Globalization of Production and the Technology Transfer Paradox

by

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Abstract

This paper develops a growth model aimed at understanding the effects of globalization of production on rate of innovation, distribution of labor income between the North and South and welfare of 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. When the South's participation in the product cycle is not too deep, further deepening of globalization of production lowers the wage of Southern labor relative to that of its counterpart in the North. This poses a technology transfer paradox similar to that discovered by Jones and Ruffin (2008): an increase in the uncompensated technology transfer from the North to the South makes the North better off. However, a point will be reached where further deepening of globalization leads to increases in relative wage of the South. For this reason, the North would eventually lose from uncompensated technology transfer as globalization deepens.

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Globalization of Production and the Technology Transfer Paradox

1 Introduction

One of the most remarkable developments in international trade in the last thirty years was the globalization of production of differentiated manufactured goods. Differentiated manufactured goods can be broadly defined as ones that emerged as a result of modern technology such as the invention of electricity as well as 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, paper and iron and steel. The 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 South as well as technological advancement in telecommunications led to the transfer of production of some of these differentiated goods to the less developed countries (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 TV, microcomputers, mobile phones and integrated circuits. This, we argue, reflects the globalization of production of differentiated goods we mentioned above. We are interested in the impacts of such globalization of production on global growth, income distribution and living standards in the North and the South.[1]

International technology diffusion and trade 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, so as 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 analyze the interaction between the technologically more advanced economies such as the US and Europe and the less developed economies (LDCs)

[1] The time path of exports of differentiated goods from China follows a similar pattern. For example, the number of units exported in 2000 divided by the number of units exported in 1987 for air conditioning machines is 833. The number of units exported in 2000 divided by the number of units exported in 1984 for household laundry equipment and color TV are, respectively, 195 and 189. In value terms, the value exported in 2000 divided by the value exported in 1985 for air conditioning machines and color TV are, respectively, 555 and 724.

such as China and India, we can understand better how the increased participation of these LDCs 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 for our analysis. We assume that technology always originates from the North and then diffuses from the North to the South through costly imitation by Southern firms. We ask: Who gain and who lose from this on-going drama of innovation and imitation? Among our findings is that there is a technology transfer paradox similar to the one discovered by Jones and Ruffin (2008).[2] The paradox is that an increase in the extent of uncompensated technology transfer from the North to the South makes the North better off.

Jones and Ruffin (2008) found that in a two-country multi-good static Ricardian world where the high-wage country (North) has superior technology in all goods over a low-wage country (South), the former can actually gain from an uncompensated transfer of its best technology to the latter, provided that the countries share the same Cobb-Douglas preferences, and the relative country size falls within a certain range. More paradoxically, this occurs when the original best industry in the high-wage country is completely wiped out. The original best sector turns from being an export good with no foreign production to being an import good with no domestic production. Thus, drastic change in comparative advantage can benefit a country. In this paper, we adopt a dynamic general equilibrium product cycle model with on-going innovation and uncompensated technology transfer (i.e. imitation) from the high-wage country to the low-wage country. Like Jones and Ruffin, whenever a good is imitated by the South, it ceases to be produced by the North, and the North turns from an exporter to an importer of the good. Country sizes can matter too, as our paradox occurs only when the labor supply in the South is sufficiently small compared with that of the North.

One stimulation for this line of research on how North-South technology transfer affects relative wage and welfare of the North and South is from Samuelson (2004). Using a Ricardian model, he argued that as the South's comparative advantage changes so that it begins to export the goods that the North used to have comparative advantage in, then as the South's productivity in these goods improve, at some point the North is going to suffer permanent loss from free trade. His main point is to give an example whereby free trade globalization can be harmful to the North. Along similar vein, Gomory and Baumol (2000) argued that, under free trade, while the North gains by helping a very underdeveloped South (which has few industries) to acquire technologies of new industries and improve productivity, it loses when the South acquires the technologies of too many new industries. Their model is quite different from ours in the sense that they emphasize economies of scale and the existence of multiple equilibria. Nonetheless, there is an interesting similarity with

[2]Similar but less striking findings are found in Beladi, Jones and Marjit (1997), Kemp and Shimomura (1988) and Ruffin and Jones (2007), which is a two-commodity version of Jones and Ruffin (forthcoming).

this paper: In this paper, we also find that the North unambiguously gains from uncompensated technology transfer to the South when the South has so far acquired relatively smaller fraction of new industries, but the North will lose from that when the South has already acquired a large fraction of new industries.

Krugman (1979) was among the first to develop a dynamic general equilibrium model of the North-South product cycle to study the effects of policies on distribution of labor income and 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 production transfer from the North to the South are autonomous, he shows that an increase in the rate of (uncompensated) production transfer raises the relative wage of the South. (In fact, the North may be hurt as a result.) Thus, there is no technology transfer paradox as mentioned above.[3] Dollar (1986) introduces capital and capital mobility in a Krugman-type model and arrives at similar conclusions.

Grossman and Helpman (1991b) analyze the product cycle by means of an expanding-variety-type innovation-driven endogenous growth model in which the rate of product innovation and rate of imitation are endogenized. They assume Northern firms engage in costly product innovation and Southern firms engage in costly imitation of North-developed products. They find that an increase in the extent of uncompensated technology transfer to the South resulting from an increase in the supply of labor in the South raises its relative wage. Like Krugman, an increase in technology transfer makes the South better off, and may or may not hurt the North.[4] Again, there is no technology transfer paradox. Glass and Saggi (2001) study outsourcing from the North to the South in a quality-ladder product cycle model similar to that of Grossman and Helpman (1991a), and they find that changes that result in faster rate of outsourcing always reduce the relative wage of the North. Yet, what they focus on is compensated technology transfer through outsourcing.

