Technological Change and the Wealth of Nations

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Abstract

We discuss a unified theory of directed technological change and technology adoption that can shed light on the causes of persistent productivity differences across countries. In our model, new technologies are designed in advanced countries and diffuse endogenously to less developed countries. Our framework is rich enough to highlight three broad reasons for productivity differences: inappropriate technologies, policy-induced barriers to technology adoption, and within-country misallocations across sectors due to policy distortions. We also discuss the effects of two aspects of globalization, trade in goods and migration, on the wealth of nations through their impact on the direction of technical progress. By doing so, we illustrate some of the equalizing and unequalizing forces of globalization.

1. INTRODUCTION

There is little disagreement that the unprecedented growth in material well-being experienced by Western countries over the past two centuries was made possible by crucial improvements in technology. Since the outset of the Industrial Revolution, pathbreaking innovations such as the steam engine, the spinning machine, gas lighting, electricity, and the telegraph opened the door to a trajectory of sustained technological change. While creating prosperity in some countries, the era of modern economic growth led to the appearance of enormous disparities in the wealth of nations. Differences in income per capita between the richest and the poorest region in the world were a modest 3:1 in 1820 and became as large as 18:1 in 2001. Disparities across countries are far greater: although they cannot easily be tracked back in time, in 2003, income per capita in the richest country (Luxembourg) was 143 times higher than in the poorest (Liberia).

Despite the obvious importance of technology in explaining modern growth and in shaping the world income distribution, quantifying the exact contribution of technical progress is not a simple task. The main difficulty is that technological progress is hard to observe and measure directly. To circumvent this problem, a useful starting point is the exercise of development accounting. It consists of choosing a functional form for the aggregate production function and using cross-country data on inputs and output to decompose differences in income per capita into differences in factor endowments (human and physical capital) and differences in total factor productivity (TFP). The goal of this decomposition is to shed light on the relative importance of productivity in explaining the differential performance of countries. The standard approach (see, e.g., Hall & Jones 1999, Caselli 2005) postulates that output per capita, y, can be represented by the following Cobb-Douglas function:

$$y = Ak^{\alpha}h^{1-\alpha}, \tag{1}$$

where k is capital per worker, h is average human capital per worker, α is a constant equal to the capital share, and A is TFP. Having data on the observables (y, k, h, α), one can compute A as a residual. Next, one can decompose the variance of y into the contribution of factor accumulation and technology. The usual result in the literature is that differences in endowments, i.e., the factor $k^{\alpha}h^{1-\alpha}$, account for only less than 50% of the observed disparities in income per capita.[1] In other words, TFP seems to be the main source of income differences.

In addition, convergence in measured TFP accounts for a large fraction of the changes in the wealth of nations. Take two success stories: China and the Republic of Korea. In 1970, the aggregate TFP of China was less than 12% of that of the United States. In 2003, it was more than 38%. In Korea, a country that started its process of fast convergence earlier, TFP was 36% of that of the United States in 1960, 46% in 1970, and 61% in 2003. In contrast, there has been no convergence in most Sub-Saharan African countries. For instance, Kenya's relative TFP was 25% (twice as high as that of China!) in 1970 and only 21% in 2003. Similarly, Niger's relative TFP was 31% in 1970 and 23% in 2003.[2]

[1]For example, Caselli (2005) found that $var\left[\log\left(k^{\alpha}h^{1-\alpha}\right)\right]/var[\log(y)] = 0.39$.

[2]The data of GDP per worker are from the Penn World Tables, version 6.2. Human capital per worker is defined using the average years of schooling in Barro & Lee (2000; update http://www.cid.harvard.edu/ciddata/ciddata.html), a 10% annual rate of return to schooling. The estimate of human capital per capita in 2003 is based on the data for year 2000. The estimates of capital stock are from Bernanke & Gürkaynak (2001). We set $\alpha = 1/3$ as customary.

The development accounting exercise has intrinsic limitations. First, it identifies technology with an unexplained residual, and second, it does not identify any ultimate cause for the observed variation in endowments and technology. Thus, while it provides evidence on the central role of productivity, it is mute about the nature of TFP differences as well as about the relationship between h, k, and A. Both economic theory and the positive empirical correlation between productivity and factor endowments (especially between human capital and TFP) suggest all factors (k, h, A) are endogenous and interlinked. For instance, both China and Korea experienced capital deepening and large improvements in the educational attainment as well as fast convergence. In contrast, neither Kenya nor Niger experienced capital deepening or technological change. Thus, it would be hazardous to infer deep causes of income differences from development accounting. Is the lack of human capita responsible for low levels of productivity? Are differences in complementary factors (human capital and TFP) what prevent capital per worker to be equalized across countries?

More recent studies have made some progress toward answering these questions. Gourinchas & Jeanne (2006) take the accounting exercise beyond its static perspective by explicitly allowing for endogenous physical and human capital accumulation. They proposed an alternative decomposition of cross-country income disparities into three components: the distance of a country from its steady state, the steady-state level a country is converging to, and residual productivity. To implement this decomposition, they used a calibrated neoclassical growth model where distortions to investments in both physical and human capital are chosen in order to match the observed pattern of saving rates and educational attainments. Their findings reinforce the basic message of the development accounting exercise, in the sense that a slow speed of convergence (i.e., the distance from the steady state) contributes little to explaining cross-country income differences. For instance, even if non-OECD countries could converge immediately to their steady state, they would fill a mere 15% of their income gap relative to the U.S. economy. Distortions that lower the steady-state level of human and physical capital instead account for approximately 28% of output differences, still leaving the lion's share, almost 58%, to unmeasured productivity.

Caselli & Feyrer (2007) provide further evidence on the source of cross-country differences in capital-labor ratios. They computed the marginal product of capital (MPK) for a large cross section of countries and found that, despite the huge variation in capital-labor ratios, MPK is remarkably similar. This result is interesting because it implies that capital is allocated efficiently across countries. To show this, they define the marginal product of reproducible capital, MPK_r, as

$$MPK_r = \alpha_r y / k_r,$$

where k_r is reproducible capital and α_r is its income share. Although the overall capital share α is thought to be approximately constant across countries, less-developed countries have a much larger share of agriculture and natural resource sectors that are intensive in nonreproducible capital. It follows that in poor countries α_r is particularly low. This correction (using α_r instead of α) turns out to be very important to obtain the result that MPK_r is almost equalized. Next, Caselli & Feyrer (2007) showed that lower capital labor ratios in poor countries are largely attributable to low endowments of human capital and low productivity. Once again, these findings suggest that differences in capital endowments are a consequence rather than a cause of underdevelopment and that computing productivity as a residual in an accounting exercise may actually underestimate its role in explaining income differences.

In this paper, we construct a model that focuses on factor-biased (directed) technological change and use it as a workhorse to analyze a variety of interacting factors that explain persistent differences in the wealth of nations. We first argue, following Acemoglu & Zilibotti (2001), that, because new technologies are developed by rich countries (the North), these technologies tend to be inappropriate for the factor endowments of poor countries. This mismatch between technologies and factor endowment in poor countries is a source of productivity differences. Moreover, we claim that the nature of recent technological development may have accentuated the importance of this channel. For instance, many less-developed countries have a scarce endowment of skilled workers that are required to operate computer-intensive technologies. This reduces the positive impact of the information technology (IT) revolution on their productivity, thereby widening the gap in the wealth of nations.

Although Acemoglu & Zilibotti (2001) assume that technologies can be copied and adopted instantaneously, in the real world, the diffusion of technologies across countries occurs slowly. This is partly due to physiological factors (e.g., new technologies embed some tacit knowledge or need to be adapted to local conditions). However, barriers to technology adoption may also have politico-economic roots, as argued by Parente & Prescott (1994, 2000) and Krusell & Rios-Rull (1997), among others. Our model uncovers some of these politico-economic factors, focusing in particular on the aftermath of a skill-biased technological wave. We show that, as a result of the skill bias of foreign technologies, the adoption of technologies developed in the North may harm incumbent firms and unskilled workers in the South, inducing them to lobby for barriers that slow down adoption. Competition policy is one of the most prominent policies affecting technology adoption. In the spirit of recent papers—see, e.g., Acemoglu et al. (2006) and Zilibotti (2008)—an extension of our model shows that the optimal competition policy may change at different stages of the process of technological convergence. Both political barriers against technology adoptions and inappropriate competition policies can thus contribute to the persistent productivity differences.

In another application, we extend the analysis to the effects of asymmetric policy distortions, e.g., sector-specific industrial policies inducing different market powers across sectors. Such policies open wedges that distort the direction of technological development and adoption. Our argument is related to a growing literature arguing that resource misallocations within countries may be a major culprit for the persistent low productivity in poor countries. Important contributions in this line of research include works by Parente et al. (2000), Banerjee & Duflo (2005), Hsieh & Klenow (2007), Restuccia & Rogerson (2007), and Song et al. (2008).

Finally, we return to the benchmark model and analyze how globalization, undoubtedly one of the most important phenomena of recent years, may affect the wealth of nations through its impact on the direction of technological progress. To this end, we open the model to international trade and labor mobility (migration). One important result of this section is to show that, as argued by Acemoglu & Zilibotti (2001) and Epifani & Gancia (2008a), globalization can lead to skill-biased technical change that benefits disproportionately skill-abundant countries. A second set of results is obtained when countries are specialized in the production of differentiated goods. Within this framework, we discuss the point made by Acemoglu & Ventura (2002) that trade can promote technological convergence across countries through changes in relative prices (the terms of trade). Finally, we show that, depending on parameter values, the endogenous reaction of technology can turn migration into an either equalizing or unequalizing force. The latter finding allows us to make contact with a long tradition of models in which globalization can trigger a cumulative process of uneven development (e.g., Matsuyama 1995, 2004; Krugman & Venables 1995).

