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The International Product Cycle and Globalization of Production

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Abstract

This paper develops a growth model aimed at understanding the potential effects of globalization of production on rate of innovation, distribution of skilled labor income between the North and South, and welfare of skilled workers in both regions. We adopt a dynamic general equilibrium product-cycle model, assuming that the North specializes in innovation and the South specializes in imitation. Globalization of production resulting from trade liberalization and imitation of the North's technology by the South increases the rate of innovation. In the initial stage of globalization of production, deeper globalization unambiguously improves the welfare of skilled labor in the North, though welfare of Southern skilled labor may still increase. In the later stage, deeper globalization of production unambiguously improves the welfare of skilled labor in the South, though welfare of Northern skilled labor may still improve.

JEL codes: F43, O31, O38.

Keywords: Product cycle, globalization, innovation, imitation

One of the most remarkable developments in international trade in the past thirty years has been the globalization of production of differentiated manufactured goods. Differentiated manufactured goods can be broadly defined as goods that emerged as a result of such inventions as electricity or computer-related technology. Examples are color TV, refrigerators, and microcomputers. These are technologically distinct from traditional goods that emerged before the twentieth century, such as textile, glass, and iron and steel. Differentiated goods were almost all originally developed by the advanced industrialized countries (North). Until about three decades ago, they were still mostly produced by the North. However, trade liberalization, policy changes in the less-developed countries (South), and technological advancement in telecommunications led to the transfer of production of some of these differentiated goods to the South because labor costs are much lower there. We call this transfer of production of differentiated goods from the North to the South globalization of production.

Table 1 illustrates the globalization of production. It shows that China's output of major industrial products increased dramatically from 1978 (beginning of reform by Deng Xiaoping) to 2005. Note, however, that the magnitudes of increase are much higher for differentiated goods, such as room air conditioners, refrigerators, color TVs, microcomputers, mobile phones, and integrated circuits. This, we argue, reflects the globalization of production of differentiated goods. We are interested in the impacts of such globalization of production on global growth and living standards in the North and the South.

International technology diffusion and trading of differentiated manufactured goods between the North and the South is well captured by Raymond Vernon's (1966) "product cycle" theory. According to Vernon, new products are usually developed in the most-advanced countries (such as the U.S. in the 1960s). During the initial period, production is located where the product is developed, to allow efficient feedback between R&D and production. When the production design, production process, and inputs become sufficiently standardized, the technology will be transferred to lower-wage countries. If we apply this theory to the technologically more-advanced economies such as the U.S. and the less-developed economies such as China and India, we can better understand how the increased participation of these countries in the globalization of production affects growth, labor income distribution between the North and the South, and living standard of workers in these regions.

Therefore, in this paper, we adopt the product-cycle framework, assuming that technology is transferred from the North to the South through costly imitation by Southern firms. That technology is transferred by imitation can be justified by the fact that Southern firms would eventually learn the technology brought by multinational corporations (MNCs) from the North. Once they have imitated the technology, Southern firms have the advantage that they are more familiar with the Southern environment and therefore can price out the Northern MNCs that brought in the technology in the first place.

Table 1: China's Output of Major Industrial Products

	Actual production			2005 output/ 1978 output
	1978	2005	Unit	
Chemical fiber	284,600	16.6 mn	tons	58.3
Yarn	2.4 mn	14.5 mn	tons	6.0
Cloth	11.0 bn	48.4 bn	meters	4.4
Silk	29,700	111,000	tons	3.7
Paper	4.4 mn	62.1 mn	tons	14.1
Plastics	679,000	23.1 mn	tons	34.0
Sugar	2.3 mn	9.1 mn	tons	4.0
Beer	400,000	31.3 mn	tons	78.3
Cigarettes	11.8 mn	193.9 mn	cases	16.4
Refrigerators	28,000	29.9 mn	units	1,068
Room ACs	200	67.6 mn	units	338,000
Washing machines	400	30.4 mn	units	76,000
Color TVs	3,800	82.8 mn	units	21,789
Motor vehicles	149,100	5.7 mn	units	38.2
Electricity	257.6 mn	2,500.3 mn	1000 kwh	9.7
Crude oil	104.1 mn	181.4 mn	tons	1.7
Coal	618.0 mn	2,205.0 mn	tons	3.6
Natural gas	13.7 mn	50.9 mn	1000 cubic meters	3.7
Hydropower	44.6 mn	397.0 mn	1000 kwh	8.9
Pig iron	34.8 mn	343.8 mn	tons	9.9
Steel	31.8 mn	353.2 mn	tons	11.1
Steel products	22.1 mn	377.7 mn	tons	17.1
Cement	65.2 mn	1,068.8 mn	tons	16.4
Plate glass	17.8 mn	402.1 mn	wt. cases	22.6
Sulfuric acid	6.6 mn	45.4 mn	tons	6.9
Chemical fertilizer	8.7 mn	51.8 mn	tons	6.0
Microcomputers	0	80.8 mn	units	N/A
Integrated circuits	30.4 mn	26,997.3 mn	units	888
Mobile phones	0	303.5 mn	units	N/A

NOTE: mn = million; bn = billion.

SOURCE: National Bureau of Statistics of China, *2007 China Statistical Yearbook*, China Statistics Press, Table 14-22.

Krugman (1979) was among the first to construct a dynamic general equilibrium model of the North–South product cycle to study the effects of policies on world income distribution and the technological gap between the North and the South. Assuming that innovation takes the form of expansion of product variety and that rate of product innovation and rate of imitation are exogenous, he shows that an increase in the rate of innovation (imitation) raises the relative wage of the North (South). He also shows that a country's wage relative to that of the other country is inversely related to its labor sup-

ply. Dollar (1986) introduces capital and capital mobility in a Krugman-type model and arrives at similar conclusions.

Modifying Krugman's model, Grossman and Helpman (1991a) endogenize the rate of product innovation and rate of imitation in an expanding-variety-type growth model. They assume Northern firms engage in costly product innovation and Southern firms engage in costly imitation of North-developed products. In contrast to Krugman, they find, among other things, that an increase in the supply of skilled labor (that is essential for both production and research) in a country raises the relative wage (which is also the terms of trade) of that country. In their model, two opposing forces are at work as the supply of a factor increases: The quantity of the factor allocated to production increases, and the demand of the factor for production also increases because the fraction of goods produced by the country increases. They find that the latter effect always dominates the former in their model.¹

We are interested in understanding the effects of the South's increased participation in global production, which we interpret as increases in the allocation of Southern skilled labor (technicians and engineers, who can be allocated to either production or imitation) to product-cycle goods. To be sure, the allocation of Southern skilled labor to product-cycle goods is not exogenous. We want to focus on two main factors that determine this allocation: trade liberalization between the North and South and costs of telecommunications in the South. We [will] justify how these two changes affect Southern allocation of labor in the product cycle. We then argue that we can use an autonomous increase in the South's allocation of labor to product-cycle goods to proxy for a decrease in the cost of telecommunications in the South.

The manufacturing sector of each country consists of traditional goods and differentiated goods. We assume that all differentiated goods are developed by the North. Before trade liberalization between the North and South, we assume that trade barriers were prohibitive. Having no trade with the North, the South did not know how to imitate the differentiated goods. Therefore, no Southern skilled labor was involved in production of differentiated goods. With no trade between the two regions, Northern firms produced agricultural goods, traditional goods, and differentiated goods and sold to the North only, while Southern firms produced agricultural goods and traditional goods and sold to the South only. However, for simplicity, we do not model the agricultural and traditional goods sectors in this paper.

Immediately after trade liberalization, the North exports differentiated goods to the South, while the South exports agricultural and traditional goods to the North. After the North exports differentiated goods to the

¹ In another paper, Grossman and Helpman (1991b) model a more complex pattern of innovation and imitation. The "inefficient follower" case in their model yields similar results as in Grossman and Helpman (1991a). The "efficient follower" case generates numerous ambiguous results, including the effect of labor supply on the relative wage of a country. In Segerstrom, Anant, and Dinopoulos' (1990) product-cycle-model, innovation takes the form of quality improvement in the North. Technology is transferred to the South through costless imitation, and the length of the product cycle (imitation lag) is exogenous. Since there is no R&D sector in the South, an increase in Southern labor supply lowers the relative wage of the South whenever the relative wage differs from 1.

South, the latter learn to imitate them eventually. In steady-state equilibrium, Southern firms imitate some but not all of the differentiated goods, produce them, and export them to the North. In steady-state equilibrium, there is trade in agricultural and traditional goods, but we do not model them in this paper for simplicity.