We are interested in understanding the effects of increased participation of the South in global production, which is caused by trade liberalization, then followed by increases in the supply of Southern (skilled) workers that participate in the product cycle. These skilled workers are tech-

[3] An increase in South's labor supply raises the relative wage of the North in Krugman's model. However, it does not constitute an increase in the extent of uncompensated technology transfer as the rate of technology transfer stays the same.

[4] In another paper, which features a "quality-ladder" innovation-driven growth model, Grossman and Helpman (1991a) analyze a more complex pattern of innovation and imitation. The "inefficient follower" case in their model yields similar results as in Grossman and Helpman (1991b). The "efficient follower" case generates a number of ambiguous results, including ambiguous effect of labor supply on the relative wage of a country.

In Segerstrom, Anant and Dinopoulos's (1990) product cycle model, innovation also 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 one.

nicians and engineers, who can work in either production or imitation activity. In the rest of the paper, "labor" always means skilled labor. The supply of Southern (skilled) labor increases gradually as the South develops because education of the work force is a gradual process. Here is the background of our model. The economies of the North and the South each consists of an agricultural sector and a manufacturing sector. The manufacturing sector of each country consists of a traditional good and possibly some 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 produce the differentiated goods. Therefore, no Southern labor was involved in production of differentiated goods. Hence, before trade liberalization, the South's manufacturing sector consists of the traditional good only. With no trade between the two regions, Northern firms produced the agricultural good, the traditional good and differentiated goods and sold to the North only, while Southern firms produced the agricultural good, and the traditional good and sold to the South only. However, we do not model the agricultural and traditional good sectors in this paper for simplicity.

Immediately after trade liberalization, the North exports differentiated goods to the South while the South exports agricultural and traditional good to North. After the North exports differentiated goods to the South, the latter eventually learns to imitate and produce some of them. In steady state equilibrium, Southern firms imitate some but not all of the differentiated goods, produce them and sell them to both the South and 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.

No Southern workers were involved in the production of differentiated goods before trade liberalization because no Southern firms had exposure to Northern technology. But even after trade liberalization, and the South imitates some differentiated goods, the extent of globalization of production is limited by the supply of (skilled) workers in the South. The supply is limited at any given date possibly because education of the work force is a gradual process. As the South develops, the supply of South's (skilled) labor increases.

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 Southern supply of labor; (ii) an increase in South's (skilled) labor supply as the South develops, leading to increased imitation of Northern goods. We shall call this second, more gradual, transition the deepening of globalization of production.

We first compare the autarky equilibrium with the free trade equilibrium keeping the supply of Southern labor L_S constant. This captures the trade liberalization stage of globalization of production. Then, assuming that there is free trade, we analyze the effects of changes in L_S on the rate of innovation, rate of imitation, income distribution between workers in the two regions, and welfare of labor in the two regions. This captures the deepening of globalization of production. The model we develop is an endogenous product cycle model inspired by Grossman and Helpman (1991b). One important innovation in this paper is that the time it takes to imitate a product is assumed to depend negatively on the quantity of resources devoted to imitation. This assumption is justified by the observation that the longer it takes, the less 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 (1982), and Teece (1976, 1977).[5] It will be seen that the incorporation of such an essential characteristic of the imitation cost function would have crucial impacts on comparative steady-states results. In particular, it gives rise to the "technology transfer paradox" similar to that discovered by Jones and Ruffin (2008), and non-monotonic effects of globalization of production on Northern and Southern welfare.

Here are 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 higher rate of innovation, higher rate of imitation and higher wage of Southern labor relative to that of the North, given that the labor is essential for both production and research in each country. Third, the labor requirement for imitating a product is higher, the larger is L_S. This has interesting consequence: As globalization of production deepens after trade liberalization, while the Southern supply of labor is still relatively small, an increase in Southern labor supply will lower the wage of the South relative to that of the North. This implies that an increase in the extent of uncompensated technology transfer from the North to the South makes the North better off in the initial stage of globalization of production, because growth becomes faster and the North's relative wage rises as globalization deepens. This poses a technology transfer paradox: Although the North is uncompensated for the technology transfers to the South, it is better off as a result of such transfers.

Eventually, however, as the labor supply in the South becomes sufficiently large, the relative wage of its labor increases as globalization of production deepens. For this reason, the North would eventually lose from increases in the extent of uncompensated technology transfer in the later stage of globalization. The key factor in determining the direction of the effect of L_S on relative wage is whether the (endogenous) increase in quantity of labor allocated to production dominates the (endogenous) increase in demand for labor in production. When L_S is small, the former effect dominates the latter. When L_S is sufficiently large, the reverse is true.

[5] Although Teece (1976a) 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.

In Section 2, we lay down the main body of the imitation model. In Section 3, we solve for the steady-state equilibrium, and in Section 4 we carry out comparative steady-state analyses. Section 5 concludes with a discussion on the caveats of the model.

2 The Imitation Model

We shall 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 4, we compute the autarky equilibrium in the North and compare the autarky and free trade equilibria.

So, in sections 2 and 3, 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 shall call this factor input 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 shall again tell the story backwards. We first assume that goods are continuously being developed, and consumers have perfect foresight about the number of goods available at each date. They are offered the price of each variety at each date. 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 or not to enter into the market. Free entry implies that, in equilibrium, all innovators and imitators earn zero economic profit. Thus, the equilibrium balanced growth rate is determined.

2.1 The Demand for goods

Following Grossman and Helpman (1991b), we assume that a representative agent in the economy (or, alternatively, one representative agent in each country in a two country world) 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 function[6]

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

subject to (i) the intertemporal budget constraint[7]

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

and (ii) instantaneous utility function [8]

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

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 (1), (2) and (3) can be broken down into an intra-temporal 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 intra-temporal optimization on the demand side) and the prices of goods $p(z)$ (determined by intra-temporal optimization on the supply side).

The intra-temporal consumer optimization problem is

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

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,

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

[6] 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 (1) is a special case as $\sigma \rightarrow 1$ leads to the same qualitative conclusion.

