\gamma} \cdot N_z. \tag{4}$$

[4] If $\gamma = 0$, then our balanced growth path results are unchanged, but there are no transitory dynamics. If we change preferences to Constant Relative Risk Aversion, then there are once again transitory dynamics, even when $\gamma = 0$, but these are somewhat more complicated.

Observe that directed technical change is a crucial ingredient in our results; it will enable the North to develop the technologies most suited to its needs, which are different from those suited to the countries in the South.

C. Analysis

We first take the technology variables N_L and N_H as given and characterize the equilibrium in the North and the South. In this section, we also assume that there is no commodity trade between the North and the South, so prices will differ across the two sets of countries. We start with an intuitive lemma. As with other proofs, unless otherwise stated, the proof of this lemma is in Appendix A.

Lemma 1 There exists J such that for $i < J$, $h(i) = 0$ and $i > J$, $l(i) = 0$.

In words, all goods with indexes below the threshold J are produced with unskilled labor, and those with indexes above J are produced with skilled labor only. This is natural given the structure of comparative advantage in (2). Using this lemma, we can write the production in sector i as:

$$y(i) = \begin{cases} p(i)^{(1-\beta)/\beta} \cdot (1-i) \cdot N_L \cdot l(i) & \text{if } \ 0 \leq i \leq J \\ p(i)^{(1-\beta)/\beta} \cdot i \cdot N_H \cdot Z \cdot h(i) & \text{if } \ J < i \leq 1 \end{cases} . \tag{5}$$

Utility maximization, in turn, gives the consumer indifference condition: $p(i)y(i) = Y$ for all $i \in [0, 1]$. These equations enable us to prove:

Lemma 2 In equilibrium,

$$\textit{for any } i < J,\ p(i) = P_L \cdot (1-i)^{-\beta} \textit{ and } l(i) = L/J, \textit{ and} \tag{6}$$

$$\textit{for any } i > J,\ p(i) = P_H \cdot i^{-\beta} \textit{ and } h(i) = H/(1-J), \tag{7}$$

where P_L and P_H are appropriately defined price indexes, and

$$\frac{P_H}{P_L} = \left(\frac{N_H}{N_L}\frac{J}{1-J}\frac{ZH}{L}\right)^{-\beta}. \tag{8}$$

Goods with higher indexes produced with unskilled labor have lower productivity, and command higher prices. The converse is true for skilled goods. Equation (8) is then obtained using the consumer indifference condition. It exploits the fact that goods markets have to clear in the North and the South separately.

To fully characterize the equilibrium for given N_L and N_H, we must determine J. Good J can be produced by either skilled or unskilled workers, and must yield zero profit in either case, thus, when $i = J$, both (6) and (7) apply. This implies:

$$\frac{P_H}{P_L} = \left(\frac{J}{1-J}\right)^{\beta}. \tag{9}$$

(8) and (9) therefore determine equilibrium relative prices and the threshold sector for a given state of relative technology, N_H/N_L. Using the fact that the consumption aggregate is the numeraire, we obtain:[5]

$$P_L = \exp(-\beta) \cdot J^{-\beta} \text{ and } P_H = \exp(-\beta) \cdot (1-J)^{-\beta}. \tag{10}$$

Noting that $Y = \int_0^1 p(i)y(i)di$, and combining this with (5), (8), (9) and (10), and then simplifying, we obtain a simple reduced form equation for GDP:[6]

$$Y = \exp(-\beta)\left[(N_L L)^{1/2} + (N_H Z H)^{1/2}\right]^2. \tag{11}$$

Since wages are equal to marginal products, we also have:

$$\frac{w_H}{w_L} = Z\left(\frac{N_H}{N_L}\right)^{1/2}\left(\frac{ZH}{L}\right)^{-1/2}. \tag{12}$$

Finally, notice that combining (12) with (8) and (9), we find that the equilibrium share of skilled workers in labor costs is always $1-J$.

D. Technological Progress in the North

We start with the assumption that there are no intellectual property rights in the South, so R&D firms in the North cannot sell their technologies to Southern firms. The relevant market for technologies is therefore the North. Since there is no commodity trade, equilibrium R&D in the North can be determined without any reference to the South.

Recalling the above discussion regarding profits of technology monopolists, and using (6) and (7), the return to inventing a new machine for skill class z is:

$$rV_z = \pi_z + \dot{V}_z, \tag{13}$$

where $\pi_L = \beta(1-\beta)\left(P_L^n\right)^{1/\beta}\int_0^J l^n(i)di = \beta(1-\beta)\left(P_L^n\right)^{1/\beta} L^n$ and $\pi_H = \beta(1-\beta)\left(P_H^n\right)^{1/\beta}\int_J^1 h^n(i)di = \beta(1-\beta)\left(P_H^n\right)^{1/\beta} ZH^n$. L^n and H^n are effectively the

[5]That is, we use the normalization $\exp\left[\int_0^1 \ln p(i)di\right] = 1$.

[6]For future reference, observe that we cannot use this expression for TFP comparisons, as the equilibrium capital stocks have already been substituted in.

"markets" for new technologies since technology monopolists can only sell machines to Northern producers employing Northern workers. The time derivative captures the fact that P_H^n and P_L^n may be changing out of the balanced growth path, so that the value of the patent to a certain machine may be different in the future. Free-entry implies that the value of a technology monopolist must be equal to the marginal cost of innovation, hence $\Gamma^{-1}x_z^{-\gamma}V_z = 1$ at all points in time.[7]

Along the Balanced Growth Path (BGP), N_L and N_H must grow at the same rate, thus the same research effort must be allocated to skill- and labor-complementary innovations ($x_L = x_H$). This is only possible if $\pi_L = \pi_H$ (since in BGP, $\dot{V}_L = \dot{V}_H = 0$). Hence, in BGP, we need

$$\frac{P_H^n}{P_L^n} = \left(\frac{ZH^n}{L^n}\right)^{-\beta}. \tag{14}$$

Using (8) and (9), this implies:

$$\frac{N_H}{N_L} = \frac{1 - J^n}{J^n} = \frac{ZH^n}{L^n}. \tag{15}$$

This equation uniquely defines the relative productivity of skilled and unskilled workers along the BGP as a function of the relative supply of skilled workers in the North. It also determines the threshold sector J^n along the BGP.

The next proposition summarizes this result and the dynamics of the economy outside the BGP in the North.

Proposition 1 There exists a unique and globally stable BGP, given by (9), (10), (12) and (15), and along this growth path, output, N_L and N_H grow at the rate

$$g = \Gamma^{1/\gamma} \cdot \left[\exp(-1) \cdot \beta \cdot (1 - \beta) \cdot (L^n + ZH^n)/r\right]^{(1-\gamma)/\gamma}.$$

There is a unique BGP, and starting from any N_L and N_H, the economy converges to this BGP. Along this path, a constant fraction of output is devoted to R&D, and the economy grows at the constant rate g. Since both N_L and N_H grow at the common rate g, the relative productivities of skilled and unskilled workers are constant. Relative productivities can change along the transition path, however.

We can note that, as in Acemoglu (1998), an increase in H^n/L^n leads to skill-biased technical change. As equation (15) shows, an increase in H^n/L^n raises N_H/N_L. The skill premium in the North is always $w_H^n/w_L^n = Z$. The skill-biased technical change induced by an increase in H^n/L^n exactly cancels the negative direct impact of this variable on relative wages (see equation(12)).

[7]Notice that if there were a consortium of R&D firms rather than small ones, we would have $(1 - \gamma)\Gamma^{-1}x_z^{-\gamma}V_z = 1$. The qualitative results are identical in the two cases.

E. Equilibrium in the South

The R&D process specified above entails a market size effect. Since there are no international intellectual property rights, the share of GDP devoted to R&D is an increasing function of the country's market size. To see this, recall that in BGP, free entry implies $x^c = \pi^c/r = [\exp(-1) \cdot \beta \cdot (1-\beta) \cdot (L^c + ZH^c)/r]^{1/\gamma}$ for each country c (a similar argument also applies away from the BGP). Therefore, the share of GDP spent on R&D is an increasing function of $L^c + ZH^c$. Since the South consists of a set of "small" economies, each will have an infinitesimal market for R&D, and the South, collectively, will not invest in R&D. Southern producers will instead import all their technologies from the North. More generally, one could also motivate the lack of substantial R&D investments in the South by weak property rights and scarcity of skills (see the discussion in the Remark below). Our assumption that each Southern country is small captures these considerations in a simple way.

We now discuss whether TFP differences might emerge even when firms in the South have equal access to the technologies in the North. To achieve this, we assume that there exists a statutory technology "monopolist" in each Southern country which copies new patents at zero cost and sells machines embodying this new technology to the producers in its country—no other firm is allowed to sell technologies. This implies that machine rental prices in the South are the same as those faced by firms in the North, $\chi_z(v) = (1-\beta)^{-1}$. Accordingly, the same capital/labor ratios will be used in production in the South and the North. Equations from subsection C therefore apply, while N_H and N_L are still given by R&D in the North as in subsection D. Thus (proof omitted):

Proposition 2 There exists a unique equilibrium in the South where J^s is given by

$$\frac{1-J^s}{J^s} = \left(\frac{N_H}{N_L}\frac{ZH^s}{L^s}\right)^{1/2}, \tag{16}$$

where for all $i < J^s$, $h_i = 0$ and $l_i = L^s/J^s$, and for all $i > J^s$, $l_i = 0$ and $h_i = H^s/(1-J^s)$, and technologies N_H and N_L are determined in the North (e.g. given by (15) in BGP). Output grows at the same rate g as in the North.

The equilibrium in the South therefore takes a very similar form to that in the North, with the only exception that technology parameters, N_H and N_L, are taken from the North. Hence, when the North is in BGP, the South is also in BGP. In particular, J^s is constant (although $J^s > J^n$), and the growth rate is equal to that of the North, g. The ratio of consumption to GDP is higher in the South, however, as there is no investment in R&D.

Remark: It can be noted at this point that similar results would be obtained if R&D were performed by skilled workers rather by using final output. In the North, h skilled workers would perform R&D while the remaining $H-h$ would work in skilled tasks. With our assumption that each Southern country is small and does not enforce international property rights, the South would once again *not* allocate any of its skilled workers to R&D, and we obtain exactly the same results as here. Moreover, in this case, even when the South consists of large countries, there will only be limited R&D investments in the South because skilled wages are high. We prefer the specification in the text as it leads to simpler expressions.

III. Productivity Differences Between the North and the South

A. TFP Differences

The concept of TFP, first introduced by Stigler (1947), decomposes output (or output growth) into a component dependent on factors of production and a component dependent on "technology". Since technology is often embedded in factors, for example capital, the distinction is not always clear, and, consequently, there is a large literature on how to measure TFP (e.g. Jorgensen, 1995).

In our model the definition of TFP is not completely unambiguous, either. In fact, there are two natural definitions of TFP here ($TFP1$ and $TFP2$), both obtained by factoring out output into the contributions of skilled and unskilled workers, capital and a residual. The former is implied by the logic of the theory, while the latter corresponds more closely to what is estimated in practice. Both TFP measures originates from aggregating sectoral TFPs, which are obtained by rewriting (5) as:

$$y_L(i) = a_L(i) \cdot K_L(i)^{1-\beta} \cdot l(i)^\beta \text{ and } y_H(i) = a_H(i) \cdot K_H(i)^{1-\beta} \cdot [Z \cdot h(i)]^\beta ,$$

where the $a_z(i)$'s are the sectoral TFPs, given by[8]

$$a_L(i) = [(1-i) \cdot N_L]^\beta \text{ and } a_H = [i \cdot N_H]^\beta , \tag{17}$$

and $K_L(i) \equiv \int_0^{N_L} k_L(i,v) = N_L P_L^{1/\beta} L/J$ for $i < J$, and
$K_H(i) \equiv \int_0^{N_H} k_H(i,v) = N_H P_H^{1/\beta} ZHL/(1-J)$ for $i > J$ denote the capital stocks used in sector i (obtained using (3)-(6)-(7)).

[8]Notice that $Z \cdot h(i)$ is the "quantity of human capital" employed in sector i using Z as the skill-premium. Z should not be part of sectoral TFP, since otherwise sectors and countries with more skilled workers would mechanically have higher TFP.

