Technological Diffusion through Trade and Imitation

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Abstract:

An endogenous growth model is developed demonstrating both static and dynamic gains from trade for developing nations due to the beneficial effects of trade on imitation and technological diffusion. The concept of learning-to-learn in both imitative and innovative processes is incorporated into a quality-ladder model with North-South trade. Domestic technological progress occurs via innovation or imitation, while growth is driven by technological advances in the quality of domestically available inputs, regardless of country of origin. In the absence of trade, Southern imitation of Northern technology leads to asymptotic conditional convergence between the two countries, demonstrating the positive effect of imitation on Southern growth. Free trade generally results in a positive feedback effect between Southern imitation and Northern innovation yielding a higher common steady-state growth rate. Immediate conditional convergence occurs. Thus, trade in this model confers dynamic as well as static benefits to the less developed South, even when specializing in imitative processes.

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The issue of whether less developed nations benefit from or are harmed by trade with industrialized nations is a recurring theme in international and development economics. Within the context of "North-South" trade, there are different aspects which can be considered. Some economists focus on the effect of North-South trade when it leads to Northern specialization in industries which exhibit positive spillovers and Southern specialization in industries lacking such positive externalities (Young 1991; Stokey 1988). Within that type of model, the less developed country (LDC) will experience negative dynamic effects which could potentially outweigh the static gains from trading with a developed country (DC). Others consider the effect of North-South trade on technological progress and diffusion (Krugman 1979; Dollar 1986; Grossman and Helpman 1991a and 1991b; Rivera-Batiz and Romer 1991; Barro and Sala-i-Martin 1995b; Glass 1997).

The purpose of this paper is to focus on the effects of North-South trade on technological progress in both countries through innovative and imitative activities, paying particular attention to the modeling of imitative research. I put forth an argument that North-South trade is beneficial to the less developed country, even if such trade leads to Southern specialization in imitative processes. In support of this claim, I demonstrate that in addition to static gains from trade, the LDC will experience dynamic gains from trade due to trade's positive effects on imitation and, consequently, on technological diffusion. I neither claim that trade is a necessary condition for imitation to occur, nor that imitation is the only manner in which technology diffuses. However, I show first that imitation allows for significant technological diffusion, thus improving growth in the imitating country, and second, that trade lowers the cost of imitation, thereby providing a dynamic boost to growth in the LDC.

The model developed in this paper relates closely to Grossman and Helpman (1991b) and Barro and Sala-i-Martin (1995b). Grossman and Helpman (1991b) develop a quality ladder model in which utility is an increasing function of the quality of goods consumed. Northern firms create new processes and products, whereas Southern firms target Northern goods for imitation; each activity increasing the quality level of goods produced domestically. Grossman and Helpman consider steady-state equilibria where the North innovates and the South imitates. The transitional dynamics leading to steady-state are not considered, nor is the possibility that the South might take over the North's position as the innovating country. The authors focus principally on detailed modeling of stochastic innovation by Northern firms, while considering stochastic Southern imitation to depend solely on the intensity of imitative research. Thus, the Grossman and Helpman model yields valuable insight into the process of innovation when faced with imitative competition. However, a more detailed analysis of the process of imitation as well as the transitional dynamics to steady-state is worthwhile when considering the effects of North-South trade on the South.

Barro and Sala-i-Martin (1995b) also develop a model of technological diffusion through imitation. They consider a varieties model in which aggregate output is a positive function of the number of varieties of intermediate goods available. Firms in the North deterministically invent new varieties of goods and drive the long-run world growth rate. Only trade in final goods is considered and, hence, the South must adaptively imitate Northern intermediate goods before it can use these as inputs in final goods production. Barro and Sala-i-Martin model the cost of imitation as an increasing function of the South/North technology ratios, thereby yielding convergence in the growth rates of the two countries in steady-state. They also consider what conditions would lead to a one-time switching of the North and South as the innovating country. However, since this model does not consider trade in intermediate goods, it rules out the possible effects of North-South trade on imitation. Furthermore, the results obtained in the Barro and Sala-i-Martin model would no longer hold if free trade in intermediate goods were considered within their model.

This paper makes two principal contributions to the existing theoretical literature on technological diffusion between a developed and a less developed country. The first is its explicit modeling of imitative processes, and the second is its modeling of the transitional dynamics to steady-state within a quality ladder model. Specifically, I incorporate the notion that both imitative and innovative research depend positively on past *learning-to-learn* in research whether in imitation or innovation. Thus, there is a positive externality both from past successful imitation and past successful innovation, although the spillover from past innovation is assumed to be greater. Furthermore, the effects of imports of capital goods from the North and transportation and communications infrastructure levels in the South are explicitly considered in the cost of imitation for the South. Hence, the issue of trade between a developed country and a less developed country is considered not only in terms of whether such trade leads to LDC specialization in imitative processes, but also in terms of how such trade might increase the diffusion of technology to the LDC. This paper is also the first to model the transitional dynamics to steady-state using a quality ladder model. Thus, steady-state equilibrium conditions, as well as transitional dynamics, are examined. The possibility of the South using imitation as a springboard to leapfrog the North, thus taking over as the lead innovating country, is also considered.

Motivation

Technology can diffuse internationally in many ways, including foreign direct investment, licensing, international labor mobility, and imitation. This paper focuses on the role of imitation in technological diffusion, along with possible spillovers embodied in that process. In order to decompose the effect of imitation from the effects of imitation with trade, the paper will first focus on imitation's contribution to technological diffusion independently of trade, and then will consider the combined effects of trade with imitation.

Learning-to-Learn

Imitation, when successful, allows for the diffusion of technology embodied in a product as imitators reverse-engineer that good. Moreover, I claim that imitation, like innovation, has learning-to-learn properties. In particular, successful imitation by a firm increases that firm's insight into how goods are engineered and improved upon. Thus, the higher the technological level of a good which the firm has successfully cloned, the more likely that it will be able to begin successfully innovating the next quality level on its own. Repeated successful imitation will therefore increase a firm's chances at successful innovation within the same product line. As an example, consider graduate studies. Graduate students first read, study, and duplicate theories at the "frontier" of their field. Once they understand basic constructs for formulating theories and have assimilated whatever knowledge is embodied in these theories, they are then (hopefully) capable of developing and presenting their own ideas and theories. In many ways, our first years in graduate school are spent "reverse-engineering" the pre-existing stock of academic knowledge. During that time, our personal understanding of the subject matter increases up to the point where we can begin "innovating" on our own. Realistically, the learning-to-learn effects from imitation should be less than those from innovation. However, this does not imply that LDCs are achieving sub-optimal results when specializing in imitation.

The Effects of Trade on Imitation

I assume that importing advanced Northern capital goods lowers the costs of imitation for Southern firms, thereby leading to higher expected profits and greater rates of Southern imitation and growth. If this holds, then trade will lead not only to static gains, but also to dynamic gains for the South (and the North). There are several intuitive arguments for asserting that there should be a positive link between trade and imitation:

1. Knowledge: Trade allows potential Southern imitators to inexpensively gain knowledge of the existence of new Northern products. Furthermore, if we think of each individual who is exposed to a good as having a certain probability of imitating it, then the number of people exposed to the good, and hence the volume of imports, should also positively affect the overall probability that the good is imitated in the South.

2. Servicing and Distribution by Importers: In practice, importing firms in LDCs distribute and often service the imports they sell. Having a pre-established distribution network facilitates future sales of imitations of these imported products. Furthermore, by servicing these imported goods, Southern importing firms increase their working knowledge of the product, thus reducing the costs of reverse-engineering the good.

3. Access to International Markets: Potential imitators know that with free trade, *if* they successfully imitate and under-price the innovating firm, they can not only capture their domestic market, but also the world market. Thus, openness to trade increases the expected returns to successful imitation as compared to the case of no trade, where imitated goods could only be sold domestically. Still, trade will also expose the imitator to Northern competition, thereby reducing the number of Southern firms willing to attempt imitation.

4. Revealed Domestic Demand: Potential Southern imitators can cheaply observe the domestic price and pattern of imports of Northern products, in lieu of more expensive test marketing, to determine which types of goods would have the greatest expected domestic profits.

5. Efficiency: Free trade implies that any potential imitator will have to compete with the lead innovating firm whose product it copies, thus insuring that resources will not be wasted on inefficient attempts at imitation.

Although I believe that all of these arguments are relevant, the model presented in this paper will focus on only the first three, namely knowledge, servicing and distribution, and access to international markets.