[7] The 'flow' version of this 'stock' equation is $I(t) - E(t) + rA(t) = \dot{A}(t)$.

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

where $\epsilon = \frac{1}{1-\alpha} > 1$ and $0 \leq \alpha \leq 1$. The parameter $\epsilon = \frac{1}{1-\alpha}$ 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.

2.2 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 separability 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

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

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 mark-up pricing rule

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

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

Using the results of the intra-temporal optimization problem, the first order condition for the intertemporal optimization is:

$$r = \rho + \frac{\dot{E}}{E}$$

The above equation states that 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 $\frac{\dot{n}}{n} \equiv g$ in the steady state, and normalize by setting the price of a new firm (or the value of a new blueprint) equal to a constant in all periods, i.e. $\frac{\dot{E}}{E} = \frac{\dot{n}}{n}$. We can then re-write the above equation as

$$r = \rho + g \tag{8}$$

2.3 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 demand function (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 supplies of labor in South and in North are assumed to be exogenous, denoted by L_S and L_N respectively.

On the balanced growth path that we analyze, the steady state is characterized by $g \equiv \frac{\dot{n}}{n} = \frac{\dot{n}_S}{n_S} = \frac{\dot{w}_N}{w_N} = \frac{\dot{w}_S}{w_S} = \frac{\dot{E}}{E} = \frac{\dot{E}_S}{E_S} = \frac{\dot{E}_N}{E_N}$, so that w_N, w_S , E, E_S, E_N, n and n_S are in constant ratio with each other over time. Here, $E = E_S + E_N$, where E, E_S and E_N are aggregate instantaneous consumption expenditure in the world, the South and the North respectively. It can be deduced from (5) to (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.[9]

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 up-front cost, and then earns the opportunity to make a constant stream of profits at each date in 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 (7), so that the price of a Northern good is

$$p_N = \frac{w_N}{\alpha}. \tag{9}$$

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 $\frac{w_S}{\alpha} < w_N$, i.e. $w_S < \alpha w_N$, then 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

[9] Differentiating (3) along the steady-state path, using $\frac{\dot{n}}{n} = \frac{\dot{p}}{p} = \frac{\dot{E}}{E} = g$, and (5), (9) and (10), we obtain the world growth rate of welfare:

$$\frac{\dot{U}}{U} = (\frac{1-\alpha}{\alpha})g$$

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

will set its price at the unconstrained profit-maximizing level, viz.,

$$p_S = \frac{w_S}{\alpha} \tag{10}$$

(b) Narrow-gap case

If $\frac{w_S}{\alpha} > w_N$, i.e. $w_S > \alpha w_N$, then 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 Grossman and Helpman (1991b).

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

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

2.3.1 Imitation Activity in the South

We assume, as in Romer (1990), that the knowledge stock in 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 that 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

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

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 labor requirement for imitation with respect to the time it takes to imitate (it increases with learning capability of Southern firms); $K_S(t_d)$ is the knowledge stock at date t_d, which the imitator treats as given. To obtain a steady state consistent with constant allocations of resource 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) $be^{-\lambda(t-t_d)}$, 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, 1991b 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 (12), since $w_S(t_d)/n_S(t_d)$ is predetermined at t_d, and it is a constant in steady state, imitation cost decreases with the time it takes to imitate at an exponential rate of $\lambda > 0$, while (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 on Figure 1. As will be elaborated later, free entry ensures that profits are equal to zero.[10]

2.3.2 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 focusses on changes in Southern supply of labor and imitation capability. The cost of each act of innovation (product development) by a Northern firm at date t_d is assumed to be

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

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 subsection 2.3.1. To obtain a steady state, we again proxy the knowledge stock in the North at date t by $n(t)$, i.e. $K(t) = n(t), \forall t$.

2.3.3 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

[10] There is time-cost trade-off only when $\lambda > r$ since only then will the decline in labor requirement in imitation 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 $b\frac{w_S}{w_N} > \frac{\pi}{r}$, which is equivalent to $b > \frac{1}{\rho+g}\left(\frac{1-\alpha}{\alpha}\right)\left(L_S - bg\xi^{\frac{\lambda}{g}}\right)$ so that the PDV of profits from imitation is lower than cost of imitation at the date the product is developed.

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 $\frac{\dot{n}}{n} = \frac{\dot{n}_S}{n_S} = g$,

$$\xi \equiv \frac{n_S}{n} = e^{-g(t_S - t_d)} = e^{-gT} \tag{14}$$

where $T \equiv t_S - t_d$ is the *equilibrium* length of the product cycle. 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, in order to compute the PDV at date t_d of a sum at t_S, a factor of $e^{-r(t_S - t_d)} = \xi^{\frac{r}{g}}$ is used.[11]

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

$$C_i = b\frac{w_S}{n_S}\xi^{\frac{\lambda}{g}} \qquad \text{at any date.} \tag{15}$$

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

2.4 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:

$$\frac{\pi_S}{r} = V_S = b\frac{w_S}{n_S}\xi^{\frac{\lambda}{g}}. \tag{16}$$

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 $V_N e^{-r(t_S - t_d)} = V_N \xi^{\frac{r}{g}}$. Therefore, the zero profit condition of a Northern firm is

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

[11] By definition, $n_S(t_S) = n(t_d) = n_0 e^{g(t_d - t_0)}$ and $n(t_S) = n_0 e^{g(t_S - t_0)}$, where n_0 is the value of n at time t_0. This implies that $\xi = \frac{n_S(t_S)}{n(t_S)} = e^{-g(t_S - t_d)}$ and this is true for all t_S, which is (14). Moreover, $\xi^{\frac{r}{g}} = (\frac{n_S}{n})^{\frac{r}{g}} = e^{-r(t_S - t_d)}$. Therefore $\xi^{\frac{r}{g}}$ is the discount factor used to compare profits at the time of imitation with profits at the time of innovation.