The paper is organized as follows: Section 2 presents the benchmark model of endogenous technical change. Section 3 introduces technology diffusion and uses the model as a workhorse to explore three sets of explanations for cross-country productivity differences: inappropriate technologies, barriers to technology adoption (and their origins), and misallocation of resources across sectors. Section 4 introduces trade in goods and imperfect labor mobility. Section 5 concludes this article.

2. THE BENCHMARK MODEL

In this section, we present the workhorse model of endogenous technical change. The benchmark model is a simplified version of Acemoglu et al. (2008)—in turn, related to Acemoglu (1998, 2002), Acemoglu & Zilibotti (2001), and Gancia & Zilibotti (2005). The key ingredients are different types of labor, skilled and unskilled workers, and factor-biased (directed) technical progress. To simplify the analysis, we abstract from physical capital accumulation. We emphasize an asymmetry in the ability of countries to "choose" technologies: New technologies are developed by rich countries (the North) and sold in their markets only, whereas new technologies need a costly investment to be adopted—possibly with delay—by less-developed countries (the South). In this leader-follower approach, the South benefits from the innovation in the North but is also subject to a constraint on its ability to choose the appropriate factor bias of technology. We characterize first the equilibrium in the North, which can be interpreted as a large, advanced country (or a collection of perfectly integrated advanced countries). In Section 3, we model how technologies diffuse to a set of less-developed countries (the South) and discuss sources of productivity differences.

2.1. Preferences

The economy is populated by infinitely lived agents who derive utility from consumption (c_t) and supply labor inelastically. Preferences of the representative agent are given by the utility function

$$U = \int_0^{\infty} e^{-\rho t} \log c_t dt,$$

where ρ is the discount rate. The representative agent sets a consumption plan to maximize utility, subject to an intertemporal budget constraint and a No-Ponzi game condition. The consumption plan satisfies a standard Euler equation:

$$\frac{\dot{c}_t}{c_t} = r_t - \rho, \tag{2}$$

where r_t is the interest rate. We remove henceforth time indexes when this causes no confusion.

2.2. Technology and Market Structure

Final output, used for both consumption and investment, is given by a CES (constant elasticity of substitution) aggregator

$$Y = \left[Y_L^{\frac{\varepsilon-1}{\varepsilon}} + Y_H^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{3}$$

where Y_L and Y_H are goods produced with unskilled labor (L) and skilled labor (H), respectively, and $\varepsilon > 1$ is the elasticity of substitution between them. Maximizing Y under a resource constraint gives the relative demand function:

$$\frac{P_H}{P_L} = \left[\frac{Y_L}{Y_H}\right]^{\frac{1}{\varepsilon}}, \tag{4}$$

where P_L and P_H are the prices of Y_L and Y_H, respectively. As usual, we take Y to be the numeràire:

$$P_L^{1-\varepsilon} + P_H^{1-\varepsilon} = 1. \tag{5}$$

The production function at the sector level is

$$Y_L = E_L\left[\int_0^{A_L} y_L(i)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}} \text{ and } Y_H = E_H\left[\int_0^{A_H} y_H(i)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}},$$

where A_L (A_H) is the measure of intermediate inputs $y_L(i)$ ($y_H(i)$) produced with unskilled labor L (skilled labor H). As in standard expanding-variety models à la Romer (1990), the range of available intermediates captures the state of technological sophistication that grows (endogenously) with innovation. The term $E_L \equiv (A_L)^{\frac{\sigma-2}{\sigma-1}}$ ($E_H \equiv (A_H)^{\frac{\sigma-2}{\sigma-1}}$) is an externality that pins down the degree of increasing returns consistent with the existence of a balanced-growth path.[3] Producers of Y_L and Y_H are competitive and maximize profits taking the price of intermediates, $p_L(i)$ and $p_H(i)$, as parametric. This yields the demand equations:

$$\frac{y_L(i)}{y_L(j)} = \left[\frac{p_L(j)}{p_L(i)}\right]^{\sigma} \text{ and } \frac{y_H(i)}{y_H(j)} = \left[\frac{p_H(j)}{p_H(i)}\right]^{\sigma}. \tag{6}$$

The intermediate-good sector is monopolistic, with each producer owning the patent for a single variety. Note that intermediate firms are monopolist in their own product market, but they behave competitively in the labor market because there they compete with a large number of firms. The production function for each intermediate input, $y_L(i)$ and $y_H(i)$, is linear in the type of labor employed,

$$y_L(i) = l(i) \quad \text{and} \quad y_H(i) = Zh(i),$$

and is subject to the resource constraints $\int_0^{A_L} l(i)di \le L$ and $\int_0^{A_H} h(i)di \le H$, where L and H are in fixed supply. The parameter $Z > 1$ will ensure that the equilibrium skill premium

[3]Note that the externality is not needed for the special case $\sigma = 2$. In the typical formulation used in the literature without the term E and with $\sigma \neq 2$ (e.g., Grossman & Helpman 1991), balanced growth can be obtained by imposing an externality in the R&D technology. Having the externality in the production function is no less general and simplifies the analysis substantially.

is positive. As all monopolists face a demand curve with the constant price elasticity of σ, it is optimal for them to set a price equal to

$$p_L(i) = p_L = \left(1 - \frac{1}{\sigma}\right)^{-1} w_L \quad \text{and} \quad p_H(i) = p_H = \left(1 - \frac{1}{\sigma}\right)^{-1} \frac{w_H}{Z}, \tag{7}$$

where w_L and w_H are the wage of unskilled and skilled workers, respectively. This pricing formula also implies that profits per firm are a fraction $1/\sigma$ of revenues:

$$\pi_L(i) = \frac{p_L l(i)}{\sigma} \quad \pi_H(i) = \frac{p_H Z h(i)}{\sigma}. \tag{8}$$

Using symmetry and labor-market clearing yields $l(i) = L/A_L$ and $h(i) = H/A_H$, which in turn allows us to express sectorial output as

$$Y_L = A_L L \quad \text{and} \quad Y_H = A_H Z H. \tag{9}$$

Note that output in each sector is a linear function of labor and the measure of available intermediates, capturing the state of technology. Substituting these into Equation 4 yields the relative price

$$\frac{P_H}{P_L} = \left[\frac{A_L L}{A_H Z H}\right]^{\frac{1}{\varepsilon}}. \tag{10}$$

Relative wages and profits can be found from Equations 7 and 8, noting that $p_L L = P_L Y_L$ and $p_H Z H = P_H Y_H$. This yields

$$\frac{w_H}{w_L} \equiv \omega = \frac{P_H Z A_H}{P_L A_L} = \left[\frac{Z A_H}{A_L}\right]^{1-\frac{1}{\varepsilon}} \left[\frac{L}{H}\right]^{\frac{1}{\varepsilon}}, \text{ and} \tag{11}$$

$$\frac{\pi_H}{\pi_L} = \frac{P_H Z H}{P_L L} = \left(\frac{A_H}{A_L}\right)^{-\frac{1}{\varepsilon}} \left(\frac{Z H}{L}\right)^{1-\frac{1}{\varepsilon}}, \tag{12}$$

where the second equation follows from Equation 10. Equation 12 shows that the relative profitability, π_H/π_L, consists of two components: a "price effect," whereby rents are higher in sectors producing more expensive goods, and a "market-size effect," whereby rents are higher in larger sectors.

2.3. Endogenous Technological Change

Innovation takes the form of the introduction of new varieties of intermediate inputs and is directed. In particular, we assume that the development of a new variety in sector H (L) requires a fixed cost of μ_H (μ_L) units of the numeràire Y. For simplicity, we assume that $\mu_H = \mu_L = \mu$. The direction of innovation is endogenous, i.e., each innovator can decide to design either an L- or an H-complement new variety. As patents are infinitely lived, the value of a firm—either V_L or V_H—is the present discounted value of its future profit stream. Free entry implies that neither V_L nor V_H can exceed the innovation cost, μ. Because P_L, P_H, and the interest rate r are constant in a balanced-growth path, then

$$V_L = \frac{\pi_L}{r} \quad \text{and} \quad V_H = \frac{\pi_H}{r}.$$

For the relative price to remain constant, A_L and A_H must grow at the same rate, which requires innovators to be indifferent between developing an L- or H-complement input. Thus, $V_L = V_H = \mu$, which requires that $\pi_H/\pi_L = 1$. Accordingly, Equation 12 yields the skill bias of technology (A_H/A_L) compatible with balanced growth[4]

$$\frac{A_H}{A_L} = \left(\frac{ZH}{L}\right)^{\varepsilon-1}. \tag{13}$$

From Equation 11, the associated skill premium is

$$\omega = Z^{\varepsilon-1}\left(\frac{H}{L}\right)^{\varepsilon-2}. \tag{14}$$

To find the growth rate of the economy, we note that along the balanced-growth path the interest rate is pinned down by any of the two free entry conditions:

$$r = \frac{\pi_H}{\mu} = \frac{P_H ZH}{\mu\sigma}. \tag{15}$$

Solving for P_H from Equation 5 yields

$$P_H = \left[1 + \left(\frac{P_H}{P_L}\right)^{\varepsilon-1}\right]^{1/(\varepsilon-1)}. \tag{16}$$

Using Equation 16 together with Equations 10, 13, and 15, we obtain an expression for r that can be substituted into the Euler Equation 2 to solve for the balanced-growth rate of the economy, g:

$$g = r - \rho = \frac{\left[L^{\varepsilon-1} + (ZH)^{\varepsilon-1}\right]^{\frac{1}{\varepsilon-1}}}{\mu\sigma} - \rho. \tag{17}$$

3. DIRECTED TECHNOLOGY ADOPTION

In this section, we extend the benchmark model to incorporate technology adoption in developing countries and use it as a workhorse to explore different explanations for the persistence of productivity differences across countries.