In addition, several empirical studies consider the possible link between trade in physical goods and technological diffusion, (Eaton and Kortum 1995; Coe and Helpman 1995; Coe, Helpman, and Hoffmaister 1995). The findings of these papers support the notion that trade contributes significantly to technological diffusion, although the exact mechanism through which trade aids in technological diffusion is not specified. However, using the Coe and Helpman (1995) data, Keller (1996) finds evidence of international R&D spillovers using randomly generated bilateral trade shares, casting doubt on the importance of trade in goods as the channel for technological diffusion when considering similar, interrelated countries.

Nonetheless, Ben-David (1996) finds that trade-based country groupings are more likely to converge than randomly selected country groupings. Ben-David and Rahman (1996) build upon this result by suggesting that convergence in trade-based country groupings can be attributed to convergence in technologies. This is demonstrated by a high incidence of total factor productivity convergence among trade-based country groups, whereas no such technological convergence is found among randomly selected country groupings. Again trade appears to be playing an important role in technological diffusion and in turn conditional convergence.

Outline of Paper

A model of technological diffusion for industries is developed in which imitation primarily involves reverse-engineering and there is a marked lack of international property right enforcement. The model incorporates the notion that an LDC will experience learning-to-learn effects even if free trade with a DC leads the LDC to specialize in imitative processes. As long as the LDC is copying and producing goods that it did not previously produce, it benefits from learning-to-learn in research. This would occur both through the diffusion of technology during the process of reverse-engineering and through the accumulation of human capital through learning-by-doing in research. For simplicity however, I focus solely on the diffusion of technology. For nice treatments of the issue of human capital accumulation and technological diffusion, see Nelson and Phelps (1966) and van Elkan (1996).

The paper is divided into two sections. Section 1 considers the benchmark case where both countries are under autarky but have sufficient interaction to make Southern imitation of Northern products possible at a significant cost. This case demonstrates the positive effects of imitation on growth through technological diffusion and spillovers in research. Section 2 then introduces trade between these two countries, when imitation is already occurring in the South. This is then compared with the previous autarky case to determine the additional effects of trade on the diffusion of technology through imitation.

SECTION 1: Autarky with Imitation

Following conventional notation for rising product quality models (Grossman and Helpman 1991a, Ch. 4; Aghion and Howitt 1992; Barro and Sala-i-Martin 1995a, Ch. 7), there are a fixed number, J, of intermediate goods, whose quality levels are improved upon through innovation (or imitation). q denotes the size of quality improvements with each innovation of a particular good, where q is assumed to be an exogenously determined constant greater than 1. The particular rung of the quality ladder at which a good of type j is located is indicated by k_j. Hence, normalizing so that all goods begin at quality 1, each subsequent innovation will make the good q times as productive as its predecessor. Thus, the quality levels of a good in sector j will rise from 1 to q with the first innovation, to q^2 with the second innovation, and to q^{k_j} with the k_j th innovation.

Following Barro and Sala-i-Martin (1995a), consider the following technology for aggregate final goods production in the North, a DC (country 1), and in the South, an LDC (country 2):

(1.1) $$Y_1 = A_1 L \; (q^{k_{1j}} x_{1k_j})^{1-a}$$
$$Y_2 = A_2 L \; (q^{k_{2j}} x_{2k_j})^{1-a}, \quad \text{where } 0 < a < 1 .$$

These aggregate production functions assume that the final goods industry is comprised of many perfectly competitive firms. A_i is a productivity parameter dependent upon country i's institutions. Since the North is the more developed country, I assume that the North's institutions such as tax laws, property rights, and government services which affect productivity are better than their Southern counterparts (i.e., $A_1 > A_2$). L_i is the labor input used by the representative firm for final goods production and $(q^{k_{ij}} x_{ik_j})$ is the quality adjusted amount of intermediate good of type j, used in country i. Hence, as the quality level of intermediate goods rises, so does final goods output, Y_i, which is assumed to be different in each country. Let the final good be the numeraire good in each country.

In this section there is no trade between the two countries and no *costless* international diffusion of technology. Each country is dependent upon its own technology level for production of intermediate goods. I assume that the cost of imitation is less than the cost of innovation. Since the Northern technology level is by definition higher than that of the South, this implies that Northern firms will initially innovate and Southern firms will initially imitate Northern technology, at least until the gap in their technology levels is eliminated.

Once knowledge of how to produce an intermediate good exists domestically, it can be produced using the final goods production function. Therefore, the marginal cost of producing an intermediate good equals the marginal cost of producing a final good, which (due to perfect competition in the final goods industry) equals the price of the final good. Since the final good is the numeraire, this implies that $MC_i = P_{Y_i} = 1$. Thus, the marginal cost of producing an intermediate good is independent of its quality level and is identical across all domestic sectors.

I also assume that knowledge of how to make a good is public knowledge within a country. One could think of countries as having domestically enforced patents which protect the lead firm's domestic monopoly of that quality good, while at the same time almost costlessly disseminating its acquired knowledge to other domestic firms. Since the last innovator in each sector is the only domestic firm legally allowed to produce the intermediate good of the latest quality level, this firm will set its price so as to wipe out sales of lower quality intermediate goods in its sector. Depending on whether $q(1-a)$ is greater than or less than the marginal cost of production of the intermediate goods, the lead firm will be able to respectively use monopoly pricing or limit pricing to capture the entire domestic market for its sector. I consider the case of $q(1-a) < MC_i$, implying that limit pricing will be used by all lead firms. In either country i, the lead firms in all intermediate goods sectors will choose a price e less than the limit price,

$$(1.2) \quad P_i = q\, MC_i \;,$$

where $MC_i = 1$ and e is arbitrarily small. This limit price reflects the fact that the lead intermediate good in any sector is q times more efficient than the second best domestically available good. Since the lowest price the producer of the second best good can charge (without having negative profits) is MC_i, the lead firm can successfully capture the entire market for this type of good by selling at any price slightly below qMC_i. The implied demand function in country i for intermediate goods in sector j is derived by maximizing profits for final goods production. At this limit price, $P_{y_i}/P_i = 1/q$, and the implied demand is

$$(1.3) \quad x_{ikj} = L_i\, [A_i\, (1-a)\, q_{kij}(1-a)\;]^{1/a} \qquad = \quad L_i\, A\, (\;)^{1/a}\; q_{kij}^{(1-a)/a}\, .$$

Let $Q_i = q_{kij}^{(1-a)/a}$ represent an aggregate index of attained quality in the domestic intermediate goods industry. We can then find an expression, using equation (1.3), for domestic aggregate demand for intermediate goods across all sectors in terms of this aggregate quality index:

$$(1.4) \quad X_i = L_i\, A\, (\;)^{1/a}\, Q_i\, .$$

Substituting the demand for intermediate goods into the aggregate production function in equation (1.1) yields aggregate output per worker:

$$(1.5) \quad = A\;(\;)^{(1-a)/a}\; Q_i\,, \qquad \text{where } 0 < a < 1.$$

Taking logs and derivatives of equation (1.5), we find the following expression for the growth rate of aggregate output per worker:

$$(1.6) \quad - \;=\; \quad + \quad .$$

Since A_i and L_i are both taken as given and the countries are not trading, it is obvious that the growth rate of each country depends solely on growth in Q_i (i.e., domestic technological progress). Hence, differences in the countries' per worker growth rates, as well as their demand for intermediate goods, depend solely on their respective rates of technological progress, either through innovation or through imitation. We therefore turn our attention to deriving the equilibrium rate of innovation and imitation in the North and South, respectively.

Resources Devoted to Northern Innovation Under Autarky.

When deciding what resources to devote to research, a potentially innovating Northern firm in sector j must consider the expected present value of profits its innovation would earn. Let us define the k_j th innovator as the firm which raises the quality level of the lead intermediate good in sector j, from rung $k_j -1$ to k_j. Then the flow of profits earned by the k_j th innovator is

(1.7) $$p_{I1k_j} = (P_1 - MC_1)\ x_{1k_j} = (qMC_1 - MC_1)\ x_{1k_j} = (q^{(a-1)/a}\ Y_1)\ q^{k_{1j}(1-a)/a}\ ,$$

where $Y_1 = L_1 A (1-a)^{1/a} MC_1^{(q-1)/q}$, and the subscript I denotes innovation.