2.5 Labor Market Clearing Conditions

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:

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

This implies that

$$\pi_N = (\frac{1-\alpha}{\alpha})\frac{w_N}{n}(\frac{L_N^p}{1-\xi}) \tag{18}$$

where $\frac{L_N^p}{n(1-\xi)}$ 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 mark-up factor $\frac{1-\alpha}{\alpha}$ times the instantaneous wage bill of production labor allocated to that good.

Similarly, labor involved in production in the South is

$$\pi_S = (\frac{1-\alpha}{\alpha})(\frac{w_S}{n_S})L_S^p \tag{19}$$

where $\frac{L_S^p}{n_S}$ 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 $L^d = a\frac{\dot{n}}{n} = ag$, which implies that

$$L_N^p = L_N - ag \tag{20}$$

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

$$L_S^p = L_S - bg\xi^{\frac{\lambda}{g}} \tag{21}$$

3 Steady-state Equilibrium

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

3.1 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 (20), we can substitute for L_N^p in (18). Using the resulting expression, we substitute for π_N in (17), to obtain

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

and, as mentioned before, $\frac{L_N - ag}{n(1-\xi)}$ 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 $1-\xi^{\frac{r}{g}}$. Interest rate r is the discount factor. The term $(\frac{1-\alpha}{\alpha})\left(\frac{L_N - ag}{1-\xi}\right)\frac{w_N}{n}$ is the instantaneous profit expressed as a fixed mark-up of instantaneous production cost. The right hand side (RHS) is the innovation cost. Note that $\frac{w_N}{n}$ 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.

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

where $h_N \equiv \frac{L_N}{a}$ is Northern labor supply in terms of innovative capacity.

Define $f(\xi, g) \equiv \frac{1-\xi^{\frac{r}{g}}}{1-\xi} = \frac{1-\xi^{\frac{\rho}{g}+1}}{1-\xi}$. It can be shown in the Appendix that $\frac{df}{d\xi} > 0$. We can easily see that $\frac{df}{dg} < 0$. In other words, the LHS of the above equation increases with ξ but decreases with g, while the RHS increases with g. By the implicit function theorem, therefore, 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.

It might seem counter-intuitive 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 goods produced in the North, increasing the profit rate of each Northern firm at each date; and (b) a greater ξ means higher rate of capital loss to the innovator due to the faster rate of imitation (i.e. profits are wiped out sooner). It is clear from (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 goods produced by Southern firms (ξ) by a smaller fraction than it raises the discount factor at the time of imitation ($\xi^{\frac{r}{g}}$, which equals $\xi^{\frac{\rho}{g}+1}$), so that effect (a) dominates effect (b), resulting in a net increase in the profit rate of the marginal Northern firm at each date, thereby inducing more entry. It turns out that the restriction "discount dominates growth" ($r > g$), which is true in our model, is crucial to the positive slope of the NN

curve.

Using (21), we can substitute for L_S^p in (19). Using the resulting expression, we substitute for π_S in (16), to obtain

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

where, as mentioned before, $\frac{L_S - bg\xi^{\frac{\lambda}{g}}}{n_S}$ 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 mark-up of instantaneous production cost $(\frac{1-\alpha}{\alpha})\left(L_S - bg\xi^{\frac{\lambda}{g}}\right)(\frac{w_S}{n_S})$. The RHS is the imitation cost. Note also that $\frac{w_S}{n_S}$ 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':

$$(\frac{1-\alpha}{\alpha})(h_S - g\xi^{\frac{\lambda}{g}}) = (\rho + g)\xi^{\frac{\lambda}{g}} \tag{23}$$

where $h_S \equiv \frac{L_S}{b}$ is Southern labor supply in terms of imitative capacity. It follows that (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 (while maintaining the same fraction of goods imitated by the South) implies that more labor is allocated to imitation and less labor allocated to production of each good, but imitation of each good 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 PDV of profits 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 as well as 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.

3.2 Relative Wage

From goods demand equation (11), we obtain $\frac{\pi_S}{\pi_N} = (\frac{w_S}{w_N})^{1-\epsilon}$. From the labor demand equations (18) and (19), we obtain another expression for the same ratio: $\frac{\pi_S}{\pi_N} = (\frac{w_S}{w_N})(\frac{L_S^p}{L_N^p})(\frac{1-\xi}{\xi})$. Therefore, equating the RHS of the last two equations, we obtain

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

The expression makes sense: Given that the labor allocated to innovation in North and labor allocated to imitation in South remain constant, and the fraction of goods produced in North remain unchanged, an increase in L_S or decrease in L_N leads to a decrease in relative wage of the South. Moreover, given L_S, L_N and the rate of innovation g, an autonomous increase in the fraction of goods produced by the South ξ leads to an increase in w_S/w_N, as the relative demand for Southern production labor increases, while the relative supply actually decreases due to the increased cost of imitation, as reflected in the increase in $\xi^{\frac{\lambda}{g}}$.

4 Comparative Steady-states Analysis

As explained in the Introduction, we study two changes: (i) the transition from autarky to globalization for a given (relatively small) supply of labor from the South; and (ii) deepening of globalization caused by an increase in the supply of labor L_S from the South.

4.1 From Autarky to Free Trade

We focus our discussion on the effects on the North. We define autarky in the North as a situation when it is self-sufficient 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) and (18) 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, the extent of participation in the product cycle by the South.

How does trade liberalization affect the rate of growth of the world? From (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 trade liberalization 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 (as the rate of innovation increases), but the price of each good relative to 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 trade liberalization.

As L_S increases after trade liberalization, more goods are imitated by South, and hence globalization of production deepens. In the next subsection, we shall analyze the effects of such a change in depth.