Consider a less-developed country, called the South. We assume the South to be skill scarce relative to the North ($H^S/L^S < H^N/L^N$) and to have a population size no larger than that of the North ($H^N + L^N \geq H^S + L^S$). The South can adopt, at a cost specified below, the technologies developed in the North. Except for these differences, the North and the South are identical. We also assume that there is no trade in goods nor international protection of intellectual property. The former assumption, i.e., the lack of trade in goods, is relaxed in Section 4.1. The latter implies that innovators in the North cannot sell their copyrights to firms located in the South, so that the Northern innovators have access to the domestic market only [see Diwan & Rodrik (1991) for an empirical motivation of this

[4]It can be shown that, from any initial state of the technology, the economy will converge monotonically to Equation 13.

assumption]. In the absence of trade, the equilibrium conditions (Equations 2–17) in the North are unaffected by the presence of the South.

In the South, equilibrium conditions analogous to those in the North also apply, but the equilibrium technology takes a different form, as the South can adopt innovations developed in the North. In particular, the South takes the state of technology in the North, A_L^N and A_H^N, as given. Technology adoption is modeled as a costly investment activity that is similar to innovation. Following Nelson & Phelps (1966), Barro & Sala-i-Martin (1997), and Acemoglu et al. (2006), and motivated by the empirical evidence in Coe et al. (2008), we assume that, owing to technological spillovers, the cost of adopting a technology in a sector, c_L and c_H, is a negative function of the technological gap in that sector:

$$c_L = \mu^S \left(\frac{A_L^S}{A_L^N}\right)^{\xi} \quad \text{and} \quad c_H = \mu^S \left(\frac{A_H^S}{A_H^N}\right)^{\xi}, \ \xi \geq 0, \tag{18}$$

where $\mu^S \geq \mu$ (the South is less efficient than is the North at innovating) and A_L^N and A_H^N represent the world technology frontiers in the two sectors. That is, the further behind a country is relative to the North in a given sector, the cheaper the technologies are to adopt in that sector. With this formulation, the total cost of adopting the entire set of z-complement technologies (with $z \in \{H,L\}$) is

$$\mu^S \int_0^{A_z^N} \left(\frac{A_z^S}{A_z^N}\right)^{\xi} dA_z^S = \frac{\mu^S A_z^N}{1+\xi}.$$

This expression shows that ξ can be interpreted as an inverse measure of barriers to technology adoption in the South.

The fact that the cost of adoption is positive (albeit arbitrarily small if $\xi \to \infty$) implies that once a firm adapts a new intermediate input to the South, it is not profitable for any others to do so. Otherwise, Bertrand competition between sellers of the same intermediate would lead to negative profits. Hence, all intermediate inputs adopted in the South are sold by local monopolists.

In a balanced-growth equilibrium, free entry implies

$$\frac{\pi_H}{\pi_L} = \frac{c_H}{c_L}, \tag{19}$$

where c_H and c_L are given by Equation 18 and depend on the distance to the technology frontier in the respective sector. Then, using Equations 12, 18, and 19, we can solve for the skill bias of the technology in the South:

$$\frac{A_H^S}{A_L^S} = \left(\frac{ZH^S}{L^S}\right)^{\frac{\varepsilon-1}{1+\varepsilon\xi}} \left(\frac{A_H^N}{A_L^N}\right)^{\frac{\varepsilon\xi}{1+\varepsilon\xi}} = \left[\left(\frac{ZH^S}{L^S}\right)\left(\frac{ZH^N}{L^N}\right)^{\varepsilon\xi}\right]^{\frac{\varepsilon-1}{1+\varepsilon\xi}}. \tag{20}$$

Technology adoption in the South depends on the skill endowment in the North as well as in the South. On the one hand, a high skill endowment in the South translates into a strong incentive to adopt skill-complement innovations [see Caselli & Wilson (2004) for evidence that countries import technologies that complement their abundant factors]. On the other hand, a high skill endowment in the North means that skill-complement innovations are relatively abundant and therefore relatively cheap to adopt. Note also that the skill bias of the Southern technology, A_H^S/A_L^S, is increasing in ξ, capturing the speed of technology transfer:

1. If $\xi = 0$ (prohibitive barriers), the South develops technologies independently from the North: $A_H^S/A_L^S = (ZH^S/L^S)^{\varepsilon-1}$.
2. If $\xi \to \infty$, adoption is free (no barriers) so that the South is using the technology of the North: $A_H^S/A_L^S = A_H^N/A_L^N$.

It is easy to show that, in a balanced-growth path, the South grows at the same rate g as the North and the two countries have the same interest rate, even in the absence of trade or factor mobility. We use this model of technology adoption to explore the three explanations for North-South productivity differences discussed in the Introduction: (*a*) technology inappropriateness, (*b*) barriers to technology adoption and inappropriate competition policies, and (*c*) inefficiencies arising from distortions that create a wedge between social and private productivity of investments in innovation/technology adoption.

To illustrate explanations *a* and *b*, it is useful to focus on the transitional dynamics associated with a shock that induces skill-biased technical progress. This exercise is interesting because skill biasedness is an important feature of technological progress in the last quarter of the twentieth century: An example is the IT revolution (see, e.g., Katz & Murphy 1992, Berman et al. 1998). Following Acemoglu (1998), we model the shock as an exogenous increase in the skill supply of the region of the world where technical change originates (i.e., the North). Alternatively, we could consider the unexpected emergence of a new general purpose technology, such as IT (see, e.g., Aghion & Howitt 1998, Helpman & Trajtenberg 1998), that reduces the cost of innovation of the skilled sector. Both shocks would induce skill-biased technical change in the North: Because $\pi_H/\mu_H > \pi_L/\mu_L$, A_H grows and A_L remains constant during the transition. We study the implications of this shock and the ensuing transition on cross-country productivity differences as well as on within-country income distribution. As we discuss below, the latter may be responsible for lobbying activities that block technology adoption.

3.1. Inappropriate Technologies

Even if countries have access to the same technologies ($\xi \to \infty$, implying that $A_H^S/A_L^S = A_H^N/A_L^N = A_H/A_L$), technologies developed in rich countries may not be appropriate for the needs of poor countries. The reason is a technology-skill mismatch: When the South uses technologies that are designed for the North's economy, it may lack the skill endowment required to operate them optimally. For example, very poor countries with low literacy rates may lack the skills that are necessary to benefit fully from the IT revolution.

To address this point formally, we start by showing that if technical change originates entirely in the North, its direction is efficient from the viewpoint of the North. An efficient allocation maximizes the PDV (present discounted value) utility of the representative consumer, given by

$$U_0 = \int_0^\infty e^{-\rho t} \log\left[Y_t - \mu\left(\dot{A}_{Lt} + \dot{A}_{Ht}\right)\right] dt,$$

where (substituting Equation 9 into Equation 3) aggregate output can be written as

$$Y_t = \left[(A_{Lt}L)^{\frac{\varepsilon-1}{\varepsilon}} + (ZA_{Ht}H)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}. \tag{21}$$

Standard analysis shows that, because the marginal cost of innovation is the same across sectors, an efficient direction of technical change equalizes the marginal product of technology across sectors, i.e., the technology maximizes output. Differentiating Equation 21 yields[5]

$$\frac{\partial Y}{A_L} = Y^{\frac{1}{\varepsilon}} L^{\frac{\varepsilon-1}{\varepsilon}} (A_L)^{\frac{-1}{\varepsilon}} \qquad \text{and} \qquad \frac{\partial Y}{A_H} = Y^{\frac{1}{\varepsilon}} (ZH)^{\frac{\varepsilon-1}{\varepsilon}} (A_H)^{\frac{-1}{\varepsilon}}.$$

Thus,

$$\frac{\partial Y}{A_L} = \frac{\partial Y}{A_H} \Leftrightarrow \frac{A_H}{A_L} = \left(\frac{ZH}{L}\right)^{\varepsilon-1},$$

which coincides with the equilibrium skill bias in the North provided in Equation 13. Hence, the direction of technology is optimal for the Northern skill composition.

An immediate implication is that if less-developed countries use the technology originating from the North, but they have a different relative skill endowment, $H^N/L^N \neq H^S/L^S$, then $A_H/A_L \neq \left(ZH^S/L^S\right)^{\varepsilon-1}$. Thus, the marginal product of technology will not be equalized in the South and the productivity of the South will be below the level that would be attained if it could chose its technological bias. To see this, define the productivity per effective unit of labor as $y \equiv Y/(ZH + L)$ and consider how the productivity gap varies with the skill bias in the technology:

$$\frac{y^N}{y^S} = \frac{ZH^S + L^S}{ZH^N + L^N} \left[\frac{1 + \left(\frac{A_H}{A_L}\frac{ZH^N}{L^N}\right)^{\frac{\varepsilon-1}{\varepsilon}}}{1 + \left(\frac{A_H}{A_L}\frac{ZH^S}{L^S}\right)^{\frac{\varepsilon-1}{\varepsilon}}} \right]^{\frac{\varepsilon}{\varepsilon-1}}.$$

The right-hand side of the expression is an increasing function of A_H/A_L because the North is assumed to be skill abundant. This shows that the skill bias of technology magnifies the productivity difference. Note also that the skill-technology mismatch disappears as $\varepsilon \to 1$. This reflects the well-known fact that, when the aggregate production function is Cobb-Douglas ($\varepsilon = 1$), the factor bias of technology is irrelevant.