Even after trade liberalization, the quantity of Southern skilled labor that participates in the product cycle is constrained by the cost of telecommunications (Internet, electronic mail, cellphone, long-distance phone, fax, etc.) in the South. We assume that there is limited labor mobility between cities and between rural and urban centers in the South. Initially, only labor hired by firms in large (or coastal) Southern cities can profitably participate in the product cycle, as the cost of telecommunications is lower there. Eventually, as telecommunication costs decrease, labor hired by firms in smaller (or inland) cities can profitably participate in the product cycle. The allocation of skilled labor in the North to product-cycle goods, however, is constant, as the North is a mature economy where telecommunications are already well developed.

We are interested in understanding the effects of (i) trade liberalization, which is equivalent to a transition from autarky equilibrium to free trade equilibrium for a given cost of communications (i.e., for a given allocation of labor from large Southern cities), and (ii) a decrease in communication costs after trade liberalization (which leads to an increase in allocation of labor due to the participation of smaller Southern cities). We call the first transition the initial stage of globalization of production and the second transition the deepening of globalization of production.

Based on the above argument, we use the increase in the allocation of skilled labor in the South to proxy for the decrease in the communication costs in the South during the deepening of globalization. We compare the autarky equilibrium with the free trade equilibrium, keeping the allocation of Southern labor constant. More important, based on free trade, we carry out comparative steady-state analyses of the effects of changes in the South's allocation of labor to product-cycle goods on the rate of innovation, rate of imitation, income distribution between skilled workers in the two regions, and welfare of skilled labor in the two regions. To this end, we develop a model of the endogenous product cycle inspired by Grossman and Helpman (1991a). One essential innovation in this paper is that the time it takes to imitate is assumed to depend negatively on the quantity of resources devoted to imitation. This assumption is justified because the longer it takes, the fewer resources are required to reverse-engineer a technology and to adapt it to a new environment. See, for example, Mansfield, Schwartz, and Wagner (1981); Mansfield et al. (1982); and Teece (1976, 1977).² We believe such a trade-off is especially important in industries where product innovation and

² Although Teece (1976) says that some firms found that, *ex post*, the cost of imitation actually increases with the time it takes to imitate (presumably when there are uncertainties in the time-cost relationship), Mansfield, Schwartz, and Wagner (1981) provide evidence of a significantly negative relationship between imitation cost and time to imitate. We think the latter result makes sense when uncertainties are small. In our model, there are no uncertainties, and therefore a time-cost trade-off is fully justified.

imitation occur at a very high pace, such as the computer industry. We are able to endogenize the steady-state imitation lag and the cost of imitation for each product. It will be seen that the incorporation of such an essential characteristic of the imitation cost function, which has largely been ignored by the literature on product-cycle theory, would have crucial impacts on comparative steady-state results.

The following is a summary of our findings. First, globalization of production resulting from trade liberalization and imitation of Northern technology by the South would increase growth of the North. Second, with free trade, when the South learns to imitate faster, it leads to a higher rate of innovation, higher rate of imitation and higher wage of Southern skilled labor relative to that of the North, given that the skilled labor is essential for both production and research in each country. Third, the larger the Southern allocation of skilled labor in the product cycle, the higher the cost of imitation is. This has interesting implications: With free trade, when the Southern allocation of labor is sufficiently small, an increase in Southern labor allocation will lower the wage of the South relative to that of the North. In other words, in the initial stage of the South's participation in the international product cycle (when its allocation of labor is small), an increase in the allocation of labor lowers the relative wage. Eventually, however, as the labor allocation in the South becomes sufficiently large, its relative wage increases as allocation increases. The key factor in determining the direction of the effect is whether the (endogenous) increase in quantity of labor allocated to production dominates the (endogenous) increase in demand for labor in production. When allocation of labor is small, the former effect dominates the latter. When allocation of labor is sufficiently large, the reverse is true.

There are two major implications of our results. First, Northern skilled workers unambiguously gain from deeper globalization of production during its initial stage (when the South's participation in the product cycle is relatively small) as growth becomes faster and its relative wage becomes higher as globalization deepens. For the South, even though its relative wage decreases with deeper globalization during its initial stage, Southern skilled labor can still gain from deeper globalization, as the growth rate becomes faster and a larger fraction of differentiated goods are produced by the low-cost South. Second, in the later stage of integration (when Southern allocation of labor reaches a sufficiently high level so that a sufficiently large fraction of goods are produced by the South through imitation), the welfare calculus of skilled labor in each region is just the opposite of the initial stage, as deepening globalization leads to an increase in the Southern wage relative to that of the North. Thus, the South unambiguously gains and the North may or may not gain.

In Section 1, we lay down the main body of the imitation model. In Section 2, we solve the steady-state equilibrium, and in Section 3 some comparative steady-state analyses are carried out. Section 4 concludes with a discussion on the caveats of the model.

1. THE IMITATION MODEL

We tell the story backwards. In this section and the next, we assume that trade liberalization (or globalization of production) has already taken

place and there is free trade in the world. We ask how the world equilibrium is affected as globalization deepens. In Section 3, we compute the autarky equilibrium in the North and compare the autarky and free equilibria.

So, in Sections 1 and 2, we consider a two-country world economy in which, in equilibrium, the North is the sole source of innovation and the other country, the South, only imitates goods from the North. In each country, there is a single factor input, which can be used to undertake three possible types of activities: innovation (product development), imitation (reverse-engineering of developed products), and production of goods. For convenience of exposition, we call this factor input human capital, or skilled labor, or simply labor. Innovation takes the form of development of a new variety of the differentiated good. Potentially, there is an infinite number of goods that can be developed, but at any given time, only a finite number of goods has been developed. Production technology is constant returns to scale, and labor is the only factor of production. We assume that the unit labor requirement for production for an imitator firm is the same as for the innovator firm once the technology is imitated.

In explaining the model, we again tell the story backwards. We first assume that goods are continuously being developed and consumers have perfect foresight of the number of goods available at each date and are offered the price of each variety. Consumer utility maximization determines the demand function of each variety. Then we explain how prices of goods are chosen by profit-maximizing producers given the producers' perfect foresight of consumers' demands. Next, we introduce the cost functions of innovation and imitation. Potential innovators and imitators decide whether to enter the market. Free entry implies that, in equilibrium, all innovators and imitators earn zero economic profit. Thus, the equilibrium balanced growth rate is determined.

The Demand for Goods

Following Grossman and Helpman (1991a), we assume that a world representative agent (or, alternatively, one representative agent in each country) chooses the time path of instantaneous expenditure $E(t)$ and instantaneous consumption $x(z)$ of good $z \in [0, n(t)]$ at each date to maximize the intertemporal welfare function³

$$(1) \quad W = \int_t^\infty e^{-\rho(\tau-t)} \log U(\tau) d\tau$$

subject to (i) the intertemporal budget constraint⁴

³ Use of the more general function $W = \int_t^\infty e^{-\rho(\tau-t)} \frac{U(\tau)^{1-\sigma} - 1}{1-\sigma} d\tau$, where equation 1 is a special case as $\sigma \rightarrow 1$, leads to the same qualitative conclusion.

⁴ The "flow" version of this "stock" equation is $I(t) - E(t) + rA(t) = A(t)$.

$$(2) \quad \int_t^\infty e^{-r(\tau-t)} E(\tau) d\tau = \int_t^\infty e^{-r(\tau-t)} I(\tau) d\tau + A(t) \text{ for all } t$$

and (ii) instantaneous utility function⁵

$$(3) \quad U(t) = \left\{ \int_0^{n(t)} [x(z)]^\alpha dz \right\}^{\frac{1}{\alpha}},$$

where $0 < \alpha < 1$, $n(t)$ denotes the most recently developed good in the world at time t , ρ = time rate of preference, r = interest rate, $U(\tau)$ = instantaneous utility at time τ , $I(\tau)$ = instantaneous income at τ , $A(t)$ = value of assets at t . In each period τ , the agent takes $A(\tau)$, $I(\tau)$, r , and prices of goods as given.

The dynamic optimization problem specified by equations 1, 2, and 3 can be broken down into an intratemporal optimization problem at time t of choosing $x(z)$ (for given $n(t)$) to maximize $U(t)$ subject to the instantaneous budget constraint, and the intertemporal optimization problem of choosing a time path of $E(t)$ to maximize W subject to the demand function of $x(z)$ (determined by intratemporal optimization on the demand side) and the prices of goods $p(z)$ (determined by intratemporal optimization on the supply side).