Since there is no trade, Northern innovators are unaffected by potential Southern imitation. However, the Northern leader's flow of profits will be completely eliminated when the next Northern innovation occurs, causing the firm to lose its leadership position. Hence, the present value of the flow of profits will increase with the time interval during which the innovator dominates the market. In turn, this time interval depends on the probability that the next Northern innovation occurs.

At each point in time within an intermediate goods industry, there is a lead firm which produces the highest quality intermediate good of that type, and follower firms which have temporarily exited the market. Combined with the assumption of costless technological diffusion within a country, this implies that within an industry, both leaders and followers face the same costs and probabilities of bringing about the next successful innovation. However, lead firms have less incentive to bring about the next innovation since doing so will eliminate or at least reduce their profits from earlier innovations. This is commonly known as the replacement effect. In the appendix, the incremental profits which could be earned by a lead firm replacing itself are shown to be lower than the incremental profits which would be earned by any given follower taking over the lead position. Since both types of firms face the same research costs but followers have greater incentives to innovate, only followers will undertake innovative research when under autarky. As a consequence, continual leapfrogging will occur within each intermediate goods sector.

Within a Northern intermediate goods sector j, presently at quality level, k_{1j}, p_{I1k_j} is the probability per unit of time that the next Northern innovation ($k_{1j}+1$) occurs. Specifically, p_{I1k_j} is assumed to follow a Poisson process which depends positively on the total resources devoted by firms to research, z_{1k_j}, negatively on the complexity, $\phi(k_{1j})$, of the good upon which firms are attempting to improve, and positively on past learning-to-learn in research, ϑ_{1k_j}, of any Northern intermediate goods firm in industry j, whether in imitative or innovative processes:

(1.8) $$p_{I1k_j} = z_{1k_j}\ f(k_{1j})\ J_{1k_j}\ , \qquad \text{where } f'(k_{1j}) < 0, \text{ and}$$

$$J_{1k_j} = \max\,(\,b_C\, q\,,\, b_I\, q\,)\ , \qquad b_I > b_C > 0\ .$$

Subscripts C and I denote copying and innovation, respectively. J_{ik_j} reflects the positive spillover effects of past learning-to-learn through imitation and/or innovation. For a particular intermediate goods sector j, q is the highest quality level attained through domestic imitation and q is the highest quality level attained through domestic innovation. If the country only has innovative experience, then $q = 0$, and if the country only has imitative experience, then $q = 0$. b_C and b_I are positive coefficients on past experience in imitation and innovation, respectively. I assume that $b_I > b_C$ to reflect the fact that realistically, innovation should possess greater learning-to-learn effects than imitation.

Combining the probability density function for the time interval between the lead firm's innovation and the next innovation in that sector with the expression for p_{I1k_j} in equation (1.7) yields an expression for the expected present value of profits for the k_jth innovation, calculated at t_{kj}:

$$(1.9) \quad E(v_{I1kj}) = (q^{(a-1)/a}\ Y_1)\ q^{\ k_{1j}(1-a)/a} / (r_1 + p_{I1kj})\ .$$

Hence, the expected present value of profits for the k_jth innovator (at the time of innovation) depend negatively on the interest rate, r_1, as well as the probability, p_{I1kj}, that the (k_j+1)th innovation will occur, wiping out all of its current sales. The equilibrium interest rate depends on the probability of innovation and hence its equilibrium value is derived later.

The expected flow of net profits in the North from research by follower firms in industry j, with present quality level k_j, can then be written

$$(1.10) \qquad P_{I1kj} = p_{I1kj}\ E(v_{I1,kj+1}) - z_{I1kj}\ .$$

This holds since the expected revenue from the (k_j+1)th innovation is $p_{I1kj}\ E(v_{I1,kj+1})$, the probability of successful innovation times the expected present value of profits *given* successful innovation. Finally, the total resource cost of innovative research in sector j, z_{I1kj}, must be subtracted from expected revenues so as to give the expected flow of net profits for the (k_j+1)th innovation.

If any innovative research is undertaken ($z_{I1kj} > 0$), free entry in research will guarantee that $P_{I1kj} = 0$. Substituting equation (1.9) into (1.10) and setting this expression equal to zero thereby yields the free entry condition:

$$(1.11) \quad z_{I1kj} = p_{I1kj}\ [\ Y_1\ q^{\ k_{1j}(1-a)/a} / (r_1 + p_{I1,kj+1})].$$

Here we see that resources devoted to R&D by followers in sector j, presently at quality rung k_j, depend positively on the present probability, p_{I1kj}, of successful innovation for the (k_j+1)th quality good, but negatively on the probability of the successful innovation of the (k_j+2)th intermediate good which will be undertaken by the next period's followers. Once we substitute in equation (1.8) for p_{I1kj} into equation (1.11), z_{I1kj} drops out, yielding an expression for the probability of successful innovation of the (k_j+2)th quality level:

$$(1.12) \quad p_{I1,kj+1} = f(k_{1j})\ J_{1kj}\ Y_I\ q^{\ k_{1j}(1-a)/a} - r_1\ .$$

At this point, it is necessary to specify the form of $f(k_{1j})$. First, for the firm that brought about the last innovation (or for all domestic firms in the case of free domestic technological diffusion) it should be the case that the increased difficulty of innovating the (k_j+2)th invention is offset by the experience gained by the lead firm while inventing the (k_j+1)th quality level. Furthermore, since demand for intermediate goods is increasing in k_j, this implies that the return to R&D would be greater in more advanced sectors. This increasing returns to scale in R&D would in turn lead to increasing aggregate growth rates as quality levels rise. Hence, the economy would have an explosive growth path.

To analyze a balanced growth path, I consider the case of constant returns to innovative research with respect to current technology levels (k_{1j}). Constant returns to innovation can be justified using the argument that there exist an infinite number of potential innovations and hence there need not be diminishing returns to innovative R&D (Romer 1990). This will mean that $f(k_{1j})$ must also offset the effect of increased demand as k_j rises. In other words, learning-to-learn and demand both imply increasing returns to scale in R&D. On the other hand, the increasing difficulty of innovation implies decreasing returns to scale. Hence, $f(k_{1j})$ must exactly offset J_{1k} and increases in demand if R&D is to exhibit constant returns to scale. With these considerations in mind, let $f(k_{1j}) = (1/z_{I1})q^{-k_{1j}/a}$, where z_{I1} is a fixed cost of doing innovative research in the North. Furthermore, since the North has been innovating, the highest quality level it has innovated in the past is equal to its current quality level. Thus, $J_{1kj} = b_I\, q\ = b_I\, q^{k_{1j}}$. Substituting for J_{1kj} and $f(k_{1j})$, we get an expression for the probability of innovation which holds for all Northern intermediate goods sectors and is independent of k_{1j}:

$$(1.13) \quad p_{I1} = \quad Y_1 - r_1\ .$$

This is the equilibrium value for p_{I1} once the equilibrium interest rate is entered into this expression. r_1 will later be shown to be constant in equilibrium. This insures that in all sectors the probability of successful innovation will also be constant in equilibrium.

Using equation (1.13), we derive the equilibrium value of total resources devoted to innovative research in sector j, currently at quality rung k_j, by substituting in equation (1.8) for p_{I1}:

$$(1.14)\quad z_{I1k_j} = q^{k_{1j}(1-a)/a}(Y_1 - r_1).$$

Note that while the resources devoted to innovative research increase as the quality level in a particular sector increases, this does not lead to greater probabilities of innovation. Instead, these increased expenditures are required in order to offset the greater difficulty of innovating as quality levels increase.

For the country as a whole, the aggregate resources devoted to innovative research across all Northern intermediate good sectors are

$$(1.15)\quad Z_{I1} = Q_1 (Y_1 - r_1).$$

Thus, aggregate resources devoted to innovation by Northern follower firms depend positively on the scale of domestic demand, the domestic marginal cost of production, and the aggregate quality index, Q_1. Conversely, the interest rate (opportunity cost); the share of labor in production, a; and the experience-adjusted cost of innovative research, z_{I1}/b_I; all affect aggregate resources devoted to innovation negatively. So aggregate resources devoted to Northern innovative research are a constant multiple of the Northern technology level. Similarly, I show in the appendix that the aggregate market value of Northern firms is also a constant multiple of Q_1.