The analysis of this section suggests an alternative approach to the empirical questions discussed in the Introduction. The development accounting literature attributes productivity differences to differences in technologies that are captured by the TFP parameter in the aggregate production function (Equation 1). To assess the importance of inappropriate technologies, one can instead assume that all countries use the same technologies, but that the skill bias of the aggregate technology reflects the direction of technological progress in the North. For instance, Acemoglu & Zilibotti (2001) considered a model that has a reduced-form representation similar to the one discussed in this section, but they allowed for differences in capital-labor ratios. In particular, their aggregate production is

$$Y = K^{\alpha}\left[(A_L L)^{\frac{\varepsilon-1}{\varepsilon}} + (ZA_H H)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{(1-\alpha)\varepsilon}{\varepsilon-1}},$$

where, in their model, $\varepsilon = 2$. They set $\alpha = 1/3$ and replace K, L, and H by the country-specific level in a particular year. Finally, they calibrated Z, A_H, and A_L so as to match the skill premium in the United States and assumed them to have the same value in all countries. This implies that all countries use the same technologies but the skill bias of

[5]Note that this condition does not concern the amount of innovation, which is suboptimally too low, but only its direction.

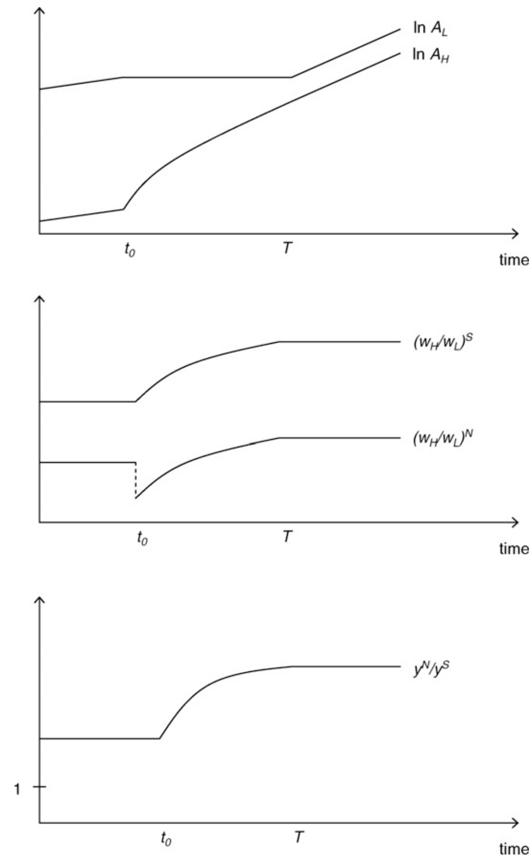

Figure 1

Skill-biased technical change after an increase in H^N.

technologies is determined by the factor endowment of the United States. They found that their model can explain up to 50% of the observed cross-country productivity differences. Reducing the elasticity of substitution between capital and labor improves further the fit of the model (see Caselli 2005). These results suggest that technological inappropriateness may be quantitatively important in explaining productivity differences.

It is also interesting to see how economies respond to a shock inducing skill-biased technical change (e.g., an increase in H^N). **Figure 1** summarizes the main features of the transition for a case in which $\varepsilon > 2$. The economy is initially in a balanced-growth equilibrium, where A_H and A_L grow at the same rate. Because the South imports without cost the technologies invented in the North, $A_H^N = A_H^S = A_H$ and $A_L^N = A_L^S = A_L$. At time t_0, there is an unexpected increase in H^N. As the shock occurs, A_L stops growing, whereas the growth rate of A_H increases discontinuously. During the transition, the growth rate of A_H slows down, as the resulting fall in the relative price P_H/P_L reduces profitability in the skilled sector and increases profitability in the unskilled sector. Eventually, innovation is restored in both sectors, and the new balanced growth features higher growth. The intermediate panel shows the dynamics of the skill premium in the North and the South. At t_0, the skill premium falls in the North. However, thereafter, the skill premium starts to rise in both countries. Because $\varepsilon > 2$, inequality increases in the long run in both the North and the South. Yet, the growth in inequality is more pronounced in the South, where the relative skill endowment has not changed. Finally, the lower panel shows that skill-biased technical change increases permanently the productivity gap between the North and the South.

3.2. Barriers to Technology Adoption

In the previous section, we assume that the South can adopt technologies invented in the North at essentially no cost. Although this is useful to isolate the effect of technology inappropriateness, the assumption that technologies diffuse immediately is clearly not realistic. First, new technologies embed some tacit knowledge that cannot be acquired instantaneously. Second, there are specific local features that may require costly adaptation of foreign technologies. Third, there are often institutional and policy barriers that limit technology diffusion. To analyze these issues, we now consider the general case in which technology adoption is costly ($\xi<\infty$). The theory is used to highlight distributional implications of technology adoption in the South that may lie behind incentives to erect barriers against adoption. To this aim, we assume that the government in the South can affect the parameter ξ through regulations on the use of foreign technologies. Setting barriers as low as possible (high ξ) fosters technology adoption and overall productivity growth in the South. However, importing foreign technologies may harm some groups of workers—in particular, low-skill workers—and incumbent monopolists in the South.

3.2.1. Workers. Consider first the effects of ξ on wages. The skill premium in the South can be obtained by substituting the expression of A_H^S/A_L^S in Equation 20 into the formula for the skill premium (Equation 11):

$$\frac{w_H^S}{w_L^S} = Z^{\frac{(\xi+1)(\varepsilon-1)}{\varepsilon\xi+1}}\left(\frac{H^S}{L^S}\right)^{\frac{\varepsilon-\xi-2}{1+\varepsilon\xi}}\left(\frac{A_H^N}{A_L^N}\right)^{\frac{(\varepsilon-1)\xi}{1+\varepsilon\xi}} = Z^{\varepsilon-1}\left(\frac{H^S}{L^S}\right)^{\frac{\varepsilon-\xi-2}{1+\varepsilon\xi}}\left(\frac{ZH^N}{L^N}\right)^{\frac{(\varepsilon-1)^2\xi}{1+\varepsilon\xi}}. \tag{22}$$

The second equality follows from Equation 13, recalling that A_H^N/A_L^N is determined by the factor endowment in the North. As $H^S/L^S<H^N/L^N$, the skill premium increases with ξ, showing that more technology transfer increases wage inequality. This effect can cause the surge of political pressure to raise barriers against technology adoption because, for instance, inequality may trigger social unrest or can make the middle class (H) powerful enough to threat the incumbent government. Note that the unequalizing effect is decreasing in H^S/L^S. Thus, countries with higher educational attainments and less inequality may be subject to less political pressure against technology adoption, which can contribute further to higher productivity. Therefore, the mechanism analyzed in this section reinforces the results of Acemoglu & Zilibotti (2001) showing that skill abundance in Southern countries reduces the TFP gap by reducing the mismatch between skills and technology.

Consider next the effect of a transition triggered by an increase in H^N. The repercussion in the South is a fall in c_H/c_L, whose effects on the technology bias are qualitatively similar to those observed in the North (depicted in **Figure 1**): The adoption of unskilled technologies is temporarily suspended, and during the transition, the South imports only skilled technologies. Because A_L^S does not grow, wage inequality increases sharply, even more so the greater the elasticity of substitution is between skilled and unskilled labor. Eventually, wage inequality settles down at a higher steady-state level.

In contrast, consider a policy response to the shock that blocks the introduction of foreign technology, i.e., it sets $\xi = 0$. The transitional dynamics are opposite in this case. Before the shock, the following balanced-growth condition holds for the South:

$$1 = \frac{\pi_H/c_H}{\pi_L/c_L} = \left(\frac{A_H^S}{A_L^S}\right)^{-\frac{1}{\varepsilon}} \left(\frac{ZH^S}{L^S}\right)^{1-\frac{1}{\varepsilon}} \left(\frac{A_H^N}{A_H^S}\frac{A_L^S}{A_L^N}\right)^{\xi}.$$

As the third term in parenthesis on the right-hand side is larger than unity, a policy reducing ξ would imply $\pi_H/c_H < \pi_L/c_L$. Thus, switching to "autarky" in innovation would induce L-biased technical change: A_L^S would grow, whereas A_H^S would remain constant until a new balanced-growth equilibrium is reached. In the new balanced-growth path, the skill premium is low. Thus, the barriers would benefit unskilled workers, at least in the short run. Note that, in the extreme case in which $\xi = 0$ and $\mu^S > \mu$, prohibitive barriers would cause divergence between the North and the South. Therefore, in the long run all factors would lose. Yet, to the extent to which future consumption is discounted, low-skill workers may still support barriers.

Although our discussion focuses on a particular episode (an exogenous increase in H^N), the thrust of the argument applies more generally. For instance, if the South had prohibitive barriers in place from the beginning, opening the sluice gate of technology transfer would halt temporarily the growth of A_L^S and accelerate that of A_L^H. Along the transition, the South would import only skilled technology and witness an increase in wage inequality. This may explain why—contrary to the prediction of standard trade models—developing countries that become more open often experience increasing inequality. To the extent to which economic reforms increase not only the trade of goods but also the transfer of technology, their effect can be to increase inequality.

3.2.2. Incumbent monopolist firms. So far, we considered the effect of technology adoption on wages and the possibility that low-skill workers may lose from the adoption of foreign technologies. In reality, the political strength of low-skill industrial workers—although varying from country to country—is often limited in developing nations. Local incumbent monopolists represent a more politically empowered lobby that may resist the introduction of new technologies. We now turn attention to these firms.