The intratemporal consumer optimization problem is

$$(4) \quad \max_{x(z)} U(t) \text{ s.t. } \int_0^{n(t)} x(z)p(z)dz = E(t).$$

The intertemporal optimization problem will be solved after we have solved the instantaneous problems on the demand side and the supply side. Hereinafter, we drop the time argument t for convenience, unless otherwise stated.

From the first order condition of the maximization problem (4), and some simple manipulation, we obtain the demand function $x(z)$ of good z ,

$$(5) \quad x(z) = \frac{p(z)^{-\varepsilon}}{\int_0^n p(s)^{1-\varepsilon} ds} E,$$

where $\varepsilon = 1/(1-\alpha) > 1$ and $0 \leq \alpha \leq 1$. The parameter $\varepsilon = 1/(1-\alpha)$ is the elasticity of substitution between any two goods. The greater α is, the greater is ε , and the less is the love of variety.

The Supply of Goods

We assume constant returns to scale in production of each good. The only fixed costs are the costs of innovation and imitation.

We assume that each good is produced by a different firm and that firms compete with each other by setting prices. The market structure is one of monopolistic competition, and each firm has certain market power over the submarket of its good. During the production stage, due to the time separa-

⁵ Alternatively, $U(\tau)$ can be regarded as quantity of final goods produced from a set of intermediate goods, with production function (3).

bility of the intertemporal profits function, each firm chooses its price, given the prices of other goods, to maximize instantaneous profit $\pi(z)$, subject to the demand function (5). Therefore, a producer solves

$$(6) \quad \max_{p(z)} \pi(z) = x(z)\{p(z) - c(z)\}$$

s.t. the demand function (5), where $c(z)$ is the unit production cost of good z .

Ignoring the effects of any single producer on the denominator of demand function (5), we obtain from the first order condition the markup pricing rule

$$(7) \quad p(z) = \frac{c(z)}{\alpha} = \frac{w}{\alpha},$$

given the assumption that the unit labor requirement for production is equal to 1 for all good z , i.e., $c(z) = w$, where $w =$ wage rate.

Using the results of the intratemporal optimization problem, the first order condition for the intertemporal optimization is

$$(7) \quad r = \rho + \frac{\dot{E}}{E}.$$

The above equation states that the growth rate of E will be higher when consumers are less impatient (more willing to invest in the future), for any given r . We define $\hat{n}/n \equiv g$ in the steady state and normalize by setting the price of a firm (or the value of a blueprint) equal to a constant in all periods, i.e., $\dot{E}/E \equiv \hat{n}/n$. We can then rewrite the above equation as

$$(8) \quad r = \rho + g.$$

A Two-Country World

To analyze the two-country world, we introduce the following notation. Among the n goods existing in the world at time t , goods 0 to n_S are produced by the South (after they have been imitated from the North), and the rest are produced by the North. Because of symmetry of all goods in the demand function, x_N stands for the demand for any good produced by a Northern firm, while x_S stands for the demand for any good produced by a Southern imitator. The variables x_N and x_S are determined by the demand function (as shown in equation 5) when the prices of the n goods are known. Because transportation cost is zero and there are no trade barriers, the producer of a good always sells to the world market. Let π_N be the instantaneous profit of a Northern firm and π_S be that of a Southern imitator firm. Wage rates in North and South are denoted by w_N and w_S , respectively. The number of Southern workers who can profitably participate in the product cycle is constrained by the cost of telecommunication in the South, which is nontrivial. When the telecommunication cost is lower, a larger fraction of Southern workers find it profitable to sell to the North. Therefore, the allocation of Southern labor that participates in global production increases with the decline in telecommunication costs in the South. The allocation

of Northern skilled labor in product-cycle goods, however, is unaffected, as the North is a mature economy where telecommunication is already well developed. For given telecommunication costs in the South, the labor allocations in the South and North are constants, which we denote by L_S and L_N , respectively.

On the “balanced growth path” that we analyze, the steady state is characterized by $g \equiv \dot{n}/n = \dot{n}_S/n_S = \dot{w}_N/w_N = \dot{w}_S/w_S = \dot{E}/E$, so that w_N , w_S , E , n , and n_S are in constant ratio with each other over time. It can be deduced from equations 5 through 7 and symmetry of all $x(z)$ in the utility function that in the steady state, π_N and π_S are constant over time. Note that the growth rate of utility is proportional to g .⁶

We assume that only the Northern firms innovate and only the Southern firms imitate in steady-state equilibrium. In equilibrium, a Northern firm develops a good by incurring an upfront cost and then earns the opportunity to make a constant stream of profits at each date in the future until the good is imitated. Later in the product’s life, a Southern firm would find it profitable to invest to imitate or reverse-engineer the product. Once a product is imitated by the South, its production location will be shifted there forever.

Before its good is imitated, a Northern innovator-producer firm prices according to equation 7, so that the price of a Northern good is

$$(9) \quad p_N = \frac{w_N}{\alpha}.$$

However, there are two pricing rules of a Southern firm after it imitates a good, according to whether, in equilibrium, the gap between w_N and w_S is large or small, as shown below.

(a) Wide-gap case

If $w_S/\alpha < w_N$, i.e., $w_S < \alpha w_N$, the unconstrained, monopoly, profit-maximizing price level of a Southern imitator firm is less than the cost of the Northern innovator, and therefore, under the assumption of price competition, the Nash equilibrium would be one at which the Southern firm will set the price at the unconstrained profit-maximizing level, viz.,

$$(10) \quad p_S = \frac{w_S}{\alpha}.$$

(b) Narrow-gap case

If $w_S/\alpha > w_N$, i.e., $w_S > \alpha w_N$, price competition between the Northern innovator and the Southern imitator would drive the Nash equilibrium price level to slightly below the cost of the high-cost firm, viz., $p_S = w_N$.

Only the wide-gap case will be discussed in this paper, since all results are qualitatively the same in the narrow-gap case, as evident in the work of, say, Grossman and Helpman (1991a).

⁶ Differentiating equation 3 along the steady-state path, using $\dot{n}/n = \dot{p}/p = \dot{E}/E = g$ and equations 5, 9, and 10, we obtain the world growth rate of welfare:

$$\dot{U}/U = [(1-\alpha)/\alpha]g.$$

Therefore, the rate of innovation is an indicator of the growth of welfare in both countries.

According to equations 5, 6, 9, and 10, instantaneous profit of a Southern firm can be expressed as

$$(11) \quad \pi_S = \pi_N \left(\frac{w_S}{w_N} \right)^{\frac{-\alpha}{1-\alpha}}.$$

Imitation Activity in the South

We assume, as in Romer (1990), that the knowledge stock in the South lowers the cost of imitation. We also assume that the relevant knowledge stock for imitating good z is the knowledge stock in the South at the time the product z is developed t_d . To imitate a product, an imitator hires workers to work at date t_d and expects the imitation to be completed at date t . We assume there is a negative relationship between the labor devoted to imitation and $t - t_d$. Specifically, the cost of imitation of good z by a Southern firm when imitation is completed at time t is assumed to be

$$(12) \quad C_i(z, t) = b \left[\frac{w_S(t_d)}{K_S(t_d)} \right] e^{-\lambda(t-t_d)} \text{ assuming that } \lambda > \rho + g,$$

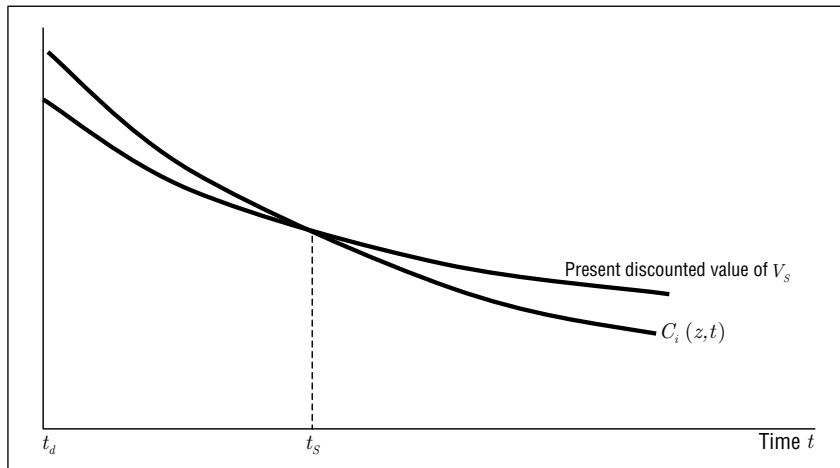
where b is a parameter; $t - t_d$ is the time it takes to imitate good z ; λ is the exogenous rate of decline of the labor requirement for imitation with respect to the time it takes to imitate; $K_S(t_d)$ is the knowledge stock at date t_d , which the imitator treats as given. To obtain a steady state consistent with constant allocation of resources in both regimes, we use $n_S(t)$ to proxy for the knowledge stock in the South at time t , i.e., $K_S(t) = n_S(t), \forall t$.

