Learning by Trading and the Returns to Human Capital in Developing Countries

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Recent evidence shows that the returns to labor and the skill premium both increase in developing countries after trade liberalization, despite the low skill content of their exports. The author explains this apparent puzzle by arguing that trade increases technology transfers from industrial to developing countries and that the transfer technology is biased in favor of skilled labor. The relative demand for skilled labor increases during the transition following liberalization, and so the gains enjoyed by skilled labor are temporary, even in the absence of supply responses. The gains become longer lasting when the transferred technology is also skill-biased.

Several recent studies have found that trade liberalization in developing countries is often associated with a large increase in the returns to labor and with an increase in wage inequality. The increase in the returns to labor should come as no surprise: labor should receive at least some of the benefits from trade. The increased differential between the wages of skilled and unskilled labor, however, is more puzzling. According to the conventional and largely substantiated view of North-South trade, the industrial "North" exports high-quality goods to the developing "South," which exports primary products or lower-technology goods to the North. Trade liberalization in a developing economy should therefore be associated with an increase in the relative demand for unskilled labor and a narrowing of wage differentials.

This article discusses a channel through which the effects of trade liberalization are transmitted to the labor market and explains why both labor returns and wage inequality can increase after liberalization. According to this view, developing economies (the South) advance by learning from the technology of industrial economies (the North). Learning is faster when trade

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links the economies of North and South, so trade liberalization in a developing country leads to more technology transfers from the North to the South. Technology transfers can take place either through the production in the South of capital goods that are already in use in the North or through the importation of capital goods from the North. Results are independent of the method of technology transfer.

The key assumption is that the transfer of technology requires skilled labor. When a developing economy liberalizes trade, it experiences more technology transfers than before. Learning about the new technology and putting it to use in the South increase the demand for skilled labor, whose wages rise over and above any rise accruing to all kinds of labor from more production. But as the South learns the new technology, the pace of transfer slows, and the benefits to labor that remain are derived entirely from the production technology. If the transferred production technology is neutral, the relative advantage that skilled labor enjoyed during the learning process ceases. Thus, with a neutral production technology, a temporary increase in the relative demand for skilled labor causes the relative advantage of skilled over unskilled labor. With a skill-biased transferred production technology, the relative increase in the demand for skilled labor can be permanent.

Some recent literature supports the idea that more trade brings about more technology transfers. Coe, Helpman, and Hoffmaister (1995) find that the research and development (R&D) spillovers from the industrial countries to the developing countries are substantial. Total factor productivity in developing countries was positively associated with R&D expenditure abroad. More important here, however, the spillovers were linked to trade flows between the industrial and developing countries. The spillover from an industrial country to a developing country was proportional to the share of the industrial country's imports in the developing country's gross domestic product.

The empirical papers cited in section I, in particular Robbins (1994, 1995b) and Hanson and Harrison (1994), identify technology transfers as the most likely reason for the increase in wage inequality. Also, Wood (1995), in a recent evaluation of the widening of wage differentials, concludes that the transfer of technology is only one of two plausible explanations for the widening (the other one being the increase in the supply of low-technology goods in world markets because of the expansion of Chinese exports).

Section I discusses the recent evidence and explains why the widening of differentials is a puzzle in light of the recent widening of wage differentials in the labor markets of the industrial world. Section II explains the main idea of learning and technology transfers. Section III formalizes the learning process. Section IV describes and solves the full model. Section V considers the adjustments that follow trade liberalization and presents the main findings of this article. Section VI briefly considers other factors that might play a role in the relation between trade liberalization and wage differentials. Section VII contains some concluding remarks.

I. The Returns to Human Capital after Trade Liberalization

The most convincing evidence supporting the widening of wage differentials after trade liberalization comes from middle-income countries in Latin America and East Asia. In each case reviewed here, other reforms took place alongside trade liberalization, so other factors might have caused the widening of differentials. But in all cases the widening of differentials followed a large increase in trade flows. As the number of cases where trade liberalization and widening of differentials are observed concurrently increases, the link between the two will gain more support.