Before starting the analysis, we note that standard endogenous growth models with expanding variety and no directed technical change, such as Romer (1990), predict no effects of innovation on incumbent firms. In such models, the entry of new firms does not affect the value of incumbents owing to the knife-edge properties of the Dixit-Stiglitz production function. Although our model does assume Dixit-Stiglitz technologies, the price effect associated with the direction of technical change has an impact on the value of incumbent firms leading to interesting politico-economic predictions. The effects of innovation on the value of incumbent firms tend to be asymmetric. When a shock triggers a transition through a change in relative prices, the value of firms in one sector falls. However, the value of incumbent firms in the sector potentially benefiting from the price change remains constant: Rents are dissipated as a result of the entry of new firms. There is no counterpart to this entry process in the sector suffering an adverse price change because in that case firms cannot exit and recover sunk costs. The change in prices must then lead to a temporary fall in the profits of these firms.

As in the previous section, we consider the effects of an unanticipated increase of H^N. In the North, if the number of firms remained constant, the increase in the skill endowment would increase the profitability of incumbent firms in the H sector. In the literature, this is termed a market-size effect. However, the entry of new firms offsets this effect and keeps the profit flow of incumbent firms in the H sector constant. The value of monopolists remains equal to $V_H^N = \mu$. In contrast, the profit of incumbents in the L sector falls, causing $V_L^N < \mu$. During the transition, the entry of firms in the skilled sector increases P_L, raising the value of firms in the L sector until this eventually returns to μ.

In the South, the value of all incumbent firms falls permanently, creating a motive for existing firms to lobby for barriers against technology adoption. To show this, consider the profit flows in the two sectors (obtained using Equations 8, 10, and 16):

$$\pi_L^S = \frac{P_L^S L^S}{\sigma} = \frac{L^S}{\sigma}\left[1 + \left(\frac{P_L^S}{P_H^S}\right)^{\varepsilon-1}\right]^{\frac{1}{\varepsilon-1}} = \frac{L^S}{\sigma}\left[1 + \left(\frac{ZA_H^S H^S}{A_L^S L^S}\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{1}{\varepsilon-1}}, \text{ and} \tag{23}$$

$$\pi_H^S = \frac{P_H^S ZH^S}{\sigma} = \frac{ZH^S}{\sigma}\left[1 + \left(\frac{P_H^S}{P_L^S}\right)^{\varepsilon-1}\right]^{\frac{1}{\varepsilon-1}} = \frac{ZH^S}{\sigma}\left[1 + \left(\frac{A_H^S}{A_L^S}\frac{ZH^S}{L^S}\right)^{-\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{1}{\varepsilon-1}}. \tag{24}$$

Note that the profit flow of firms in the low-skill (high-skill) sector is increasing (decreasing) in the skill bias of the technology (A_H^S/A_L^S). In turn, the skill bias of the technology is increasing in both H^N/L^N and H^S/L^S (see Equation 20). Thus, the profit flow of firms in the low-skill sector is higher in the new balanced-growth equilibrium, because H^N/L^N is larger than in the initial equilibrium. The profit flow of firms in the high-skill sector is instead lower in the new balanced-growth equilibrium. Recall, however, that the steady-state value of firms equals π_L^S/r and π_H^S/r, respectively, in the two sectors. The interest rate increases unambiguously owing to the market-size effect (see Equation 17).[6] Thus, V_H necessarily falls, while the sign of the change of V_L is, in principle, ambiguous because both π_L^S and r increase. However, the apparent ambiguity can be resolved to conclude that V_L is also lower in the new steady state. To see why, note that, using Equations 23, 17, and 20, the steady-state value of a firm, π_L^S/r, can be expressed as

$$V_L^S = \mu\frac{L^S}{L^N}\left[\frac{1 + \left(\frac{H^S/L^S}{H^N/L^N}\right)^{\frac{(\varepsilon-1)(1+\xi)}{1+\varepsilon\xi}}\left(\frac{ZH^N}{L^N}\right)^{\varepsilon-1}}{1 + \left(\frac{ZH^N}{L^N}\right)^{\varepsilon-1}}\right]^{\frac{1}{\varepsilon-1}}. \tag{25}$$

The analysis of Equation 25 shows that V_L^S is decreasing in H^N/L^N.

To understand this result, recall that in a balanced-growth equilibrium $V_L^S = c_L = \mu^S(A_L^S/A_L^N)^{\xi}$ and $V_H^S = c_H = \mu^S(A_H^S/A_H^N)^{\xi}$. Thus, the fall in the value of Southern firms reflects the fact that the distance of the South from the technology frontier increases in all sectors. This is intuitive, as skill-biased technical change increases the mismatch between

[6]Note that r is the same in the North and the South in a balanced-growth equilibrium in spite of no trade. The interest rate is instead generally different during transitions.

the technologies invented in the North and the factor endowment of the South. However, the current section highlights the fact that the effect of the technology mismatch on the productivity gap can be magnified by politico-economic forces creating a push for raising barriers to technology adoption.[7]

3.3. Market Power, Growth, and Development

Innovation and technology transfer may also be slowed down by inappropriate policies that regulate the degree of competition between firms. The extent to which incumbent firms should be granted market power on their own product line is a classical theme in the endogenous growth literature. To address it formally, let us return to Equation 7. A monopolist in the low-skill sector charges a price $p_L = (1 - 1/\sigma)^{-1} w_L$. Now assume that there exists a competitive fringe of firms that can copy the technology and produce the same intermediate good. However, this fringe faces higher costs of production and needs $(1 - 1/\tilde{\sigma})^{-1}$ workers to produce one unit of the intermediate, where $(1 - 1/\sigma)^{-1} \geq (1 - 1/\tilde{\sigma})^{-1} > 1$. The parameter $\tilde{\sigma}$ captures both technological factors and government regulation affecting entry. In this generalization, the competitive fringe will not be active in equilibrium but will force the monopolist to charge a limit price equal to the marginal cost of the fringe:

$$p_L = \left(1 - \frac{1}{\tilde{\sigma}}\right)^{-1} w_L. \tag{26}$$

Thus, a lower $\tilde{\sigma}$ corresponds to a less competitive market, and setting $\tilde{\sigma} = \sigma$ corresponds to the unconstrained monopoly (maximum market power).

Monopoly power is traditionally associated with an inefficient resource allocation, as monopolists set prices different from marginal costs and underproduce. Thus, static efficiency would be achieved by setting $\tilde{\sigma} \to \infty$. However, since the early 1990s, the endogenous growth literature has emphasized that the appropriation of monopoly rents is key to providing firms with the incentive to make innovative investments. Consequently, the growth literature has advocated a strong protection of intellectual property rights, although this view has been recently challenged (see Boldrin & Levine 2008). The empirical evidence is ambiguous. For instance, Aghion et al. (2005) found a nonmonotonic relationship between market power and innovation. They rationalized their findings in a model where innovation is maximized when preinnovation rents are small and postinnovation rents are large. Increasing competition has a stronger effect on preinnovation rents when competition is initially low—so a procompetitive reform fosters innovation. In contrast, increasing competition in an already highly competitive environment, e.g., where incumbent firms are operating at similar technological levels, more significantly affects postinnovation rents and reduces innovation.

As in standard endogenous growth models, our benchmark model predicts that the growth rate is maximized by granting monopolists the maximum power, i.e., setting $\tilde{\sigma} = \sigma$. Furthermore, there is no static inefficiency in our model due to the inelastic supply of labor and due to the fact that labor cannot be used in other sectors. Thus, the growth-maximizing policy is also the optimal policy. In this section, we extend the model to show that under reasonable assumptions an excess of monopoly power may harm growth.

[7]A shock decreasing H^N/L^N would have an opposite long-term effect: The value of all incumbent firms in the South would be higher in the new steady state characterized by a lower mismatch and a smaller technology gap.

Moreover, we relate this analysis to the process of development, and we highlight how inappropriate competition policies may slow down technological convergence.

Whereas most of the existing literature on competition policy and growth analyzes the process of innovation in the industrialized world, recent research has shifted its focus to the relationship between competition policy and technological convergence in the development process. Acemoglu et al. (2006) argue that in countries behind the technological frontier there is a trade-off between the innovation and imitation activities carried out within firms. They argue that investments and the adoption of well-established technologies through imitation are fostered by long-term relationships between firms, between firms and banks, or between firms and their managers. In contrast, turnover and flexible contractual arrangements favor the selection of entrepreneurial skills, ultimately enhancing firms' innovative capabilities. Industrial policy, especially competition policy, determines what contracts are chosen in equilibrium. In particular, barriers to competition strengthen the position of insider firms and their managers. While harming the selection of the most productive firms, these policies can promote investments in poor economies where credit market imperfections are the most binding constraint. For this reason, barriers to competition may have been useful to promote growth and technological convergence in countries such as France, Italy, Korea, and Japan that adopted interventionist industrial policies after World War II [see Zilibotti (2008) for more discussion], so long as they were sufficiently far from the technology frontier. However, the theory emphasizes that, as economies approach the technology frontier, more market-oriented strategies implying lower barriers to competition are necessary to promote further technological convergence. This is because at the later stage technological convergence requires more human capital and selection to foster both genuine innovation and the adaptation of more sophisticated technologies. Such change of strategy can clash with the interests of insider firms that thrived as a result of the high barriers to competition.