4.2 Deepening of Globalization: an increase in L_S

The effects of changes in L_S, b, and λ on g, ξ, $\xi^{\frac{\lambda}{g}}$ and w_S/w_N are summarized in Table 2. Note that $\xi^{\frac{\lambda}{g}}$ is a measure of the part of imitation cost that accounts for time-cost trade-off. From the table, it is shown that an increase in L_S leads to an increase in g, ξ and $\xi^{\frac{\lambda}{g}}$; an increase in λ raises both g and ξ, but lowers $\xi^{\frac{\lambda}{g}}$.[12] An increase of L_S raises the labor requirement for the imitation of each good 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 crucial impact on Southern wage relative to that of the North.

In this subsection, we only explain in detail the effects of L_S on w_S/w_N, as they are the most interesting ones. In section 4.3, we investigate the welfare effects of changes in L_S. In the section 4.4, we discuss the effects of an increase in the learning capability λ of the South.

From (24), we can deduce that there are three effects of an increase in L_S on w_S/w_N:

(I) Direct effect: given g and ξ, an increase in supply 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 $\xi^{\frac{\lambda}{g}}$ is sufficiently small, it is negative (i.e. an increase in g lowers w_S/w_N).[13]

(III) Indirect effect from ξ: an increase in ξ raises 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.

The three effects are 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 $L^i = bg\xi^{\frac{\lambda}{g}}$ 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

$$\frac{L_S^p}{L_N^p} = (\frac{w_S}{w_N})^{-\epsilon}(\frac{\xi}{1-\xi})$$

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

[13] In the extreme case that $\xi^{\frac{\lambda}{g}} \to 0$, the effect of g on the denominator of (24) approaches zero.

which follows directly from (24).

Effect I shifts RA_p to the right as L_S increases. Effect II shifts RA_p to the right (left) if an increase in g raises (lowers) $\frac{L_S - L^i}{L_N - L^d}$, which will be true when $\xi^{\frac{\lambda}{g}}$ is sufficiently small (large). See footnote 13. Effect III shifts RD_p to the right (and its effect increases with ξ).[14] First of all, we shall find the sufficient condition for an increase in L_S to lower w_S/w_N. We make use of the NN curve (22) and SS curve (23) to substitute for the terms $L_N - ag$ and $L_S - bg\xi^{\frac{\lambda}{g}}$ respectively in (24):

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

It should be borne in mind that we need $w_S/w_N < \alpha$, as stated in the Wide Gap Case in section 2.3.[15] From the above equation, and defining $\theta(h_N, \lambda) = [\frac{\lambda-(1-\alpha)h_N}{\lambda+\rho}]^{\frac{\lambda}{\rho}}$, we obtain

Result 1 *For a given λ (which is greater than r in equilibrium), 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 the Appendix. ■

When L_S increases, g and ξ both increase, as shown in Figure 2. 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 $\xi^{\frac{\lambda}{g}}$. If $\xi^{\frac{\lambda}{g}}$ 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 South, ξ, and 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 for any given relative wage (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 $\Gamma(h_N, \lambda) \equiv (h_N + \frac{\alpha\rho}{1-\alpha})(\frac{\lambda}{\lambda+\rho})^{[\lambda-(1-\alpha)h_N]/[(1-\alpha)h_N+\rho]}$, we obtain

[14] This is so because $\frac{d}{d\xi}(\frac{\xi}{1-\xi}) = \frac{1}{(1-\xi)^2}$, which increases with ξ.

[15] We know there exist combinations of exogenous variables and parameters that satisfy this condition, because, at the very least, we can keep h_S and h_N unchanged while lowering a until the RHS of (24) is less than α.

Result 2 *For a 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 the Appendix. ■

Since $\xi^{\frac{\lambda}{g}}$ (an indicator of the cost of imitation) increases with L_S in equilibrium, when h_S is large, $\xi^{\frac{\lambda}{g}}$ 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.

The intuition for this result is: When L_S is sufficiently large given L_N, the fraction of goods produced by 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 for any given relative wage (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 $\frac{\partial}{\partial L_S}\left(\frac{w_S}{w_N}\right) < 0$ to a zone where $\frac{\partial}{\partial L_S}\left(\frac{w_S}{w_N}\right) > 0$. In other words, in the initial stage of globalization of production, 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 globalization, 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 wage relative to Southern workers. Thus, the purchasing power of their 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. This is the technology transfer paradox.

However, at the later stage of globalization of production, 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 globalization deepens at this stage. Northern relative wage is lower. Numerical simulation, shown in Appendix D, shows that Northern welfare continues to increase with L_S initially, but it eventually declines as globalization further deepens.

The topic panel of Figure 6 summarizes the non-monotonic effect of an increase in L_S on w_S/w_N. Although Results 1 and 2 only demonstrate that the curve is downward sloping when L_S is small and upward sloping when L_S is large, numerical simulation indeed shows that the curve is U-shaped and continuous over the entire range of L_S. Numerical simulation also shows the non-monotonic effect of L_S on welfare per Southern worker Ω_S and welfare per Northern worker Ω_N. Refer to Appendix D for the simulation results. (Appendix D is for the benefits of the referees only, and is not intended to be published for the sake of space.)

4.3 Welfare analysis of deepening of globalization

Defining E_N as the total Northern consumption expenditure at a certain date τ, and making use of (3), (5), (9), (10), we obtain aggregate Northern instantaneous utility at date τ (where the time argument is hereafter omitted for simplicity)

$$\begin{aligned} U_N &= \left\{ (n-n_S) \left[\frac{\left(\frac{w_N}{\alpha}\right)^{-\epsilon} E_N}{(n-n_S)\left(\frac{w_N}{\alpha}\right)^{1-\epsilon} + n_S \left(\frac{w_S}{\alpha}\right)^{1-\epsilon}} \right]^{\alpha} + n_S \left[\frac{\left(\frac{w_S}{\alpha}\right)^{-\epsilon} E_N}{(n-n_S)\left(\frac{w_N}{\alpha}\right)^{1-\epsilon} + n_S \left(\frac{w_S}{\alpha}\right)^{1-\epsilon}} \right]^{\alpha} \right\}^{\frac{1}{\alpha}} \\ &= \left[(n-n_S) \left(\frac{w_N}{\alpha}\right)^{1-\epsilon} + n_S \left(\frac{w_S}{\alpha}\right)^{1-\epsilon} \right]^{\frac{1-\alpha}{\alpha}} E_N \end{aligned}$$

noting that $\epsilon = 1/(1-\alpha)$.