Robbins (1994, 1995b) examines data for Chile and Colombia. For Chile, he examines household survey data for 1957–92 to see if there were any marked changes in the earnings structure after trade liberalization took place beginning in 1975. He finds that although the skill composition of imports exceeded that of exports, skilled labor did not suffer a relative drop in earnings after trade liberalization. The returns to skilled labor increased by more than conventional trade theory would predict and also by more than changes in labor supply would predict. He concludes that the most likely explanation for the observed changes was the importation of capital that was complementary to skilled labor. Robbins finds a similar situation in Colombia. Using household data for Bogotá for 1976–89, he examines the response of wage differentials to the large rise in exports after the 1984 devaluation. He finds that wage inequality increased and attributes this to changes in the composition of the demand for labor that are induced by trade.

Pessino (1995) finds similar results for Argentina after 1990, also using household data. However, trade does not play an important part in her analysis, so it is not clear whether the widening of differentials could be attributed to trade. In more recent work, Robbins (1995a) examines household data for Argentina, Costa Rica, the Philippines, and Taiwan (China) and also finds similar results. Trade liberalization increased the relative demand for skilled labor in virtually all cases.

Hanson and Harrison (1994) examine plant-level data for 1984–90 in Mexico, where trade liberalization took place beginning in 1985. They find that wage inequality increased after liberalization, despite the relatively low skill content of Mexico's exports. They conclude that the most likely cause of the rise in wage inequality was the importation of skill-biased technology from abroad.

Tan and Batra (1995) present another set of related data. They do not explicitly look at the implications of trade liberalization; rather they calculate the wage premium paid by firms that engaged in R&D, worker training, and export activities in Colombia, Mexico, and Taiwan (China). Using firm-level data and controlling for other firm characteristics, they find that firms that engaged in technology-advancing activities paid all their workers a premium over and above the wages paid by other firms but that the premium paid to skilled workers far exceeded that paid to unskilled workers. Although the direct contribution of exports was less important than that of R&D and worker training, Tan and

Batra claim that trade liberalization increased the R&D activities of firms and the demand for skilled labor. They do not explore the links between trade involvement and technology-advancing activities at the level of the firm.

The experience of developing countries with wage inequality reflects the experience of industrial countries, which started somewhat earlier. A well-documented fact is that beginning sometime in the mid-1970s, the industrial world experienced a negative shock at the unskilled end of the labor market, which intensified in the 1980s. Despite growth in the economy overall, the wage and employment prospects of unskilled labor suffered relative to those of skilled labor and in some cases absolutely as well. The shock in labor markets of industrial countries did not have the same implications everywhere. It caused real wage reductions for unskilled labor in the United States and high unemployment in the major European economies, but what is more important here is the source of the shock. One view claims that trade with low-wage economies caused the shock in industrial countries. If this is true, however, the relative wages of unskilled labor in developing economies that opened up to trade would have *risen*, not fallen. The data summarized in this section contradict this view.[1] In another view, skill-biased technological progress caused the shock in industrial countries. Recent technological advances, such as computerization, require more skilled labor than the technologies they are replacing. As new investment crowds out unskilled labor, its wages relative to those of skilled labor fall.

The technology transfers modeled in this article cause more wage inequality in developing countries because the *transfer* technology is biased in favor of skilled labor. If the transferred production technology is also biased in favor of skilled labor, the inequality is reinforced. The skill-biased technology that comes into operation because of trade causes more wage inequality. So the implication for the debate of "trade versus technology" is that neither trade nor technology alone causes inequality; rather both act together. My approach does not contradict the existence of Hecksher-Ohlin effects on wage differentials. Instead, it disputes the view that the Hecksher-Ohlin effects on wages dominate in the transition from steady state in a semiclosed economy to steady state in an open one.

II. Trade and Learning

In this section, I follow recent literature and assume that technological improvements result from activities that use skilled labor as an input. I refer to these activities as R&D (or, when the reference is explicitly to developing countries, as imitation). I interpret R&D broadly to include all activities that lead to new discoveries, as well as imitation and assimilation activities that lead to the adoption of products or techniques known elsewhere.