The theory described above breaks with the stark prediction that high monopoly power is best for growth. Moreover, it argues that as growth and technology adoption become more human-capital intensive the optimal policy becomes more procompetitive. However, neither their theory nor the model of directed technical change presented in the previous section deals with human capital accumulation. In this section, we augment the model of directed technical change with educational investments. The extension identifies a mechanism by which excessive monopoly power has a negative effect on innovation and growth. In particular, when firms appropriate too large a share of the surplus, all other factors lose and, in particular, the return to human capital investment falls. Thus, the optimal policy depends on the extent to which countries rely on human capital accumulation for their growth and development process.

Because our argument applies to both innovation and technological convergence, we restrict attention to the one-country version of the model. We assume that H can be accumulated. To obtain a balanced-growth path where A_L, A_H, and H grow at the same rate, we modify the technology in the H-intensive sector by assuming that

$$Y_H = E_H \left[\int_0^{A_H} y_H(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}},$$

where $E_H \equiv (A_H)^{\frac{\beta\sigma-\beta-1}{\sigma-1}} H^{-\beta}$. For simplicity, we set $Z = 1$. Given symmetry and full employment, we obtain that $Y_H = H^{1-\beta} A_H^{\beta}$. Although this assumption on E_H may appear restrictive, we view it as a reduced-form representation of more realistic models that allow us to keep the analysis within the framework of the previous sections. For instance, a production function of the form $Y_H = \left(\frac{H}{A_H}\right)^{1-\beta} \int_0^{A_H} x_i^\alpha di$, where intermediates x_i are produced using the numeràire good, would produce very similar results [see, e.g., Dalgaard & Thustrup Kreiner (2001) for a similar specification of technology].

Total profits in the H sector are equal to a fraction $1/\tilde{\sigma}$ of revenue. Thus, profits per firm are $\pi_H = P_H(H/A_H)^{1-\beta}/\tilde{\sigma}$, whereas the wage per unit of human capital is $w_H = P_H\left(1-\frac{1}{\tilde{\sigma}}\right)\left(\frac{A_H}{H}\right)^\beta$. Along the balanced-growth path, the return from investing in innovation must be equal to the return from investing in human capital:

$$\frac{\pi_H}{\mu} = \frac{P_H}{\tilde{\sigma}\mu}\left(\frac{H}{A_H}\right)^{1-\beta} = r = \frac{P_H}{c_e}\left(1-\frac{1}{\tilde{\sigma}}\right)\left(\frac{A_H}{H}\right)^\beta = \frac{w_H}{c_e},$$

where c_e is the cost of education (acquiring one unit of H). This arbitrage condition pins down the balanced-growth ratio:

$$h \equiv \frac{H}{A_H} = \frac{\tilde{\sigma}-1}{c_e}. \tag{27}$$

Finally, as in the benchmark model, relative prices along the balanced-growth path are determined by the indifference condition between innovating in the two sectors:

$$\frac{\pi_H}{\pi_L} = \frac{P_H}{P_L}\frac{h^{1-\beta}}{L} = 1 \rightarrow \frac{P_H}{P_L} = \frac{L}{h^{1-\beta}}.$$

Using this, together with Equation 16, we can solve for the profit levels:

$$\pi_H = \frac{h^{1-\beta}}{\tilde{\sigma}}\left[1+\left(\frac{L}{h^{1-\beta}}\right)^{\varepsilon-1}\right]^{1/(\varepsilon-1)} \quad \text{and} \quad \pi_L = \frac{L}{\tilde{\sigma}}\left[1+\left(\frac{h^{1-\beta}}{L}\right)^{\varepsilon-1}\right]^{1/(\varepsilon-1)}.$$

Note that, for a given h, profits are a negative function of $\tilde{\sigma}$. Given that profits are a share $1/\tilde{\sigma}$ of revenues, a low $\tilde{\sigma}$ tends to increase monopoly rents. However, a high profit rate (low $\tilde{\sigma}$) compresses wages and thus the return to human capital. This has the effect of reducing the equilibrium level of h and hence of profits, because human capital is a complementary factor in production. This second effect implies that, when human capital can be accumulated, maximizing monopoly power is no longer the growth-maximizing policy. The growth-maximizing degree of competition depends on how important human capital is in production.

To see this, substitute Equation 27 into π_L, then use $r = \pi_L/\mu$ and Equation 2 to solve for the balanced-growth rate:

$$g = \frac{1}{\tilde{\sigma}\mu}\left[L^{\varepsilon-1}+\left(\frac{\tilde{\sigma}-1}{c_e}\right)^{(1-\beta)(\varepsilon-1)}\right]^{\frac{1}{\varepsilon-1}} - \rho.$$

What $\tilde{\sigma}$ maximizes g? To answer this question, consider the following cases:

1. If $\beta \rightarrow 1$ or $c_e \rightarrow \infty$ or L is very high, meaning that human capital is relatively unimportant or very scarce, then g is decreasing in competition, $\tilde{\sigma}$, as in the benchmark model. Thus, in developing countries where human capital accumulation is not an important engine of growth, some anticompetitive arrangements may be growth enhancing.

2. If instead $L \to 0$, then it is easy to show that g is maximized for $\tilde{\sigma} = 1/\beta$. That is, the more relevant human capital is in production (low β), the lower the growth-maximizing level of monopoly power.

More generally, the more countries' growth relies on human capital accumulation, the more they need competitive markets. For instance, in a poor economy in transition where human capital investments are not yet profitable and where growth relies entirely on the adoption of foreign technologies, protecting monopoly rents accelerates the convergence path. Once investment in human capital starts, however, monopoly rents that are too high can become a barrier to growth.

3.4. Distortions and Technology Misallocation

The analysis of Section 3.1 shows that, conditional on the cost of innovation, the decentralized equilibrium achieves an efficient direction of technological development in the North. This result hinges on the lack of distortions that are asymmetric across sectors. A recent literature has emphasized that resource misallocation may be an important source of productivity differences across countries (see, e.g., Parente et al. 2000, Hsieh & Klenow 2007). According to this view, even though high-productivity technologies are adopted by some firms in developing countries, these firms must compete on unequal grounds with local firms using less-productive technologies. This can be due to political linkages or other distortions. For instance, Song et al. (2008) constructed a model focusing on China where discrimination in the financial sector allows large state-owned firms to survive and compete for the allocation of labor and capital with private firms that are more technologically advanced.

This literature has generally ignored another channel through which discriminatory policies affect aggregate productivity, i.e., via its influence on the direction of technical progress. To study this effect, recall that in each sector the profit share is $1/\sigma$. Assume now that σ varies across sectors. Then, Equation 12 becomes

$$\frac{\pi_H}{\pi_L} = \frac{\sigma_L P_H Z H}{\sigma_H P_L L} = \frac{\sigma_L}{\sigma_H}\left(\frac{A_H}{A_L}\right)^{-\frac{1}{\varepsilon}}\left(\frac{ZH}{L}\right)^{1-\frac{1}{\varepsilon}}. \tag{28}$$

Consider the North first. Imposing the arbitrage condition that innovation be equally profitable in both sectors, $\frac{\pi_L}{r} = \frac{\pi_H}{r} = \mu$, and using Equation 28, we can solve for the equilibrium technology:

$$\frac{A_H^N}{A_L^N} = \left(\frac{\sigma_L^N}{\sigma_H^N}\right)^{\varepsilon}\left(\frac{ZH^N}{L^N}\right)^{\varepsilon-1}. \tag{29}$$

We have already seen that efficient technologies, equating the marginal product of innovation across sectors, require $\frac{A_H^N}{A_L^N} = \left(\frac{ZH^N}{L^N}\right)^{\varepsilon-1}$. Comparing this with Equation 29 shows that, so long as $\sigma_L \neq \sigma_H$, the efficiency condition is not satisfied, thereby implying a low aggregate productivity. The reason is that less-competitive sectors, where rents are more protected, attract too much innovation relative to the social optimum.

In the South, the efficiency condition for the direction of technology adoption is different from that in the North, as the marginal cost of technology adoption is endogenous and differs across the two sectors. In particular, using Equation 18, the marginal costs of technology adoption are

$$\frac{\partial(c_H A_H^S)}{\partial A_H^S} = c_H(1+\xi) \quad \text{and} \quad \frac{\partial(c_L A_L^S)}{\partial A_L^S} = c_L(1+\xi). \qquad (30\text{a, b})$$

Efficiency then requires $(\partial Y^S/\partial A_H^S)/(\partial Y^S/\partial A_L^S) = c_H/c_L$. Using Equations 30a, 30b, and 18, it is easy to show that the "efficient" A_H^S/A_L^S coincides with Equation 20, proving that the laissez-faire equilibrium achieves an efficient direction of technology adoption. Thus, as in the case of the North, any asymmetric markup policy leading to a deviation from Equation 20 would introduce distortions.[8] However, Equations 30a and 30b also make clear that the social marginal costs of adoption are higher than the private costs, c_L and c_H. The reason is that a firm adopting a new technology increases the cost of future adoption. This negative externality is ignored by decentralized firms and leads to an inefficient level of investment in technology adoption.