Resources Devoted to Southern Imitation under Autarky

All Southern firms involved in R&D will choose to do imitative research so long as the resources required for imitation are less than or equal to the resources required for innovation. Each potential imitator considers the expected present value of profits successful imitation would yield. The lead Southern firm's profits go to zero when the next successful imitation occurs and limit pricing wipes out its sales. Again, if technology diffuses costlessly within the South, then the lead imitator has the same research costs, but lower incentives than follower firms to imitate the next quality level. So as in the North, all research is undertaken by followers in the market and continual leapfrogging occurs within each Southern intermediate goods sector.

Similarly to the probability of innovation, the probability per unit of time, p_{C2k_j}, that an intermediate good of quality rung (k_j+1) is copied in the South depends positively on the resources spent by Southern firms in terms of output devoted to reverse engineering, z_{C2k_j}, negatively on the complexity, $f_C(k_j)$, of the good which is being copied, and positively on past learning-to-learn in that domestic industry:

$$(1.16)\quad p_{C2k_j} = z_{C2k_j}\, f_C(k_j)\, J_{2k_j}, \qquad f'(k_j) < 0, \text{ and}$$

$$J_{2k_j} = \max(b_C\, q, b_I\, q), \qquad b_I > b_C > 0,$$

where q and q are the highest quality levels attained in sector j through Southern imitation and innovation, respectively. If no Southern firm in sector j has ever innovated, then $q = 0$.

Cost of Imitation

Two new aspects arise when considering imitative activity, as opposed to innovative activity. The first concerns the method through which imitative firms gather information about innovations, and the second relates to the question of what happens to imitative activity as the technology gap between the two countries diminishes.

Firms are able to gather information about foreign goods by expending certain costs that are a negative function of the interaction between the two countries. Possible types of interaction which reduce the costs of gathering information about foreign goods include trade, foreign direct investment, international labor mobility, media, and communications infrastructure. Let w reflect the amount of interaction, as measured by imports of high technology goods, M, and the quality of transportation and communications infrastructure, F, between the two countries:

(1.17) $w = l_1 M + l_2 F$.

Furthermore, as the Southern technology level approaches that of the North, the cost of imitation increases. This reflects decreasing returns to imitation as the South imitates more and more of the existing Northern inventions, thereby decreasing the pool of potential goods to imitate. To reflect these two notions, I consider the sector-specific cost of imitation as having three separate terms:

$z_{C2}(\ )^{s} (e^{-w} + 1)$, where $s > 0$ and $=$.

The first term parallels the fixed cost in innovative research, z_{Ii}, and will be represented by z_{Ci}. The second term depends on the ratio of the Southern quality level to the Northern quality level in sector j, , and reflects the increasing cost of imitation as Southern technology approaches that of the North. Finally, the third term $(e^{-w} + 1)$ reflects lower costs of gathering information with high levels of exposure to imports and high quality of infrastructure.

Since the cost of imitation is changing with changes in the North-South technology gap, there will be a transition path for the South before reaching steady-state. To analyze this transition path, I consider a representative industry (denoted by the subscript a) which is defined not as the median industry, but rather as an average of all intermediate goods industries. This is needed to avoid any jumpiness in quality improvements that would occur if contemplating the behavior of an individual sector. The cost of imitation faced by the average intermediate goods industry therefore depends on the ratio of the aggregate Southern quality level to the aggregate Northern quality level, :

(1.18) $z_{C2a}(\ )^{s} (e^{-w} + 1)$, where $s > 0$ and $=$.

Let us first consider steady-state conditions for both countries, and then derive the transitional dynamics for the South as it approaches steady-state.

Steady-State under Autarky

To find an expression for the growth rate of the Northern aggregate quality index, we first look at the proportionate change in Q_1, given successful innovation. In this case, $q^{k_{1j}(1-a)/a}$ will rise to $q^{(k_{1j}+1)(1-a)/a}$. Therefore, the proportionate change in Q_1 due to a successful innovation in any given sector is $q^{(1-a)/a} - 1$. We then consider the expected proportionate change in Q_1. The probability of success occurring in one of the Northern intermediate goods industries is p_{I1}, and is constant across sectors. Hence, the expected proportionate change in Q_1 per unit of time is:

(1.19) $E(\ ) = p_{I1} (q^{(1-a)/a} - 1)$.

Each intermediate goods sector will experience successful innovations at random time intervals, leading to uneven increases in the quality level within each sector. However, I assume that there are many intermediate goods sectors (i.e., J is large) in the economy, which are independent of each other. Hence, the Law of Large Numbers holds, and the aggregate quality index, Q_1, will grow in a smooth manner. Then equation (1.19) can be used as an approximation for $1/Q_1$. Substituting equation (1.13) into the right-hand side of equation (1.19) yields

(1.20) $= (q^{(1-a)/a} - 1) [\ \ Y_1 - r_1]$.

From equation (1.6), we see, taking the levels of population and infrastructure as given, that the above term will drive Northern output growth.

An expression for the growth rate of the Southern aggregate technology level can be found using the steady-state probability of imitation. Again, I consider the representative Southern intermediate goods sector, which is an average of all Southern intermediate goods sectors. In steady-state, the technological gap between the two countries is constant, implying that the number of goods which can potentially be imitated is also constant. Thus, while imitative research exhibits decreasing returns to scale during transition to steady-state, it faces constant returns to scale in steady-state. In order for this to be the case, consider $f_C(k_{2a}) = [1/\zeta_{C2}\, s(e^{-w} + 1)]q^{-k_{2a}/a}$. Then, since $J_{C2ka} = b_C\, q^{k_{2a}}$, and assuming free entry into research, the probability of successful imitation for the representative Southern sector is

(1.21) $p_{C2ka} = \quad Y_2 - r_2 \; .$

Notice that the higher the cost of imitative research, $\zeta_{C2}(\ ^*)s(e^{-w} + 1)$, the lower the probability of successful imitation. Thus, when ω is high (i.e., when there is a good communications and transportation infrastructure level), this fixed cost term for imitation is lower, leading to a higher probability of successful imitation. Also, the smaller the steady-state gap in technology levels between the North and the South, the lower the probability of successful imitation, all else equal. Given this steady-state probability of Southern imitation, growth in Southern technology is

(1.22) $\quad = (q^{(1-a)/a} - 1)\, [\ Y_2 \;\; - \;\; r_2\ ]\ .$

Household's Optimization

In each country, infinitely lived households maximize a constant intertemporal elasticity of substitution utility function:

(1.23) $\quad e^{-r\, t}\, (c_{it}^{1-q} - 1)/(1 - q)\; dt \;\; ,$

where c_{it} is consumption per capita at time t. r is the subjective discount rate and $(1/q)$ is the elasticity of the intertemporal substitution common to both countries. This optimization problem yields the usual expression for the growth rate of consumption:

(1.24) $\quad = \;(\, r_i - r)\ .$

The Aggregate Quality Index

The aggregate budget constraint for each country is given by

(1.25) $Y_i = C_i + X_i + Z_i\, ,$

where C_i, X_i, and Z_i are the total resources devoted to consumption, to production of intermediate goods, and to research,respectively. Solving for C_1 and substituting equations (1.5) and (1.4) for Y_1 and X_1, and (1.13) and (1.15) for Z_1, we see that C_1 is a constant multiple of Q_1:

(1.26) $C_1 = Q_1\, \{L_1\, [1 - (\ )] - p_{I1} \;\; \}\ ,$

where $L_1 = L_1\, A\, ((1-a)/q)^{(1-a)/a}$. Similarly, C_2 is a constant multiple of Q_2. Thus, in equilibrium, both countries' aggregate consumption, aggregate output, aggregate intermediate goods demand, and aggregate resources devoted to research are all constant multiples of the aggregate domestic quality level, Q_i. This implies that the growth rates of each of these variables is equal to the domestic growth rate of Q_i. Let us refer to this growth rate as γ_i. The growth rate of the aggregate quality level in equations (1.20) and (1.22) for the North and South, respectively, is derived from firms' market behavior, and the growth rate of consumption in equation (1.24) is derived from household optimization. Thus, for each country, we set the growth rate of consumption equal to the growth rate of domestic technology in order to find the steady-state interest rate in each country:

$$(1.27) \quad r \;\; = r + q\,(\;\; Y_I - r\,)/(\;\; + q\,)$$

$$r \;\; = r + q\,(\,Y_2 - r\,)/(\;\; + q\,).$$

To return to growth rates, subtract r from the above equations and divide by q :

$$(1.28) \quad \gamma \;\; = (\;\; Y_1 - r\,)/(\;\; + q\,),$$

$$\gamma \;\; = (\,Y_2 \; - r\,)/(\;\; + q\,),$$

where $Y_i = \;\; L_i\,A\,(1\text{-}a)^{1/a}MC_i\,(q\text{-}1)/q$, and $MC_i = 1$.