The alternative definitions of TFP arise because these sectoral TFP can be aggregated in two different ways. The first definition comes, simply, from (1) and (17).

$$Y = A(J, N_L, N_H) \cdot \exp\left(\int_0^J \ln K_L(i)^{1-\beta} l(i)^\beta di + \int_J^1 \ln K_H(i)^{1-\beta} \left[Zh(i)\right]^\beta di\right), \qquad (18)$$

where $A(J, N_L, N_H) \equiv \exp\left(\int_0^1 \ln a(i)di\right)$ is obtained from separating the terms with factor content from the technology terms. By using (17) and solving the integral we obtain our first measure of TFP, $TFP1$:

$$TFP1 \equiv A(J, N_L, N_H) \equiv \left[N_L^J N_H^{1-J} (1-J)^{-(1-J)} J^{-J}\right]^\beta \cdot \exp[-\beta]. \qquad (19)$$

To introduce the alternative definition of TFP, define the value of the aggregate capital stock by $K = K_L + K_H$ where $K_L \equiv \int_0^J K_L(i)di = N_L P_L^{1/\beta} L$, and $K_H \equiv \int_J^1 K_H(i)di = N_H P_H^{1/\beta} ZH$. Output can be written as (details in the Appendix):

$$Y = B(J, N_L, N_H) \cdot \left[K_L^{1-\beta} L^\beta\right]^J \left[K_H^{1-\beta} (ZH)^\beta\right]^{1-J}, \qquad (20)$$

where our second measure of TFP, $TFP2$, is

$$TFP2 \equiv B(J, N_L, N_H) \equiv \left[N_L^J N_H^{1-J} (1-J)^{-(1-J)} J^{-J}\right]^\beta \cdot \left[(1-J)^{-(1-J)} J^{-J}\right] \exp[-\beta]. \qquad (21)$$

In (19), we use the correctly aggregated labor and capital inputs, given the sectoral structure of our model, so (19) measures "true" TFP differences. In contrast, this sectoral structure is ignored in (21), and only aggregate stocks of labor and capital are factored out. This adds the term $\left[(1-J)^{-(1-J)} J^{-J}\right]$ to the TFP measure. Although (19) is the correct measure in our model, (21) is closer to what is estimated in empirical work, where using the exact sectoral structure of the economy is often infeasible.

Notice also that (18) and (20) already factor out skills using the correct factor shares, βJ for unskilled workers, and $\beta(1-J)$ for skilled workers, which means that the direct effect of differences in skill supplies on output are already controlled for. (19) and (21), therefore, do not directly depend on H and L, and TFP differences will not arise in our model due to mismeasurement of the human capital of workers. Instead, TFP differences will arise because both TFP measures depend on the threshold sector, J. J determines the extent to which skilled and unskilled workers are employed in sectors (tasks) for which they may not have a comparative advantage. So the level of J affects aggregate productivity, and economies with different threshold sectors will have different TFP levels.

We start our analysis with a simple lemma (proof omitted):

Lemma 3 For given N_H and N_L, $A(J, N_L, N_H)$ ($TFP1$) is an inverse U shaped function of J with a unique global maximum at $J^m \equiv N_L/(N_L + N_H)$.

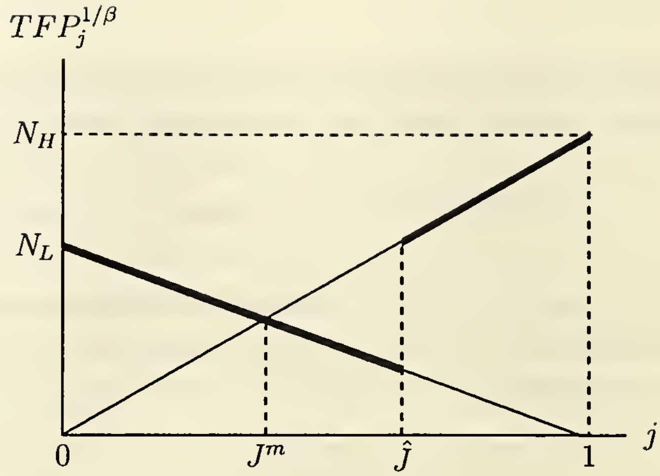

Figure 2: Sectoral TFP's.

Lemma 3 has an intuitive geometric representation. Figure 2 plots a monotonic transformation of the sectoral TFPs $(a(i)^{1/\beta})$ defined in (17). At $J^m \equiv N_L/(N_L + N_H)$, the two schedules cross. Hence, $TFP1$ is maximized, when an economy adopts the unskilled technology in all sectors $j \leq J^m$ and the skilled technology in all sectors $j > J^m$. The figure also draws an arbitrary value of the threshold sector $(\hat{J})$, where TFP is not maximized.

Proposition 3 Suppose N_H/N_L is given by the BGP equilibrium condition in the North, (15). Then, $J^s > J^n = J^m \equiv \arg\max A(J, N_L, N_H)$. Moreover,

1. Then, $A(J^n, N_L, N_H) > A(J^s, N_L, N_H)$.

2. If either (i) $ZH^n \leq L^n$, or (ii) $ZH^n > L^n$ and $\bar{\lambda} ZH^n/L^n > ZH^s/L^s$ where $\bar{\lambda} < 1$, then $B(J^{n*}, N_L^*, N_H^*) > B(J^s, N_L, N_H)$.

Therefore, $TFP1$ is always larger in the North, and $TFP2$ is also larger in the North as long as either the North is not very abundant in skills, or otherwise, if there is a large enough gap between the skill endowments of the North and the South. The reason why this second measure might give ambiguous answers is that the skill composition of the labor force has an independent effect on $TFP2$. In particular, an economy with very few unskilled workers may appear to have lower TFP, according to this measure, because it allocates skilled workers to tasks and sectors where their productivity is relatively low (e.g. those sectors with $i < 1/2$). The conditions in part 2 of the proposition ensure that this is not the case. In our calibration below, we will take the North to be the U.S., and in this case, $ZH^n \leq L^n$ is satisfied, so that $TFP2$ is also unambiguously larger in the North.

Intuitively, this proposition shows that when R&D is carried out in the North only, and is *directed*, TFP will be larger in the North than in the South, even though there are no barriers to technology transfer. In particular, as $H^s/L^s < H^n/L^n$, TFP is larger in the North than in the South because some sectors in the South employ unskilled workers, though productivity would be higher if production were carried out by skilled workers using skilled technologies. The reason is that there is an insufficient number of skilled workers in the South to allocate to all tasks performed by skilled workers in the North.[9] As we will see in more detail in section V, if R&D firms could sell to Southern producers, they would invest more in unskilled technologies, and productivity in the South would not be as low. Similarly, as noted above, if the South could perform R&D, it would direct it to unskilled machines, and the TFP gap would be smaller. It is therefore the combination of the South importing technologies from the North and directed technical change in the North that underlies the TFP differences between the South and the North.

Proposition 3 has an immediate corollary (proof omitted):

Corollary 1 There are no TFP differences between the North and the South in sector i for all $i \leq J^s$ or $i \geq J^n$. Sectoral TFP is larger in the North than in the South for all $i \in (J^s, J^n)$.

This Corollary can also be illustrated using Figure 2. If the South sets the threshold sector at $J^s = \hat{J}$, sectoral TFPs will be as drawn by thick lines in the figure. The South is using unskilled workers in sectors $j \in \left(J^m, \hat{J}\right)$, where the technologies developed by the North make it more productive to use skilled workers. All productivity differences between the South and the North therefore originate in these "medium-tech" sectors, $i \in (J^s, J^n)$. The South concentrates its scarce endowment of skilled workers in a few highly complex tasks. Since technology is common knowledge, in these complex tasks and in the sectors where the North also uses unskilled workers, the South is as productive as the North. The productivity gap emerges instead in those sectors where it is easier to substitute unskilled workers for skilled workers— i.e. those tasks with intermediate i's. This pattern may explain why India, which has relatively few skilled workers and low TFP compared to the U.S. (approximately half of the U.S. level), has a relatively efficient software industry, but appears to have low productivity in a range of more traditional industries.

[9] Notice that in this model TFP differences between the North and the South would arise even for arbitrary N_H and N_L, because skilled and unskilled workers would be performing different tasks in the two sets of countries. However, in this case, the South could have higher TFP than then North. Directed technical change ensures that the North has higher TFP than the South, as it implies that N_H/N_L takes the value that maximizes North's TFP (using TFP1 —whereas using TFP2, directed technical change does not maximize the North's TFP, but tends to increase it).

B. A Simple Calibration

In this subsection, we investigate whether the TFP differences predicted by our model are quantitatively important. Equations (19) and (21) give the TFP levels (with the two different measures) in a country as functions of the world technology and the country's threshold sector, J. Given the technology parameters, we can determine J, and calculate the TFP differences predicted by our model using the relative skill supplies we observe in the data.

We construct the variable H/L as the ratio of the population over age 25 with higher education to those over 25 without higher education in 1985 from the Barro-Lee data set.[10] We choose $\beta = 0.7$, since β is the share of labor in national income in our economy, and set Z to make the predicted U.S. skill premium equal to 1.82, that is the college premium in the U.S. in 1988 (Katz and Murphy, 1992, p. 43),[11] which implies $Z = 1.82$. With these assumptions, we can use equations (19) and (21) with the values for H/L for each country and calculate the predicted TFP relative to the U.S. (whose TFP is normalized to 1).

We denote these predicted (relative) TFP levels by $\hat{A}$ (for $TFP1$) and by $\hat{B}$ ($TFP2$). A value of 0.5, for example, implies that the country in question is predicted to have TFP equal to one half of the U.S. TFP. Notice that in this calculation, we are not using any data about these countries' level of income or investment. The levels of $\hat{A}$ and $\hat{B}$ are simply those predicted by our theory given each country's H/L. In practice, a number of other factors, including distortions, corruption, wars, slow diffusion, and barriers to technology transfer, are likely to create TFP differences. Moreover, measures of human and physical capital used in practice may understate true differences in the amount accumulated factors across countries (e.g. our calculations assume that a college graduate in the U.S. is the same as a college graduate in the LDCs). We should therefore not expect a perfect fit between our predicted TFPs and the data. Nevertheless, evaluating the quantitative importance of predicted TFP differences and their correlation with the actual differences is informative.

Klenow and Rodriguez (1997) (based on Bils and Klenow, 1998) and Hall and Jones (1998) (henceforth, KR and HJ) calculate TFP levels for 98 and 127 countries, respectively, using data on output, capital, labor and school attainment. The availability of data on higher school attainment reduces the two samples to 96 and 102 countries. Moreover, we exclude oil producers and Trinidad (a total of eight countries) from the KR sample,

[10] Web address for Barro-Lee data http://www.worldbank.org/html/prdmg/grthweb/ddbarle2.htm, see also Barro and Lee (1993). We thank Pete Klenow for the data on TFP levels from Bils and Klenow (1998) and Klenow and Rodriguez (1997) and Chad Jones for data from Hall and Jones (1998).

[11] The results are not sensitive to variations in β. If instead of $\beta = 0.7$ as in Klenow and Rodriguez (1997), we choose $\beta = 2/3$ as in Hall and Jones (1998), the results are almost identical.

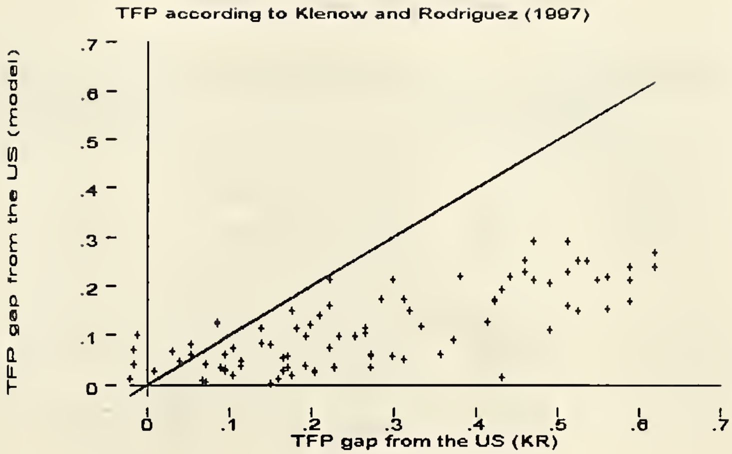

Figure 3: Actual (KR) vs. Predicted TFP Gap. TFP measure: $\hat{A}$.

since these countries appear to have unrealistically high TFP levels, suggesting that the effect of natural resources on output is not well accounted for by measured inputs for these countries.

We denote the (relative) TFP measures of KR and HJ by B_{KR} and B_{HJ}, and report them, as well as our measures, in our Appendix Table A1.[12] We start by comparing our $\hat{A}$ measures to B_{KR}'s and B_{HJ}'s, which will be informative regarding the quantitative importance of our predicted TFPs. In particular, recall that our m ,del suggests that there will be "true" TFP (productivity) differences across countries, even when technology can flow freely. It is however important to determine whether these TFP differences can be sizeable. We next turn to $\hat{B}$'s to evaluate the potential importance of our mechanism to account for TFP differences in practice. Since $\hat{B}$'s are more closely related to measured TFPs, they are more appropriate for this latter comparison.