1. Wood (1995), who in earlier work claimed that the widening of wage differentials in the industrial North was associated with trade, claims that the widening of wage differentials associated with trade growth in developing countries is a recent phenomenon. In the early 1970s there was some evidence that wage differentials narrowed in southern European countries that liberalized trade.

A firm producing with the most advanced known technology can improve its productivity only by undertaking R&D aimed at new discovery. This is likely to be the cause of technological change in the more advanced countries. But producers in less advanced countries are not likely to be using the most advanced known technology. For them, it is cheaper to copy other firms' technologies than to attempt to make new discoveries. Imitation has a higher probability of success than R&D aimed at an original discovery: learning from the mistakes of others is cheaper than learning from one's own. (See Tan and Batra 1995 for a summary of some case studies that find that technological progress in developing countries is achieved through imitation.) Given the low-wage advantage that developing countries enjoy, if a firm in a developing country succeeds in imitating a production process implemented by firms in a richer trading partner, it is also likely to succeed in selling its product to the more advanced country.

Trade induces more imitation in a developing country by giving its producers several types of incentives to learn fast the technology of the North. First, trade between two countries exposes producers in each to the capital equipment and techniques used in the other. Trade increases the probability that imitation in the South will succeed because the traded goods embody the transfer of information about new products and techniques. Nelson (1970) makes a related distinction between "experience" and "inspection" goods. In general, producers in developing countries might be aware that producers in other countries use superior techniques or that producers elsewhere produce better varieties of goods. But producers in developing countries that are exposed to the superior goods through trade are more likely to imitate those products and techniques.

Second, even with a given probability of successful imitation, the competition from trading partners increases the firm's incentives to innovate. The trading partners enter the market with superior goods, which can drive domestically produced goods out of the market. This occurs regardless of whether firms in the South move from monopolistic to competitive conditions, which may or may not increase R&D activities. Producers in the South have more incentives to imitate the superior technology of the North, in order to be able to compete with newcomers, retain their domestic market share, and export to markets in the North.

Third, after trade liberalization, the developing country can import more capital and other intermediate goods from the North. In this case, the R&D technology should be interpreted as a learning-how-to-use technology, rather than as a learning-how-to-produce technology. This interpretation is consistent with the plausible assumption that skilled labor is needed to show the rest of the workforce how to put imported capital goods into productive use.

These ideas imply that when a developing country liberalizes trade, it devotes more resources to imitating the technology of its trading partners and participates in more technological transfers. But how well does the available international R&D data for developing countries measure this broad concept of R&D? It is a well-documented fact that R&D activities are heavily concentrated in a few industrial countries and that developing countries undertake very few of them (see, for example, Coe and Helpman 1995 and Coe, Helpman, and Hoffmaister 1995). Nevertheless, a first potential test of the ideas presented here is whether trade liberalization is associated with more R&D, however narrow its empirical definition. In an empirical analysis, imitation in the context discussed here should be interpreted broadly to include all new production activities in the South that are influenced by the exposure of its economy to that of the North.

III. A Formalization of the Learning Technology

In this section, I formalize the idea of a technological transfer by assuming that the speed of learning depends on the difference between the knowledge of producers in a country and the knowledge of its trading partners. Trade liberalization leads to more technology transfers because it enlarges the set of technological innovations that become known to producers in developing countries.

I measure the state of technology by the number of capital varieties in existence (Romer 1990). Capital varieties are differentiated but not necessarily superior to one another. Here, I look for a symmetric equilibrium with the same quantity of each known variety of capital. More capital varieties lead to more total factor productivity because each variety has diminishing returns to scale. This assumption gives the same results for the returns to human capital as the alternative assumption of improvements in the quality of capital goods, which provides another appealing way of measuring the state of technology (Grossman and Helpman 1991b).

Borrowing ideas from Grossman and Helpman (1991a), I assume that the level of technology in the North improves through original expensive research and that a lower level of technology in the South improves through cheaper imitation of the North's technology. To simplify the analysis, I assume that the level of technology in the North is independent of the activities of firms in the South. In addition, because the economy of the North is not of interest in this analysis, I simplify further by assuming that the technology of the North improves at exogenous rate g.