We see above that the growth rate in the North depends positively on the coefficient for past innovative experience, b_I; the scale of domestic demand; the marginal cost of production; and the size of each innovation, q; since these all positively affect profits. On the other hand, the subjective discount rate, r; the willingness to substitute intertemporally, q; the labor share; and the cost of research, ζ_{I1}; all affect Northern growth negatively. Similarly, the steady-state growth rate of the South depends positively on the coefficient for past imitative experience and negatively on the fixed cost of imitation.

In steady-state, the technology gap between the North and the South is constant and therefore both countries grow at the same rate. This implies that even though there is no trade and there are no international capital flows, there is interest rate equalization between the two countries in steady-state.

Setting the steady-state growth rates in the North and the South equal to each other yields an expression for the steady-state South/North aggregate quality ratio

$$(1.29) \quad {}^{*} = \{ \qquad \}^{1/s} \;=\; [\;\;(\;\;)^{1/a} \qquad]^{1/s}\;.$$

This expression reflects the relative profitability of R&D in both countries under autarky. Note also that higher w's (i.e., better transportation and communications infrastructure levels) imply lower costs of imitation and therefore higher steady-state values of *. If the steady-state value of * is less than one (i.e., $Q < Q$), then the South will remain the imitating country. While the South will grow in steady-state at the same rate as the North, its income level will always remain less than that of the North. In other words, conditional convergence will result. On the other hand, if * is greater than one (i.e., $Q > Q$), then the South will converge in absolute terms with the North and take over the role of lead innovating country once equals one. This will be a one-time switch. If the South leapfrogs the North, it will remain in the leadership position forever since it must have the comparative advantage in innovation in order to leapfrog the North. The growth rate of both countries will then be determined by the Southern steady-state growth rate, which will be greater than that of the North when innovating.

Previous assumptions with regard to institutions ($A_1 > A_2$) and learning-to-learn in imitation as opposed to innovation ($b_I > b_C$) tend to keep the North in the leadership position. On the other hand, the assumption that the Southern labor force is larger than the Northern labor force, favors the profitability of research in the South under autarky. For the remainder of the paper, I assume that the North has the long-run comparative advantage in innovation, and therefore the South remains the imitating country forever.

Southern Imitation versus Innovation

Under autarky, Southern imitation in no way affects the Northern market. However, the decision to imitate Northern technology instead of trying to innovate on its own greatly benefits the South in terms of growth. In particular, if the South chose to innovate rather than imitate it would in steady-state grow at a rate dependent upon (b_I /ζ_{I2}) instead of $(b_C/z_{C2} \;\; s(e\text{-}w+1))$. By assumption, ($\zeta_{I2} > \zeta_{I1}$) and ($A_1 > A_2$) implying (all else equal) a lower growth rate in the South relative to the North if both are independently innovating. Since the more developed country, the North, is defined as having a more efficient R&D sector, it by definition grows more quickly than the South if both are independently innovating. However, when the South imitates, the two countries will in steady-state grow at the same rate, determined by Northern innovation. Hence, it is obvious that the South will enjoy a higher steady-state growth rate under autarky with imitation than under autarky with innovation. Moreover, during its transition to steady-state, the South will grow more quickly than the North.

Transitional Dynamics in the South

Since the equilibrium interest rate and growth rate in the North are constant and unaffected by Southern imitation, the North is always in steady-state and does not have a transition path. However, the interest rate and growth rate in the South are changing as the gap in the countries' technologies changes. Therefore, the South will have a transition path to steady-state. As previously mentioned, I solve for the transition path of the South based on the transition path of the constructed average Southern intermediate goods industry *a*.

Since the interest rate in the South is not constant along the transition path, we must now consider the following expression for the expected present value of profits for the lead Southern imitator in the average sector *a*:

(1.30) $E(v_{C2ka}) = p_{C2ka}\ [-\ (r_2(v) + p_{C2ka}(v))dv]ds$,

where $r_2(v)$ is the rate of return in the South at time v and $p_{C2ka}(v)$ is the probability at time v that the intermediate good of quality rung $(k_{2a}+1)$ is copied.

Free entry into imitative research implies that for all points in time, the expected present value of profits from successful imitation times the probability of success at imitation must equal the resource cost of imitation:

(1.31) $p_{C2ka}\, E(v_{C2,ka+1}) = p_{C2ka}\{p_{C2,ka+1}\ [-\ (r_2(v) + p_{C2ka+1}(v))dv]ds\} = z_{C2ka}$.

Differentiating both sides of equation (1.31) (using Leibniz's rule for the left-hand side) yields an expression for the Southern interest rate

(1.32) $r_2 = \quad - \quad - \quad + (p_{C2ka} p_{C2,ka+1} / z_{C2ka}) - p_{C2,ka+1}$

$= s \quad + (p_{C2ka} p_{C2,ka+1} / z_{C2ka}) - p_{C2,ka+1},$

where the first term is a capital gains term, the second is a dividend term, and the third reflects the Schumpetarian concept of creative destruction caused by the next imitation.

The transition path for the South, which is derived in the appendix, is described by a system of autonomous differential equations in the variables, and χ_2, where $\chi_2 = C_2/Q_2$:

(1.33) $= \ - \ = \ - \ g_1$

$= (q^{(1-a)/a} - 1)\{L_2[1 - (\ )] - \chi_2\} - \gamma_1$, and

$= \ - \ = \ \{(\ -1)(q^{(1-a)/a} - 1)(L_2(1-\ ) - \chi_2) +$

$q^{(1-a)/a}(\ )(q-1)MC_2\} \ - \ (s\,\gamma_1 + p_{C2,ka+1} + r).$

$= 0$ is downward sloping in $(\ , \chi_2)$ space. Furthermore, as increases (causing a rise in z_{C2}), decreases. The slope of $= 0$ depends on s and q. If $s > q$, $= 0$ is downward sloping and an increase in χ_2 leads to a decrease in . On the other hand, if $s < q$, the $= 0$ is upward sloping and an increase in χ_2 leads to an increase in . In either case, there is an upward sloping stable saddle path. If is initially below its steady-state value, and χ_2 will rise monotonically until they reach their steady-state values. During this transition, / is positive but decreasing monotonically toward zero. This implies that Southern technology is rising faster than Northern technology during the transition. However, as the pool of intermediate goods left to be copied dwindles, diminishing returns to imitation set in, thus lowering growth in until steady-state is reached. So the South is growing more quickly than the North during the transition but slows down until steady-state is reached. Thus, asymptotic conditional convergence results as is consistent with empirical findings of

Barro and Sala-i-Martin (1991). This also implies that the interest rate is initially greater in the South than the North, but gradually falls until it is equal to that of the North in steady-state. Hence, the diffusion of technology generates interest rate equalization between the two countries. Similarly to / , $/\chi_2$ is also positive but decreasing during the transition. This implies that Southern consumption is initially growing more quickly than Southern technology. However, the growth rate of consumption decreases more quickly than that of Q_2 until they are equal in steady-state.

As an experiment, consider what happens if *w* increases due to an exogenous increase in the quality of Southern transportation and communications infrastructure. This would cause the $= 0$ locus to shift up and right. When $s > q$, the $= 0$ locus shifts up and right, and when $s < q$, it shifts down and right. In either case, χ_2 immediately jumps down to the new stable saddle path, and then rises gradually until it reaches its new steady-state value. Since the aggregate quality level does not instantaneously jump up, this initial fall in the consumption/quality ratio reflects an initial fall in Southern consumption as investors shift money away from consumption toward imitative research due to a rise in the Southern interest rate. Even though χ_2 is increasing during the transition, it will approach a new steady-state value which is lower than before the increase in *w*. Still, the initial fall in consumption is temporary. Steady-state consumption

is greater than before. Interestingly, this points to a conflict between the short- and long-run consequences of an improvement in infrastructure for Southern consumption. In terms of technology, rises as Southern technology increases more quickly than Northern technology during the transition. Furthermore, the new steady-state level of $*$ is now higher. Thus, increased interaction between the North and the South leads to a smaller steady-state technology gap between the two countries. As previously mentioned, this could lead to the South taking over as the lead innovating country if this pushes $*$ above 1.