Total instantaneous factor income in the North is equal to $w_N L_N + (n-n_S)\pi_N$; total instantaneous investment expenditure in the North is equal to $w_N ag$. Trade balance implies that investment expenditure plus consumption expenditure must be equal to total income in the North. Therefore, we have

$$\begin{aligned} w_N ag + E_N &= w_N L_N + (n-n_S)\pi_N \\ \implies \quad E_N &= w_N (L_N - ag) + (n-n_S)\pi_N \end{aligned}$$

But (18) implies that $(n-n_S)\pi_N = \left(\frac{1-\alpha}{\alpha}\right) w_N (L_N - ag)$. Therefore,

$$E_N = \frac{1}{\alpha} w_N (L_N - ag)$$

Since all Northern workers are identical, Northern consumption expenditure per Northern worker, denoted by e_N, is

$$e_N = \frac{1}{\alpha} w_N \left(\frac{L_N - ag}{L_N} \right)$$

and instantaneous utility per Northern worker, denoted by u_N, is

$$u_N = \left[(n-n_S) \left(\frac{w_N}{\alpha}\right)^{1-\epsilon} + n_S \left(\frac{w_S}{\alpha}\right)^{1-\epsilon} \right]^{\frac{1-\alpha}{\alpha}} e_N$$

Note that $U_N = L_N u_N$ because U is homogeneous of degree one in the vector of consumption of goods in equation (3).

Substituting for e_N in the above expression, we have, at any date τ,

$$u_N = n^{\frac{1-\alpha}{\alpha}} \left[(1-\xi) + \xi \left(\frac{w_S}{w_N} \right)^{\frac{-\alpha}{1-\alpha}} \right]^{\frac{1-\alpha}{\alpha}} \left(\frac{L_N - ag}{L_N} \right)$$

From (1), we know that welfare of each Northern worker at date 0, which can be any starting date we define, is

$$\Omega_N(0) = \int_0^\infty e^{-\rho\tau} \log u_N(\tau) d\tau$$

If the economy is in steady state from date 0 onwards, then, noting that $n(\tau) = n(0)e^{g\tau}$, while ξ, $\frac{w_S}{w_N}$, and g are constant over time, we have

$$\begin{aligned} \Omega_N(0) &= \int_0^\infty e^{-\rho\tau} \left\langle \left(\frac{1-\alpha}{\alpha} \right) \left\{ \log n(0) + g\tau + \log \left[(1-\xi) + \xi \left(\frac{w_S}{w_N} \right)^{1-\epsilon} \right] \right\} + \log \left(\frac{L_N - ag}{L_N} \right) \right\rangle d\tau \\ &= \frac{1}{\rho} \left\langle \left(\frac{1-\alpha}{\alpha} \right) \left\{ \log n(0) + \log \left[(1-\xi) + \xi \left(\frac{w_S}{w_N} \right)^{\frac{-\alpha}{1-\alpha}} \right] \right\} + \log \left(\frac{L_N - ag}{L_N} \right) \right\rangle + \left(\frac{1-\alpha}{\alpha} \right) \frac{g}{\rho^2} \end{aligned} \tag{26}$$

Correspondingly, for the South, at date τ, instantaneous utility of each Southern worker is

$$u_S = n^{\frac{1-\alpha}{\alpha}} \left[\xi + (1-\xi) \left(\frac{w_S}{w_N} \right)^{\frac{\alpha}{1-\alpha}} \right]^{\frac{1-\alpha}{\alpha}} \left(\frac{L_S - bg\xi^{\frac{\lambda}{g}}}{L_S} \right)$$

In steady state, therefore, welfare of each Southern worker at date 0 is

$$\Omega_S(0) = \frac{1}{\rho} \left\langle \left(\frac{1-\alpha}{\alpha} \right) \left\{ \log n(0) + \log \left[\xi + (1-\xi) \left(\frac{w_S}{w_N} \right)^{\frac{\alpha}{1-\alpha}} \right] \right\} + \log \left(\frac{L_S - bg\xi^{\frac{\lambda}{g}}}{L_S} \right) \right\rangle + \left(\frac{1-\alpha}{\alpha} \right) \frac{g}{\rho^2} \tag{27}$$

With the help of equations (26) and (27), we can evaluate the effects of changes in L_S on the steady state welfare of the North and of the South. Using numerical simulation, the result of which is contained in Appendix D and the middle panel of Figure 6, we show that steady state Ω_N increases in the initial stage of deepening of globalization as predicted. Steady state Ω_N continues to climb even as $\frac{w_N}{w_S}$ falls in response to increases in L_S in the later stage of globalization, apparently because the effects of increases in ξ and g dominate that of decreases in $\frac{w_N}{w_S}$. But Northern welfare peaks out at some level of L_S, and begins to fall as L_S increases further. This is the point when the effect of $\frac{w_N}{w_S}$ begins to dominate those of ξ and g. This non-monotonic effect on Northern welfare as the South expands bears some resemblance to the finding of Samuelson (2004): When the South has already imitated a large fraction of goods developed by the North, any further increase in the fraction will hurt the North.