Figures 3 and 4 plot the relative TFP of each country ($\widehat{gap}_A = 1 - \hat{A}$) on the vertical axis, and the TFP measures calculated by KR and HJ ($gap_{KR} = 1 - B_{KR}$ and $gap_{HJ} = 1 - B_{HJ}$) on the horizontal axis. We also draw the 45^0 line in all figures. A country further away from the origin has lower TFP relative to the U.S., whose observation lies exactly on the origin. Since our first measure $\hat{A}$ ($TFP1$) corresponds to true TFP differences, but not necessarily to the way TFP is calculated in practice, we only want to evaluate how large these TFP differences are. We can get a sense by comparing the variance of $\hat{A}$ to the variance of B_{KR} and B_{HJ}. The variance of our measure is

[12]HJ and KR report productivity differences per unit of human capital. Since they use a Cobb-Douglas framework, these can be easily transformed into TFP differences. In particular, denoting the labor productivity differences estimated by these papers by b_{KR} and b_{HJ}, we have $B_{KR} = (b_{KR})^{0.42}$ and $B_{HJ} = (b_{HJ})^{2/3}$. It is these TFP numbers that we use.

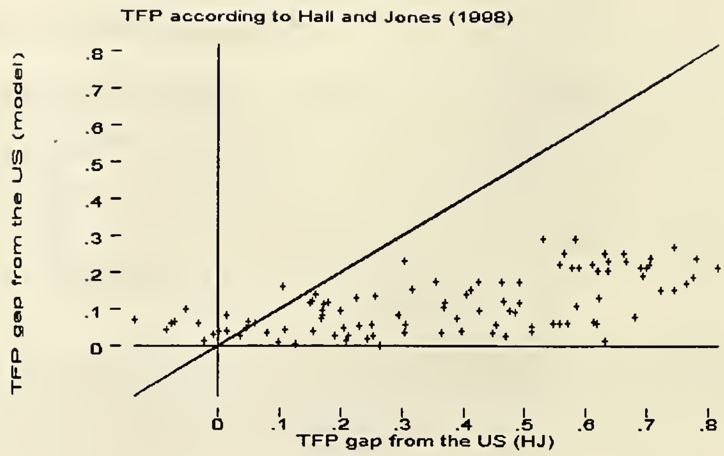

Figure 4: Actual (HJ) vs. Predicted TFP Gap. TFP measure: $\hat{A}$.

approximately 20% of the variance of B_{KR} and 10% of the variance of B_{HJ}. For example, the largest TFP gap predicted by our model is a TFP level equal to 30% of the U.S. level, whereas the largest gaps are in KR and HJ are 82% and 62%. We conclude from this evidence that our model predicts sizable true TFP differences even when all countries have access to the same technology, though these differences are smaller than those found in the data by KR and HJ.

As noted above, however, $TFP1$ does not correspond to the TFP measures estimated in practice. So to evaluate how much of the variation in the data could actually be driven by our mechanism, we need to compare B_{KR} and B_{HJ} to our $\hat{B}$'s ($TFP2$'s). Figures 5 and 6 plot $\widehat{gap_B} = 1 - \hat{B}$ on the vertical axis, and the $gap_{KR} = 1 - B_{KR}$ and $gap_{HJ} = 1 - B_{HJ}$ on the horizontal axis, and show a much better fit between the data and our model.

For a quantitative comparison, in Table 1 we report the coefficients and R^2 from a linear regression of our measures on B_{KR} and B_{HJ} (for completeness, Table 1 also reports the same regressions using $\hat{A}$). A perfect fit would correspond to a constant equal to 0, slope coefficient, $\hat{\alpha}$, equal to 1 and $R^2 = 1$. Obviously, measurement error and other important determinants of TFP ignored in our theory imply that there will not be a perfect fit, but how close we are to such a fit is informative. The slope coefficient is also identical to the statistic suggested by KR as a summary measure of how much a variable explains variations in another variable in a similar context (their suggested measure is $\hat{\alpha} = Cov((B_s, \hat{B})/Var(B_s))$. As an alternative, we also report a "constrained R^2", $\Re_s^2 = 1 - Var(B_s - \hat{B})/Var(B_s)$. This is the R^2 from a regression if we constrain the slope to be equal to 1 and the constant 0. $\Re^2$ would be equal to 1, if there were a perfect fit between our model and the data. All three measures, $\hat{\alpha}$, R^2 and $\Re^2$, are informative regarding how much of the measured TFP differences our model can account for.

Table 1. Comparison between predicted and actual TFPs.

	TFP from KR			TFP from HJ			CTFP from HJ	
	$\hat{A}$	$\hat{B}$	$\tilde{B}$	$\hat{A}$	$\hat{B}$	$\tilde{B}$	$\hat{B}$	$\tilde{B}$
c.	0.02	0.07	0.02	0.04	0.11	0.04	0.09	0.01
	(2.21)	(3.64)	(1.79)	(3.86)	(5.22)	(3.55)	(4.05)	(1.02)
$\hat{\alpha}$	0.34	0.68	0.71	0.19	0.39	0.46	0.42	0.48
	(11.2)	(11.0)	(18.7)	(8.10)	(8.08)	(13.7)	(9.70)	(16.0)
R^2	0.60	0.59	0.80	0.40	0.39	0.68	0.49	0.74
$\Re^2$	0.49	0.57	0.79	0.29	0.40	0.61	0.48	0.65

Note: t-statistics in brackets. Each column reports the linear regression of the specified measure (Â≡TFP1– or B̂≡TFP2) on the TFP measures calculated by Klenow and Rodriguez (1997) and Hall and Jones (1998). More specifically, we regress $\widehat{gap}_A$ ≡(1-Â) or $\widehat{gap}_B$ ≡(1-B̂) on $\widehat{gap}_s$ ≡(1-TFP$_s$). $\Re^2_s$ is the constrained R^{2}measuring the fit constraining the constant to be zero and the slope coefficient to be one. B̃ is the TFP2 measures constructed using the skill variables of Klenow and Rodriguez (1997) instead of using fraction of population with higher education divided by fraction with no higher education. CTFP includes an adjustment to the TFP calculated by HJ which is discussed in the text.

Our first measures of how much of the TFP variations in the data could be explained by our mechanism, the slope coefficients from the regression of actual TFPs on our predicted ε ries, are $\hat{\alpha}_{KR} = 0.68$ (KR data) and $\hat{\alpha}_{HJ} = 0.39$ (HJ data). As for our other measure of fit, we obtain: $\Re^2_{KR} = 0.57$ and $\Re^2_{HJ} = 0.40$. Therefore, despite the absence of any barriers to technology adoption, slow diffusion or other factors affecting technology choices in our calculations, our model accounts for between 39 and 68 percent of the variation in the data.

More concretely, for example, our model predicts that Mozambique, a country with practically no workers with higher education in 1985, should have a TFP equal to 42% of the U.S. level, while the relative TFPs calculated by KR and HJ are, respectively, 53% and 47%. Indonesia, on the other hand, should have a TFP of 53% according to the model, while measured TFPs vary between 62% (KR) and 39% (HJ). Nevertheless, our model is less successful in capturing the TFP gap for some other countries, like India and the Philippines, which have very low TFP levels, even relative to their low levels of educational attainment. In the case of India, for example, the model predicts a TFP of 74% of the U.S. level, while India's TFP is between 40% and 50% of the U.S. level in KR and HJ.[13]

[13]At this point, we can note that there is one degree of arbitrariness in our calibration: comparative advantage of skilled and unskilled workers is parameterized by $(1-i)$ and i. For any increasing function $f(.)$, using $f(1-i)$ and $f(i)$ would give similar theoretical results but different quantitative results. We chose $(1-i)$ and i for analytical tractability. Also as we will see in the next section commodity trade reduces TFP differences, and here we are making the calculations assuming no trade.

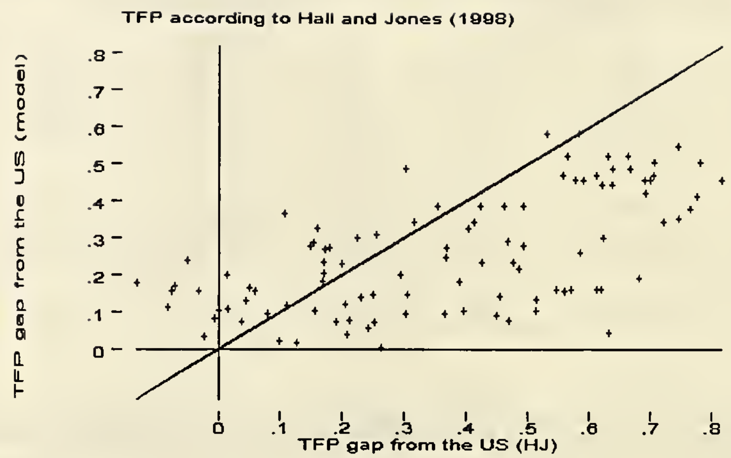

Figure 5: Actual (KR) vs. Predicted TFP Gap. TFP measure: $\hat{B}$.

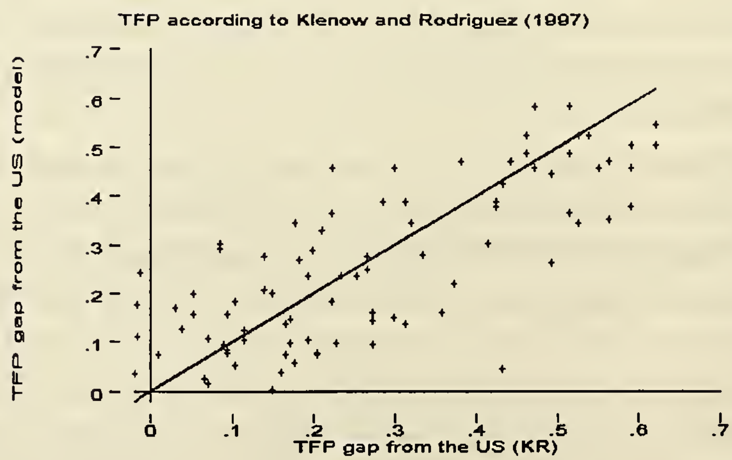

Figure 6: Actual (HJ) vs. Predicted TFP Gap. TFP measure: $\hat{B}$.

It might be argued, however, that by using variations in the number of workers with higher education only, our approach exaggerates differences in H/L across countries. Moreover, it is sometimes suggested that the contribution of higher education is smaller than that of secondary schooling.[14] Although college-noncollege distinction may come closest to our skilled-unskilled distinction, it is useful to check the robustness of our results by using an alternative measure of H/L estimated using differences in primary and secondary school attainments as well. For this purpose, we reconstruct our $TFP2$ measure ($\tilde{B}$) using H/L reported by Klenow and Rodriguez (1997) which are based on educational attainments, quality of schooling and labor force experience. Using this alternative measure of relative skill endowment actually improves the fit of our predicted series. The slope of the two regression lines increase to $\hat{\alpha}_{KR} = 0.72$, and to $\hat{\alpha}_{HJ} = 0.46$ (KR data), while our measure $\Re^2$ increases to $\Re^2_{KR} = 0.79$ and $\Re^2_{HJ} = 0.61$ (see Table 1).[15]

Table 1 shows that our calibration results are somewhat better with the TFP measures calculated by KR than those calculated by HJ. One possible reason may be that HJ – as well as many earlier authors – implicitly assume skilled and unskilled workers to be perfect substitutes, and use the same skill premium to calculate the human capital endowments of countries with different relative supplies of skill. In our model, this is not the correct procedure, as skilled and unskilled workers are imperfect substitutes, and the skill premium varies across countries (see Psacharopoulos, 1973, Table 8.4, p. 132 for skill premia for a number of countries). It is, however, possible to construct "corrected" TFP numbers from those of HJ. In particular, let estimated TFPs be:

$$\ln \widehat{TFP} = \ln Y - (1-\beta)\ln K - \beta \ln\left(L + \left(\frac{w_H}{w_L}\right)_{US} H\right),$$

whereas according to our model the correct TFP measure is:

$$\ln CTFP \equiv \ln B(J, N_L, N_H) = \ln Y - (1-\beta)\ln K - \beta \ln\left(L^J (ZH)^{1-J}\right)$$

We can then calculate an estimate of corrected TFP from HJ and KR as follows:

$$\ln \widehat{CTFP}_s = \ln \widehat{TFP}_s - \beta(1-J)\ln\left(\frac{ZH}{L}\right) + \beta \ln\left(1 + 1.82\frac{H}{L}\right)$$

[14]Even the contribution of secondary schooling to output has been challenged, e.g. Benhabib and Spiegel (1994) and Pritchett (1997). However, Krueger and Lindahl (1998) show that this is due to measurement error, exacerbated by the methods used in these papers.