It is tempting to say that trade liberalization, which would also cause an increase in *w*, would have similar effects. However, this would ignore the interaction of imitation and innovation once trade is allowed. For this reason, I now open up the two countries to free trade to properly analyze the effects of trade on both imitation and innovation.

SECTION 2: Imitation with Trade

Free trade is introduced in this section, assuming that the two countries are starting from their previous steady-state positions where the North is innovating and the South is imitating. Let the Northern final good be numeraire. I assume that the marginal cost of production is greater in the North than in the South ($1 = MC1 > MC2$). I further assume that trade is balanced so there are no capital flows. With free trade, firms can now use imports of intermediate goods in final goods production. Hence, once trade is allowed, Southern firms will import any intermediate goods that had not yet been copied, and export the Southern final good, as well as any lead intermediate goods which they had previously copied. These importing firms will then be responsible for distribution and servicing of these intermediate goods. While doing this, the importing firms will learn a great deal about the goods they are selling to the final goods producers. Specifically, they will learn which products are in greatest demand, what are the most recent developments within the industry, how to adapt the goods to local conditions if necessary, and how to fix or replace the goods they sell. Hence, as seen in equation (1.17), importing large quantities of intermediate goods leads to smaller costs of gathering information on foreign products and, in turn, reduces the total costs of imitation, $z_{C2}\ s(e^{-w} + 1)$.

For a given transportation and communication infrastructure, firms in countries with relatively high import levels will therefore face lower necessary resource requirements in order to attempt imitation. Of course, this decision will, as previously discussed, also depend on past learning-to-learn in all types of research. If a Southern firm succeeds at copying the good it previously imported and can underprice the Northern lead firm, then both countries will switch to using these copied intermediate goods in their final goods production.

When the two countries open up to free trade starting from their previous steady-state positions, the technological gap between the two may either be positive or zero. In the first situation, Southern firms must first imitate all quality levels between that of the South and the North in order to be able to eventually imitate the lead Northern goods.

Northern firms are now concerned with the joint probability of losing their market to either the next innovation or to a lower-priced imitation. The expected profits of the Northern intermediate goods firms therefore now also depend on the probability of successful imitation. Furthermore, since the South can immediately import higher quality Northern intermediate goods for use in final goods production, it is no longer limited by its ability to produce its own intermediate goods. This implies that so long as the North remains the lead innovating country, the Southern growth rate will be determined by Northern technological progress.

When the countries open up to free trade, the Southern firms in the intermediate goods sectors will have to decide whether they wish to only import intermediate goods, or if they will initially import but then try to imitate in order to take over the world market from the lead Northern good. Similarly to the previous autarky case, imitating firms will consider the expected present value of profits to determine the amount of resources to devote to imitative processes. However, in the previous case, Southern firms were only considering the imitation of a good one quality rung above the current *Southern* quality level in that sector. In this case, if the South opens to free trade starting with its initial quality level in a particular sector below that of the North, then Southern firms in that sector will be contemplating imitation of Northern goods several quality rungs above their own experience level. Consequently, the resources required to bring about successful imitation of lead goods that are several quality levels ahead of the Southern firm's experience will be greater than in the autarky case where Southern firms were moving up the quality level one rung at a time. I interpret these higher resource costs as reflecting the need to imitate all quality levels between the current lead Southern good and the lead Northern good. Hence, there is a tradeoff involving the technology gap between the North and the South. A larger gap implies lower costs of imitation for each level that is being imitated, but it also implies that many more levels must be imitated before profits can be earned by the Southern firm under free trade.

This implies that Southern firms in sectors where the initial technological gap between the North and the South is relatively small or zero will undertake imitative research since the expected present value of profits will be greater than or equal to the expected research costs. However, firms in sectors that are far behind their Northern counterparts will choose not to devote any resources to imitative attempts since for them the expected resource costs needed for imitation would be greater than the expected present value of profits. I consider the two simplest cases, that of an initial value of which is so low that *no* Southern firms will imitate once free trade begins, and that of an initial value of equal to one (but with the North as the inherent lead innovating country) so that *all* Southern firms decide to imitate.

No Southern Imitation

If the initial value of is very low when the North and South begin trading with each other, then Southern firms know that the expected profits from successful imitation of lead goods is less than their expected research expenditures. Hence, they will choose to simply import the goods from the North. As soon as the South is able to import and use higher quality Northern intermediate goods, there is a level jump in Southern output. This can be thought of as the static gain from trade. Furthermore, in that situation, Northern innovating firms do not have to worry about potential imitation of their goods. The behavior of the Northern firms is therefore identical to that of the previous autarky case, except that greater expected profits (due to increased market size under free trade) lead to a greater rate of technological innovation. Thus, the growth rate in the North is unambiguously greater than under autarky:

(2.1) $\gamma_1 = [\ (L_1A + L_2A)(1-a)^{1/a}\ MC_1\ \ - r] / (\ \ + q\ ),$

where $MC_1 = 1$.

The Northern aggregate quality index/technology level will grow at the above rate. However, since Southern firms are no longer imitating (or innovating), Southern technology will stop growing altogether. As a result, there is constant divergence between Northern and Southern technology levels in this case. This may seem to be a negative outcome for the less developed country. However, trade allows the South to immediately enjoy the benefits of higher quality Northern intermediate goods, and insures immediate conditional convergence between the North and the South. The South now grows at the same rate as the North, which is greater than the previous steady-state autarky growth rate. Thus, free trade is a clear improvement for both countries relative to autarky.

Imitation in All Southern Intermediate Goods Sectors

Now suppose that *all* intermediate good sectors in the South had succeeded at imitating the lead Northern good in their sector prior to opening up to free trade with the North, but the North remains as the inherent lead innovating country due to a comparative advantage in the cost of innovation. Then, when trade begins, Southern firms with imitations of lead Northern goods in hand will immediately capture the world market for that type of intermediate good because of their marginal cost of production advantage. As soon as the next round of Northern innovation displaces the lead Southern imitation in a given sector, the lead Southern firm will begin attempting to imitate this new quality level. This Vernon-type product cycle will continue in all sectors. Since the Southern cost of imitation is less than the Northern cost of innovation, Southern firms will be able to keep up with the pace of Northern innovation, often having to wait for the next innovation to occur before being able to imitate again with a lag. Furthermore, since there are many intermediate good sectors, the Law of Large Numbers implies that the aggregate South/North quality level ratio will remain approximately constant and equal to 1 in this situation. Hence, there will be no transition path. To derive the steady-state conditions, I proceed as before by looking at the equilibrium probabilities of innovation and imitation.

Case of Drastic Innovations ($q > MC_1 / MC_2$)

Lead Northern firms will have to compete with Southern imitators as well as Northern follower firms. Consider the case where the size of quality improvements, q, is sufficiently large relative to the North/South marginal costs of production ratio that a Northern firm can hold the world market with only a single quality level improvement over a Southern copy. In this case, the lead Northern firm will now choose a price e less than the limit price, P_{1j}, at which it can prevent the sale of Southern imitations of the previous lead good:

(2.2) $P_{1j} = qMC_2$,

where e is arbitrarily small.

Free trade will affect expected profits from (and, in turn, total resources devoted to) innovation in two ways. On the one hand, free trade will imply a larger market and thus greater demand for lead intermediate goods. On the other hand, innovators will now face the possibility of losing their market to imitating Southern firms, as well as to innovating Northern firms. Thus, the lead Northern firm will have greater profits while it retains its leadership position in its sector, but will most likely face diminished tenure since its flow of profits will go to zero if either a Southern firm succeeds in imitating this good or if a follower Northern firm successfully brings about the next innovation.

If a lead Southern firm successfully imitates the lead product in its sector, it faces a marginal cost advantage relative to the Northern lead firm. Hence, it will use limit pricing to capture the entire world market for that good. Specifically, since the lowest price a Northern firm can charge is MC_1, a Southern imitator can charge e less than MC_1 and still earn positive profits. Thus, the price of the intermediate good when produced in the South will be e less than

(2.3) $P_2 = MC_1 = 1$,

where e is arbitrarily small. As expected, the demand for this intermediate good is greater when the South produces it than when the North produced it since the price of the good has dropped with imitation. Furthermore, successful Southern imitators face a greater flow of profits while producing the highest quality good under free trade than under autarky, since they are now selling to the world market.