The above imitation cost function indicates that the unit labor requirement for imitation is composed of the product of two parts: (i) $1/n_S(t_d)$, which is inversely related to the cumulative experience of imitation in the South at the time when the product was developed, and (ii) $b e^{-\lambda(t-t_d)}$, which decreases exponentially with the time it takes to imitate. The first term captures the knowledge spillovers from previous imitational R&D (See, for example, Grossman and Helpman 1991a and Romer 1990). Mansfield, Schwartz, and Wagner (1981) give some evidence about the negative relationship between cost of imitation and the time to imitate, which is consistent with the second term above.

According to equation 12, since $w_S(t_d)/n_S(t_d)$ is predetermined at t_d and it is a constant, imitation cost decreases with the time it takes to imitate at an exponential rate of $\lambda > 0$, while equation 11 implies that the present discounted value (PDV) of profits derived from an imitated product decreases at an exponential rate of r . It follows that as long as $\lambda > r$, there will be a

time at which it becomes profitable for a Southern firm to imitate from a Northern firm, as shown in Figure 1. As will be elaborated later, free entry ensures that profits are equal to zero.⁷

Figure 1: Determination of Date of Imitation of a Good



NOTE: $C_i(z, t)$ is the cost of completing the imitation of good z at date t when the good is developed at date t_d . In equilibrium, the good is imitated at date t_s , when the profit of the imitator is driven to zero due to free entry into the imitation business.

Innovation Activity of the North

We assume that innovation is completed immediately after resources are devoted to it. This is an innocuous assumption since our analysis focuses on changes in Southern allocation of labor and imitation capability. The cost of innovation (product development) by a Northern firm at date t_d is assumed to be

$$(13) \quad C_d(t_d) = a \frac{w_N(t_d)}{K(t_d)},$$

where a is a parameter, $K(t_d)$ is the knowledge stock at date t_d when innovation takes place, and $1/K(t_d)$ captures the knowledge spillovers from previous product development in the North in the spirit discussed in the previous subsection. To obtain a steady state, we again proxy the knowledge stock in the North at date t by $n(t)$, i.e., $K(t) = n(t)$, $\forall t$.

⁷ There is time-cost tradeoff only when $\lambda > r$, since only then will the decline in labor requirement be faster than the decline in PDV of profits from imitation. Therefore, the condition is a necessary condition for the existence of a steady-state equilibrium. We also need to assume that $bw_S/w_N > \pi/r$, which is equivalent to $b > (1-\alpha)(L_S - bg\xi^{\lambda/g})/[\alpha(p+g)]$ so that the PDV of profits from imitation is lower than the cost of imitation at the date the product is developed.

Profits to Northern Innovators and Southern Imitators

Let V_N be the PDV of future profits that can be earned by a Northern innovator (for a product developed at time t) when no imitation will ever take place. Recall that π_N is the instantaneous profit of a Northern firm at any time τ ($t < \tau$). Thus,

$$V_N = \int_t^\infty e^{-r(\tau-t)} \pi_N d\tau = \frac{\pi_N}{r}.$$

Let V_S be the PDV of profits of a Southern imitator (for a product imitated at time t) and recall that π_S is the instantaneous profit of a Southern imitator at any time τ ($t < \tau$). Therefore,

$$V_S = \int_t^\infty e^{-r(\tau-t)} \pi_S d\tau = \frac{\pi_S}{r}.$$

Let t_s be the *equilibrium* imitation date of a good that is developed at date t_d . It follows that the index of this good is exactly n_s at time t_s . It can be easily shown that in steady state, when $\dot{n}/n = \dot{n}_s/n_s = g$,

$$(14) \quad \xi \equiv \frac{n_s}{n} = e^{-g(t_s-t_d)} = e^{-gT},$$

where $T \equiv t_s - t_d$ is the *equilibrium* length of the product cycles. There are several interpretations of the variable ξ in steady state: first, ξ represents the equilibrium fraction of products produced in the South in steady state; second, ξ can also be regarded as the (inverse) technological gap between the South and the North; third, to compute the PDV at date t_d of a sum at t_s , a factor of $e^{-r(t_s-t_d)} = \xi^{r/g}$ is used.⁸

It follows from equations 12 and 14 that the reduced form of the cost of imitation in equilibrium is

$$(15) \quad C_i = b \frac{w_S}{n_S} \xi^{\lambda/g} \text{ at any date.}$$

The component $\xi^{\lambda/g}$ is the part of the imitation cost that accounts for the time-cost trade-off in imitation.

Zero-Profit Conditions for Firms

Free entry implies that no firms can make any positive net profit, properly discounted. This implies that, for the Southern firm, the PDV of profits equals the cost of imitation in equilibrium:

⁸ By definition, $n_s = n_0 e^{g(t_s-t_0)}$ and $n = n_0 e^{g(t_s-t_0)}$, where n_0 is the value of n at time t_0 . This implies that $\xi = n_s/n = e^{-g(t_s-t_0)}$, which is equation 14. Moreover, $\xi^{r/g} = (n_s/n)^{r/g} = e^{-r(t_s-t_0)}$. Therefore, $\xi^{r/g}$ is the discount factor used to compare profits at the time of imitation with profits at the time of innovation.

$$(16) \quad \frac{\pi_S}{r} = V_S = b \frac{w_S}{n_S} \xi^{\lambda/g}.$$

Moreover, free entry without barriers ensures that the PDV of profits of the Northern innovator is equal to the cost of innovation. The profit of the Northern firm, however, does not last forever. It ends when the product is imitated. The PDV of this loss is equal to $V_N e^{-r(t_s - t_d)} = V_N \xi^{r/g}$. Therefore, the zero profit condition of a Northern firm is

$$(17) \quad \frac{\pi_N}{r} (1 - \xi^{r/g}) = V_N (1 - \xi^{r/g}) = a \frac{w_N}{n}.$$

Labor Market Clearing Conditions

For a given cost of telecommunications, the number of Southern workers who find it profitable to participate in global production, L_S , is predetermined. Labor in each country is allocated endogenously between production and either product development (in the North) or imitation (in the South).

Labor involved in production in the North is

$$\begin{aligned} L_N^p &= \int_{n_S}^n \frac{c(z)}{w_N} x(z) dz \\ &= \frac{\alpha}{w_N} \int_{n_S}^n p_N(z) x(z) dz \\ &= \frac{\alpha}{w_N (1 - \alpha)} \int_{n_S}^n \pi_N dz \\ &= \left(\frac{\alpha}{1 - \alpha} \right) (1 - \xi) \pi_N \frac{n}{w_N}. \end{aligned}$$

This implies that

$$(18) \quad \pi_N = \left(\frac{1 - \alpha}{\alpha} \right) \frac{w_N}{n} \left(\frac{L_N^p}{1 - \xi} \right),$$

where $L_N^p/n(1-\xi)$ is the instantaneous production labor input for a good produced in the North. In other words, the instantaneous profit of a good produced in the North is simply a markup factor $(1-\alpha)/\alpha$ times the instantaneous wage bill of production workers for that good.

Similarly, labor involved in production in the South is

$$(19) \quad \pi_S = \left(\frac{1-\alpha}{\alpha} \right) \left(\frac{w_S}{n_S} \right) L_S^p,$$

where L_S^p/n_S is the instantaneous production labor input for a South-produced good.

Now, define L^d = labor devoted to product development in the North. Therefore, $L^d + L_N^p = L_N$. Equation 13 implies that $L^d = a(\dot{n}/n) = ag$, which implies that

$$(20) \quad L_N^p = L_N - ag.$$

Similarly, according to equation 15, labor devoted to imitation in the South is $L^i = C_i(\dot{n}_S/w_S) = b(\dot{n}_S/n_S)\xi^{\lambda/g} = bg\xi^{\lambda/g}$. Since $L^i + L_S^p = L_S$, we have

$$(21) \quad L_S^p = L_S - bg\xi^{\lambda/g}.$$

2. STEADY-STATE EQUILIBRIUM

The model is now fully characterized by the following equations: Equation 8 is the interest rate–growth rate relationship; equations 16 and 17 are the zero-profit conditions for the firms; equations 18 and 19 represent instantaneous profits of these firms as fixed markups of instantaneous production costs; equations 20 and 21 are labor market clearing conditions in the North and South, respectively.