[15]KR's appendix reports estimates of Y/L and H/Y (where Y stands for GDP) relative to the U.S.. From these date, we calculate H/L relative to the U.S. and also report these in Table A1. The H/L ratio in the U.S. is normalized to 0.508, which corresponds to the ratio of workers with higher education to those without in 1985. Although we only report results for $TFP2$,we also obtain similar results the above if we combine the KR measure of H/L with our $TFP1$.

for s =KR and HJ.

Using this corrected TFP measure ($CTFP$) improves the fit of our predicted TFPs to the HJ data (see Table 1). This is true both when we use our measure of H/L ($\hat{B}$), and when we use the alternative measure of skill intensity provided by KR ($\tilde{B}$). In particular, when we regress our predicted series on the corrected TFPs, the estimated value of the constant falls and in one case becomes non-significant, while the slope of the regressions increases to $\hat{\alpha} = 0.42$ (our H/L) and $\hat{\alpha} = 0.48$ (KR's H/L). The R^2 also increase significantly (to 0.39 and 0.74, respectively). Our alternative measure of fit also increases to $\Re^2 = 0.48$ (our H/L) and $\Re^2 = 0.63$ (KR's H/L).[16]

Overall, we conclude that the mechanism suggested in this paper can be quantitatively important, and can account for approximately between 40 and 70 percent of the variation we observe in TFPs across countries.

IV. Trade and Technology

We now consider a world where all commodities $i \in [0,1]$ are traded internationally. We assume that intellectual property rights are not enforced in the South. The main result in this section is that free trade implies *TFP convergence,* but causes *GDP divergence.*

We use the convention that H^s is the total number of skilled workers in the South and L^s is the supply of unskilled workers, as well as the supplies in a representative country in the South. International trade implies that commodity prices are equalized in all countries. Moreover, since different commodities can only be produced by skilled or unskilled workers, factor price equalization is also guaranteed. As a result, countries will now adopt the same technology (same threshold J^T). More specifically, we have

$$\frac{P_H^T}{P_L^T} = \left(\frac{J^T}{1-J^T}\right)^{\beta} = \left(\frac{N_H^T}{N_L^T}\frac{ZH^w}{L^w}\right)^{-\beta/2}, \tag{22}$$

and

$$\frac{w_H^T}{w_L^T} = Z\left(\frac{N_H^T}{N_L^T}\right)^{1/2}\left(\frac{ZH^w}{L^w}\right)^{-1/2},$$

where $L^w = L^s + L^n$ and $H^w = H^s + H^n$ are the world supplies, P_H^T and P_L^T are the world prices and w_H^T and w_L^T are world wages with free trade.

As patents are not enforced internationally, the balanced growth equilibrium condition, (14), is unchanged; Northern R&D firms continue to consider H^n and L^n as their

[16]While KR do not assume skilled and unskilled workers to be perfect substitutes, they use – like HJ – the same skill premium to calculate the human capital endowments of countries with different relative supplies of skill. If we apply to the TFP calculated by KR the same correction which is applied to the TFP calculated by HJ, the results of Table 1 do not change substantially, and, in fact, the fit of our model improves marginally. For example, we obtain $\Re^2 = 0.71$ (our H/L) and $\Re^2 = 0.79$ (KR's H/L).

markets. Thus, (world) prices have to adjust in order to satisfy (14). This implies that in the BGP, world relative prices will only depend on the factor endowment of the North. Formally,

$$\frac{P_H^T}{P_L^T} = \left(\frac{J^T}{1-J^T}\right)^{\beta} = \left(\frac{ZH^n}{L^n}\right)^{-\beta}. \tag{23}$$

This equation implies that along BGP with trade, world prices and threshold sector, J^T, will be equal to those prevailing in the North before trade. However, world prices must also satisfy the world market clearing equation, (22), which depends on world supplies rather than the supplies of the North only. The state of relative technology therefore has to change. In particular, since the supply of unskilled workers has increased, the relative productivity of skilled workers has to increase to ensure that (23) is satisfied. More specifically, (22) and (23) imply

$$\frac{N_H^T}{N_L^T} = \left(\frac{ZH^n}{L^n}\right)^{1/2} \left[\frac{H^n}{L^n}\left(\frac{H^w}{L^w}\right)^{-1}\right]^{1/2}, \tag{24}$$

which is larger than the closed economy ratio, since $(H^n/L^n) > (H^w/L^w)$. In other words, *trade induces skill-biased technical change.*[17] More specifically, the direction of technical change depends on the relative market sizes (H/L) and relative prices (p_H/p_L). Market sizes for technologies do not change, because inventors continue to sell their machines in the North only. But trade, at first, increases the relative price of skill intensive goods --i.e. equation (22) at a given N_H/N_L. This makes skill-complementary innovations more profitable and accelerates the creation of skill-complementary machines. In the after-trade BGP, the South, therefore, concentrates its unskilled production in fewer sectors and uses a larger number of skill-complementary machines, while the structure of production in the North reverts back to its pre-trade form. Nevertheless, since technologies are now more skill-complementary, skilled workers have higher relative productivities and wages.

In the next proposition, we characterize how the world economy adjusts to trade opening. To simplify the discussion, we limit our analysis to an unanticipated switch from a world of completely closed economies to one of free trade:

Proposition 4 Suppose that the relative technologies and prices before trade, $(N_H/N_L)^n$, relative prices and wages in the North $(P_H^n/P_L^n)^n$ and $(w_H^n/w_L^n)^n$, and the equilibrium thresholds J^n and J^s are as given by (12), (14), (15) and (16). Consider an unanticipated opening of the world economy to free trade. Then, upon trade opening P_H/P_L, J and w_H/w_L increase in the North and decrease in the South, and are equalized. The system then converges to a new balanced growth path, with $(N_H/N_L)^T > (N_H/N_L)^n$, while the

[17] This possibility is first raised by Wood (1994), though it is not clear what the mechanism that Wood has in mind. Acemoglu (1998) also establishes this effect in a model of directed change.

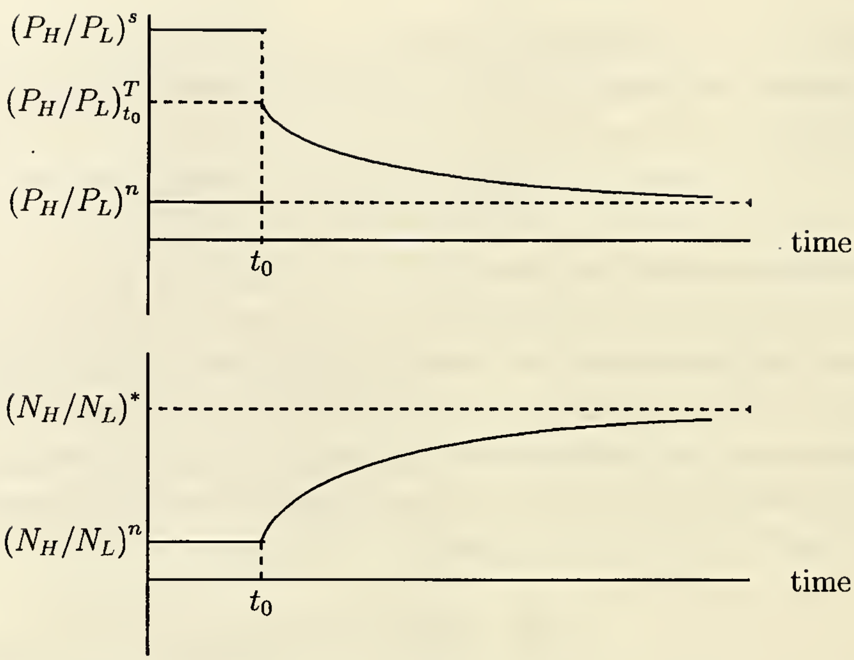

Figure 7: Dynamics of prices and technology after trade opening.

world price ratio P_H/P_L decreases to $(P_H/P_L)^T = (P_H/P_L)^n$ and the world threshold sector J decreases to $J^T = J^n$. w_H/w_L, the world skill-premium, continues to increase after trade opening and reaches a new level $(w_H/w_L)^T > (w_H/w_L)^n$. The PGP growth rate of the economy is the same as before trade (g).

The dynamics of prices and technology are described in Figure 7. At the moment the trade regime changes (t_0), the level of technology is predetermined at $(N_H/N_L)^n$. The effects are therefore the same as in the standard trade theory. As the North is more abundant in skills, the relative price of skilled intensive goods and the skill premium increases in the North and falls the South (upper quadrant). What is different in our theory, however, is the adjustment after this initial response. The change in commodity prices, i.e. the higher level of P_H/P_L, encourages more skill-complementary innovations, and N_H/N_L increases (lower quadrant). The world economy reaches a balanced growth path, as the productivity of skilled workers increases sufficiently, and the relative price of skill intensive goods return to their pre-trade levels in the North, i.e. $(P_H/P_L)^T = (P_H/P_L)^n$. The skill premium in the North increases, not only due to standard trade reasons, but also due to the induced skill-bias technical change. Moreover, the change in technologies implies that the skill premium in the South may also increase, because the standard trade effect is being countered by skill-biased technical change induced by trade opening. Accordingly, increased trade openness in this model can raise wage inequality both in the North and the South, and may have larger effects in the North than predicted by traditional calculations.[18]

Since the world relative price of skill intensive goods returns to that of the North before trade, and the North and the South use the same threshold sector J^T, free trade implies that unskilled workers are used in fewer sectors in the South, i.e. J^s falls. Which sectors employ skilled workers in the South, however, is indeterminate as any part of the skilled production could be carried out in the North and imported to the South or vice versa. What is unambiguous is that, overall, the South will import skill-intensive goods and export unskilled goods. Finally, because the market size for new technologies is unchanged and world prices return to those of the North before trade, the long-run growth rate is unaffected and remains at g.

The next proposition compares the GDP levels between the South and the North before and after trade:

Proposition 5 Let Y_n be the GDP in the North and Y_s the GDP in the South before trade and Y_n^T and Y_s^T GDPs after trade, then $Y_n^T/Y_s^T > Y_n/Y_s$. That is, after trade opening, GDP differences between the North and the South widen.

Trade unambiguously *amplifies GDP differences* between the South and the North. As we saw above, trade induces new technologies to be further biased towards skilled workers. This reduces the productivity of unskilled workers both in the South and the North, and because the South is more abundant in unskilled workers, its relative situation with respect to the North deteriorates after this change. A number of other papers also obtain the result that trade may lead to more relative inequality among countries (e.g. Krugman (1987), Feenstra (1991) and Young (1991)). Nevertheless, the mechanism in these papers is quite different from ours. Typically, trade induces less developed countries to specialize in sectors which benefit less from learning-by-doing than the sectors in which the North specializes. In contrast, in our model, trade changes the direction of technical progress in the North, and leads to larger income differences via this channel. Additionally, in these models trade leads to both TFP and GDP divergence, which is different from our result, as we see next:

Proposition 6 Let A_n^T and A_s^T denote after trade TFP in the North and in the South, respectively, using $TFP1$, and let B_n^T and B_s^T be the $TFP2$ measures in the North and

[18]Thus, trade opening may be the cause of the increase in wage inequality in the U.S. over the past twenty years. Some of the arguments against the trade explanation, that wage inequality also increased in many LDCs, and that skilled-unskilled labor ratios increased all industries, may be invalid in this setting. These changes may be due to skill-biased technical change induced by trade. Another critique of the trade explanation, that the prices of skill-intensive products did not increase in the U.S., may also be less valid in this model, as in the long-run P_H/P_L returns to its pre-trade level.

South. Then, $A_n^T = A_s^T$ and $B_n^T = B_s^T$. That is, after trade opening, TFP differences between the North and the South disappear.

Despite causing GDP divergence, trade therefore leads to TFP convergence. Furthermore, not only do TFP differences decrease, but they actually *disappear.* The reason for TFP equalization is *factor price equalization.* TFP is low in the South when unskilled workers perform tasks for which they have little comparative advantage. Commodity trade, however, ensures factor price equalization and induces firms in the South to employ unskilled workers only in the tasks performed by unskilled workers in the North. Since the productivity of unskilled workers in these sectors is the same in the North and the South, and likewise for skilled workers, TFP differences disappear.

