

**North-South Technological Diffusion:  
A New Case for Dynamic Gains from Trade\***

Michelle Connolly

Department of Economics, Duke University  
305 Social Sciences Box 90097, Durham, NC 27708-0097  
email: [connolly@econ.duke.edu](mailto:connolly@econ.duke.edu)

working papers available at  
<http://www.econ.duke.edu/~connolly>

September 20, 1999

Abstract:

This paper studies the transitional dynamics in a quality ladder model of endogenous growth in which North-South trade leads to technological diffusion through reverse engineering of intermediate goods. The concept of learning-to-learn is incorporated into both imitative and innovative processes, which in turn drive domestic technological progress. International trade with imitation leads to feedback effects between Southern imitators and Northern innovators who compete for the world market. Consequently, both regions face transition paths dependent on their relative technologies. Using numerical solutions we see that rates of innovation and imitation are initially high but fall as the technology gap decreases in transition to steady-state. Increased interaction between the two regions leads to higher world growth, demonstrating dynamic benefits to the South of increased trade with a more developed region. Despite faster per capita output growth, transition costs lead to decreased Northern welfare, although this loss is attributable to the lack of intellectual property rights rather than trade per se. The fall in Northern innovation as the technology gap between the two regions is reduced may explain the slowdown of measured total factor productivity growth in OECD countries over the last 30 years.

\*I would like to thank Robert Evenson, Xavier Sala-i-Martin, and T.N. Srinivasan for their guidance with the original version of this paper. I also appreciate helpful comments and suggestions from Willem Buiters, Alison Butler, Elias Dinopoulos, Amy Glass, James Harrigan, Louise Keely, Kent Kimbrough, Edward Leamer, Philip Levy, Enrique Mendoza, Robert Mundell, Pietro Peretto, David Prentice, Nouriel Roubini, Jose Victor Rios Rull, Diego Valderrama, Kei-Mu Yi, and seminar participants at Columbia University, the Federal Reserve Bank of New York, and Yale University. Diego Valderrama provided valuable research assistance. I remain responsible for any errors.

## I. Introduction

This paper considers the dynamic implications of North-South trade for both developed and developing nations. In particular, the paper shows the transitional dynamics for both countries resulting from technological diffusion through reverse engineering of traded intermediate goods. Since trade forces competition across countries for markets, the dynamic implications of technological diffusion are critical to understanding not only the evolution of technology in less developed countries (LDCs) but also the rate of innovation in developed countries (DCs). Most of the current endogenous growth literature emphasizes technology as the engine of growth. This suggests that consideration of not only where leading technology is being created, but also where it is diffusing and whether or not this process feeds back and affects the original source of the technology, is crucial to understanding time paths for both DCs and LDCs. Such a framework may explain not only the catch up phase seen in newly industrialized countries but also the slowdown of measured total factor productivity growth in OECD countries over the last 30 years.

The model developed here is related to that of Grossman and Helpman (1991b) and Barro and Sala-i-Martin (1997). However, this paper aims to make three contributions to the existing literature on North-South technological diffusion. First, it derives the transitional dynamics of a quality ladder model under free trade. Of particular interest are the transitional dynamics experienced by the South in the case in which its firms successfully imitate Northern technology, with the possibility of using imitation as a springboard to leapfrog Northern firms. One might think of the Japanese automakers, Acura, Lexus, and Infinity, that initially reverse engineered European luxury cars in order to better design their own luxury automobiles, eventually increasing their share of the luxury automobile market from 4.4% in 1986 to 26.6% in 1991.<sup>1</sup> Second, the paper introduces the notion that both imitation and innovation depend positively on past *learning-to-learn* in research, whether imitative or innovative. Thus, there is a positive externality both from past imitation and past innovation, although the spillover from

---

<sup>1</sup> Bolton (1993), p.36.

innovation is assumed to be greater. Learning-to-learn differs from the more common notion of learning-by-doing in that the skills gained are applicable to different types of research, as opposed to being limited to the exact task in which the learning occurs. Learning-to-learn implies that countries which are simply given technology will have a more difficult time moving beyond that technology than countries which actively created or imitated the technology on their own. Third, imports of Northern capital goods and the quality of Southern infrastructure are explicitly considered in modeling the cost of imitation for the South.