4. GLOBALIZATION, TECHNOLOGY, AND THE WEALTH OF NATIONS

The forces of globalization have always been seen as major determinants of the wealth of nations and of the world income distribution. Ever since David Ricardo first introduced the notion of comparative advantage, traditional trade theory has focused on understanding the sources of the gains from trade and their distribution for a given technology. However, to the extent to which technology is the prominent factor in determining cross-country income disparities, the focus of the literature has shifted to the role of trade as a vehicle of technology transfer. Moreover, trade and globalization can have first-order effects on the direction of technological change that can have significant effects on productivity differences. This section is devoted to reviewing some of the key mechanisms whereby globalization can alter cross-country income disparities through its impact on the direction of technological change.[9]

We consider two aspects of globalization: trade in goods and international labor mobility (migration). To study the former, we start by relaxing the assumption that final goods are not traded in the benchmark two-factor model of endogenous technical change. We then use the model to illustrate the effects of both North-South and North-North trade on technology and relative income. A key finding of this exercise is that, as argued by Acemoglu & Zilibotti (2001) and Epifani & Gancia (2008a), globalization can lead to skill-biased technical change that benefits disproportionately skill-abundant countries. Next, we study how trade, specialization, and migration affect the world income distribution in a single factor version of the model. We see that, once technology is endogenized, trade and migration can have both equalizing and unequalizing effects. In particular, as emphasized by Acemoglu & Ventura (2002), trade can promote technological convergence across countries through changes in relative prices (the terms of trade). International labor mobility, instead, can either amplify or dampen income and technology differences, depending on the value of the elasticity of substitution between goods.

[8]Epifani & Gancia (2008b) provide a more detailed analysis of asymmetries in market power as a source of inefficiency.

[9]For a more extensive treatment of the links between trade, innovation, and growth, see Grossman & Helpman (1991) and Ventura (2005).

4.1. North-South Trade and Skill-Biased Technical Change

We start by allowing for trade in final goods, Y_L and Y_H, in the North-South model of Section 2. This exercise, first discussed in Acemoglu & Zilibotti (2001), shows that trade leads to skill-biased technical change, which in turn can cause divergence in output per worker across countries. The intuition for this result is that trade with skill-scarce countries increases the price of skill-intensive goods, and this accelerates the introduction of skill-complement innovations. As a consequence, the skill premium increases. Given that the North is skill abundant, it benefits relatively more from such a change in factor prices.

To see this, suppose that a skill-abundant North and a skill-scarce South are integrated into a single market for Y_L and Y_H, which we call the World. In this scenario, the relative price of goods (Equation 10) is determined by world demand and supply:

$$\frac{P_H}{P_L} = \left[\frac{A_L L^W}{A_H Z H^W}\right]^{\frac{1}{\varepsilon}}, \tag{31}$$

where A_H and A_L are assumed to be identical everywhere (i.e., we consider the case of no barriers to technology adoption in Southern countries, $\xi \to \infty$), while H^W and L^W are the world endowments of skilled and unskilled workers, respectively. Suppose now that L^W increases, because unskilled-labor abundant countries like China and India join the world trading system. Not surprisingly, Equation 31 shows that the immediate effect, for a given technology, is a rise in the relative price of the skill-intensive good. But what happens once technology is allowed to adjust?

Recall from Equation 12 that the profitability of a skill-complement innovation depends both on the size of its market, which is proportional to the skill endowment of the North, and the price of the skill-intensive good. Given our assumption that intellectual property rights are not protected in the South, the increase in L^W due to globalization does not affect the market for innovations, because inventors continue to sell their blueprint in the North only. Hence, the increase in the relative price of skill-intensive goods unambiguously increases the relative profitability of skill-complement innovations:

$$\frac{\pi_H}{\pi_L} = \frac{P_H Z H^N}{P_L L^S} = \frac{ZH^N}{L^N}\left[\frac{A_L L^W}{A_H Z H^W}\right]^{1/\varepsilon}. \tag{32}$$

This change in the relative incentives to innovate leads to a transition with skill-biased technical change along which A_H/A_L grows, until a new balanced-growth path is reached. In the new long-run equilibrium, innovations must be equally profitable in both sectors ($\pi_H = \pi_L$). Imposing this condition, we obtain

$$\frac{A_H}{A_L} = \left(\frac{ZH^N}{L^N}\right)^{\varepsilon}\left(\frac{L^W}{ZH^W}\right), \tag{33}$$

which shows that an increase in L^W makes technology more skill biased.

The effect on the skill premium can be found from Equation 11:

$$\frac{w_H}{w_L} = \frac{P_H Z A_H}{P_L A_L} = \left(\frac{ZH^N}{L^N}\right)^{\varepsilon-1}\left(\frac{L^W}{H^W}\right), \tag{34}$$

where we have used Equations 31 and 33. Intuitively, in the new balanced-growth equilibrium, skilled workers earn a higher wage, not just because they are scarcer, but also because technologies are more skill biased.[10]

What are the implications of this technological adjustment for North-South income differences? Given that trade creates a single market for goods, it equalizes both commodity and factor prices across countries (note that full specialization is ruled out by the assumption that each sector employs a specific factor). Thus, the relative income (or productivity) per effective unit of labor of a Northern economy with endowments L^N and H^N and a Southern country with endowments L^S and H^S can be expressed as

$$\frac{y^N}{y^S} = \left(\frac{ZH^S + L^S}{ZH^N + L^N}\right)\left(\frac{L^N + \omega H^N}{L^S + \omega H^S}\right),$$

where $\omega \equiv w_H/w_S$ is the skill premium. A simple derivation shows that a higher skill premium increases y^N/y^S so long as the North is skill abundant:

$$\frac{\partial(y^N/y^S)}{\partial\omega} > 0 \quad \text{if} \quad \frac{H^N}{L^N} > \frac{H^S}{L^S}. \tag{35}$$

Intuitively, a country benefits relatively more from an increase in the reward of its abundant factor. We therefore conclude that skill-biased technical change induced by the increase in L^W (globalization) amplifies the income gap between Northern and Southern economies.

4.2. Trade, Market Size, and Inequality

We now show that even trade integration between similar countries can have analogous effects. As argued in Epifani & Gancia (2008a), trade can raise the skill premium, and, hence, income differences between skill-abundant and skill-scarce economies, because skill-intensive activities are more complex and benefit more from the diversification opportunities offered by larger markets.[11] The point is made more easily in a static version of the model in Section 2.[12]

First, we generalize the sectorial production functions to allow for asymmetries in the elasticity of substitution across inputs:

$$Y_L = \left[\int_0^{A_L} y_L(i)^{\frac{\sigma(L)-1}{\sigma(L)}} di\right]^{\frac{\sigma(L)}{\sigma(L)-1}} \quad \text{and} \quad Y_H = \left[\int_0^{A_H} y_H(i)^{\frac{\sigma(H)-1}{\sigma(H)}} di\right]^{\frac{\sigma(H)}{\sigma(H)-1}}.$$

We make the crucial assumption that $\sigma(L) > \sigma(H)$, meaning that the benefit from having a wider array of intermediate inputs is stronger in the skill-intensive sector. This assumption

[10]Comparing Equation 34 to Equation 11, we can immediately verify that the endogenous reaction of technology amplifies the effect of North-South trade on the skill premium. This point is made in Acemoglu (2003), where the implications for skill premia across countries are studied extensively.

[11]Matsuyama (2007) argued instead that the act of exporting requires more skilled labor, and obtained similar results.

[12]The reason why we use a static approach is that the model in this section would feature unbalanced growth, with one sector disappearing asymptotically. In the interest of simplicity, the static version allows us to abstract from such a complication. For the interested reader, a similar model of unbalanced growth is built in Acemoglu & Guerrieri (2008).

appears reasonable, as skill-intensive goods are typically more complex and highly differentiated (see Epifani & Gancia 2006, 2008a).

Second, given that we are interested in North-North trade, we assume that intellectual property rights are fully enforced everywhere and we allow for trade in the intermediates, $y_L(i)$ and $y_H(i)$. As in the previous sections, each intermediate input is produced by a monopolist and the pricing rule (Equation 7) still applies.[13] Given that the model is static, we now solve for the state of technology, A_L and A_H, by introducing a fixed cost of μ units of labor that each firm must pay. We can still think of the fixed cost as the innovation costs required to design a new variety. Free entry implies that the number of varieties in each sector will increase until the operating profits made by each firm is exactly equal to the fixed cost, $p_z y_z/\sigma(z) = \mu w_z$, for $z \in \{L, H\}$. Together with the pricing Equation 7, this condition pins down uniquely the scale of production of each firm, $y_L = \mu[\sigma(L) - 1]$ and $y_H = \mu Z[\sigma(H) - 1]$. Imposing labor market clearing for the world economy $[A_H(y_H/Z + \mu) = H^W$ and $A_L(y_L + \mu) = L^W]$ and using y_z yield the number of firms per sector:

$$A_H = \frac{H^W}{\mu\sigma(H)} \quad \text{and} \quad A_L = \frac{L^W}{\mu\sigma(L)}. \tag{36}$$

Notice that, because firm size is constant, the number of varieties in each sector is proportional to the world endowment of the relevant factor.

To solve for the skill premium, we observe that the wage bill is now equal to the revenue of a sector because profits are used to cover the fixed costs, which are now in units of labor. Thus,

$$\frac{w_H H^W}{w_L L^W} = \frac{P_H Y_H}{P_L Y_L} = \left(\frac{Y_H}{Y_L}\right)^{\frac{\varepsilon-1}{\varepsilon}}, \tag{37}$$

where we have used Equation 4. Using y_H, y_L, and Equation 36 to solve for Y_H and Y_L and rearranging Equation 37 yield

$$\frac{w_H}{w_L} = \omega\left(H^W, L^W\right) = \kappa^{\frac{\varepsilon-1}{\varepsilon}}\left(L^W\right)^{\frac{\sigma(L)-\varepsilon}{\varepsilon[\sigma(L)-1]}}\left(H^W\right)^{-\frac{\sigma(H)-\varepsilon}{\varepsilon[\sigma(H)-1]}},$$

where κ is an unimportant constant.