An implication of Proposition 6 is that the intuition that technology flows eliminate TFP differences is correct in an economy with free trade and factor price equalization. Access to the same technology and factor price equalization ensure the production structure to be the same in all countries. In other words, there is a common J^T such that all countries use unskilled workers only in sectors (tasks) with $j \leq J^T$. This emphasizes, however, that free technology flows, by themselves, are not sufficient for TFP equalization. Countries with different factor prices will use available technologies in different ways, causing unequal TFPs.

In fact, if we introduce iceberg transport costs at the rate τ in international trading (so that when 1 unit is exported, $1 - \tau$ units arrive at the destination country), then we lose factor price equalization and TFP differences re-emerge. In particular, when $\tau > 0$, $H^n/L^n > H^s/L^s$ implies that $(P_H/P_L)^n < (P_H/P_L)^s$ —more specifically, if there is actual trade, it is straightforward to see that $(P_H/P_L)^n = (1-\tau)^2(P_H/P_L)^s$. Then equation (9) implies that $J^n < J^s$, so there will be TFP differences. We state this as a proposition (proof in the text):

Proposition 7 Suppose there are (iceberg) transportation costs in international trade, then for $\tau > 0$, there will be TFP differences between the North and the South.

More generally, other sources of deviations from factor price equalization will also ensure that TFPs are not equalized. Since factor price equalization is strongly rejected as a description of international factor prices (e.g. Bowen, Leamer, and Sveikauskas, 1987),[19] we conclude that international trade will reduce TFP differences, but even with international trade, TFP differences between less and more developed economies will not disappear, even though they have equal access to the leading technologies.

[19] Here we refer to absolute factor price equalization, not to conditional factor equalization of Leontieff and Trefler (see Trefler, 1993).

A central result of this section, that international trade affects TFP differences between the North and the South, receives some empirical support. A regression of the TFP estimates for non-OECD countries on the index of trade openness provided by HJ yields a slope coefficient of 0.25 ($t = 4.4$, KR) and 0.30 ($t = 4.0$, HJ). Quantitatively, a one standard deviation increase in the index of trade openness is associated with a TFP increase of 0.088 (KR data) and of 0.105 (HJ data).[20]

V. Intellectual Property Rights and Technology

A. Equilibrium with Full Property Right Enforcement

If intellectual property rights were enforced in the South, revenues from technology sales in these countries would accrue, not to statutory monopolists, but to the R&D firms in the North. This would encourage R&D firms to design new technologies for the Southern market, too, potentially reducing the "inappropriateness" of technologies to the South.[21] This possibility is investigated in this section.

We assume that there is no commodity trade. The demand for machines is now the sum of the demands from the South and the North. Since demands for machines are still isoelastic, R&D firms continue to set the same price as above. Then, profits for the two types of innovations are $\hat{\pi}_L = (1-\beta)\beta\left[\left(\hat{P}_L^s\right)^{1/\beta} L^s + \left(\hat{P}_L^n\right)^{1/\beta} L^n\right]$ and $\hat{\pi}_H = (1-\beta)\beta Z\left[\left(\hat{P}_H^s\right)^{1/\beta} H^s + \left(\hat{P}_H^n\right)^{1/\beta} H^n\right]$ where $\hat{P}_L^n$ is the price index for unskilled goods in the North under full property right enforcement, and the other price indexes are defined similarly. N_L and N_H are determined, as before, to equate returns to innovating in the two sectors, thus ensure $\hat{\pi}_H = \hat{\pi}_L$. Given $\hat{N}_H$ and $\hat{N}_L$, the equilibrium in the South and North is determined as in subsection II.C. It can be shown that the steady-state growth rate of the world economy is given by:

$$\hat{g} = \exp(-1) \cdot (1-\beta) \cdot \beta \cdot \left(L^n + L^s + Z\left(\sqrt{\sigma} H^n + \sqrt{\sigma\mu} H^s\right)\right)$$

where $\mu \equiv (H^s/L^s)/(H^n/L^n) < 1$ and σ is a constant, $\sigma \in [\mu, 1]$ which depends on the relative size of the North and the South economy. In particular, σ is increasing in L^s/L^n.[22]

[20] This is only evidence of a positive correlation between trade openness and TFP, as we are not correcting for the possibile endogeneity of trade openness. HJ run a similar regression for their whole sample, and obtain similar results, using OLS and IV. Since our theory implies that trade should reduce the TFP gap between rich and poor countries, we have repeated here the regression for the subsample of non-OECD countries.

[21] This point, though not other results of this paper or this section, is also noted by Diwan and Rodrik (1991).

[22] The expression for $\hat{g}$ is obtained using the expressions (8), (9), (10), (15) and (16). Also $\sigma = (\hat{N}_H/\hat{N}_L)/N_H^*/N_L^*$ where ^denotes full property right enforcement and * denotes no property right enforcement. Lemma 4 in Appendix B provides a more detailed characterization of the term σ.

The main question for the focus of the paper is how TFP and GDP differences compare between the worlds with and without international enforcement of intellectual property rights. We start with GDP differences.[23]

Proposition 8 Let Y_n be GDP in the North and Y_s GDP in the South without property right enforcement, and $\hat{Y}_n$ and $\hat{Y}_s$ GDPs with property right enforcement, then $\hat{Y}_n/\hat{Y}_s < Y_n/Y_s$.

Property right enforcement leads to GDP convergence. With intellectual property rights enforced in the South, technologies produced in the North are more suited to the needs of the South. This leads to faster improvements in labor-complementary technologies than skill-complementary technologies, and narrows the output gap between the South and the North.

The results on TFP convergence are more complicated. When property rights are enforced, two changes occur relative to the environment of Section II. First, more R&D is directed towards unskilled technologies (the BGP N_H/N_L ratio falls), leading to TFP convergence. Second, both the South and the North increase the range of goods which are produced with unskilled technologies, as implied by equation (9). The effect of this second force is ambiguous, and we cannot conclude that property right enforcement always reduces TFP differences. Numerical calculations show, however, that the region of the parameter space where TFP leads to divergence is extremely small. Moreover, there exists a relatively non-restrictive parameter condition which rules out this possibility analytically, but this condition is complicated, so we state the relevant proposition and prove it in Appendix B (available upon request). Here, we simply note that for most parameterizations, enforcement of intellectual property rights leads not only to GDP convergence but also to TFP convergence.[24]

[23] An important issue in this section is the transfer of machine sales revenues from Southern monopolists to R&D firms in the North. To simplify the analysis, we assume that these monopolists continue to exist and sell the new machines to local producers, but they are now owned by Northern inventors. So their revenues are tranferred to the North. This assumption implies that GDP in the South is unaffected by whether these rents remain in the country or not, and can be compared to the GDP without property rights. However, GNP and consumption in the South cannot be directly compared, and even when there is GDP convergence, as shown here, there may be consumption divergence.

[24] For the parameters we used in the calibration of Section III.B (which were chosen to match the wage premium and educational attainment of the U.S. i.e. $Z = 1.82, H/L = 0.51$), the introduction of property right enforcement leads unambiguously to TFP convergence as long as the South has a relative skill endowment less than 0.0225 the endowment of the North (i.e. $H^s/L^s \geq 0.0225H^n/L^n$). Moreover, even if we consider the case in which the South has no skilled workers at all, the result that TFP differences decline with property rights can only be reversed when that the market size of the South is more than a thousand times larger than that of the North. This is, clearly, highly unrealistic. This numerical result is highly robust, and even very large perturbations of the parameters do not lead to any significant change.

A number of interesting observations can be made at this point. First, although the introduction of intellectual property rights will generally reduce TFP differences, it does not, in itself, ensure TFP equalization. In particular, if the market size for technologies in the North is larger than the one in the South, new technologies will be designed to make use of North's labor force even with property right enforcement, and the same argument as in the previous section will then imply larger TFP in the North than in the South. For our explanation for cross-country differences in TFP to be valid we do not need property rights not to be enforced. Even with full property right enforcement, there will be TFP differences. Interestingly, however, if the South is much larger than the North, in a world with full property right enforcement, the South might have higher TFP than the North. The reason is that, in this case, R&D firms in the North would design technologies complementary to unskilled workers to exploit the larger Southern market, and this time, skilled workers in the North would have low productivity, leading to the reverse TFP differences.

Second, the introduction of intellectual property rights may lead to a temporary TFP slowdown in the North. If ϕ' is sufficiently negative (i.e. γ large), the eventual growth rate of output and TFP will not be much higher with than without property rights. However, in the absence of property rights, TFP in the North is maximized, whereas it is not when intellectual property rights are enforced. Therefore, during the adjustment process, TFP in the North will grow at a slower rate than usual for a while, and grow faster due to the larger market size of the world. Essentially, the introduction of intellectual property rights would direct technical change towards the needs of the South, and away from the needs of the North, which is the source of the temporary TFP slowdown.

Finally, if we have both free trade (factor price equalization) and property right enforcement, TFP differences will disappear (as a result of free trade—see previous section). But there will continue to be GDP differences. In particular, using the same arguments as above, we can show that

$$\frac{\hat{N}_H^T}{\hat{N}_L^T} = \frac{1 - \hat{J}^T}{\hat{J}^T} = \frac{ZH^n + ZH^s}{L^n + L^s}.$$

This implies that the GDP gap will depend on the size of population of the South population relative to that of the North. If the South is relatively small, most technologies will continue to be developed for the North's workforce, and the North will still be richer than the South. However, since $\hat{N}_H^T/\hat{N}_L^T$ is less than N_H/N_L given by (15), GDP differences in this case will be smaller than those in Section II (without trade and property right enforcement).

B. Prisoner's Dilemma in Property Rights Enforcement

The analysis in the previous subsection shows that the South may benefit from the enforcement of intellectual property rights. When these rights are enforced, technologies produced in the North are more appropriate for the needs of the countries in the South. An important question is therefore why intellectual property rights may not be enforced.

The first possibility is that even if property right enforcement is beneficial to the South, contracting problems in these less developed countries may make it difficult to enforce intellectual property rights. Second, even with property right enforcement, R&D firms in the North may be unable to sell their technologies to firms in the South, because differences in other factors may require adjustments in these technologies which can only be made locally.

There are also three other reasons suggested by our analysis, which deserve a brief discussion. First, a social planner aiming at maximizing the consumption of the agents in the South may not want property right enforcement. Property right enforcement would help making new technologies more suited to the needs of the labor force of the South, but as noted above, it also causes a transfer of resources from the South to the North (via the payments for machines). Second, enforcement of intellectual property rights would destroy the monopoly rents accruing to the statutory monopolies in the South. Accordingly, they may campaign against the introduction of property rights. As it is also emphasized by Mokyr (1990), Krusell and Rios-Rull (1995) among others, the presence of rents that will be destroyed by a change in economic organization may block progress.

Finally, there's also a classic prisoner's dilemma among the countries in the South. To see this, consider a situation in which property right enforcement decisions are taken by each country's government, which has the objective of maximizing GDP. Assume that property right enforcement increases the present value of consumption in the South. Suppose that property rights are enforced in all Southern countries. Each individual government in the South, however, has an incentive to deviate and reduce the enforcement of property rights within its borders. This change will only have a small effect on the overall market for technologies, and hence, on the technologies developed in the North. The individual country has therefore little to lose by this deviation, but gains a large amount by saving the transfer of income to the R&D firms in the North. As a result, with many small countries in the South, the unique equilibrium in the game where each government chooses the degree of enforcement will be one with no property rights enforcement. This suggests that the enforcement of intellectual property rights internationally may require a coordinated effort.

VI. Human Capital and Convergence

Since differences in skill composition are the source of income and TFP differences, it is useful to understand why countries may end up with different levels of skills. In this section, we endogenize the skill acquisition decision of individuals. In particular, we consider an overlapping generations model in continuous time, where within each generation agents are heterogeneous in the length of time that they need to spend at school in order to become skilled. We characterize the equilibrium of this economy, and show that within the context of the model, differences between the South and the North can be captured as a difference in the distribution of schooling costs. We then show that a Southern country which experiences a reduction in the costs of schooling will accumulate more skills, and the gap of GDP and TFP between this country and the North will decline.

In each country, a continuum v of unskilled agents are born every period, and each faces a flow rate of death equal to v, so that the population is constant at 1 (as in Blanchard, 1985). Each agent chooses upon birth whether to acquire the education required to become a skilled worker. It takes T_x periods for agent x to become skilled, and during this time, he earns no labor income. The distribution of T_x is given by the function $G_c(T)$ in country c. The distribution of T is the only source of heterogeneity in this economy, and may be due to credit market imperfections, or to differences in innate ability, and it is also influenced by government policy towards education. The rest of the setup is unchanged. To simplify the exposition, we assume that $G_c(T)$ has no mass points. We assume that there is no commodity trade and no property right enforcement in the South.