There are two strands in the growth literature which consider different aspects of trade and technology. The first strand focuses on the effect of North-South trade when it leads to Northern specialization in industries exhibiting positive spillovers and Southern specialization in industries lacking such positive externalities (Young 1991; Stokey 1988<sup>2</sup>). Within that type of model, the LDC experiences negative dynamic effects which could potentially outweigh the static gains from trading with a DC. For example, in Young's (1991) model growth is driven by learning-by-doing in production. This learning-by-doing is bounded within the production of any given good, but exhibits positive spillovers across goods. Once learning-by-doing for a given good is exhausted in one country, then a second country which begins production of the same good will not benefit from any learning-by-doing. Combined with the assumption of no international technological diffusion, this implies that if trade leads an LDC to specialize in the production of goods previously produced in the DC, then it will experience technological progress at a rate less than or equal to its autarky rate. Hence, the LDC will face dynamic losses from trade that could possibly outweigh the static gains from trade with a DC.

The second strand of literature considers 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;<sup>3</sup> Barro and Sala-i-Martin 1997; Glass 1997). In this last category of papers, some consider feedback effects

---

<sup>2</sup>Stokey's model considers specialization in a traditional sector with no learning-by-doing versus specialization in industries with learning-by-doing, but does not consider North-South trade.

<sup>3</sup>Rivera-Batiz and Romer (1991) consider the effect of increased economic integration through trade between two similar, developed countries rather than between a DC and an LDC.

between the North and the South in steady-state, but do not analyze transitional dynamics for either region (in particular Grossman and Helpman 1991a and 1991b). Barro and Sala-i-Martin on the other hand derive transitional dynamics for the South but can not consider the possibility of a feedback effect for the North since they assume no trade in intermediate goods. Hence, no transition path exists for the North.

This paper combines considerations from both strands of the literature. In relation to the first strand, this paper considers what happens if the South specializes in imitation, an activity assumed to have smaller positive externalities than innovation. In relation to the second strand, this paper also considers the effects of North-South trade on technological progress in both regions. However, since trade causes a feedback effect between Northern and Southern research, the feedback effect in turn affects not only the steady-state, but also the transition to steady-state in both the North and the South. Hence, the issue of North-South trade is considered not only in terms of whether trade leads to LDC specialization in imitation, but also in terms of how such trade affects the diffusion of technology to the South and in turn worldwide growth.

I find that for reasonable parameter values, increasing Southern openness to intermediate good imports causes large initial increases in rates of innovation and imitation. These rates then fall in transition to steady-state but remain above previous steady-state levels. This increased interaction between the two regions leads to higher world growth, demonstrating dynamic benefits for the South of increased trade with a more developed region even if it ends up specializing in imitative activities. If one considers only the steady-state effects this would be welfare enhancing for both countries. However, there are transition costs, borne principally by the North. Because the transition to steady-state is very long, the welfare loss during transition outweighs the steady-state welfare gain for the North. Still, we see that the welfare loss in the North is due to a lack of internationally enforced intellectual property rights rather than trade liberalization by the South. While the South unambiguously gains from trade liberalization, its welfare gain is even greater when liberalization is combined with increased intellectual property rights enforcement.

The paper is organized as follows. Section II provides empirical motivation for the modeling of imitation. Section III develops the model. Section IV describes the transitional dynamics and steady-state results under trade with imitation. Section V concludes.

## **II. Imitation**

The focus of this paper is on reverse engineering since this channel of technological diffusion is more closely linked to trade than other possible channels of diffusion such as labor mobility or foreign direct investment. Moreover, in a survey of 26 U.S. firms whose technology had diffused to non-U.S. competitors, Mansfield and Romeo (1980) found that U.S. firms felt that reverse engineering was the most frequent channel through which technology “leaked-out.”

Successful imitation allows for the diffusion of technology embodied in a product as imitators reverse-engineer that good. Moreover, 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. So imitation not only makes a firm better at future imitation, but also improves its chances of successfully inventing the next quality level on its own.<sup>4</sup> For example, Advanced Micro Devices, Inc. and Samsung both initially specialized in reverse engineering and cloning leading edge technology, but have since switched to innovative research.<sup>5</sup>

Hence, learning-to-learn differs from learning-by-doing in that the skills gained are general and thus applicable to different types of research within an industry. This suggests that a country that is handed technology will not be able to move beyond that technology as easily as if the country had created or imitated that technology on its own in the past. In other words, there is a tradeoff between facing a lower access cost to technology today if being given the foreign technology and a greater experience adjusted cost of imitation

---

<sup>4</sup>This is much like graduate studies, where the first years in graduate school are spent reverse-engineering the pre-existing stock of academic knowledge. During that time, students attain the skills and detailed understanding of the subject matter necessary to hopefully “innovate” on their own.