As expected, the trend of steady state Ω_S is just opposite of that of Ω_N. As shown in Appendix D and the bottom panel of Figure 6. In the initial stage of globalization, Ω_S first falls with L_S, apparently because the effect of $\frac{w_S}{w_N}$ dominates those of ξ and g. But welfare per Southern worker reaches a trough at a point where $\frac{w_S}{w_N}$ is still decreasing, apparently because the effects of increases in g and ξ begin to dominate that of decreases in $\frac{w_S}{w_N}$. Not surprisingly, steady state Ω_S continues to climb with L_S as $\frac{w_S}{w_N}$ rises with L_S in the later stage of globalization. See Figure 6 and Appendix D.

4.4 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. Casual observation tells us that this form of technological progress in the South may also play an important in effects of the deepening of globalization through the effect of λ on ξ.

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 $\xi^{\frac{\lambda}{g}}$. (See also footnote 12 for the derivation.) From (25), it follows that w_S/w_N increases unambiguously ■

The intuition is: An increase in λ lowers $\xi^{\frac{\lambda}{g}}$, 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 (22). Moreover, since $\frac{\lambda}{g}$ also increases (according to footnote 12), we conclude from (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 supply of Southern labor would unambiguously increase the relative wage of the South, and thus improve the welfare of the Southern workers. The North, though, may or may not gain as a result.

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 labor in the North. This is the technology transfer paradox. In the later stage of globalization of production, deeper globalization unambiguously improves the welfare of labor in the South. Northern workers would eventually lose from deepening of globalization. Such contrasting effects on the North arise because an increase in the supply of Southern labor that participates in the product cycle has a non-monotonic impact on the wage of Southern labor relative to that of the North, as shown in Figure 6.

There are two reasons for the existence of technology transfer paradox in our paper. First, a deepening of globalization of production leads to a higher fraction of differentiated goods being produced by the South (resulting in lower average real price of differentiated goods), which in turn leads to higher rate of product innovation, making more goods available to Northern (as well as Southern) workers. The rate of innovation increases because production is transferred more quickly to the South, leaving more resources for each Northern firm to expand production and earn higher profit rate at each date, inducing more entry into innovation. Second, when the fraction of goods produced by the South is relatively small, a deepening of globalization boosts the relative supply of Southern production labor more than it boosts the relative demand for Southern production labor, leaving the relative wage of the South lower. This increases the purchasing power of Northern workers.

In Jones and Ruffin (2008), however, the paradox arises because there is a drastic change in comparative advantage of the good whose technology is transferred to the South, turning the North from an exporter to an importer of that good. Their model and ours share the same feature that the North turns from an exporter to an importer after the technology transfer. Our model has the added feature that some of the resources released in the North now go to R&D, boosting the rate of innovation. Their paradox requires that the countries share the same Cobb-Douglas preferences, whereas our paradox holds for CES preferences. In this sense, the condition for our paradox is a little more general.

5 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, deepening of globalization of production can lead to a non-monotonic effect on the wage of Southern labor relative to that of the North since Southern labor requirement for imitating a product increases endogenously as globalization of production deepens. This in turn leads to non-monotonic effects on the welfare of Northern and Southern workers.

In the initial stage of globalization, the deepening of globalization of production lowers the relative wage of the South. Thus, the North's labor unambiguously gains from deeper globalization due to the increase in the purchasing power of its wage as well as from the faster rate of innovation. This is the technology transfer paradox: An increase in the extent of uncompensated technology transfers from the North to the South makes the North better off. Eventually, however, as South's supply of labor in the product cycle gets sufficiently large, deepening of globalization causes the relative wage of South to increase. For this reason, a point will be reached where deepening of globalization begins to reduce Northern welfare. This result bears some resemblance to that of Samuelson (2004), who conjectures that the North would first gain but eventually lose from uncompensated technology transfer to the South as the transfer intensifies.

In any case, Southern workers necessarily gain from improvement of the South's speed of imitation through an increase in their learning capability, as this unambiguously increases their wage relative to that of the North as well as enhances the rate of innovation.

For further research, we can model the situation when the North is compensated for the technology transfer to the South. This can be done by assuming that production is transferred through FDI or outsourcing. Another direction for extension may be to endogenize a Southern firm's decision as to whether 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 $\frac{\partial f}{\partial \xi} = \frac{1}{(1-\xi)^2}\{-(1-\xi)(\frac{\rho}{g}+1)\xi^{\frac{\rho}{g}} + (1-\xi^{\frac{\rho}{g}+1})\} = \frac{1}{(1-\xi)^2}\{(\frac{\rho}{g})\xi^{\frac{\rho}{g}+1} + 1 - (\frac{\rho}{g}+1)\xi^{\frac{\rho}{g}}\}$. Define the expression inside the curly brackets as $h(\xi, g)$. Thus, $\frac{\partial f}{\partial \xi} = \frac{1}{(1-\xi)^2}h(\xi, g)$. It is clear that $h(\xi, g) = 0$ at $\xi = 1$, for any g. Moreover, we compute $\frac{\partial h}{\partial \xi} = (\frac{\rho}{g})\xi^{\frac{\rho}{g}}(\frac{\rho}{g}+1) - (\frac{\rho}{g}+1)(\frac{\rho}{g})\xi^{\frac{\rho}{g}-1}$, 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 $\frac{\partial f}{\partial \xi} = \frac{1}{(1-\xi)^2}h(\xi, g)$, we have $\frac{\partial f}{\partial \xi} > 0$ for any given g, as long as $0 < \xi < 1$.

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 $\xi \to 1$ 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 (22) and solving for g: $g_{min} = (1-\alpha)h_N - \alpha\rho$. The maximum g is found from solving for g in (22) as $\xi \to 1$: $g_{max} = (1-\alpha)h_N$.

From Figure 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 condition for (a) and (b) respectively are:

$$\xi < (\frac{\lambda - g}{\lambda + \rho})^{\frac{g}{g+\rho}} \qquad \text{and} \qquad \xi < (\frac{\lambda}{\lambda + \rho})^{\frac{g}{g+\rho}}.$$

It is clear that the first of the above conditions implies the second one. A necessary condition for the first inequality to hold is $\lambda > g$. 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 is true iff $h_N < \lambda(\frac{1}{1-\alpha})$.