We now define a BGP as a situation in which H/L and the skill premium remain constant. In BGP, there is a single-crossing property: if an individual with cost of education T_x chooses schooling, another with $T_{x'} < T_x$ must also acquire skills. Therefore, there exists a cutoff level of talent, $\bar{T}$, such that all $T_x > \bar{T}$ do not acquire education. Although H/L is in general a complicated function of past education decisions, if we assume that we are near BGP and v is small, it takes the simple form:

$$\frac{H^c}{L^c} \approx \frac{G_c(\bar{T}_c)}{1 - G_c(\bar{T}_c)}. \tag{25}$$

The agent with talent $\bar{T}$ needs to be indifferent between acquiring skills and not. When he does not acquire any skills, his return at time t is:
$R^{ne} = \int_t^{\infty} \exp[-(r+v)(\tau - t)] w_L(\tau) d\tau = w_L \int_0^{\infty} \exp[-(r+v-g)\tau] d\tau = w_L(r+v-g)$
where $r+v$ is the effective discount rate and we have used the fact that along the BGP, wages grow at the rate g as given in Section II, the rate of technical progress in the North. If in contrast the agent with $\bar{T}$ decides to acquire education, he receives nothing for a segment of time of length $\bar{T}$, and receives w_H thereafter. Therefore, the return to agent

$\bar{T}$ from acquiring education, $R^e(\bar{T})$, can be written as: $R^e(\bar{T}) = \int_{t+\bar{T}}^{\infty} \exp[-(r+v)(\tau - t)]w_H(\tau)d\tau = \exp[-(r+v-g)\bar{T}]w_H/(r+v-g)$. In BGP, for $\bar{T}$ to be indifferent, we need $R^e(\bar{T}) = R^{ne}$ at all times, so in country c, $w_H^c/w_L^c = \exp\left[(r+v-g)\bar{T}_c\right]$. Inverting this equation and substituting into (25), we obtain the relative supply of skills as a function of the skill premium:

$$\frac{H^c}{L^c} = \frac{G_c\left(\ln\left(w_H^c/w_L^c\right)/\left(r+v-g\right)\right)}{1 - G_c\left(\ln\left(w_H^c/w_L^c\right)/\left(r+v-g\right)\right)}. \tag{26}$$

The equilibrium of each country is given by the intersection of the relative supply (26) with the relative demand for skills determined by (12) above for a given N_H/N_L. N_H/N_L is in turn determined from (15) given H^n/L^n, which can be calculated by substituting the skill premium of the North, $w_H^n/w_L^n = Z$, into (26). Since (12) defines w_H/w_L as a decreasing function of H/L, and (26) traces an increasing relation between w_H/w_L and H/L, there is always a unique equilibrium for each country.

We need the supply of skills to be larger in the North, so fewer people should choose to acquire skills in the South. This implies that the function G_c in the North should first-order stochastically dominate that in the South. To see this, recall that our analysis above shows that skill premia are higher in the South (in accordance with the findings of Psacharopoulos, 1973, Table 8.4). If the South and the North had the same G function, then more, rather than less people, would acquire skills in the South. There could be a number of reasons for this difference in the propensity to invest in skills (i.e. for the differences in G's). Government subsidies for education are more extensive in the North, reducing the costs of education as captured by G, and individuals have better access to credit and typically longer life expectancy. All these factors make investments in skills more desirable.

The next proposition summarizes the equilibrium in this case:

Proposition 9 World BGP equilibrium with endogenous skill acquisition is characterized as follows: $w_H^n/w_L^n = Z$ and (26) for $c = n$ determine the relative supply of skills in the North, equation (15) then determines the relative state of technology, N_H/N_L. Given N_H/N_L, equations (12) and (26) for $c = s$ determine the equilibrium in the South. The BGP is locally stable.

The most interesting conclusion of this analysis with endogenous skills is that the change in the function G_c for a country will lead to a change in its supply of skills relative to the North, and therefore to TFP convergence or divergence. In particular, since the balanced growth path is stable, when the North is in BGP, a country with less than its long run relative supply of skills will gradually accumulate skills and experience faster than average TFP growth. Therefore, countries that improve their skill composition relative to the U.S. should also experience TFP convergence. This pattern receives some support from the historical accounts of development of Korea and Japan, whereby the process of adopting new technologies and productivity convergence for these countries coincided with rapid skill accumulation (see for example, Rhee, Ross-Larson and Pursell, 1984; Lockwood, 1968).

VII. Local Technologies and Divergence

So far, our analysis has assumed that firms in the South use technologies developed in the North. In practice, Southern firms may decide not to import Northern technologies, and use instead "local technologies". This is especially relevant for unskilled workers. Many new unskilled technologies turn formerly complex tasks into simpler ones that can be efficiently performed by unskilled workers. But, when these technologies are not sufficiently advanced, they may not be very useful to unskilled workers in relatively skill-intensive sectors. For example, advanced computers and software enable firms to use relatively unskilled workers, while tracking inventories automatically, but this would not have been possible with the computers of twenty years ago. A firm employing unskilled workers would then have been obliged to find other methods of inventory control.

To discuss these issues, we assume, in this section, that unskilled workers can also produce output in sector i by using local technologies. To simplify the analysis, we make local technologies symmetric to those imported from the North, that is, a local monopolist owns each local technology and sells machines embedding the relevant technology to the local producers. In particular, equation (2) now changes to:

$$\begin{aligned} y(i) &= \max\left\{\left[\int_0^{N_L} k_L(i,v)^{1-\beta}dv\right]\cdot[(1-i)\cdot l(i)]^\beta ; M(i)k_M^{1-\beta}l(i)^\beta\right\} \\ &\quad + \left[\int_0^{N_H} k_H(i,v)^{1-\beta}dv\right]\cdot[i\cdot Z\cdot h(i)]^\beta , \end{aligned}$$

where $M(i)$ is the productivity of local technology in sector i. We also assume that the marginal cost of local machines is $(r+\delta)/(1-\beta)$, as for the machines imported from the North, so that they will have the same prices. The only difference is that technologies imported from the North improve steadily —at the rate g in BGP— while the productivity of local technologies remains constant at $M(i)$.

The next proposition follows immediately (proof omitted):

Proposition 10 Producers in the South use local technologies in sector $i \leq J^s$ as long as $M(i) > (1-i)N_L$. Eventually, all local technologies are abandoned. Suppose the North is in BGP, then, until all local technologies are abandoned, GDP and TFP in the South diverge from their values in the North.

When local technologies are available, the South does not always use the technology of the North, even though it has access to it. In particular, when the labor-complementary technologies of the North are not very advanced, local technologies may suit the needs of a country better than the skill-complementary Northern technologies. Our assumption that most technical change takes place in the North implies that local technologies will not improve as quickly as Northern technologies. Thus, while it uses local technologies, both the GDP and TFP of the South will fall relative to the North. Nevertheless, at some point, it will become beneficial for the South to start importing technologies from the North, and income and TFP inequality between the South and the North will eventually stabilize.

VIII. Conclusion

In this paper, we have developed a model with TFP differences between less developed and advanced economies. Richer countries have higher TFP levels, despite the fact that firms in all countries have access of the same set of technologies. The source of TFP differences is the difference in the supply of skills between the South and the North. The North has more skilled workers, and employs them in tasks performed by unskilled workers in the South. Furthermore, we made two crucial, but plausible, assumptions: most new technologies are developed in the North, and technical change is directed, in the sense that more profitable technologies get developed and upgraded faster. The larger supply of skills in the North implies that new technologies are relatively skill-complementary, whereas the South, which employs unskilled workers in most tasks and sectors, needs more labor-complementary technologies. This mismatch between the skills of the South and technologies imported from the North is the source of the TFP differences.

In the data, there is a high degree of correlation between the skill composition and the TFP differences across countries. Moreover, even though it ignores a range of relevant factors, such as distortions in technology transfer, slow diffusion, corruption, etc., our model can account for a sizable fraction of the TFP differences we observe in practice.

As well as proposing a new explanation for TFP differences, our model suggests a number of potentially important determinants of TFP. First, commodity trade influences technological developments. In particular, free-trade implies that the South specializes in tasks that can be performed efficiently by unskilled workers, and ensures TFP convergence. Nevertheless, trade without property right enforcement also encourages the North to develop further skill-complementary technologies, which do not yield much benefit to the

South. So despite causing TFP convergence, trade amplifies GDP differences between the South and the North. Second, the extent of intellectual property rights in the world is also a major factor in TFP differences. If the South, collectively, enforces intellectual property rights, this will encourage Northern R&D firms to develop technologies more suited to the needs of the countries in the South, reducing the TFP gap between rich and poor countries. Finally, our model suggests a stylized pattern of convergence and divergence of TFP and GDP across countries. Southern countries which improve their skills base relative to the North will experience faster TFP growth, and converge to the TFP and income levels of these richer countries. In contrast, countries will diverge from the North when they prefer to use local technologies, rather than import those developed in the North. But this process will eventually come to an end, and as all less developed countries start importing and using Northern technologies, cross-country income and TFP differences will stabilize.

Clearly, our model has abstracted from important determinants of TFP, such as slow diffusion of new technologies, and economic and political distortions in the process of technology adoption. This has been done in order to emphasize that even in this environment of free technology flows and no distortions, there will be TFP differences between less and more developed countries, essentially because new technologies are developed to suit the needs of advanced economies. Our results suggest that this source of TFP differences might be considerable and should be taken into account when assessing the sources of output differences across countries. How slow diffusion of new technologies and distortions interact, both qualitatively and quantitatively, with forces emphasized in this paper is an area for future research.

Appendix A: Proofs of Main Results

Proof of Lemma 1: The profit of a firm using technology z in sector i is:

$$\Pi_z(i) = p(i)y(i) - \int_0^{N_z} \chi_z(\nu)k_z(i,\nu)d\nu - w_z z_i \tag{27}$$

where $z \in \{L, H\}$. We proved in the text that profit maximization implies that $\chi_z(\nu) = (1-\beta)$ and $k_z(i,\nu) = k_z(i) = \left(p_i\left((1-i)^\beta D_z + i^\beta(1-D_z)\right)\right)^{\frac{1}{\beta}} z_j$, where $D_z = 1$ if $z = L$ and $D_z = 0$ if $z = H$. Thus, we can use (27) to write per worker profit:

$$\begin{aligned}\zeta_z(i) \equiv \frac{\Pi_z(i)}{z_i} &= \left(p(i)\left((1-i)^\beta D_z + i^\beta(1-D_z)\right)\right)^{\frac{1-\beta}{\beta}} N_z - \\ & (1-\beta)\left(p(i)\left((1-i)^\beta D_z + i^\beta(1-D_z)\right)\right)^{\frac{1}{\beta}} N_z - w_z \end{aligned}\tag{28}$$

where competition implies that, in equilibrium, $\Pi_z(i) \leq 0$, $\forall i$. Now, first note $\zeta_H(i) - \zeta_L(i)$ is a strictly increasing function of i over $[0,1]$. Next, observe that Cobb-Douglas technology in (1) implies that all goods $i \in (0,1)$ have to be produced. So $\forall i$ we must have either $\zeta_L(i) = \Pi_L(i) = 0$ or $\zeta_H(i) = \Pi_H(i) = 0$ or both. Finally, it is not possible that in equilibrium some skilled (unskilled) workers are unemployed, because this would imply that the wage of this skill class falls to zero, hence, from (28), there would exist a profitable deviation. Thus a positive measure of variety of goods must be produced using skilled (unskilled) workers. It therefore follows that there must exist J (where $0 < J < 1$) such that $\zeta_H(J) - \zeta_L(J) = 0$, and $\zeta_H(i) - \zeta_L(i) > 0$ for all $i > J$ and vice versa for $i < J$. QED

Proof of Lemma 2: To derive a contradiction, suppose that for some $i' < i'' < J$ it is $p(i')(1-i')^\beta \neq p(i'')(1-i'')^\beta$. Consider two firms in sectors i', i'', both using unskilled technologies. In equilibrium, these two firms must make zero profits. However, substituting $D_z = 1$ in equation (28) gives a contradiction. Thus, for all $i \leq J$, $p(i) = P_L(1-i)^{-\beta}$ for some P_L. A similar argument establishes that for all $i \geq J$, $p(i) = P_H i^{-\beta}$.