<sup>5</sup>AMD reverse engineered and cloned Intel's 386 and 486 chips in the 80's and early 90s, but has since begun developing its own microprocessor chips, first the K5 and now the K6. Similarly, Samsung moved from imitating technology to developing its own, particularly successfully with DRAM computer chips.

and innovation in the future because of the foregone learning that would have occurred through reverse-engineering. There is therefore an issue of hysteresis to be considered, which has important implications for LDCs and their technological development.

I additionally assume that importing advanced Northern capital goods lowers the Southern cost of imitation because of general exposure to imports,<sup>6</sup> and servicing and distribution by local importing firms.<sup>7</sup> Moreover, trade also provides access to international markets for successful imitators.<sup>8</sup>

Several empirical studies consider the possible link between general imports and technological diffusion (Eaton and Kortum 1996a and 1996b; Coe and Helpman 1995; Coe, Helpman, and Hoffmaister 1997<sup>9</sup>; Keller 1998; Coe and Hoffmaister 1999). Trade based convergence clubs also provide evidence that trade is likely an important channel for technological diffusion (Ben-David 1993; Ben-David 1996; Ben-David and Rahman 1996). Finally, Connolly (1998), using panel data for developed and less developed countries, finds a significant positive relationship between high technology imports from DCs as a share of GDP and domestic innovation and imitation. Moreover, the importance of high technology imports to domestic research is far greater in developing countries than in developed countries. This may reflect the fact that since LDCs are often not highly integrated with DCs, the role of trade in physical goods is all the more important for the diffusion of technology to the LDC. Thus trade appears to play an important role in technological diffusion and, in turn, conditional convergence, particularly for developing nations.

---

<sup>6</sup>For example, if each individual exposed to a good has a certain probability of imitating it, then the number of people exposed to the good should positively affect the overall probability that the good is imitated.

<sup>7</sup> Lesley (1924) provides anecdotal evidence of three independent U.S. imitations of previously imported European Portland cement during the late 1800s: by an individual who used Portland cement in construction, by a company that made concrete products, and by a large importing firm that distributed Portland cement within the U.S. The importance of exposure to a good is also demonstrated in Thompson's (1992) study of 3,500 U.S. sewing machine patents, in which he finds that patenting activity followed sewing machine sales both geographically and temporally.

<sup>8</sup> Sokoloff (1988) finds that U.S. counties from 1790 to 1846 with access to navigable waterways had higher patenting rates than counties without such access. Moreover, he finds an increase in county patenting rates after the introduction of new waterways in or adjacent to these counties. Thus, both exposure to goods and access to larger markets appear to play important roles in research activity.

<sup>9</sup> Coe, Helpman, and Hoffmaister (1997) consider machine and equipment imports rather than general imports.

### III. The Model.

The model develops a framework for technological diffusion, in which imitation involves reverse-engineering in the absence of international property rights enforcement. The South experiences learning-to-learn effects even if trade with the North leads to Southern specialization in imitative research. As long as the South clones goods that it did not previously produce, it benefits from learning-to-learn in research.<sup>10</sup> 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. Here however, I abstract from human capital accumulation to keep the model tractable.<sup>11</sup>

The effects of international trade with imitation are considered, assuming that the two countries are starting from steady-state positions with the South completely closed to intermediate goods imports and the North is the lead innovating country. I assume that trade is balanced so there are no international capital flows. Hence the domestic interest rate is determined by domestic technology. With trade, firms can use imports of intermediate goods in final goods production. 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.<sup>12</sup> Since the South can immediately import higher quality Northern intermediate goods for use in final goods production, it is no longer limited by its own ability to produce intermediate goods. This implies that Southern output growth will be determined by Northern technological progress.

Furthermore, since importing firms are responsible for distributing and servicing these intermediate goods, they learn a great deal about the goods they are selling. Specifically, they learn which products are in greatest demand, what are the most recent

---

<sup>10</sup>This contrasts with Young's (1991) model which assumes that if learning-by-doing for a given good is exhausted in one country, then a second country which begins production of the same good will not benefit from any learning-by-doing.

<sup>11</sup>For seminal treatments of the issue of human capital accumulation and technological diffusion, see Nelson and Phelps (1966) and van Elkan (1996).

<sup>12</sup>Assuming the Southern firm can underprice the Northern lead firm, both countries will switch to using copied intermediate goods in their final goods production whenever they are available.

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, importing intermediate goods lowers the cost of imitation. Thus, for a given infrastructure level and past learning-to-learn, countries with greater openness to imports face lower costs of imitation.