Rate of Innovation and Technological Gap

To solve the system of simultaneous equations, we reduce it to a system of two equations and two unknowns involving g and ξ . Using equation 20, we can substitute for L_N^p in equation 18. Using the resulting expression, we substitute for π_N in equation 17 to obtain

$$\frac{1}{r} \left(\frac{1-\alpha}{\alpha} \right) \left(\frac{L_N^p}{1-\xi} \right) \frac{w_N}{n} (1-\xi^{r/g}) = a \left(\frac{w_N}{n} \right),$$

and, as mentioned before, $L_N^p/n(1-\xi)$ is the instantaneous production labor input of a Northern-produced good. The above equation is a zero-profit condition for a Northern innovator. The left-hand side (LHS) is the PDV of the stream of the instantaneous profits of a product developed in the North, taking into account the fact that the stream of profits will terminate upon imitation by multiplying by $1-\xi^{r/g}$. Interest rate r is the discount factor. The term $(1-\alpha)L_N^p w_N / [\alpha n(1-\xi)]$ is the instantaneous profit expressed as a fixed markup of instantaneous production cost. The right-hand side (RHS) is the innovation cost. Note that w_N/n can be canceled from both sides of the equation, meaning that changes in w_N and n have no effect on the reduced-form

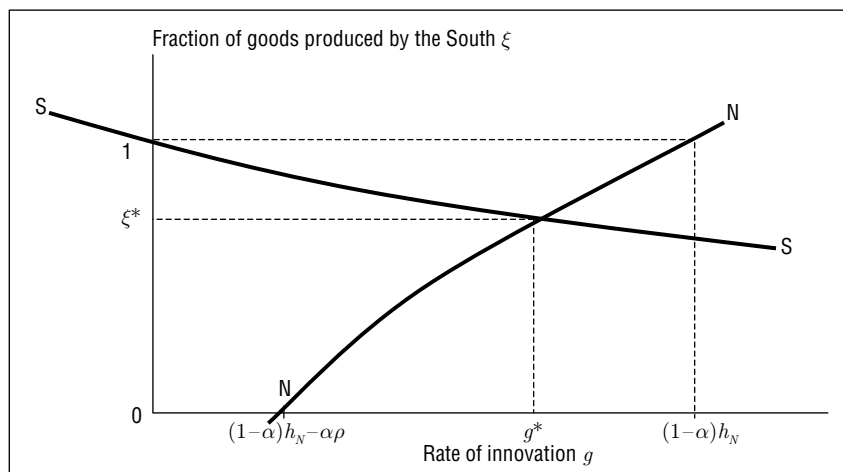
equilibrium relationship between g and ξ in the North. Invoking equation 8, we obtain the reduced-form “no-arbitrage condition” in the North (see Grossman and Helpman 1991a).

$$(22) \quad \frac{1-\alpha}{\alpha} (h_N - g) \left(\frac{1-\xi^{\frac{\rho}{g}+1}}{1-\xi} \right) = (\rho + g),$$

where $h_N \equiv L_N/a$ is the effective allocation of labor for innovation in the North.

Define $f(\xi, g) \equiv (1-\xi^{r/g})/(1-\xi) = (1-\xi^{\rho/g+1})/(1-\xi)$. Since $r = \rho + g > g$, in the steady state, it can be shown that $df/d\xi > 0$ and $df/dg < 0$ (See Appendix A). By the implicit function theorem, it is clear that equation 22 represents an upward sloping curve NN in the (g, ξ) space, as shown in Figure 2. Therefore, the Northern no-arbitrage condition shows a positive relation between g and ξ .

Figure 2: Equilibrium Values of g and ξ



NOTE: An increase in L_S shifts the SS curve up and increases g , but the magnitude of g is bounded from above by $(1-\alpha)h_N$.

It might seem counterintuitive that the rate of innovation increases *despite* an increase in the rate of imitation. This is true because there are two opposing forces in action: (a) for a given n , a greater ξ leads to fewer firms in the North, increasing the profit rate of each Northern firm; and (b) a greater ξ means greater rate of capital loss to the innovator due to imitation. It is clear from equation 22 that as long as the rate at which values of products are discounted (r) is greater than the rate at which products are created (g), an increase in ξ raises the proportion of Southern firms (ξ) by a greater fraction than it raises the discount factor at the time of imitation ($\xi^{r/g}$), so that effect (a) dominates effect (b), resulting in a net increase in the instantaneous profit of the marginal Northern firm, thereby inducing more entry. It turns out that the restriction “discount dominates growth” ($r > g$) is crucial to the positive slope of the NN curve.

Using equation 21, we can substitute for L_S^p in equation 19. Using the resulting expression, we substitute for π_s in equation 16, to obtain

$$\frac{1}{r} \left(\frac{1-\alpha}{\alpha} \right) L_S^p \left(\frac{w_S}{n_S} \right) = b \left(\frac{w_S}{n_S} \right) \xi^{\lambda/g},$$

where, as mentioned before, L_S^p/n_S is the instantaneous production labor input of a Southern-produced good. The above equation is a zero-profit condition for a Southern imitator. The LHS is the PDV of a stream of instantaneous profits of a product imitated by a Southern firm, which is a fixed markup of instantaneous production cost $(1-\alpha)L_S^p w_S/(\alpha n_S)$. The RHS is the imitation cost. Note also that w_S/n_S can be canceled from both sides of the equation, meaning that changes in w_S and n_S have no effect on the reduced-form equilibrium relationship between g and ξ in the South. Invoking equation 8, we obtain the “Southern no-arbitrage condition”:

$$(23) \quad \left(\frac{1-\alpha}{\alpha} \right) (h_S - g\xi^{\lambda/g}) = (\rho + g)\xi^{\lambda/g},$$

where $h_S \equiv L_S/b$ is the effective allocation of labor for imitation from the South. It follows that equation 23 represents a downward sloping curve in the (g, ξ) space. It is shown as curve SS in Figure 2. Intuitively, a higher rate of innovation implies that more labor is allocated to imitation and less labor allocated to each good, but each imitation needs more labor input. Smaller scale of production of each imitated good, which translates into lower profit for each imitated product, combined with higher labor requirement for each act of imitation means that gross profit from each imitation cannot cover the cost of imitation. Therefore, ξ , the fraction of goods produced by the South, must decrease so as to increase the scale of production of each imitated variety and to reduce the cost of imitation. This would restore the zero-profit condition. Thus, in the steady state, the dynamic equilibrium in the South requires that an increase in the rate of innovation must be accompanied by a decrease in the fraction of goods produced by the South.

Relative Wage

From equation 11, we obtain $\pi_s/\pi_N = (w_S/w_N)^{1-\varepsilon}$. From equations 18 and 19, we obtain another expression for the same ratio:

$\pi_s/\pi_N = (w_S/w_N)(L_S^p/L_N^p)[(1-\xi)/\xi]$. Therefore, equating the RHS of the last two equations, we obtain

$$(24) \quad \frac{w_S}{w_N} = \left[\left(\frac{L_N - ag}{L_S - bg\xi^{\lambda/g}} \right) \left(\frac{\xi}{1-\xi} \right) \right]^{1-\alpha}.$$

The expression is quite intuitive: Given that the labor allocated to innovation in the North and labor allocated to imitation in the South remain constant, and the fraction of goods produced in the North remains unchanged, an increase in L_S or decrease in L_N leads to a decrease in the relative wage of the South.

3. COMPARATIVE STEADY-STATE ANALYSIS

We study two changes: (i) the transition from autarky to globalization for a given (relatively small) allocation of labor from the South; and (ii) the deepening of globalization caused by a decrease in the cost of communication, which triggers an increase in the allocation of labor L_S from the South.

From Autarky to Globalization

We focus our discussion on the effects on the North. We define autarky in the North as self-sufficiency in agricultural, traditional and differentiated goods. What does the steady state look like under autarky in the North? Note that equations 1 through 9, 13, and 20 continue to hold, while equations 17, 18, and 20 hold by setting $\xi=0$, as there is no imitation. It is, therefore, clear that the steady-state growth rate is obtained from equation 22 by setting $\xi=0$. With trade liberalization and imitation of some differentiated goods by the South, ξ increases. The steady-state value of ξ is dependent on L_S , which is in turn determined by the number of Southern workers who are employed by firms that can communicate effectively with the North so as to profitably conduct trade with them. Thus, L_S is determined by the cost of telecommunications, such as the costs of access to the Internet, mobile phones, international phone calls, and fax services.⁹

How does globalization affect the rate of growth of the world? From equation 22, we can see that g increases as ξ increases from zero. Thus, the North grows faster with globalization of production made possible by trade liberalization in differentiated goods and technology acquisition by the South through imitation. What are the effects of globalization on the living standard of Northern workers? We see that not only is there more variety of differentiated goods available for consumption in the North, but the price of each good relative to the Northern wage is either unchanged (if it continues to be produced in the North) or lower (if its production is now transferred to the South). Therefore, the living standard of each Northern worker increases from autarky to the initial stage of globalization.