We can then rewrite equation (5) as follows:

$$y(i) = \begin{cases} P_L^{(1-\beta)/\beta} N_L l(i)(1-i)^{-\beta} & \text{if } \ 0 \leq i \leq J \\ P_H^{(1-\beta)/\beta} N_H Z h(i) i^{-\beta} & \text{if } \ J < i \leq 1 \end{cases}. \tag{29}$$

Next, recall that consumers' utility maximization implies that $p_i y_i = Y$ for all $i \in (0,1)$. Then, since $p(i) = P_L(1-i)^{-\beta}$, for all $i \leq J$, we have $y_i = y(0)(1-i)^{-\beta}$. Similarly, for all $i \geq J$, we have $y_i = y(1)i^{-\beta}$. Furthermore, (29) implies that $y(0) = P_L^{(1-\beta)/\beta} N_L l(0)$ and $y(1) = P_H^{(1-\beta)/\beta} N_H h(1)$. Hence, $l(i)$ $(h(i))$ must be equal in all sectors using unskilled (skilled) workers. Thus, $l(i) = L/(1-J)$ and $h(i) = H/J$.

We finally need to prove that P_H/P_L is given by (8). Observe that, since $p_i y_i = Y$ (and, in particular, $p(0)y(0) = p(1)y(1)$), $p(0) = P_L$ and $p_1 = P_H$, then:

$$\frac{P_L}{P_H} = \frac{y(1)}{y(0)} = \frac{P_H^{(1-\beta)/\beta} N_H H/(1-J)}{P_L^{(1-\beta)/\beta} N_L L/J} \tag{30}$$

where the second equality is obtained by using (6), (7) and (29). Rearranging terms in (30) establishes (8). QED

Proof of Proposition 1:

Proof of existence and uniqueness of BGP is in the text. We start with the growth rate along the BGP (g). From (4) we know that $g = \Gamma x_L^{1-\gamma} = \Gamma x_H^{1-\gamma} = \Gamma x^{1-\gamma}$ where the last equality exploits the fact that in BGP $x_H = x_L = x$. Recall, first, that free entry in R&D implies that $\Gamma x_z^{-\gamma} = V_z = r/\pi_z$. Thus, in a balanced growth equilibrium, $x = (\Gamma\pi/r)^{1/\gamma}$, and $g = \Gamma^{1/\gamma}(\pi/r)^{(1-\gamma)/\gamma}$. In order to derive the expression of π, observe that $\pi = \pi_L = \exp(-1)\beta(1-\beta)L^n/J = \exp(-1)\beta(1-\beta)\left(L^n + ZH^n\right)$, where the first equality follows from (10) and the second follows from (15).

Consider now stability. Define $n \equiv N_H/N_L$ and $\kappa \equiv x_H/x_L$ (so, $\dot{n}/n = \dot{N}_H/N_H - \dot{N}_L/N_L$ and $\dot{\kappa}/\kappa \equiv \dot{x}_H/x_H - \dot{x}_L/x_L$). Recall that free entry implies $\Gamma x_z^{-\gamma} V_z = 1$ at all points, so

$$\frac{\dot{x}_z}{x_z} = \frac{\dot{V}_z}{\gamma V_z} = \frac{r}{\gamma} - \frac{\pi_z(n)}{\gamma\Gamma x_z^{\gamma}}$$

where $\pi_L(n) = \beta(1-\beta)\left(P_L^n\right)^{1/\beta} L^n = \exp[-1]\,\beta(1-\beta)L^n\left(1+\sqrt{n\cdot ZH^n/L^n}\right)$ and $\pi_H(n) = \beta(1-\beta)\left(P_H^n\right)^{1/\beta} H^n = \exp[-1]\,\beta(1-\beta)H^n\left(1+\left(1/\sqrt{n\cdot ZH^n/L^n}\right)\right)$(the second equalities in both expressions follow from (8)-(9)-(10)). Clearly, $\pi_L'(n) > 0$ and $\pi_H'(n) < 0$. Next, observe that (4) implies that $\dot{n}/n = x_H^{1-\gamma}\left(1-\kappa^{1-\gamma}\right)$. We can then write the following system of differential equations describing transitory dynamics:

$$\begin{aligned} \frac{\dot{n}}{n} &= x_H^{1-\gamma}\left(1-\kappa^{1-\gamma}\right) \\ \frac{\dot{\kappa}}{\kappa} &= \left[\gamma\Gamma x_H^{\gamma}\right]^{-1}\left[\pi_H(n) - \pi_L(n)\right] \\ \frac{\dot{x}_H}{x_H} &= \frac{r}{\gamma} - \frac{\pi_H(n)}{\gamma\Gamma x_H^{\gamma}} \end{aligned} \tag{31}$$

The stability properties of this dynamic system are "block-recursive". Note, in particular, that although x_H affects the speed of growth of both n and κ in first two equations, it does not affect the sign of the dynamics of neither of these two variables. We can therefore determine first the stability of n and κ, and then characterize the behavior of x_H. Figure 8 gives this argument diagrammatically. Recall that n is the only predetermined

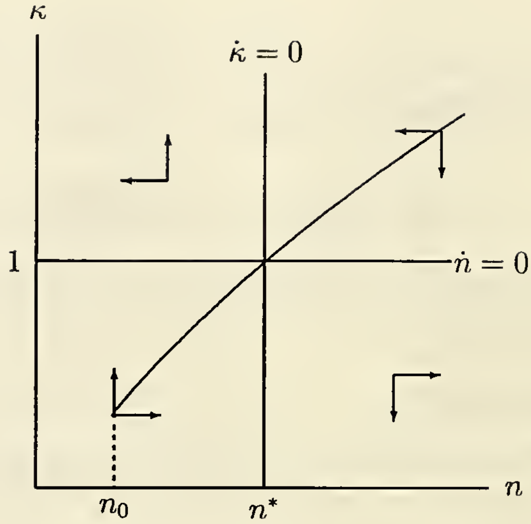

Figure 8: Transitional dynamics.

variable. Starting from any $n < n^*$, (e.g. n_0 in Figure 8) we have $\kappa < 1$, and the system monotonically converges to $n = n^*$ and $\kappa = 1$. The converse applies when $n > n^*$.

Finally, the inspection of the third equation of (31) shows that given the dynamic adjustment of n and $\pi_H(n)$, there exists a unique trajectory of x_H converging to the BGP with $\dot{x}_H = 0$. Since x_H is not predetermined, x_H will be set in equilibrium along this converging trajectory at every point of time. QED.

Derivation of Equations (20) and (21): Substitute for $y(i)$ using (2), $l(i) = L/J$, $h(i) = H/(1-J)$, $k_L(i,v) = P_L^{1/\beta} L/J$ and $k_H(i,v) = P_H^{1/\beta} ZH/(1-J)$ in (18):

$$
\begin{aligned}
Y &= \exp\left(\int_0^J \log(1-i)^\beta di + \int_J^1 \log i^\beta di\right) \times \\
&\quad \left[N_L \left(P_L^{1/\beta} L/J\right)^{1-\beta} (L/J)^\beta\right]^J \times \left[N_H \left(P_H^{1/\beta} ZH/(1-J)\right)^{1-\beta} (ZH/(1-J))^\beta\right]^{1-J}
\end{aligned}
$$

Now, using the fact that $K_L = N_L P_L^{1/\beta} L$ and $K_H = N_H P_H^{1/\beta} ZH$, we obtain:

$$
Y = B(J, N_L, N_H) \left[{K_L}^{1-\beta} L^\beta\right]^J \times \left[{K_H}^{1-\beta} (ZH)^\beta\right]^{1-J}
$$

where integration establishes that $B(J, N_L, N_H)$ is as defined in equation (19).

Proof of Proposition 3: (Part 1)Recall that technology parameters, N_L and N_H, are the same in all economies. Then, equation (15) implies that $J^n = \frac{N_L}{N_L+N_H} = J^m$ as defined in Lemma 3. Therefore, TFP is maximized, along BGP, in the North. Since $\frac{H^s}{L^s} < \frac{H}{L}$, Proposition 2 – and, in particular, equation (16) – implies that $J^s > \frac{N_L}{N_L+N_H}$. Applying again Lemma 3 establishes that TFP in the South is strictly less than TFP in the North.

(Part 2)With the alternative definition of TFP, (19), we have that $B(J, N_L, N_H)$ is also an inverse U-shaped function with a maximum at $J^{m'}$ where:

$$\frac{1-J^{m'}}{J^{m'}} = \left(\frac{N_H}{N_L}\right)^{\frac{\beta}{1+\beta}}.$$

From (15), we have $(1-J^n)/J^n = ZH^n/L^n > (1-J^n)/J^n = Z\sqrt{(H^n/L^n)(H^s/L^s)}$. This implies that $N_H \leq N_L$, i.e. $ZH^n \leq L$, is sufficient to guarantee $B(J^n, N_L, N_H) > B(J^s, N_L, N_H)$. So if $ZH^n \leq L$, the desired result is established.

Next, consider the case where $ZH^n > L^n$, so that $N_H > N_L$. Let $\lambda \equiv (H^s/L^s)/(H^n/L^n) < 1$. Then, $\exists\bar{\lambda} < 1$such that if $\lambda < \bar{\lambda}$, then $B(J^s, N_L, N_H) > B(J^s, N_L, N_H)$. This follows immediately by observing that if $\lambda = 0$, then $B(J^s, N_L, N_H) = \min_J B(J, N_L, N_H) = N_L$ and $B(J, N_L, N_H)$ is continuous in J. QED.

Proof of Proposition 4: First, trade ensures that commodity prices, P_L^T and P_H^T are equalized. Equation (9) in Section II.C still determines J in each country given prices. P_L and P_H are now the same in the North and the South, so $J^{Ts} = J^{Tn} = J^T$.

Next, observe that when the (unanticipated) trade opening occurs, N_H/N_L is given (predetermined). This implies – given equations (8)-(9)-(12) – that immediately after trade opening $(P_H/P_L)^n < (P_H/P_L)^T_{t0} < (P_H/P_L)^s$, $J^n < J^T_{t0} < J^s$ and $(w_H/w_L)^n < (w_H/w_L)^T_{t0} < (w_H/w_L)^s$.

After the impact effect of trade opening, the state variables N_H and N_L change, as now the BGP condition, (23), is no longer satisfied. This condition will be satisfied again when $(P_H/P_L)^T = (P_H/P_L)^n$. Since after trade opening $(P_H/P_L)^T > (P_H/P_L)^n$, we have $\pi_H^T > \pi_L^T$. Transitory dynamics can be characterized by an argument identical to that of Proposition 1. In particular, (31) applies exactly except that the second differential equation has a different "zero". Therefore, our previous argument immediately implies that after trade opening $x_H^T > x_L^T$ until N_H/N_L converges to $(N_H/N_L)^T$ as given by (24). As N_H/N_L increases, the world skill premium increases, and P_H/P_L and J decline. QED

Proof of Proposition 5: Equation (11) implies that the ratio of GDP in the North to GDP in the South is:

$$\frac{Y_n}{Y_s} = \left[\frac{(L^n)^{1/2} + (\frac{N_H}{N_L}ZH^n)^{1/2}}{(L^s)^{1/2} + (\frac{N_H}{N_L}ZH^s)^{1/2}}\right]^2 \tag{32}$$

which is strictly increasing in N_H/N_L since $H^n/L^n > H^s/L^s$. Trade increases N_H/N_L (from Proposition 4), so it increases Y_n/Y_s. QED

Proof of Proposition 6: Recall that $TFP1$ is:

$$A(J, N_L, N_H) = \left[N_L^J N_H^{1-J}(1-J)^{-(1-J)} J^{-J}\right]^\beta \cdot \exp[-1] \tag{33}$$

Since $J^s = J^n$ with trade, TFP in the North and the South are equalized The same argument applies to $TFP2$, $B(J, N_L, N_H)$. QED

Proof of Proposition 8: Once again relative GDPs are given by (32). Enforcement of property rights reduces N_H/N_L (see Lemma 4 in Appendix B), and hence leads to GDP convergence. QED

Proof of Proposition 9: As before, equilibrium in the North can be characterized without reference to the South, since there are no property rights or commodity trade. Equation (15) still determines equilibrium R&D choices for given relative supplies. The skill premium in the North is still equal to Z. Combining this with (26), for $c = n$, gives the BGP in the North. Given N_H and N_L, (12) gives the skill premium in the South, and combining this with (26) for $c = s$ gives the BGP skill premium and relative supplies in the South.