In the South, producers engage in R&D to discover ways either to imitate the innovations used elsewhere or to learn how to use imported machinery. In order to write an equation for the learning technology, I denote the number of varieties of known capital goods in the North by A. Of these, the South already uses several varieties, B. B can never exceed A, and normally it is strictly less than A. Following Rivera-Batiz and Romer (1991), I assume that the production technology uses three factors of production—unskilled labor, denoted L; human capital (or skill), denoted H; and all the varieties of the capital goods known in the economy. In contrast, the more skill-intensive imitation technology activity uses only human capital as an input.

The number of varieties of capital goods increases according to the learning technology, which depends on the input of human capital and on the number of varieties of capital at home and abroad. I write the learning technology in the South as

$$\dot{B} = \lambda H_B \Phi(B, A - B) \tag{1}$$

where B has already been defined as the number of varieties of capital goods already copied (the stock of knowledge in the developing economy), λ is a constant, H_B is the stock of human capital employed in the imitation process, and $\Phi(B, A - B)$ is a homogeneous function, increasing in both its arguments, and concave.

The function $\Phi(.)$ is the main new element in the model and the key to the results. Two features are important. First, imitating the technology of the North is a skill-biased activity in that it uses skilled labor (human capital) but not unskilled labor. The fact that no unskilled labor or capital is used in imitation is a simplification. What is important is that, relative to the production technology, more human capital and less unskilled labor are used in R&D.

Second, the function $\Phi(.)$ captures the idea that learning is easier when there is already a lot of knowledge and also when there is more knowledge to acquire. Thus, holding constant the stock of knowledge in the developing country, exposure to more knowledge abroad raises the speed of learning at home for given inputs into R&D. For convenience, I assume that at $A = B$; that is, when there are no more capital varieties to be copied, $\Phi = B$. This and the other technical assumptions on $\Phi(.)$ imply that

$$\Phi(B, A - B) = \Phi(1, A/B - 1)\, B \equiv \phi(A/B)B. \tag{2}$$

$\phi(.)$ increases in its argument at a decreasing rate and satisfies $\phi(1) = 1$.

Using equation 2, equation 1 becomes

$$\frac{\dot{B}}{B} = \lambda\phi(A/B)H_B. \tag{3}$$

Equation 3 gives the rate of technological progress in the economy of the developing country, which, with fixed labor supply, in the steady state is also the rate of growth of aggregate output. The function $\phi(A/B)$ represents the advantage of the imitator over the inventor. If $A = B$, $\phi = 1$ and equation 3 can be interpreted as a process of discovery. But with $A > B$, which will always be the case if the economy of the South is less technologically advanced than the economy of the North, $\phi > 1$ and imitation is cheaper (that is, more productive for a given human capital input) than original discovery.

IV. GROWTH EQUILIBRIUM

Equilibrium is described by the evolution of capital varieties, B, given an arbitrary initial value, market-clearing prices for the three factors of production, and the allocation of human capital between production and imitation. I assume a constant supply of each type of labor in order to isolate the effects of trade liberalization that work through the demand for labor. (The implications of variable supply are discussed briefly in section VI.) Factors are fully employed, and the allocation of human capital between its two uses is at the point where marginal returns in each use are equal.

The consumption side of the model is not specified, so the model does not need to include trade flows. I assume instead that output is divided between final consumption and capital and obtain equilibrium output and capital stock from the market-clearing conditions in factor markets. In order to do that, I next specify the production technology.

The production technology uses the three factors of production—the known varieties of capital, human capital, and unskilled labor—to produce output that is subsequently sold in competitive markets at a unit price (the numeraire). To avoid integer problems, suppose that the capital varieties lie on a continuous line and that the representative production unit employs $x(i)$ units of each capital variety i. The production function is

$$Y = H_Y^{\alpha} L^{\beta} \int_0^B x(i)^{1-\alpha-\beta} di \tag{4}$$

where Y denotes output, H_Y denotes the human capital used in the production of goods, L denotes the unskilled labor input, and α and β are positive parameters that sum to a number less than 1.