In the initial stage of globalization, only large cities in the South engage in imitation and trade of differentiated goods with the North as the cost of access to telecommunication is lower compared with small Southern cities. As the cost of telecommunication decreases, firms in smaller Southern cities find it profitable to engage in the product cycle. This leads to an increase in L_S and thus a deepening of globalization. In the next subsection, we analyze the effects of such a change in depth.

⁹ In some countries, such as China, L_S can be increased by a relaxation of rural–urban migration policy, which in the past controlled the number of people who could migrate from rural to urban areas.

Deepening of Globalization: an Increase in L_S

The effects of changes in L_S , b , and λ on g , ξ , $\xi^{\lambda/g}$, and w_S/w_N are summarized in Table 2.¹⁰ Note that $\xi^{\lambda/g}$ is a measure of the part of the imitation cost that accounts for the time–cost trade-off. From the table, it is shown that an increase in L_S leads to an increase in g , ξ , and $\xi^{\lambda/g}$; an increase in λ increases both g and ξ but lowers $\xi^{\lambda/g}$. An increase of L_S increases the cost of imitation in equilibrium since each good is imitated earlier in the new steady state. An increase in λ , on the other hand, lowers the cost of imitation in equilibrium, since the cost of imitation falls faster with time to imitate. It will be shown below that the effect of L_S on the cost of imitation has a crucial impact on the Southern wage relative to that of the North.

Table 2: Comparative Steady-State Results

	g	ξ	$\xi^{\lambda/g}$	w_S/w_N
$L_S \uparrow$	\uparrow	\uparrow	\uparrow	\uparrow or \downarrow
$b \downarrow$	\uparrow	\uparrow	\uparrow	\uparrow
$\lambda \uparrow$	\uparrow	\uparrow	\downarrow	\uparrow

NOTES: \uparrow indicates an increase, \downarrow indicates a decrease, L_S is South’s allocation of labor to product-cycle goods, b is imitation labor requirement parameter, λ is time vs. imitation-cost trade-off rate, g is growth rate, ξ is North–South technology gap, $\xi^{\lambda/g}$ is time-dependent component of imitation cost.

In this subsection, we only explain in detail the results concerning w_S/w_N , as it is the most interesting. In the next section, we discuss the effects of an increase in the learning capability λ of the South.

There are three effects of an increase in L_S on w_S/w_N :

(I) Direct effect: An increase in total allocation of labor L_S lowers w_S/w_N in the same way as in Krugman (1979).

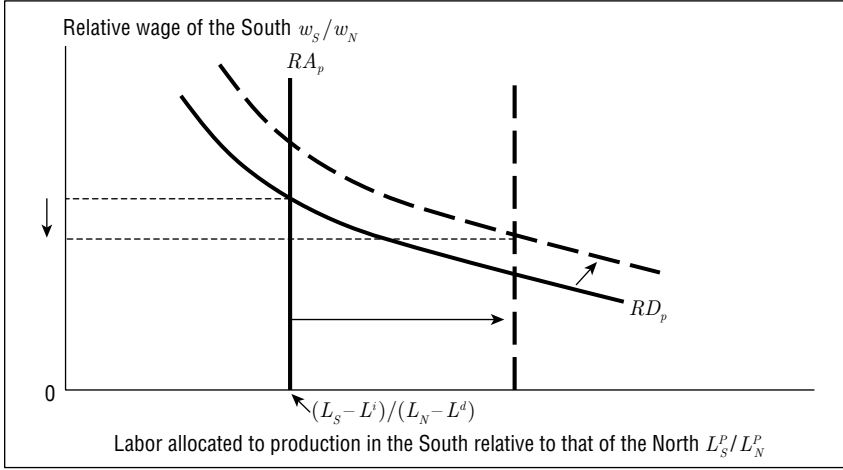
(II) Indirect effect from g : An increase in g lowers the allocation of labor to production in both the North and the South. This effect is ambiguous, but when $\xi^{\lambda/g}$ is sufficiently small, it is negative (i.e., an increase in g lowers w_S/w_N).¹¹

(III) Indirect effect from ξ : An increase in ξ increases the fraction of goods produced in the South but lowers the fraction of goods produced by the North, thereby increasing the demand for production labor in the South and reducing the demand for production labor in the North, pushing up w_S/w_N . The effect becomes larger as ξ increases.

¹⁰ An increase in λ shifts SS to the right and raises g and ξ . From equation 23, since g increases, $\xi^{\lambda/g}$ must be lower; as ξ is larger, λ/g must be larger to make $\xi^{\lambda/g}$ smaller. An increase in L_S shifts SS up, resulting in higher g and ξ . From equation 23, it is clear that $\xi^{\lambda/g}$ must increase too.

¹¹ In the extreme case that $\xi^{\lambda/g} \rightarrow 0$, the effect of g on the denominator of equation 24 approaches zero.

Figure 3: Effects of Increase in Southern Labor Allocation When L_S Is Small



NOTE: These are the effects of an increase in L_S when $h_S < h_N \theta$.

The three effects are clearly depicted in Figure 3. The solid RA_p curve shows the labor allocated to production in the South relative to that in the North. It is represented by

$$\frac{L_S^p}{L_N^p} = \frac{L_S - L^i}{L_N - L^d},$$

where $L^i = bg\xi^{\lambda/g}$ and $L^d = ag$. The solid RD_p curve shows the demand for production labor in the South relative to that in the North. It is represented by

$$\frac{L_S^p}{L_N^p} = \left(\frac{w_S}{w_N} \right)^{-\varepsilon} \left(\frac{\xi}{1-\xi} \right),$$

which follows directly from equation 24.

Effect I shifts RA_p to the right as L_S increases. Effect II shifts RA_p to the right if an increase in g raises $(L_S - L^i)/(L_N - L^d)$, which will be true when $\xi^{\lambda/g}$ is sufficiently small. Effect III shifts RD_p to the right (and its effect increases with ξ).¹² First of all, we find the sufficient condition for an increase in L_S to lower w_S/w_N . We make use of the NN curve (equation 22) and SS curve (equation 23) to substitute for the terms $L_N - ag$ and $L_S - bg\xi^{\lambda/g}$, respectively, in equation 24:

¹² This is so because $d[\xi/(1-\xi)]/d\xi = 1/[(1-\xi)^2]$, which increases with ξ .

$$(25) \quad \frac{w_S}{w_N} = \left[\frac{a}{b} \left(\frac{\xi^{1-\frac{\lambda}{g}}}{1 - \xi^{1+\frac{\rho}{g}}} \right) \right]^{1-\alpha}.$$

From this equation, and defining $\theta(h_N, \lambda) = \{[\lambda - (1-\alpha)h_N]/(\lambda + \rho)\}^{\lambda/\rho}$, we obtain

Result 1 For given $\lambda > r$, if h_S is sufficiently small relative to h_N so that $h_S < h_N \theta$, then w_S/w_N falls as L_S increases.

Proof See Appendix B.

When L_S increases, g and ξ both increase. As shown in Figure 3, effect I always shifts the relative supply curve RA_p to the right. Effect II might shift RA_p to the left or right, depending on the magnitude of $\xi^{\lambda/g}$. If $\xi^{\lambda/g}$ is sufficiently small (which is true when h_S is small), effect II shifts RA_p to the right. Effect III always shifts the relative demand curve RD_p to the right, but its effect is small when ξ is small (which is true when h_S is small). Therefore, when h_S is sufficiently small relative to h_N , the combined effects of I and II dominate effect III, lowering the equilibrium w_S/w_N , as shown in Figure 3.

The intuition for this result is: When L_S is sufficiently small given L_N , the fraction of goods produced by the South, ξ , and the rate of innovation, g , are both relatively small. In this case, an increase in L_S leads to a higher percentage increase in the relative supply of labor for production (because of the small g) than the percentage increase in the relative demand of labor for production (because of the small ξ). Thus, relative wage w_S/w_N decreases.