It is shown below that $\frac{h_S}{h_N} = (\xi^{\frac{\lambda}{g}})_{max}$: From (23), $\frac{1-\alpha}{\alpha}(h_S - g\xi^{\frac{\lambda}{g}}) = (g+\rho)\xi^{\frac{\lambda}{g}}$, which implies $\frac{h_S}{\xi^{\frac{\lambda}{g}}} - g = \frac{(g+\rho)}{\frac{1-\alpha}{\alpha}} \Rightarrow \frac{h_S}{\xi^{\frac{\lambda}{g}}} = \frac{\frac{g}{\alpha}+\rho}{\frac{1-\alpha}{\alpha}} \Rightarrow (\xi^{\frac{\lambda}{g}})_{max} = \frac{\frac{1-\alpha}{\alpha}}{\frac{g_{min}}{\alpha}+\rho}h_S = \frac{h_S}{h_N}$. Therefore, $h_S < h_N\theta$ implies

$$\frac{h_S}{h_N} < [\frac{\lambda - (1-\alpha)h_N}{\lambda + \rho}]^{\frac{\lambda}{\rho}}$$

$$\Rightarrow \xi^{\frac{\lambda}{g}} < (\frac{\lambda - g_{max}}{\lambda + \rho})^{\frac{\lambda}{\rho}} < (\frac{\lambda - g}{\lambda + \rho})^{\frac{\lambda}{\rho}} < (\frac{\lambda - g}{\lambda + \rho})^{\frac{\lambda}{g+\rho}}$$

$$\Rightarrow \xi < (\frac{\lambda - g}{\lambda + \rho})^{\frac{g}{g+\rho}}.$$

Therefore,

$$h_S < h_N\theta \text{ and } h_N < \lambda(\frac{1}{1-\alpha}) \ \Rightarrow \ \frac{\partial}{\partial L_S}\left(\frac{w_S}{w_N}\right) < 0. \ \blacksquare$$

C Proof of Result 2

Since an increase in L_S raises both g and ξ, the sufficient condition 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 condition for (a) and (b) respectively are

$$\xi > (\frac{\lambda - g}{\lambda + \rho})^{\frac{g}{g+\rho}} \qquad \text{and} \qquad \xi > (\frac{\lambda}{\lambda + \rho})^{\frac{g}{g+\rho}}$$

It is obvious that the second condition above implies the first. From the proof in Appendix B, we have $h_S/\xi^{\frac{\lambda}{g}} = (\frac{g}{\alpha} + \rho)/(\frac{1-\alpha}{\alpha})$, which implies $(\xi^{\frac{\lambda}{g}})_{min} = [(\frac{1-\alpha}{\alpha})/(\frac{g_{max}}{\alpha} + \rho)]h_S = h_S/(h_N + \frac{\alpha\rho}{1-\alpha})$. Therefore,

$$h_S > \Gamma$$
$$\Rightarrow \xi^{\frac{\lambda}{g}} > (\frac{\lambda}{\lambda+\rho})^{\lambda - g_{\max}/(g_{\max}+\rho)} > (\frac{\lambda}{\lambda+\rho})^{\frac{\lambda-g}{g+\rho}}$$
$$\Rightarrow \xi > (\frac{\lambda}{\lambda+\rho})^{\left(\frac{\lambda-g}{g+\rho}\right)\frac{g}{\lambda}} > (\frac{\lambda}{\lambda+\rho})^{\frac{g}{g+\rho}}.$$

Again, if $h_N < \lambda(\frac{1}{1-\alpha})$ then $\lambda > g$. Therefore,

$$h_S > \Gamma \text{ and } h_N < \lambda(\frac{1}{1-\alpha}) \ \Rightarrow \ \frac{\partial}{\partial L_S}\left(\frac{w_S}{w_N}\right) > 0. \ \blacksquare$$

D Numerical Simulation

(This appendix is not intended to be published.) I use the Goal Seek routine in Microsoft Excel to simulate the model in this paper. The simulation helps me to confirm that (a) w_S/w_N is U-shaped when plotted against L_S on the horizontal axis; (b) Ω_N (called "W_N per wkr" in the Excel worksheet) is an inverted U when plotted against L_S, and the curve reaches a peak after the curve of w_S/w_N (called "wS/wN" in the Excel worksheet) reaches its trough; (c) Ω_S (called "W_S per wkr" in the Excel worksheet) is U-shaped when plotted against L_S, and it reaches its trough before the curve of w_S/w_N reaches its trough.

In the simulation, we set $\alpha = 0.7$, $a = 25$, $b = 2000$, $\rho = 0.05$, $\lambda = 0.5$, $L_N = 20$, and L_S ranges from 10 to 1690. Athough b is much larger than a, L_S^p/L_S is equal to about 0.7 throughout the range of L_S, while L_N^p/L_N is also about 0.7 throughout the range of L_S. Note that the values of A, B, C, D and E have to be greater than zero so as to meet the restrictions imposed on the model.

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Table 2: Comparative Steady-states Results				
	g	ξ	$\xi^{\frac{\lambda}{g}}$	w_S/w_N
$L_S \uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\downarrow$ or $\uparrow$
$b \downarrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$\lambda \uparrow$	$\uparrow$	$\uparrow$	$\downarrow$	$\uparrow$
$\uparrow$ indicates an increase				
$\downarrow$ indicates a decrease				
L_S is South's supply of labor				
b is Imitation labor requirement parameter				
λ is Time vs. imitation-cost trade-off rate				
g is Growth rate				
ξ is N-S Technology gap				
$\xi^{\frac{\lambda}{g}}$ is Time-dependent component of Imitation cost				