Once the South opens up to intermediate goods trade, Northern firms will be able to sell to a larger market, but will now be concerned with the joint probability of losing their market either to the next innovation or to a lower-priced imitation. Relative to being closed to intermediate goods imports, where Southern firms only needed to imitate Northern goods one quality rung above the current *Southern* quality level, trade forces Southern firms to imitate lead Northern goods, possibly several quality rungs above their own experience level. Still since trade in physical goods allows for reverse-engineering, it is possible for Southern firms to imitate Northern goods several quality levels ahead of the technology currently produced in the South. Of course, the cost and speed of imitation in each sector will depend on exactly how great a technology gap needs to be bridged by Southern imitators.

Following conventional notation for rising product quality models (Grossman and Helpman 1991a and 1991b; Aghion and Howitt 1992; Barro and Sala-i-Martin 1995 and 1997), there are a fixed number,  $J$ , of intermediate goods, whose quality levels are improved upon through innovation (or imitation).  $q$ , an exogenously given constant greater than 1, reflects the size of quality improvements with each innovation, while  $k$  reflects the rung at which the good is located on a quality ladder. Normalizing so all goods begin at quality level 1, the quality level of an intermediate 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.

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. I extend the basic setup of Barro and Sala-i-Martin (1995, Ch. 7) to an open economy situation. The resulting aggregate final goods production, undertaken by many perfectly competitive firms, in the North (country 1) and the South (country2) is:

$$(1) \quad Y_1 = A_1 L_1^a \sum_{j=1}^J [q^{k_{1j}} (\hat{x}_{1k_j} + \hat{x}_{2k_j}^*)]^{1-a},$$

$$Y_2 = A_2 L_2^a \sum_{j=1}^J [q^{k_{2j}} (\hat{x}_{1k_j}^* + \hat{x}_{2k_j})]^{1-a}, \quad 0 < a < 1.$$

$A$  is a productivity parameter dependent upon the country's institutions, such as tax laws, property rights, and government services, and  $L$  is the labor input used by the representative firm for final goods production. Since the North is the more developed country, its institutions such as tax laws, property rights, and government services that affect productivity are likely to be better than their Southern counterparts implying  $A_1 > A_2$ .<sup>13</sup>  $\hat{x}_{1k_j}$  and  $\hat{x}_{2k_j}^*$  ( $\hat{x}_{2k_j}$  and  $\hat{x}_{1k_j}^*$ ) are respectively, domestic and imported intermediate goods of type  $j$  used in the North (South). So  $q^{k_{1j}} (\hat{x}_{1k_j} + \hat{x}_{2k_j}^*)$  is the quality-adjusted amount of a particular intermediate good used in Northern final goods production. Hence, as the quality level of intermediate goods rises, so does final goods output, which is assumed to be different in each country. The Northern final good is used as numeraire.

Each country is dependent upon its own technology level for intermediate goods production. Consistent with the empirical findings of Mansfield, Swartz, and Wagner (1981), I assume that the cost of imitation is less than the cost of innovation. Since Northern technology is more advanced than Southern technology, Northern firms initially innovate and Southern firms 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,  $MC_i$ , of producing a final good, which, due to perfect competition in the final goods industry, equals the price of the final good (i.e.  $MC_i = P_Y$ ). So the marginal cost of producing an intermediate good is independent of its quality level and is identical across all domestic sectors. Since the

Northern final good is numeraire,  $MC_1=1$ . Further, since I am interested in the case where the South specializes in imitative activities under free trade with the North, I assume that marginal costs are greater in the North than in the South ( $MC_1 > MC_2$ ).

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 that protect the lead firm's domestic monopoly of that quality good, while at the same time costlessly disseminating acquired knowledge to other domestic firms. Since the last innovator in each sector is the only firm legally allowed to produce the highest quality intermediate good, it will use limit pricing to wipe out sales of lower quality intermediate goods in its sector.<sup>14</sup> Even without domestic patent protection, the existence of any fixed cost to imitation will effectively preclude domestic imitation of a domestic good.

For simplicity, I assume that innovations are drastic, i.e. the size of quality improvements,  $q$ , is greater than the North/South marginal cost of production ratio. Then a Northern firm can hold the world market with a single quality level improvement over a Southern copy.<sup>15</sup> However, a Southern firm can capture the world market from the lead firm by imitating the lead Northern good, since it can underprice the Northern firm because of lower marginal costs. Hence, there is a Vernon-type product cycle where production shifts from the North to the South with successful Southern imitation and back with subsequent Northern innovation.