Aggregate output Y is divided between consumption and investment in new capital goods. For exposition purposes, suppose that the property rights to each variety of capital are owned by a patent holder or by the single importer who first succeeded in imitating (or importing and adapting) the variety. The patent holder, a monopolist, then licenses this product to a manufacturer, who supplies it at a unit price to the patent holder. The patent holder decides how much of the capital variety to order on the basis of the price for selling it back to manufacturers. That price, the price of the capital variety, is denoted $p(i)$. Assuming for simplicity that capital fully depreciates after one period, $p(i)$ equals the static marginal product of $x(i)$,

$$p(i) = \frac{\partial Y}{\partial x(i)} = (1-\alpha-\beta) H_Y^{\alpha} L^{\beta} x(i)^{-\alpha-\beta}. \tag{5}$$

Because the patent holder has to pay one unit price for each unit of capital goods, the per period profit accruing from the sale of the capital variety is $p(i)x(i) - x(i)$. The monopolist chooses the quantity of $x(i)$ supplied to maximize profit, so the equilibrium quantity of each capital variety supplied maximizes the expression

$$p(i)x(i) - x(i) = (1-\alpha-\beta)H_Y^{\alpha}L^{\beta}x(i)^{1-\alpha-\beta} - x(i). \tag{6}$$

The maximization condition is

$$(1-\alpha-\beta)^2 H_Y^{\alpha}L^{\beta}x(i)^{-\alpha-\beta} - 1 = 0. \tag{7}$$

Equation 7 gives the equilibrium condition in the market for each capital variety i, given the inputs of the other factors of production.

Substitution of $x(i)$ from equation 7 into equation 5 gives the monopolist's price for the capital good:

$$p(i) = \frac{1}{1-\alpha-\beta} > 1. \tag{8}$$

The difference between the equilibrium price and the cost of capital, $p(i) - 1$, is the monopolist's profit from owning the patent for the capital variety.

Because the $x(i)$ that solves equation 7 and the $p(i)$ in equation 8 are independent of i, I can drop i and write x for the equilibrium quantity of each capital variety and p for the equilibrium price. It follows that the aggregate capital input into the production technology, the integral of all B varieties of $x(i)$, is simply Bx. The production function then becomes

$$Y = BH_Y^{\alpha}L^{\beta}x^{1-\alpha-\beta}. \tag{9}$$

Equilibrium in the market for unskilled labor, given the fixed labor supply L, gives the solution for the unskilled wage. The marginal product of labor is obtained from equation 9 and is equated to the unskilled wage, w_L, to give

$$\beta BH_Y^{\alpha}L^{\beta-1}x^{1-\alpha-\beta} = w_L. \tag{10}$$

The allocation of human capital between the two activities—imitation and production—takes place such that the rewards to human capital in each are equalized. The rewards to human capital in production are equal to the marginal product of human capital, $\partial Y / \partial H_Y$. In the imitation technology, the profit from employing one more unit of human capital is the present discounted value of profit from the discovery, given by $[(px - x)\lambda\phi(A/B)B]/r$ for a constant discount rate r. Equating this expression with the marginal product of human capital in the production technology and making use of equation 7 to substitute out x give the solution for H_Y:

$$H_Y = \frac{\alpha r}{(\alpha+\beta)(1-\alpha-\beta)\lambda\phi(A/B)}. \tag{11}$$

The only remaining equation for full characterization of the solution is the one for the wages of skilled labor. This is obtained by differentiating the production function with respect to human capital and equating the result to the wage rate:

$$\alpha B H_Y^{\alpha-1} L^{\beta} x^{1-\alpha-\beta} = w_H. \tag{12}$$

Equations 3, 7, 10, 11, and 12 are uniquely solved for the paths of B, x, H_Y, w_L, and w_H, given an initial value for B, labor supply L, and human capital supply H, where $H_B = H - H_Y$. The path of output can then be obtained from equation 9.