When $q > MC_1/MC_2$, the lead Southern firm can only lose its market to the next

Northern innovation. This is due to the fact that the Southern firm has to successfully imitate the lead Northern good in order to capture the world market. Hence, only another innovation can dislodge the lead Southern firm's hold of that particular intermediate goods sector.

Steady-State Probabilities of Innovation and Imitation with Trade

Following the methodology described in the autarky case, we use the expected flow of profits, along with the assumption of free entry in research, to derive the equilibrium probabilities of innovation and imitation in the North and the South, respectively:

(2.4) $p_{I1} = [\ W_2\ (MC_1 - MC_2\ )] - r_2\ ,$

$p_{C2} = \{\ (MC_2 - \ )\ W_1 - \ \ (MC_1 - MC_2)\ W_2\ \}$
$/\ [1 + r - \ \ (MC_1 - MC_2)\ W_2],$

where

$W_1 = [L_1 A\ (\ )^{1/a} + L_2 A\ ]\ (1-a)^{1/a}$

$W_2 = [L_1 A + L_2\ A\ (\ )^{1/\alpha}]\ (1-a)^{1/a}$ and $MC_1 = 1$.

Since both countries grow at the same rate, driven by technological progress in the North, they face the same equilibrium world interest rate, $r = r_1 = r_2$. Given the constant equilibrium interest rate, the above expressions also represent steady-state probabilities of innovation and imitation.

Notice that the steady-state probability of innovation depends positively on the term $(b_C\ /\ \zeta_{C2}\ (e^{-w}+1))$. This implies that the greater the learning-to-learn spillover from past imitative experience and the lower the fixed cost of imitation, the greater the probability of innovation in equilibrium. Therefore, if the South imports many high technology goods, implying a high ω and a low fixed cost of imitation, then the Northern probability of innovation will be higher, all else equal. This reflects a pushing forward of Northern innovation when faced with competition from low cost imitation.

Similarly to the probability of innovation, the probability of imitation is positively affected by the coefficient of past innovative experience divided by the fixed cost of innovation in the North. This again implies that competition between imitating Southern firms and innovating Northern firms drives up the rates of both innovation and imitation. The parameters for imitation however, enter ambiguously in equation (2.4). This reflects the fact that these parameters on the one hand, positively affect a prospective imitator's probability of success and profits during its tenure, but on the other hand, decrease the potential imitator's expected tenure due to increased probability of further innovation.

The Aggregate Economy under Free Trade

Since at any one point in time each country may be using intermediate goods produced in different countries, final goods production is

(2.5) $Y1 = A1\ L\ \ \ [(\ q_{k1j}\ x_{1kj}\ ) + (\ q_{k1j}\ x\ \ )]\ 1\text{-}a$

$Y2 = A2\ L\ \ \ [(\ q_{k1j}\ x\ ) + (\ q_{k1j}\ x_{2kj}\ )]1\text{-}a\ ,$

where $0 < a < 1$ and asterisks denote imports. Substituting in the implied demand functions and dividing through by the work force yields an expression for the aggregate output per worker in each country:

(2.6) $= Q1\ A\ (1-\alpha)(1-a)/a\,[D(\ )(1-a)/a\ + (1-D)]$

$= Q1\ A\ (1-\alpha)\ (1-a)/a\,[D\ q^{(a-1)/a} + (1-D)\ (\ )(1-a)/a],$

where D is the proportion of sectors with production in the North and $(1-D)$ is the proportion of sectors with production in the South. So aggregate output per worker in both countries is increasing in $Q1$, the aggregate quality level of the North. In turn, this implies that both countries will be growing at the same rate, which will be equal to the growth rate of $Q1$. Again, aggregate resources devoted to research and aggregate consumption in both countries are constant multiples of the Northern aggregate index of attained quality. Hence, we set the growth rate of $Q1$ (derived using the equilibrium probability of innovation) equal to the growth rate of consumption in equation (1.24) from household optimization to find an expression for the equilibrium world interest rate, assuming that both countries face the same r and q:

(2.7) $r^* = r + q\,[\,W_2\,(MC1 - MC2) - r\,]\,/\,(\ + q\,)$.

To return to the growth rate of the economies, subtract r from equation (2.7) and divide by q:

(2.8) $\gamma = \gamma = [\,W2\ (MC1 - MC2) - r\,]\,/\,(\ + q\,)$,

where $MC1 = 1$. In both countries, the growth rate depends negatively on the cost of imitation. Hence, the higher the level of Southern imports of intermediate goods, the lower the cost of imitation and the greater the growth rate in both countries. Nonetheless, as imports of capital goods and the quality of transportation and communications infrastructure increase (i.e., ω increases), there exists a lower bound on the cost of imitation equal to $zC2$. Hence, the South can *not* simply lower its cost of imitation to zero, causing the growth rate of both countries to go to infinity. This lower bound to the cost of imitation effectively rules out such an outcome.

As previously mentioned, when free trade is allowed, Northern firms on the one hand, enjoy higher profits while they are able to sell to the world market, but on the other hand, will most likely face decreased tenure. Hence, there will be either a positive or a negative feedback effect between innovation and imitation depending upon which of these two effects dominates. To see exactly what conditions determine the sign of the feedback effect, I compare the growth rate in this case of free trade with imitation with the previous autarky growth rate. In so doing, I find that the free trade growth rate with imitative competition is greater than the Northern autarky growth rate if

(2.9) $>$,

where $MC1=1$. The left-hand side of this expression shows that all else equal, the lower the experience-adjusted cost of imitation, $\zeta_{C2}(e-w+1)/b_C$, relative to the experience-adjusted cost of innovation, ζ_{I1}/b_I, the more intensely Northern firms will undertake research. Hence, if the experience-adjusted cost of imitation is sufficiently low relative to the experience-adjusted cost of innovation, then the North (and the South) will grow more quickly in the case of free trade with imitation than in the previous autarky case. Intuitively, this might be thought of in light of today's computer industry, where lead innovating firms know that they will be imitated/cloned quickly and, hence, they actually push their research forward even more quickly than when faced with less imitative competition. The right-hand side of this expression shows, *ceteris paribus*, the larger the world market relative to the Northern market (i.e., the larger the Southern market), the more likely will the Northern firms be to increase the intensity of their research, thereby increasing the growth rate of both economies. This reflects the scale effects present in the demand for and, hence, the profitability of intermediate goods.

I previously assumed that the experience-adjusted cost of imitation is lower than the experience-adjusted cost of innovation. Furthermore, the size of the world market is obviously greater than the size of the Northern market alone. It is therefore likely that condition (2.9) holds and both the North and the South face a higher steady-state growth rate than in the previous autarky cases. This result is similar to that of the Grossman and Helpman (1991a) varieties model of North-South trade and the inefficient followers case of the quality-ladder model.

Imitation in a Subset of Southern Intermediate Goods Sectors

It is more likely that some Southern sectors will give up imitation altogether, while other sectors will continue to imitate once trade between the North and the South begins. This implies that divergence between the Southern and the Northern aggregate quality levels will occur since these indices depend on the quality levels in all sectors. However, for the sectors where Southern imitation continues, the South-North quality ratio within that industry will remain approximately at its steady-state value of 1. Which Southern sectors continue to imitate after opening to free trade will depend on the past learning-to-learn in that sector prior to facing Northern competition. Nonetheless, the South will continue to grow with the North and, hence, conditional convergence still results.

Conclusion

This paper presents an endogenous model of growth through technological progress, demonstrating both static and dynamic benefits for less developed countries when trading with developed countries. The concept of learning-to-learn in both imitative and innovative research is introduced, and a potential mechanism through which trade directly affects the process of imitation is explicitly modeled. Transitional dynamics and the determinants of comparative advantage in innovation are derived for the case of imitation without trade. This demonstrates positive dynamic effects for the South of technological diffusion through imitation. Finally, free trade with imitation generally leads to greater growth rates than imitation under autarky, implying a dynamic gain from trade for both the innovating and the imitating country.

This paper thus provides another argument, especially from the point of view of developing nations, in favor of free trade. In particular, these results suggest that developing nations should not fear that free trade might cause their firms to specialize in imitation. This may be a temporary stage during which the developing country is catching up with developed nations. It may then take over the leadership position in certain sectors, or it may always remain the follower country. Nonetheless, the developing country will grow much more quickly both in the short and long run if it allows free trade and comparative advantage in innovation to determine whether any domestic industries will eventually take over leadership positions, rather than trying to isolate itself from the world in the hopes of forcing its industries to develop in a vacuum.