Based on the size of the technology gap within an intermediate goods sector, there will be one of three possible types of producers of intermediate goods: Northern firms facing Northern competition, Northern firms facing Southern competition, and Southern firms facing Northern competition. Whenever a Southern firm successfully imitates the lead Northern firm, production will shift to the South. Let  $D$  represent the proportion of

---

<sup>13</sup> While this characterization is used in the benchmark calibration of the model, the qualitative results follow even if this assumption does not hold.

<sup>14</sup> Depending on whether  $q(1-a)$  is greater than or less than the marginal cost of production, the lead firm will respectively use monopoly or limit pricing to capture the entire domestic market for its sector. I assume  $q(1-a) < MC_i$ , implying limit pricing by all lead firms.

<sup>15</sup> If instead,  $MC_1/MC_2 > q$ , then the lead Northern firm can not under-price the Southern firm when it comes up with the next innovation. In fact, the lead Northern firm will not even be able to sell its lead product since its innovation would be more expensive in cost per quality units than the imitated second

intermediate goods sectors with production in the North and  $(I-D)$  represent the proportion of sectors with production in the South. Moreover, within sectors with Northern production, there are two types of Northern firms; those that face Southern competition (because Southern technology is less than two quality levels behind) and those that do not (because Southern technology is more than two quality levels behind and innovations are drastic). Let  $I$  represent the fraction of Northern sectors which face Southern competition, and  $(I-I)$  represent the fraction that do not. Then the domestic and foreign intermediate goods used for domestic production can be rewritten as

$$\begin{aligned}
(2) \quad \hat{x}_{Ik_j} &= D_j(Ix_{Ik_j} + (I-I)x_{I(I-I)k_j}) \\
\hat{x}_{2k_j}^* &= (I-D_j)x_{2k_j}^* \\
\hat{x}_{Ik_j}^* &= D_j(Ix_{Ik_j}^* + (I-I)x_{I(I-I)k_j}^*). \\
\hat{x}_{2k_j} &= (I-D_j)x_{2k_j}
\end{aligned}$$

where  $x_{Ik_j}$ ,  $x_{I(I-I)k_j}$  and  $x_{2k_j}$  respectively represent intermediate good inputs from Northern firms competing with Southern firms, Northern firms competing with Northern firms, and Southern firms. Then the aggregate production functions from equation (1) can be rewritten as

$$\begin{aligned}
(3) \quad Y_1 &= A_1 L_1^a \sum_{j=1}^J \{ q^{k_j} [ D_j(Ix_{Ik_j} + (I-I)x_{I(I-I)k_j}) + (I-D_j)x_{2k_j}^* ] \}^{1-a} \\
Y_2 &= A_2 L_2^a \sum_{j=1}^J \{ q^{k_j} [ D_j(Ix_{Ik_j}^* + (I-I)x_{I(I-I)k_j}^*) + (I-D_j)x_{2k_j} ] \}^{1-a} .
\end{aligned}$$

Since there are three categories of firms producing intermediate goods, there will be three different limit prices for these goods. Specifically, lead Northern firms facing only Northern competition will charge a price slightly below the limit price of  $qMC_1$  to

---

quality good. In that case, the Northern firm would have to innovate twice before it could market its product.

prevent sales of older technology on the world market.<sup>16</sup> Lead Northern firms facing Southern competition will choose a limit price of  $qMC_2$ . Finally, lead Southern firms always compete with Northern firms and hence set their limit price equal to  $MC_1$  in order to capture the world market from the lead Northern firm.<sup>17</sup>

In either country  $i$ , for a given limit price,  $P_i$ , implied demand for intermediate goods in sector  $j$  is

$$(4) \quad x_{ik_j} = L_i [ A_i (1-a) q^{k_{ij}(1-a)} \frac{P_{Y_i}}{P_i} ]^{1/a}$$