The steady state of the system is found by looking for a steady state for B. Because $\phi(.)$ is not a linear function, if A is growing at exogenous rate g, equation 3 implies that in the steady state B must grow at the same rate. Therefore, in the long run, the economies of both North and South must grow at the same rate (a result known since Krugman's 1979 pioneering paper), though obviously their income levels might differ. Substitution of the steady-state growth rate into equation 3 gives the steady-state relation between the level and rate of growth of technology and human capital:

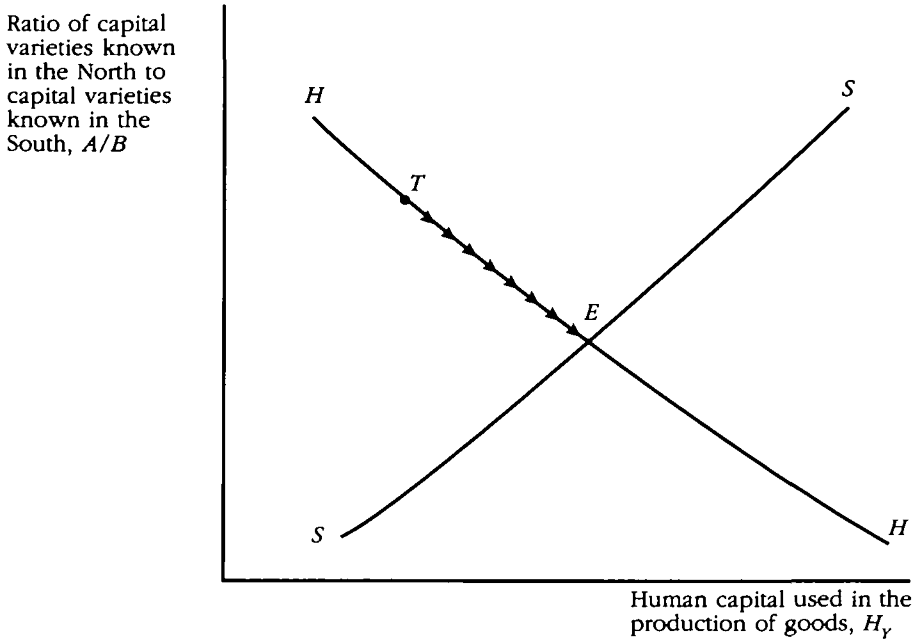
$$\lambda\phi(A/B)(H - H_Y) - g = 0. \tag{13}$$

I illustrate the solution with a simple diagram that is useful in the analysis of trade liberalization (section V). Equations 13 and 11 give unique solutions for H_Y and A/B, as illustrated in figure 1. The line HH is a representation of equation 11 and shows the condition under which the returns to human capital are equalized in the two activities in which human capital takes part. HH has a negative slope because a higher A/B makes imitation more rewarding, so the input of human capital into production falls. The line SS shows the steady-state condition of equal growth rates in the two economies (equation 13). SS slopes up because, for a given growth rate abroad, a higher A/B increases the domestic growth rate because it facilitates imitation. To maintain a constant growth rate requires switching human capital from imitation to production.

Under the simplifying assumption that human capital is perfectly (and instantaneously) mobile between production and imitation, the economy is always at some point on the HH line. That point is determined by the value of the exogenous variable A and the value of the predetermined variable B. Because equation 3 is a stable differential equation in B, the economy is always tending to the intersection of the two curves in figure 1 along HH, as shown by the arrows (ignore point T for the moment).

With knowledge of B and H_Y from figure 1, it is possible to obtain a unique solution for the path of x from equation 7, a unique solution for the path of output from equation 9, and unique solutions for the paths of wages from equations 10 and 12.