Finally, to analyze the local dynamics, augment the dynamic system in (31) with a differential equation in $\zeta = H^n/L^n$. Recall that we only need to describe North's equilibrium (the world economy continues to be block recursive, so we can solve the North's equilibrium first, without reference to the South). Around the North's BGP, we have:

$$\begin{aligned}\frac{\dot{\zeta}}{\zeta} &= \frac{\partial\left(H^n/L^n\right)/\partial t}{H^n/L^n} = \frac{\dot{H}^n}{H^n} - \frac{\dot{L}^n}{L^n} = v\Gamma_n\left[\ln\left(w_H^n/w_L^n\right)/\left(r+v-g\right)\right]/H^n - \\ & \quad v\left[1-\Gamma_n\left[\ln\left(w_H^n/w_L^n\right)/\left(r+v-g\right)\right]\right]/L^n\end{aligned}$$

Using a first-order Taylor approximation, we write:

$$\frac{\dot{\zeta}}{\zeta} = d_1\left[w_H^n/w_L^n - \left(w_H^n/w_L^n\right)^{SS}\right] - d_2\left[n - n^{SS}\right] \tag{34}$$

where $d_1 > 0$ and $d_2 > 0$, and the superscript SS denotes steady-state. Then, using equations (8) and (12) from the text, we can replace relative wages and end-up with the system of linear differential equations which applies around the BGP:

$$\begin{aligned}\frac{\dot{n}}{n} &= -a_1(\kappa - 1) \\ \frac{\dot{\kappa}}{\kappa} &= -b_1\left(n - n^{SS}\right) \\ \frac{\dot{x}_H}{x_H} &= c_1\left(n - n^{SS}\right) + c_2(x_H - x_H^{SS}) \\ \frac{\dot{\zeta}}{\zeta} &= -(d_1/2 + d_2)(\zeta - \zeta^{SS}) + d_1(n - n^{SS})/2\end{aligned}$$

The second equation generally depends on relative skill supplies in the North, $\zeta = H^n/L^n$, but this dependence disappears in the neighborhood of the BGP. Therefore, the system continues to be block-recursive, so starting from $n < n^{SS}$, we have $x_H > x_L$, $n = N_H/N_L$ increases to its BGP value. Similarly, if H^n/L^n is less than its BGP value, it also increases towards that value. Given the behavior of N_H/N_L determined in the North, H^s/L^s in the South also converges to its BGP level following equation (34). QED

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Appendix A (Continued)

Table A1

Country	B_{KR}	B_{HJ}	A	B	B_2	H/L	$(H/L)_2$	J
Algeria	0.996	0.841	0.858	0.673	0.814	0.024	0.067	0.834
Benin	0.559	0.442	0.780	0.530	0.596	0.006	0.012	0.908
Botswana	0.778	0.309	0.788	0.543	0.767	0.007	0.048	0.902
Cameroon	0.702	0.422	0.788	0.543	0.710	0.007	0.031	0.902
Central African Republic	0.410	0.293	0.760	0.498	0.531	0.004	0.006	0.924
Congo	0.915	0.533	0.876	0.708	0.770	0.031	0.049	0.814
Egypt	.	0.800	0.905	0.768	.	0.048	.	0.778
Gambia	0.487	0.417	0.709	0.419	0.573	0.001	0.010	0.961
Ghana	0.509	0.362	0.795	0.556	0.632	0.008	0.017	0.896
Kenya	0.451	0.301	0.788	0.543	0.597	0.007	0.012	0.902
Lesotho	0.487	0.333	0.771	0.515	0.624	0.005	0.016	0.916
Liberia	0.487	.	0.839	0.636	0.586	0.017	0.011	0.854
Malawi	0.380	0.218	0.760	0.498	0.529	0.004	0.006	0.924
Mali	0.463	0.337	0.748	0.478	0.541	0.003	0.007	0.934
Mauritius	0.801	0.846	0.878	0.713	0.807	0.032	0.064	0.812
Mozambique	0.529	0.469	0.709	0.419	0.582	0.001	0.011	0.961
Niger	0.380	0.255	0.732	0.453	0.494	0.002	0.004	0.945
Rwanda	0.539	0.435	0.748	0.478	0.612	0.003	0.014	0.934
Senegal	0.577	0.507	0.827	0.613	0.642	0.014	0.018	0.866
Sierra Leone	.	0.696	0.771	0.515	.	0.005	.	0.916
South Africa	0.790	0.596	0.858	0.673	0.812	0.024	0.066	0.834
Sudan	.	0.379	0.795	0.556	.	0.008	.	0.896
Swaziland	0.688	0.575	0.827	0.613	0.728	0.014	0.036	0.866
Togo	0.410	0.234	0.831	0.621	0.536	0.015	0.007	0.862
Tunisia	0.915	0.776	0.871	0.699	0.788	0.029	0.056	0.820
Uganda	0.475	0.369	0.748	0.478	0.591	0.003	0.012	0.934
Zaire	0.438	0.295	0.780	0.530	0.558	0.006	0.008	0.908
Zambia	0.410	0.184	0.788	0.543	0.596	0.007	0.012	0.902
Zimbabwe	0.568	0.307	0.807	0.577	0.649	0.010	0.019	0.885
Barbados	0.861	0.830	0.917	0.794	0.911	0.058	0.141	0.762
Canada	1.021	1.023	0.988	0.964	0.994	0.239	0.397	0.612
Costa Rica	0.829	0.635	0.963	0.902	0.837	0.131	0.080	0.680
Dominican Rep.	0.778	0.610	0.927	0.817	0.785	0.068	0.054	0.747
El Salvador	0.735	0.631	0.884	0.725	0.748	0.035	0.041	0.804

Country	B_{KR}	B_{HJ}	A	B	B_2	H/L	$(H/L)_2$	J
Guatemala	0.818	0.828	0.886	0.730	0.758	0.036	0.045	0.802
Haiti	0.529	0.410	0.788	0.543	0.594	0.007	0.012	0.902
Honduras	0.666	0.507	0.882	0.721	0.716	0.034	0.033	0.807
Jamaica	0.586	0.378	0.871	0.699	0.694	0.029	0.028	0.820
Mexico	1.113	0.950	0.935	0.836	0.905	0.079	0.135	0.733
Nicaragua	0.728	0.429	0.937	0.840	0.745	0.081	0.041	0.730
Panama	0.807	0.487	0.961	0.896	0.861	0.125	0.095	0.686
Trinidad & T.	1.202	0.851	0.882	0.721	0.969	0.034	0.255	0.807
USA	1.000	1.000	1.000	1.000	1.000	0.508	0.508	0.520
Argentina	0.829	0.749	0.943	0.853	0.885	0.089	0.114	0.721
Bolivia	0.643	0.453	0.937	0.840	0.730	0.081	0.036	0.730
Brazil	0.896	0.831	0.927	0.817	0.810	0.068	0.065	0.747
Chile	0.728	0.546	0.943	0.855	0.835	0.091	0.078	0.719
Colombia	0.850	0.706	0.919	0.800	0.820	0.060	0.070	0.758
Ecuador	0.795	0.530	0.972	0.923	0.830	0.157	0.075	0.660
Guyana	0.475	0.277	0.849	0.656	0.951	0.020	0.207	0.844
Paraguay	0.747	0.524	0.903	0.765	0.782	0.047	0.053	0.780
Peru	0.728	0.551	0.965	0.907	0.812	0.136	0.066	0.676
Uruguay	0.702	0.695	0.942	0.851	0.826	0.088	0.073	0.722
Venezuela	1.029	0.890	0.955	0.882	0.905	0.111	0.134	0.698
Bangladesh	0.778	0.893	0.839	0.636	0.722	0.017	0.034	0.854
Burma	0.438	0.255	0.846	0.649	0.561	0.019	0.009	0.847
China	.	0.224	0.813	0.587	.	0.011	.	0.880
Hong Kong	0.948	1.075	0.939	0.844	0.940	0.083	0.184	0.727
India	0.509	0.415	0.890	0.737	0.623	0.038	0.015	0.797
Indonesia	0.620	0.388	0.780	0.530	0.703	0.006	0.030	0.908
Iran	0.987	0.744	0.866	0.689	0.840	0.027	0.081	0.825
Iraq	1.102	.	0.909	0.778	0.865	0.052	0.098	0.773
Israel	0.929	0.874	0.995	0.984	0.971	0.316	0.261	0.578
Japan	0.824	0.757	0.980	0.943	0.932	0.190	0.171	0.639
Jordan	1.148	0.999	0.960	0.895	0.912	0.124	0.143	0.687
Korea	0.772	0.695	0.964	0.903	0.891	0.133	0.120	0.679
Malaysia	0.824	0.587	0.849	0.656	0.839	0.020	0.080	0.844
Nepal	0.577	.	0.831	0.621	0.608	0.015	0.014	0.862
Pakistan	0.681	0.684	0.849	0.656	0.681	0.020	0.025	0.844
Philippines	0.568	0.368	0.985	0.956	0.755	0.217	0.044	0.624
Singapore	1.012	1.051	0.900	0.759	0.881	0.045	0.110	0.784

Country	B_{KR}	B_{HJ}	A	B	B_2	H/L	$(H/L)_2$	J
Sri Lanka	0.715	0.537	0.827	0.613	0.798	0.014	0.060	0.866
Syria	1.192	1.032	0.939	0.844	0.914	0.083	0.145	0.727
Taiwan	0.886	0.844	0.960	0.895	0.911	0.124	0.141	0.687
Thailand	0.628	0.514	0.910	0.780	0.740	0.053	0.039	0.771
Austria	0.948	0.986	0.919	0.800	0.927	0.060	0.162	0.758
Belgium	0.929	0.985	0.959	0.891	0.972	0.120	0.264	0.690
Cyprus	0.795	0.747	0.974	0.927	0.883	0.163	0.113	0.656
Denmark	0.840	0.792	0.987	0.960	0.972	0.229	0.263	0.617
Finland	0.834	0.809	0.973	0.925	0.954	0.160	0.213	0.658
France	1.017	1.082	0.958	0.888	0.939	0.117	0.183	0.692
Germany	0.906	0.940	0.939	0.844	0.956	0.083	0.218	0.727
Greece	0.834	0.769	0.946	0.862	0.893	0.095	0.122	0.714
Hungary	.	0.441	0.939	0.844	.	0.083	.	0.727
Iceland	0.961	0.955	0.951	0.871	0.951	0.103	0.207	0.707
Ireland	0.886	0.795	0.952	0.876	0.937	0.106	0.180	0.703
Italy	1.017	1.134	0.930	0.823	0.935	0.072	0.175	0.742
Malta	0.861	0.820	0.884	0.725	0.902	0.035	0.131	0.804
Netherlands	0.992	0.964	0.973	0.925	0.972	0.160	0.264	0.658
Norway	0.906	0.788	0.972	0.922	0.984	0.156	0.315	0.661
Poland	.	0.381	0.937	0.840	.	0.081	.	0.730
Portugal	0.807	0.829	0.903	0.765	0.796	0.047	0.059	0.780
Spain	0.970	1.070	0.933	0.830	0.905	0.075	0.134	0.738
Sweden	0.896	.	0.983	0.950	0.970	0.203	0.258	0.631
Switzerland	0.911	0.920	0.964	0.904	0.966	0.134	0.246	0.678
Turkey	0.735	0.632	0.897	0.752	0.741	0.043	0.039	0.789
United Kingdom	0.906	1.007	0.969	0.915	0.957	0.147	0.221	0.668
Yugoslavia	0.688	0.487	0.947	0.863	0.843	0.096	0.083	0.713
Australia	0.934	0.902	0.992	0.976	0.985	0.279	0.323	0.594
Fiji	0.766	0.574	0.903	0.765	0.854	0.047	0.090	0.780
New Zealand	0.850	0.736	0.999	0.997	0.991	0.435	0.368	0.539
Papua N. G.	0.539	0.362	0.771	0.515	0.606	0.005	0.013	0.916
Reunion	.	0.645	0.827	0.613	.	0.014	.	0.866
Czechoslovakia	.	0.387	0.936	0.838	.	0.080	.	0.732
Romania	.	0.319	0.923	0.807	.	0.064	.	0.753
Soviet Union	.	0.603	0.960	0.894	.	0.122	.	0.688

See next page for notes.

Variable Definitions:

B_{KR}: TFP measure calculated by Bils and Klenow (1998) and Klenow and Rodriguez (1997). See text.

B_{HJ}: TFP measure calculated by Hall and Jones (1998). See text.

A: Predicted TFP1, see equation (18) in the text. Calculated with H/L from Barro-Lee (column 6).

B: Predicted TFP2, see equation (20) in the text. Calculated with H/L from Barro-Lee (column 6).

B_2: Predicted TFP2. Calculated with H/L from Klenow and Rodriguez (column 7).

H/L: Fraction of the population aged over 25 with higher education divided by fraction without in 1985. From Barro-Lee.

$(H/L)_2$: Human capital by worker calculated by Klenow and Rodriguez (1997). U.S. value noramlized to 0.508, same as H/L from column 6.

J: Threshold sector from the model, used in calibration. See equation (15) in the text.