Substituting in the appropriate limit prices and  $MC_i$  for  $P_{Y_i}$ , and aggregating across intermediate goods sectors transforms (3) into:

$$(5) \quad Y_1 = L_1 Q_1 \{ D [ I ( MC_2^{(a-1)/a} - 1 ) - q^{(1-a)/a} + 1 ] + 1 \}$$

$$Y_2 = L_2 Q_2 MC_2^{(1-a)/a} \{ D [ I ( MC_2^{(a-1)/a} - 1 ) - q^{(1-a)/a} + 1 ] + q^{(1-a)/a} \},$$

where  $L_i = L_i A_i^{1/a} \left( \frac{1-a}{q} \right)^{(1-a)/a}$  and  $Q_i = \sum_{j=1}^J q^{k_{ij}(1-a)/a}$  represents an aggregate domestic quality index. Note that aggregate production in both countries depends on the Northern aggregate quality index since limit pricing with free trade insures that only the highest quality technology will be used. Hence, even when intermediate goods are produced in the South, their quality level is the same as the lead Northern quality level. Taking  $A_i$ ,  $L_i$ , and  $MC_2$  as given, each country's output depends directly on  $Q_i$ . In steady-state,  $D$  and  $\lambda$  will both be constant since the probabilities of innovation and imitation are constant in steady-state. Hence, both countries' steady-state growth rates depend solely on Northern technological progress, at least so long as the North remains the lead innovating country. Still international trade and the subsequent risk of losing the market for a given intermediate good to Southern imitation, causes the Northern rate of innovation to depend

---

<sup>16</sup>This limit price reflects the fact that the lead intermediate good in any sector is  $q$  times more efficient than the second best good. Since the lowest price the producer of the second best good can charge is  $MC_1$ , the lead firm can capture the entire market for this good by selling at any price slightly below  $qMC_1$ .

<sup>17</sup>With drastic innovations, the lead Southern firm must imitate the lead Northern good to capture the world market. Hence, only another innovation can dislodge the lead Southern firm.

on the Southern rate of imitation.<sup>18</sup> We therefore turn our attention to modeling innovation and imitation by firms in both countries.

Firms decide how many resources to devote to research based on the expected present value of profits for successful research, which depends on the probabilities of innovation and imitation. Within an intermediate goods sector  $j$ , presently at quality level  $k_j$ ,  $p_{Ik_j}$  is the probability per unit of time that the  $(k_j+1)$ th innovation occurs. Specifically,  $p_{Ik_j}$  follows a Poisson process, which depends positively on resources devoted to research,  $z_{Ik_j}$ , and past industry specific domestic learning-to-learn,  $\mathbf{J}_{k_{ij}}$ , and negatively on the complexity,  $\mathbf{f}_{Ii}(k_j)$ , of the good upon which firms are attempting to improve:

$$(6) \quad p_{Ik_j} = z_{Ik_j} \mathbf{f}_{Ii}(k_j) \mathbf{J}_{k_{ij}}, \quad \text{where}$$

$$\mathbf{J}_{k_{ij}} = \max ( \mathbf{b}_C q_C^{k_{ij}}, \mathbf{b}_I q_I^{k_{ij}} ), \quad \mathbf{b}_I > \mathbf{b}_C > 0, \quad \text{and}$$

$$\mathbf{f}_{Ii}(k_j) = (1/z_{Ii}) q^{-k_j/a}.$$

Subscripts  $C$  and  $I$  denote copying and innovation, respectively.  $\mathbf{J}_{k_{ij}}$  reflects the positive spillover effects of past learning-to-learn through imitation or innovation. For a particular domestic intermediate goods sector  $j$ ,  $q_C^{k_{ij}}$  is the highest quality level attained through imitation and  $q_I^{k_{ij}}$  is the highest quality level attained through innovation. If the country has no imitative experience,  $q_C^{k_{ij}} = 0$ , and if it has no innovative experience,  $q_I^{k_{ij}} = 0$ .<sup>19</sup>  $\mathbf{b}_C$  and  $\mathbf{b}_I$  are positive coefficients on past imitative and innovative experience, respectively.  $\mathbf{b}_I > \mathbf{b}_C$  since there should be greater learning-to-learn effects in innovation than in imitation. Learning therefore makes future research easier. On the other hand,  $\mathbf{f}_{Ii}(k_j)$  reflects the increased difficulty of inventing higher quality goods, implying a lower probability of success, all else equal. One can think of this as reflecting the notion that innovations that come later, do so because they are more difficult. This difficulty term further includes a country specific fixed cost of innovation,  $\mathbf{z}_{Ii}$ .

---

<sup>18</sup>Since it is likely that imitation of the lead good occurs before the next innovation in a sector, both Northern leaders and followers will attempt innovation.

<sup>19</sup>I assume that each country has experience in at least one type of research. If not, then  $\mathbf{J} = I$ .

The forms assumed for  $\mathbf{J}_{k_{ij}}$  and  $\mathbf{f}_i(k_j)$  guarantee constant returns to innovative research with respect to current technology levels ( $k_{ij}$ ). This setup is needed to consider a balanced growth path in steady-state. Furthermore this setup is reasonable if there are an infinite number of potential innovations, implying no diminishing returns to innovative R&D (Romer 1990).