Figure 1. *Equilibrium with Technological Transfers*



V. TRADE LIBERALIZATION

I now consider the influence of trade on the relative returns to skilled and unskilled labor. I first solve explicitly for the relative returns to skilled and unskilled labor by dividing equation 12 by equation 10 to get

$$\frac{w_H}{w_L} = \frac{\alpha}{\beta}\frac{L}{H_Y}. \tag{14}$$

Relative returns are independent of capital (or the state of technology) because, according to the Cobb-Douglas assumption, technology is neutral. Substitution of H_Y from equation 11 into equation 14 gives the relative returns to skilled and unskilled labor as

$$\frac{w_H}{w_L} = \frac{L(\alpha + \beta)(1 - \alpha - \beta)\lambda}{\beta r}\phi(A/B). \tag{15}$$

The key result in equation 15 is that the higher the fraction of the technology of the North that the South has imitated, the lower the relative rate of return to human capital. This result occurs because the imitation technology uses human capital but not unskilled labor. Human capital enjoys an advantage as long as there is still a lot of technology to imitate. But the more imitation that has already taken place, the less the advantage enjoyed by skilled labor.

As equation 15 shows, the only unknown influencing the relation between the returns to skilled and unskilled labor is the ratio A/B. I therefore analyze the influence of trade liberalization on relative returns with reference to figure 1.

Trade influences equilibrium in this model by enlarging the technology set that becomes known in the South. In the formal model this can be shown by an enlargement in set A. Looking at the steady-state equilibrium in figure 1, it is clear that set A does not influence relative equilibrium returns. It influences only the set B that is imitated in the South, because the solution for the ratio A/B is independent of A. Thus, in the steady state a country that trades has a higher *level* of technology and higher *absolute* returns to labor (from equations 10 and 12) than a country that trades less but has the same growth rate and the same relative returns to labor.

The results are different during the adjustment following liberalization. Suppose that trade liberalization is accompanied by a once-and-for-all rise in the set A that is known in the South. (Obviously, the increased knowledge will take place over time as foreign goods are experienced in the South, giving rise to more sluggish dynamic effects than the ones described here.) The effect of an increase in A is an increase in the rate of return to imitation. Producers in the South shift human resources out of production and into R&D. Because unskilled labor is not useful in the R&D technology, the relative returns to skilled labor rise immediately after trade liberalization. In figure 1, an increase in A for a given initial level of B shifts the (temporary) equilibrium to a point such as T. The relative return to human capital is higher at T because there has been an increase in the relative demand for it by firms engaged in R&D.

Both the increase in set A and the shift of human capital to R&D lead to the introduction of more capital varieties in the South and to an increase in the rate of growth of its economy. Eventually, the number of capital varieties copied increases sufficiently to restore the ratio of known varieties, A/B, to its pretrade level. At this point the advantage of skilled labor over unskilled labor evaporates, and human capital moves back to production, as the demand for it drops in the R&D sector. The rate of growth of the economy of the South at this point drops down to the rate of growth of the economy of the North. In the diagram, for as long as the economy is above point E, both the rate of growth of the economy of the South is higher than the rate of growth of the economy of the North and the relative demand for human capital is higher than it was previously. But when the economy reaches E, both values drop to their previous steady-state levels.

Thus, the relative gain that skilled labor receives from trade liberalization is temporary, even for a fixed supply of human capital and unskilled labor. Human capital in this formulation has a comparative advantage only during the transition to a higher steady state, which takes place after trade liberalization. When the transition is complete, both human capital and unskilled labor gain from the opening up to trade, but relativities do not change.

VI. Caveats and Extensions

The increase in the relative demand for human capital after trade liberalization is temporary because the imported production technology is neutral; that is, the new varieties of capital copied in the South are not better complements for human capital than for unskilled labor. I briefly consider here three cases in which richer results could be obtained. In the first case, the imported technology is not neutral but is biased in favor of skilled labor. This is a plausible assumption to make, given the increase in the rate of return to human capital—largely attributed to new technology—that has taken place in industrial countries. If the capital varieties invented in the North are more complementary to skilled than to unskilled labor, then it is natural that the varieties copied in the South will bias productivities in favor of skilled labor.

If technology is biased in favor of skilled labor, the number of capital varieties B will enter the expression for relative wages, equation 14, with a positive sign.[2] Then, for given supplies, the increase in the technology set of the South that results from trade liberalization will lead to a permanent and ever-increasing gain in the relative rate of return to human capital. Such gains will mirror any gains to skilled labor in industrial countries.