Appendix

Decision to Undertake Research

Under Autarky. Comparing profits of leaders replacing themselves, π_{lead}, with profits of followers taking over the lead position, π_{fol}. Since the lead firm will now be selling a product twice as productive as its nearest competitor, it will be able to use a price slightly below q^2MC_i. However, it will also lose its profits from its previous innovation, which was priced slightly below qMC_i. Hence, the lead firm's incremental gain in profits from replacing itself is

$$\Delta\pi_{lead} = B\,[\,(q^2 - 1)\, q^{-1/a}\, q^{(k_{ij}+1)(1-a)/a} - (q-1)\, q^{k_{ij}(1-a)/a}],$$

where

$$B = L_i\, A\,\{[(1-a)/q]^{1/a} MC_i\,.$$

On the other hand, the follower simply goes from having no profits to having positive profits when it takes over the lead position. Hence, the incremental gain for the follower is

$$\Delta\pi_{fol} = B\,(q-1)\, q^{(k_{ij}+1)(1-a)/a}\,.$$

The gain to the follower firm is greater so long as $q^{1/a} > 1$, which is guaranteed by the model's initial assumptions that $q > 1$ and $0 < a < 1$.

Under Free Trade: Three Scenarios

Scenario 1: Neither the lead Northern innovation (at quality level k_{1j}) nor the $(k_{1j}-1)^{th}$ innovation has yet been copied (i.e., the South is still far from catching up with the North). Thus, the lead Northern firm's closest competitor is the Northern follower that had invented the $(k_{1j}-1)^{th}$ innovation. This situation yields the same limit pricing scheme and outcomes as in autarky described above except that $B=(L_1A + L_2A)\{[(1-a)/q]^{1/a} MC_1$. Only followers will do research.

Scenario 2: The lead Northern innovation (at quality rung k_{1j}) has not yet been imitated, although the $(k_{1j} - 1)$th innovation has been imitated. If the lead Northern firm replaces itself, it will now be selling a product twice as productive as its nearest competitor (which is a Southern imitator). Hence, it will be able to use a limit price slightly below $q^2 MC_2$. However, it will also lose its profits from its previous innovation, which was sold at a price slightly below qMC_2. Thus, the lead firm's incremental gain in profits from replacing itself is

$$\Delta\pi_{lead} = D\,[\,(q^2 MC_2 - MC_1)\, q^{-1/a}\, q^{(k_{1j}+1)(1-a)/a} - (qMC_2 - MC_1)\, q^{k_{1j}(1-a)/a}],$$

where

$$D = (\,L_{1A}\,(MC_1/MC_2)^{1/a} + L_{2A}\,)[(1-a)/q]^{1/a}.$$

On the other hand, the follower goes from having zero profits to having positive profits. When the follower replaces the lead firm, it must set its price so as to not only capture the market away from the ex-lead Northern firm, which is one quality level behind, but also to prevent the Southern imitating firm, which is now two quality levels behind, from reentering the market. Hence, its limit price will be the smaller of qMC_1 and $q^2 MC_2$. Since we assume that $q > MC_1/MC_2$, this implies that the lower of the two is qMC_1. Therefore, the follower will sell its new innovation at a price ε below qMC_1 when it takes over the lead position. Hence, the incremental gain for the follower (so long as the Southern firms are at least two steps behind) is

$$\Delta\pi_{fol} = D\,(q - 1)\, MC_1\, q^{(k_{1j}+1)(1-a)/a}\text{ , where } D \text{ is defined above.}$$

The incremental gain to the follower is greater than to the leader so long as $q^{-1} + q^{1/a} - q^{(1-a)/a} > 1$. Again, the assumptions that $q>1$ and $0 < a < 1$ are sufficient to guarantee that the follower firm has greater incentive to innovate than the lead firm and therefore only followers will undertake innovative research.

Scenario 3: Imitation of the lead Northern innovation has already occurred. In this case, both the leaders and the followers will have the same costs and incentives to bring about the next innovation. Hence, both leaders and followers will undertake innovative research.

Market Value of Firms

The only firm with market value in any given sector is the lead firm since it is the only firm currently producing intermediate goods. Its market value is simply its expected present value of profits for its innovation, $E(v_{ikj})$, in equation (1.9). Using the free entry condition in equation (1.13) to find an expression for $r_i + p_{ikj}$, and substituting this into $E(v_{ikj})$ yields

$$E(v_{ikj}) = \quad q^{k_{ij}(a-1)/a}\ .$$

Thus, the value of the lead firm is simply the expected profits of its innovation, which coincides with the expected cost of bringing about the k_jth innovation. Aggregating across sectors, the aggregate market value of firms, V, is also a constant multiple of the aggregate quality index, Q_i:

$$V = E(v_{ikj}) = \quad Q_i\ .$$

Transitional Dynamics under Autarky

Let us define an intermediate goods sector specific budget constraint

(A1) $\quad y_{2ka} = x_{2ka} + c_{2ka} + z_{C2ka}$, where

$$y_{2ka} = \quad = q^{k_{2a}(1-a)/a}\, \Lambda_2\,,$$
$$x_{2ka} = \quad = q^{k_{2a}(1-a)/a}\, \Lambda_2\,(\ )\,,$$
$$c_{2ka} = \quad = q^{k_{2a}(1-a)/a}\, \{\Lambda_2\,[1-(\ )] - p_{C2}\ \}\,,$$
$$z_{C2ka} = \quad = q^{k_{2a}(1-a)/a}\, p_{C2}\ ,$$

$q_{k2a}{}^{(1-a)/a}$ = , and $\Lambda_2 = L_2\, A\, (\ )^{(1-a)/a}$.

As mentioned earlier, the growth rate of the aggregate quality level Q_2 is

(A2) $= p_{C2ka}\, (q^{(1-a)/a} - 1) = z_{C2ka}\, f_C(k_a)\, J_{C2ka}\, (q^{(1-a)/a} - 1)$.

Substituting for z_{C2ka} using the sector specific budget constraint ($z_{C2ka} = y_{2ka} - x_{2ka} - c_{2ka}$), equation (A2) yields

(A3) $= (y_{2ka} - x_{2ka} - c_{2ka})\, f_C(k_a)\, \vartheta_{C2ka}\, (q^{(1-a)/a} - 1)$
$= (y_{2ka} - x_{2ka} - c_{2ka})\ \ q_{k2a}{}^{(a-1)/a}\, (q^{(1-a)/a} - 1)$.

Substituting in for y_{2ka} and x_{2ka}, we get an expression for the growth rate of the Southern aggregate quality level, which is independent of the quality level k_j:

(A4) $= \{\ 2[1-\ (\ )] - \chi_2\}\, (q^{(1-a)/a} - 1)$, where

$\Lambda_2 = L_2\, A\, (\ \ )^{(1-a)/a}$ and $\chi_2 =$.

Since = , we know that

(A5) $= \ - \ = \ - \ g_1$

$= (q^{(1-a)/a} - 1)\ \{\ L_2[1- (\ )] - \chi_2\} - \gamma_1$.

This is the first of two needed differential equations. Next, we want to derive a differential equation for χ_2, which will be constant in steady-state. Since $\chi_2 = C_2/Q_2$, we know that $_2/\chi_2 = (_2/C_2) - (_2/Q_2)$. We already have an expression for $_2/Q_2$, so we now need an expression for $_2/C_2$. With no population growth $_2/C_2 = _2/c_2$. Hence, we can substitute equation (1.32) for r_2 into the growth rate of consumption in equation (1.24) yielding

(A6) $= \ [s \ \ + (p_{C2ka} p_{C2,ka+1} / z_{C2ka}) - p_{C2,ka+1} - r]$

$= \ \{\ [s\ (q^{(1-a)/a} - 1)(L2(1- \ \ ) - \chi_2) +$
$L2\ q^{(1-a)/a}(\ )(q-1)MC2\ \ ] - (s\ \gamma_1 + p_{C2,ka+1} + r)\}$.

Subtracting equation (A4) from equation (A6) yields the second differential equation

(A7) $= \ -$
$= \ \{(\ \ -1)(\ q^{(1-a)/a} - 1)(\ L2\ (1- \ \ ) - \chi_2\ ) +$

$q^{(1-a)/a}(\ )(q-1)MC2\ \}\ \ -\ \ (s\ \gamma_1 + p_{C2,ka+1} + r)$.

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