Since we will focus on situations where the North innovates and the South imitates, I use subscripts to denote innovative and imitative activities and omit country subscripts when possible without confusion. Within a Southern intermediate goods sector  $j$ , presently at quality level  $k_{2j}$ ,  $p_{Ck_{1j}}$  is the probability per unit that a Northern intermediate good of quality rung  $k_{1j}$  is copied. Similarly to the probability of innovation, the probability of imitation depends positively on resources spent by firms in terms of output devoted to reverse engineering,  $z_{Ck_j}$ , negatively on the complexity,  $\mathbf{f}_C(k_{1j})$ , of the good being copied, and positively on past learning-to-learn in that domestic industry:

$$(7) \quad p_{Ck_{1j}} = z_{Ck_j} \mathbf{f}_C(k_{1j}) \mathbf{J}_{2k_j}, \quad \mathbf{f}'(k_j) < 0, \text{ where}$$

$$\mathbf{J}_{k_{2j}} = \max(\mathbf{b}_C q_C^{k_{2j}}, \mathbf{b}_I q_I^{k_{2j}}), \quad \mathbf{b}_I > \mathbf{b}_C > 0,$$

$$\mathbf{f}_C(k_{1j}) = \frac{1}{z_{C2} \hat{q}_j^s (e^{-w} + 1)} q^{-k_{1j}/a}, \quad \mathbf{s} > 1, \text{ and } \hat{q}_j = \frac{q^{k_{2j}}}{q^{k_{1j}}}.^{20}$$

Relative to the cost of innovation, two new factors enter into the cost of imitation,  $z_{C2} \hat{q}_j^s (e^{-w} + 1)$ . The first term,  $z_{C2}$ , parallels the fixed cost in innovative research,  $z_{Ii}$ . The second term,  $\hat{q}_j^s$ , depends on the South/North technology ratio in sector  $j$  and reflects the increasing cost of imitation as Southern technology approaches that of the North. Hence, there are decreasing returns to imitation as the pool of goods that can be targeted for imitation decreases.  $\mathbf{s}$  affects how quickly the cost of imitation rises as the technology gap falls. Since the experienced gained from imitation increases one to one with  $\hat{q}$ ,  $\mathbf{s}$  must be greater than 1 for the probability of imitation to fall as  $\hat{q}$  increases. This guarantees a smooth transition. Finally, the third term,  $(e^{-w} + 1)$ , reflects lower costs of gathering

---

<sup>20</sup>Note that if the South has only been imitating,  $\mathbf{J}_{k_{2j}} = \mathbf{b}_C q_C^{k_{2j}} = \mathbf{b}_C q^{k_{1j} + k_{2j} - k_{1j}} = \mathbf{b}_C q^{k_{1j}} \hat{q}_j$ .

information about foreign goods with greater interaction,  $w$ , between the two countries, as measured by Southern openness to imports of intermediate goods,  $M$ , and communications and transportation infrastructure quality,  $F$ :  $w = M^{h_1} F^{h_2}$ .<sup>21</sup>

Since the cost of imitation is increasing as the North-South technology gap decreases, the probability of imitation, and consequently the probability of innovation, both change in transition to steady state.

### Transitional Dynamics

Since the probabilities of innovation and imitation of a particular industry depend on the South/North technology ratio within that industry, these equilibrium probabilities are industry specific. To characterize the transition path for the aggregate economies, I consider representative domestic industries (denoted by the subscript  $a$ ), defined as an average of all domestic intermediate goods industries. The cost of imitation faced by the representative Southern industry then depends on the aggregate South/North technology ratio,  $\hat{Q}$ :

$$(8) \quad z_{c2_a}(\hat{Q})^s (e^{-w} + 1), \quad \text{where } \hat{Q} = \frac{Q_2}{Q_1}.^{22}$$

Since the probabilities of innovation and imitation in the representative industry change with  $\hat{Q}$ , the interest rates and growth rates will also change during the transition to steady-state. The interest rates will be determined by a free entry condition. Equilibrium probabilities of innovation and imitation will be determined by the functional forms presented in (6) and (7), combined with resources devoted to research based on an aggregate budget constraint. Finally, household utility maximization will determine consumption growth. Given these three components, we will be able to characterize the transitional dynamics for the economy.