Such a situation, however, cannot be a long-run steady state. Eventually, the relative supplies of factors will adjust endogenously in response to the higher rate of return to human capital. A new steady state will then be reached when the rise in the supply of human capital offsets exactly the increase in the relative demand for human capital that results from the biased technology. How long the gain to human capital will persist when the technology transfers are not neutral depends on the speed with which the supply of human capital catches up with the shift in relative demands.

In the second case, human capital might enjoy a more long-lasting increase in relative demand if the production of capital goods is more human capital-intensive than the production of consumption goods (see Keller 1994). In the model presented in this article, both consumption and capital goods are produced by the same technology. But if capital goods embody more up-to-date technology, it might be more reasonable to assume that there are two separate production sectors in the economy: one producing consumption goods and one producing capital goods. If the capital goods sector requires more human capital than the consumption sector, then the fact that foreign capital varieties are copied at a faster rate after trade liberalization is another reason why the relative demand for human capital will increase. Producers will shift human capital to the capital goods

2. I do not attempt to formalize this idea here, which can be done by replacing the Cobb-Douglas production function by a nested constant elasticity of substitution function, because of the additional complexity.

sector of the economy. Relative wages for skilled labor will then rise either until it becomes too expensive to copy any more capital varieties or until the domestic supply of human capital increases to offset the gains in relative wages.

The first two cases considered in this section share a common property. They both imply that the technology transferred to the South makes the aggregate production function more skill-biased than it was before the liberalization of trade. The correction mechanism is an increase in the relative supply of skilled labor. Another plausible supply response, however, is likely to reinforce the increase in the relative returns to human capital in the period immediately following trade liberalization, even if the liberalization shock is neutral.

It is common to think of developing countries as having a large potential supply of unskilled labor, which is either underemployed in agriculture or discouraged because of the lack of jobs and is waiting for an opportunity to enter formal employment. The response of this supply to a positive shock can be fast, certainly faster than the response of skilled labor, which needs to be trained. It follows that when trade liberalization increases the demand for both kinds of labor, the wages of skilled labor increase more than the wages of unskilled labor, because the initial rise in unskilled wages is checked by the response of the supply of unskilled labor. Eventually, however, the supply of educated labor catches up, restoring the wage differentials.

Thus, the third case for an increase in the relative wages of skilled labor occurs even without biased technology transfers because the supplies of the two types of labor respond differently to an increase in aggregate labor demand. As in the other cases considered in this section, the situation just described is not likely to be a long-run equilibrium. Eventually, labor will train in response to the higher rate of return to skill and the relative advantage of skilled labor will erode away. The length of time that skilled labor can maintain an advantage over unskilled labor for the reasons outlined here depends on the speed with which unskilled labor "migrates" to the skilled sector, through education and training, relative to the speed with which it responds to the higher demand for unskilled labor.

VII. Conclusions

The widening of the skilled-unskilled wage differential that has been observed in developing countries that have liberalized trade is not a puzzle. Trade acts as a channel for the transfer of technology from industrial to developing countries. In the formal model described and solved in this article, the technology imported from the North into a developing country is neutral. It gives a temporary advantage to skilled labor over unskilled labor because the importation and assimilation process needs the services of skilled labor. Trade liberalization moves the economy of the developing country on to a permanently higher level of technology, although its rate of growth in the new equilibrium is not likely to be higher than it was before liberalization.

Skilled labor enjoys a relative advantage during the transition to the higher-level technology, which is reflected in higher relative wages for the duration of the transition. Of course, if the imported technology is biased in favor of skilled labor, skilled labor gains a permanent increase in relative demand. The correction mechanism then is the increase in the supply of skilled labor to meet the higher demand.

The response of the relative supply of skilled and unskilled labor to the trade liberalization might also cause a temporary widening in wage differentials. The supply of unskilled labor in a developing country is likely to be more elastic in the short run than the supply of skilled labor because of the existence of underemployed workers in agriculture or discouraged rent seekers waiting for new job opportunities. If this is the case, any overall increase in labor demand associated with trade liberalization will have a larger short-run impact on the wages of skilled labor than on the wages of unskilled labor, until the supply of skilled labor also increases to match the higher demand.

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