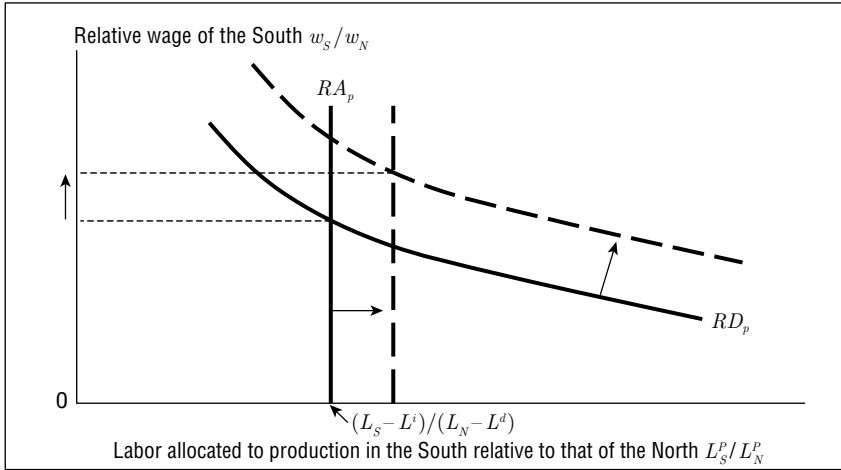
Next, we find the sufficient condition for w_S/w_N to increase when L_S increases. Once again, making use of equation 25, and defining $\Gamma(h_N, \lambda) \equiv [h_N + \alpha\rho/(1-\alpha)] [\lambda/(\lambda + \rho)]^{[\lambda - (1-\alpha)h_N]/[(1-\alpha)h_N + \rho]}$, we obtain

Result 2 For given λ , if h_S is sufficiently large relative to h_N so that $h_S > \Gamma(h_N, \lambda)$, then w_S/w_N rises as L_S increases.

Proof See Appendix C.

Since $\xi^{\lambda/g}$ (an indicator of the cost of imitation) increases with L_S in equilibrium, when h_S is large, $\xi^{\lambda/g}$ is also large, so that effect II shifts RA_p to the left. Moreover, effect III shifts RD_p to the right, and its effect is sufficiently strong when ξ is sufficiently large. As before, effect I shifts the RA_p curve to the right, but its effect is (partially) offset by effect II, as shown in Figure 4. In this case, the combined effects of II and III dominate that of effect I, raising the equilibrium w_S/w_N .

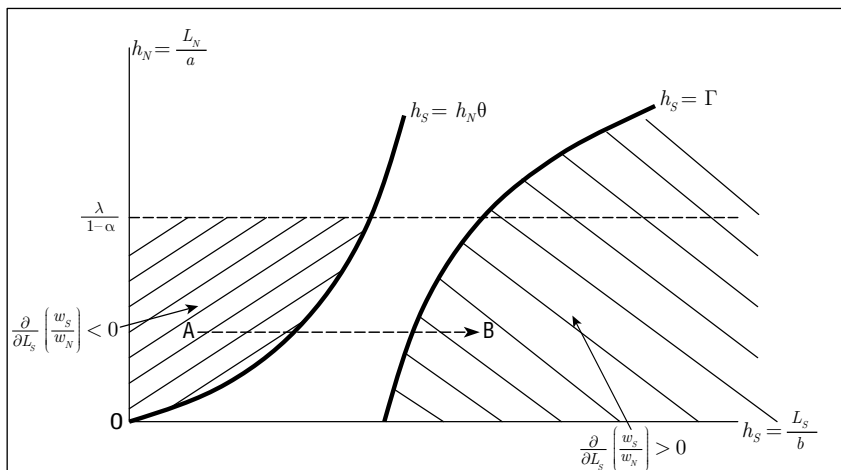
Figure 4: Effects of Increase in Southern Labor Allocation When L_S Is Large



NOTE: These are the effects of an increase in L_S when $h_S > \Gamma$.

The intuition for this result is: When L_S is sufficiently large given L_N , the fraction of goods produced by the South, ξ , and the rate of innovation, g , are both relatively large. In this case, an increase in L_S leads to a lower percentage increase in the relative supply of labor for production (because of the large g) than the percentage increase in the relative demand of labor for production (because of the large ξ). Thus, the relative wage w_S/w_N increases.

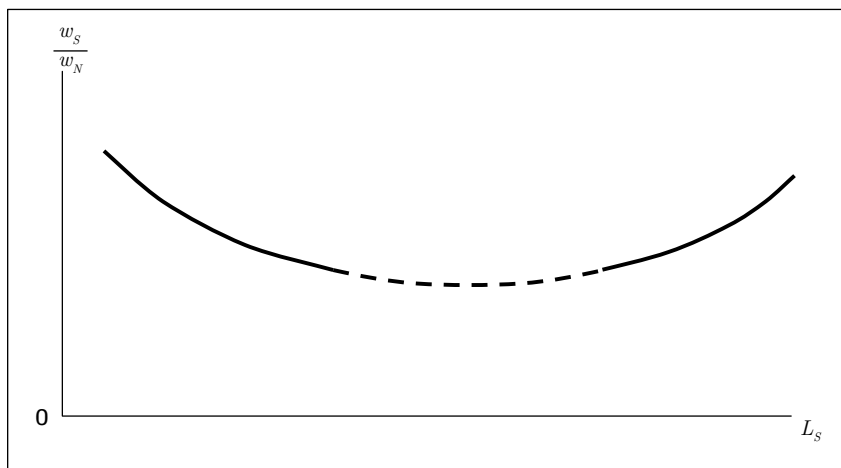
Figure 5 summarizes Results 1 and 2. For a given value of h_N , starting from a point where L_S is small, an increase in L_S gradually moves the world from a zone where $\partial(w_S/w_N)/\partial L_S < 0$ to a zone where $\partial(w_S/w_N)/\partial L_S > 0$. In other words, in the initial stage of the South's integration with the North, when L_S is small, increases in L_S tend to lower the relative wage of the South. As L_S increases further, a point will be reached such that increases in L_S tend to raise the relative wage of the South. In the first zone (e.g., point A), in the initial stage of integration, an increase in L_S leads to a larger fraction of goods being produced by the low-cost region. Therefore, the average price of goods is lower than before, everything else being equal. In addition, Northern workers earn higher wages relative to Southern workers.

Figure 5: The Non-Monotonic Effect of L_S on w_S/w_N 

NOTE: For given value of h_N , as h_S increases so that the world moves from point A to point B, $\frac{\partial}{\partial L_S} \left(\frac{w_S}{w_N} \right)$ switches sign from negative to positive.

Thus, their real wage must increase. Moreover, the rate of innovation is faster, making more goods available to consumers. All three factors contribute to higher welfare for Northern workers. However, at the later stage of the South's integration with the North, when L_S is sufficiently large so that the world is in the second zone (e.g., point B), increases in L_S lead to a higher relative wage for the South. By the same logic as before, it is clear that Southern workers are better off as integration deepens at this stage. The Northern relative wage is lower. However, the North can still gain from further integration, since the average price of goods is cheaper, and the rate of innovation is faster.

Figure 6 summarizes the non-monotonic effect of an increase in L_S on w_S/w_N .

Figure 6: Effect of Deepening of Globalization on Relative Wage of South

Increase in Learning Capability of South

We can think of the increase in λ as an increase in the learning capability of the South in the sense that they learn to imitate faster, or that the learning curve is steeper.

Result 3 An increase in λ leads to increases in g , ξ , and w_S/w_N .

Proof From the results in Table 2, an increase in λ leads to increases in g and ξ but a decrease in $\xi^{\lambda/g}$. (See also footnote 10 for the derivation.) From equation 25, it follows that w_S/w_N increases unambiguously •

The intuition is: An increase in λ lowers $\xi^{\lambda/g}$, a component of the cost of imitation that depends on the time to imitate. Hence, Southern firms imitate more goods at each date, and ξ increases. Since an increase in ξ encourages more firms in the North to innovate, g also increases, according to equation 22. Moreover, since λ/g also increases (according to footnote 10), we conclude from equation 25 that effect II is always dominated by effect III, leading to an increase in w_S/w_N . (There is no effect I.)

Therefore, an increase in the fraction of goods produced by the South through an improvement in the imitative capability of the South, rather than an increase in the allocation of labor, would unambiguously increase the relative wage of the South and thus improve the welfare of the Southern workers.

Let us summarize our main results. Analyzed from the perspective of product-cycle theory, globalization of production resulting from trade liberalization between the North and the South and imitation of Northern technology by the South would increase growth of the North. In the initial stage of globalization of production, deeper globalization unambiguously improves the welfare of skilled labor in the North, though welfare of Southern skilled labor may still increase. In the later stage of production globalization, deeper globalization of production unambiguously improves the welfare of skilled labor in the South, though welfare of Northern skilled labor may still improve. This is caused by the fact that an increase in the allocation of Southern skilled labor that participates in the product cycle has a non-monotonic impact on the wage of Southern skilled labor relative to that of the North.