We are now in the position to study the effects of trade between similar countries. In particular, suppose that globalization induces an enlargement of the world economy that leaves H^W/L^W unchanged (yet, individual countries i may differ in H^i/L^i). This will be the case if two sets of countries with similar aggregate endowments, say North America and Europe, integrate their markets. To see what happens to the skill premium, notice that this experiment is isomorphic to multiplying the endowments of both H^W and L^W by a common factor $\lambda > 1$. The elasticity of the skill premium to such a change in scale is easily computed as

$$\frac{\partial\omega(\lambda H, \lambda L)}{\partial\lambda}\frac{\lambda}{\omega} = \frac{(\varepsilon-1)[\sigma(L) - \sigma(H)]}{\varepsilon[\sigma(L) - 1][\sigma(H) - 1]} > 0, \tag{38}$$

where the positive sign follows from the assumptions $\varepsilon > 1$ and $\sigma(L) > \sigma(H)$. Thus, an increase in market size raises the skill premium. The intuition for this result is simple: Trade

[13]Note that, also in this model, trade equalizes factor prices, so that wages are identical in all the trading countries.

expands the range of available intermediate inputs, thereby increasing productivity. In relative terms, however, output grows more in the skill-intensive sector, where input variety is more valuable ($\sigma(L) > \sigma(H)$). With an elasticity of substitution in consumption greater than one ($\varepsilon > 1$), the higher relative productivity in the skill-intensive sector increases its share of total expenditure and therefore also the relative wage of skilled workers.

The implications for cross-country income disparities depend crucially on which countries we consider. If we compare newly integrated countries that differ in size, globalization has an equalizing effect. The reason is that, being part of the same world market, small countries now enjoy the same scale economies as do large countries. However, if we consider countries differing in skill abundance that were already integrated before the market enlargement (e.g., inequality between European countries), the globalization shock has an unequalizing effect. This follows from the fact that the market size expansion increases the skill premium, which is more beneficial for skill-abundant countries.

4.3. Specialization, Migration, and Technology Differences

The models discussed so far share the property that trade equalizes factor prices. Yet, even a cursory look at international data suggests that factor rewards may be far from equal. It is thus important to study the impact of trade on technology when we deviate from factor price equalization. We do this now by analyzing a one-factor version of the model in which we break factor price equalization by assuming that each country produces a single differentiated good. We show that, when countries are specialized, trade may prevent income differences from exploding, even in the absence of technological spillovers. Interestingly, the lack of factor price equalization has the additional implication that workers have incentives to move toward high-wage countries. By exploring this possibility, we also briefly discuss how migration may shape technology and the wealth of nations. Perhaps surprisingly, we see that migration can be either an equalizing or unequalizing force.

Assume that there is only one type of labor (L) and that the world economy is populated by two countries only, North and South, producing differentiated goods:

$$Y = \left[Y_N^{\frac{\varepsilon-1}{\varepsilon}} + Y_S^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}},$$

where Y_N is the final good produced in the North and Y_S is the one produced in the South.[14] Sectorial production functions are

$$Y_S = E_S \left[\int_0^{A_S} y_S(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}} \quad \text{and} \quad Y_N = E_N \left[\int_0^{A_N} y_N(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}},$$

where $E_S \equiv (A_S)^{\frac{\sigma-2}{\sigma-1}}$ ($E_N \equiv (A_N)^{\frac{\sigma-2}{\sigma-1}}$). Notice that A_N and A_S now capture the state of technology in the North and South, respectively. Thus, the two countries benefit from different technologies that evolve independently. The rest of the model, however, is essentially identical to the benchmark case.

[14]Equivalently, one can assume $L^N = 0$ and $H^S = 0$. In both cases, countries produce differentiated goods, as in the Armington model. Complete specialization can also be derived as the equilibrium outcome of more general models. For example, Gancia & Bonfiglioli (2008) obtained specialization by adding Ricardian comparative advantage in a model of endogenous technical change with a continuum of goods.

Given that there is only one factor, per capita income differences are now summarized by the relative wage, w_N/w_S. To find it, we can use Equation 11 with the appropriate change of notation:

$$\frac{w_N}{w_S} = \frac{P_H Y_H L_S}{P_S Y_S L_N} = \left[\frac{A_N}{A_S}\right]^{1-1/\varepsilon} \left[\frac{L_S}{L_N}\right]^{1/\varepsilon}, \tag{39}$$

where L_N and L_S are the labor endowments of the North and South, respectively. It is instructive to compare this with the relative wage in autarky, where $P_N = P_S = 1$:

$$\frac{w_N}{w_S} = \frac{A_N}{A_S}.$$

Note first that, so long as $\varepsilon > 1$, trade tends to reduce the effect of technological differences, A_N/A_S, on relative income. The intuition for this result is that terms of trade movements (P_N/P_S) create productivity spillovers whereby high productivity in one country also benefits the trading partner: After trade opening, demand for the good produced by the low-income, low-productivity country increases, leading to a favorable change in the relative price P_N/P_S. Second, under free trade, small countries tend to be relatively richer, because the price of their products is relatively high. This result, which is typical in trade theory, may no longer hold when technology is endogenous.

To solve for the equilibrium productivity gap, A_N/A_S, consider the R&D sector. We assume that the cost of designing a new intermediate input is μ_N for the North and μ_S for the South, with $\mu_N < \mu_S$. This captures the higher R&D potential of the North. A first important result is that trade based on specialization prevents A_N/A_S from exploding. The intuition is that an increase in A_N/A_S leads to a fall in the relative price of Northern products P_N/P_S, and this discourages further innovation in the North. In other words, for the same reason why the skill-bias A_H/A_L (in Section 2) settles to an equilibrium level, the productivity gap here converges to a constant value. To find it, we impose the familiar R&D arbitrage condition, $\pi_N/\mu_N = r = \pi_S/\mu_S$. Analogous to Equation 13, this condition yields

$$\frac{A_N}{A_S} = \left(\frac{\mu_S}{\mu_N}\right)^{\varepsilon} \left(\frac{L_N}{L_S}\right)^{\varepsilon-1}, \tag{40}$$

which, together with Equation 39, implies

$$\frac{w_N}{w_S} = \left(\frac{\mu_S}{\mu_N}\right)^{\varepsilon-1} \left(\frac{L_N}{L_S}\right)^{\varepsilon-2}. \tag{41}$$

With free trade, countries with a better R&D technology (low μ) are relatively richer, but the world income distribution is stable in the sense that both countries grow at the same rate.

On the contrary, in autarky the growth rate of each country is determined independently. Using Equation 17 with the appropriate change of notation we get

$$g_N = \frac{L_N}{\mu_N \sigma} - \rho \quad \text{and} \quad g_S = \frac{L_S}{\mu_S \sigma} - \rho.$$

Thus, so long as $L_N/\mu_N \neq L_S/\mu_S$, countries in autarky are on a divergent path. This result, that trade helps to sustain a stable income distribution through changes in relative prices, was first emphasized by Acemoglu & Ventura (2002) in a model of growth through capital accumulation. Our analysis extends their finding to a model with technological change.[15]

A second interesting result concerns the effect of population size on income differences. Whereas Equation 39 shows that small countries tend to be richer because they enjoy high export prices, Equation 41 suggests that the effect of country size is more complex once technology is endogenous. The new mechanism at work is that larger markets attract more innovation (see Equation 40). When $\varepsilon > 2$, the market size effect dominates the adverse relative price effect, so that larger countries are now wealthier. This finding has important implications for the impact of migration on income differences. To see this, assume that workers move toward the country with higher wages, but that mobility is imperfect, so that some workers are always left in both nations. For example, this could be the case if workers have heterogeneous mobility costs. In this scenario, the effect of migration depends crucially on the value of ε. If $\varepsilon < 2$, migration is an equalizing force: Workers move to the country where they are scarce, which tends to reduce wage differentials. On the contrary, if $\varepsilon > 2$, the endogenous reaction of technology implies that migration increases the relative wage of the recipient country. It follows that workers move to the country where they are abundant. In this case, migration is an unequalizing force that can make a symmetric equilibrium unstable and give rise to multiple equilibria: As workers move to one country, the local wage increases, thereby attracting more workers. Matsuyama (1995, 2004), Krugman & Venables (1995), and others have proposed models of this type, which emphasize how globalization can generate a cumulative process of uneven development.

5. CONCLUSIONS

Technology is the most important element in explaining cross-country income differences. In this paper, we illustrate how theories of directed technological change and adoption can help explain why some countries are so much more productive than others. Rather than providing an exhaustive survey, we opt for building a workhorse model that is rich enough to encompass some, albeit certainly not all, of the most credited theories of TFP differences. In particular, we discuss three possible explanations: technological inappropriateness, barriers to technology adoption, and technological inefficiencies due to misallocations of resources within countries. We also study how various aspects of globalization can affect technical change and productivity differences.

Despite important advances made in the literature in recent years, several questions remain open. Among them, two issues are particularly relevant: First, our focus on technology has led us to abstract almost entirely from other sources of growth. Integrating physical and human capital accumulation into models of endogenous technical progress and studying their interaction in explaining productivity differences seem a fruitful avenue for future research. Second, one of the most important remaining challenges is to quantify the empirical merits of the complementary mechanisms illustrated in this paper. We hope that the unified theoretical framework that we have proposed can prove useful to make progress in these crucial tasks.

[15]The result that trade opening generates convergence depends on the absence of technology transfer in autarky. Gancia & Bonfiglioli (2008) showed that, when the South can copy the technology of the North, trade can lead to divergence: As countries specialize in different sectors, R&D becomes more concentrated on the goods produced by the North. Thus, trade-induced specialization can shift the direction of technical progress in favor of rich economies.

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