4. CONCLUSION AND CAVEATS

Analyzed from the perspective of product-cycle theory, globalization of production resulting from trade liberalization between the North and the South and imitation of Northern technology by the South would increase the rate of innovation and growth of the North. However, an increase in the South's participation in the product cycle can lead to a non-monotonic effect on the wage of Southern skilled labor relative to that of the North. In the initial stage of the South's participation in the international product cycle, when the cost of telecommunications is relatively high, the South's allocation of skilled labor is small. An increase in the allocation of Southern skilled labor to product-cycle goods caused by a decrease in the cost of telecommunications lowers the relative wage of the South. Eventually, however, as the South's allocation of skilled labor in the product cycle gets sufficiently

large, the relative wage of the South increases as its skilled labor allocation increases. Thus, in the initial stage of the South's participation in the product cycle, the North unambiguously gains from deeper globalization of production due to the increase in real wages as well as the faster rate of innovation. In the later stage of the South's participation in the product cycle, the South unambiguously gains from deeper globalization of production for the same reason. However, it does not mean that the South necessarily loses in the initial stage or the North necessarily loses in the later stage. Both regions can gain from deeper globalization of production as a higher fraction of goods are produced in the low-cost South and as the rate of innovation increases so that a larger variety of goods are available at each date.

In any case, Southern skilled labor necessarily gains from deeper globalization of production by improving its imitation capability through learning to imitate faster, as this unambiguously increases the Southern relative wage as well as enhances the rate of innovation.

For further research, we can endogenize a firm's decision to imitate or innovate a product, possibly assuming the capability to innovate depends positively on the experience in imitation. It will be interesting to see how our results change with these modifications.

APPENDIX A

Proof that NN is upward sloping

Bear in mind that $0 < \xi < 1$. We compute

$$\frac{\partial f}{\partial \xi} = \frac{1}{(1-\xi)^2} \{-(1-\xi)\left(\frac{\rho}{g} + 1\right)\xi^{\frac{\rho}{g}} + (1-\xi^{\frac{\rho+1}{g}})\} = \frac{1}{(1-\xi)^2} \left\{ \left(\frac{\rho}{g}\right)\xi^{\frac{\rho}{g}+1} + 1 - \left(\frac{\rho}{g} + 1\right)\xi^{\frac{\rho}{g}} \right\}.$$

Define the expression inside the braces as $h(\xi, g)$. Thus,

$$\frac{\partial f}{\partial \xi} = \frac{1}{(1-\xi)^2} h(\xi, g). \text{ It is clear that } h(\xi, g) = 0 \text{ at } \xi = 1, \text{ for any } g. \text{ Moreover,}$$

we compute $\frac{\partial h}{\partial \xi} = \left(\frac{\rho}{g}\right)\xi^{\frac{\rho}{g}-1}\left(\frac{\rho}{g} + 1\right) - \left(\frac{\rho}{g} + 1\right)\left(\frac{\rho}{g}\right)\xi^{\frac{\rho}{g}-1}$, which is less than zero since

$\xi < 1$. Therefore, $h(\xi, g)$ increases as ξ decreases, for any given g . Accordingly, as long as $0 < \xi < 1$, it must be true that $h(\xi, g) > 0$ for any given g . Since

$$\frac{\partial f}{\partial \xi} = \frac{1}{(1-\xi)^2} h(\xi, g), \text{ we have } \frac{\partial f}{\partial \xi} > 0 \text{ for any given } g, \text{ as long as } 0 < \xi < 1.$$

APPENDIX B

Proof of Result 1

From equation 22, we see that g increases as ξ increases in order to maintain Northern market equilibrium. Therefore, $\xi = 0$ and $\xi \rightarrow 1$ define the lower and upper limit, respectively, of the value that g can take in the steady state. It can be shown that the minimum g is found from setting $\xi = 0$ in equation 22 and solving for g : $g_{min} = (1-\alpha)h_N - \alpha\rho$. The maximum g is found from solving for g in equation 22 as $\xi \rightarrow 1$: $g_{max} = (1-\alpha)h_N$.

From Figure 2 and Table 2, an increase in L_S raises both g and ξ .

Therefore, the sufficient conditions for $\frac{w_S}{w_N}$ to decrease as L_S increases are

(a) $\frac{\partial RHS}{\partial \xi} < 0$ and (b) $\frac{\partial RHS}{\partial g} < 0$ in equation 25. The necessary and sufficient

conditions for (a) and (b), respectively, are:

$$\xi > \left(\frac{\lambda - g}{\lambda + \rho} \right)^{\frac{g}{g+\rho}} \quad \text{and} \quad \xi > \left(\frac{\lambda}{\lambda + \rho} \right)^{\frac{g}{g+\rho}}.$$

The first of the above conditions implies the second one. Of course, h_N has to be sufficiently small relative to λ to ensure $\lambda > g$, and a sufficient condition for this is $\lambda - g_{\max} > 0$. This implies that $h_N < \lambda \left(\frac{1}{1-\alpha} \right)$.

It is shown below that $\frac{h_S}{h_N} = (\xi^{\lambda/g})_{\max}$: From equation 23,

$$\frac{1-\alpha}{\alpha} (h_S - g \xi^{\lambda/g}) = (g + \rho) \xi^{\lambda/g}, \quad \text{which implies}$$

$$\frac{h_S}{\xi^{\lambda/g}} - g = \frac{(g+\rho)}{\frac{1-\alpha}{\alpha}} \Rightarrow \frac{h_S}{\xi^{\lambda/g}} = \frac{\frac{g}{\alpha} + \rho}{\frac{1-\alpha}{\alpha}} \Rightarrow (\xi^{\lambda/g})_{\max} = \frac{\frac{1-\alpha}{\alpha}}{\frac{g}{\alpha} + \rho} h_S = \frac{h_S}{h_N}. \quad \text{Therefore,}$$

$h_S < h_N \theta$ implies

$$\begin{aligned} \frac{h_S}{h_N} &< \left[\frac{\lambda - (1-\alpha)h_N}{\lambda + \rho} \right]^{\frac{\lambda}{\rho}} \\ &\Rightarrow \xi^{\lambda/g} < \left(\frac{\lambda - g_{\max}}{\lambda + \rho} \right)^{\frac{\lambda}{\rho}} < \left(\frac{\lambda - g}{\lambda + \rho} \right)^{\frac{\lambda}{\rho}} < \left(\frac{\lambda - g}{\lambda + \rho} \right)^{\frac{\lambda}{g+\rho}} \\ &\Rightarrow \xi < \left(\frac{\lambda - g}{\lambda + \rho} \right)^{\frac{g}{g+\rho}} \bullet \end{aligned}$$

APPENDIX C

Proof of Result 2

Since an increase in L_S raises both g and ξ , the sufficient conditions for $\frac{w_S}{w_N}$ to increase are (a) $\frac{\partial RHS}{\partial \xi} > 0$ and (b) $\frac{\partial RHS}{\partial g} > 0$ in equation 25. It turns out that the necessary and sufficient conditions for (a) and (b), respectively, are

$$\xi > \left(\frac{\lambda - g}{\lambda + \rho} \right)^{\frac{g}{g+\rho}} \quad \text{and} \quad \xi > \left(\frac{\lambda}{\lambda + \rho} \right)^{\frac{g}{g+\rho}}.$$

It is obvious that the second condition above implies the first. From

the proof in Appendix B, $h_S / \xi^{\lambda/g} = \left(\frac{g}{\alpha} + \rho \right) / \left(\frac{1-\alpha}{\alpha} \right)$, which implies $(\xi^{\lambda/g})_{\min} = \left[\left(\frac{1-\alpha}{\alpha} \right) / \left(\frac{g_{\max}}{\alpha} + \rho \right) \right] h_S = h_S / \left(h_N + \frac{\alpha \rho}{1-\alpha} \right)$. Therefore,

$$\begin{aligned} h_S &> \Gamma \\ &\Rightarrow \xi^{\lambda/g} > \left(\frac{\lambda}{\lambda + \rho} \right)^{\lambda / (g_{\max} + \rho)} > \left(\frac{\lambda}{\lambda + \rho} \right)^{\frac{\lambda - g}{g+\rho}} \\ &\Rightarrow \xi > \left(\frac{\lambda}{\lambda + \rho} \right)^{\frac{g}{g+\rho}} \bullet \end{aligned}$$

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