Consider the following expression for the expected present value of profits for the lead Southern imitator in the average sector  $a$ :

---

<sup>21</sup>The levels of  $F$  and  $M$  are taken as given.

$$(9) \quad E(v_{Ck_{1a}}) = \mathbf{p}_{Ck_{1a}} \int_t^{\infty} e^{-\int_t^v [r_2(v) + p_{Ik_{1a}}(v)] dv} ds,$$

where  $r_2(v)$  is the rate of return in the South at time  $v$  and  $p_{Ik_{1a}}(v)$  is the probability at time  $v$  that the intermediate good of quality rung  $(k_{1a}+1)$  is invented.<sup>23</sup> Free entry into research implies that at all times, the expected present value of profits from successful imitation times the probability of success at imitation must equal the cost of imitation:

$$(10) \quad p_{Ck_{1a}} E(v_{Ck_{1a}}) = p_{Ck_{1a}} \mathbf{p}_{Ck_{1a}} \int_t^{\infty} e^{-\int_t^v [r_2(v) + p_{Ik_{1a}}(v)] dv} ds = z_{Ck_{1a}}.$$

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

$$(11) \quad r_2 = \frac{\dot{z}_{Ck_{1a}}}{z_{Ck_{1a}}} - \frac{\dot{p}_{Ck_{1a}}}{p_{Ck_{1a}}} + \frac{\dot{\mathbf{p}}_{Ck_{1a}}}{\mathbf{p}_{Ck_{1a}}} + \frac{p_{Ck_{1a}} \mathbf{p}_{Ck_{1a}}}{z_{Ck_{1a}}} - p_{Ik_{1a}}$$

$$= (\mathbf{s} - 1) \frac{\dot{\hat{Q}}}{\hat{Q}} + \frac{p_{Ck_{1a}} \mathbf{p}_{Ck_{1a}}}{z_{Ck_{1a}}} - p_{Ik_{1a}},$$

where the first term is a capital gains term, the second is a dividend term, and the third reflects loss of the market when the next innovation occurs.<sup>24</sup>

The same approach yields the following expression for the Northern interest rate

$$(12) \quad r_1 = \frac{p_{Ik_{1a}} \mathbf{p}_{Ik_{1a}+1}}{z_{Ik_{1a}}} - p_{Ik_{1a}+1} - p_{Ck_{1a}+1} + p_{Ik_{1a}+1} p_{Ck_{1a}+1} - \frac{\dot{I}}{I} \left( \frac{I}{I + D} \right)$$

<sup>22</sup>Of course, if  $\hat{Q}$  becomes greater than 1, the average Southern industry will be innovating.

<sup>23</sup>As is common in quality ladder models (Barro and Sala-I-Martin 1995), I assume that firms pool their risks by forming syndicates. Then individual firms need only worry about expected returns rather than the randomness of these returns. Of course the syndicates must not be so large as to internalize the distortions present in the model.

<sup>24</sup>This holds since  $\frac{\dot{z}_{C2k_{1a-2a}}}{z_{C2k_{1a-2a}}} = \frac{\dot{p}_{C2k_{1a-2a}}}{p_{C2k_{1a-2a}}} + \frac{\dot{\mathbf{p}}_{C2k_{1a}}}{\mathbf{p}_{C2k_{1a}}} + (\mathbf{s} - 1) \frac{\dot{\hat{Q}}}{\hat{Q}}$ .

where  $D = \frac{q MC_2 - q^{-1} MC_2^{-1/a}}{1 - q^{-1}}$ . At this point it is useful to consider  $I$ , the fraction of Northern sectors facing Southern competition, more explicitly. Assuming a normal distribution of  $\hat{q}_j$ ,  $I = \hat{Q}$  when  $0 \leq \hat{Q} \leq 1$ , so  $\dot{I} / I = \dot{\hat{Q}} / \hat{Q}$  within that range. Hence the last term reflects capital losses as more Northern industries face Southern competition.

Let us define the budget constraint for the average intermediate goods sector in each country as the country's aggregate budget constraint divided by  $J$ , the number of sectors:

$$(13) \quad y_{ik_a} = x_{ik_a} + c_{ik_a} + z_{ik_a}.$$

Specifically,

$$(14) \quad y_{1k_a} = \frac{Y_1}{J} = L_1 q^{k_{1a}(1-a)/a} \{ D [ I ( MC_2^{(a-1)/a} - 1 ) + 1 - q^{(1-a)/a} ] + 1 \},$$

$$y_{2k_a} = \frac{Y_2}{J} = L_2 q^{k_{2a}(1-a)/a} MC_2^{(1-a)/a} \{ D [ I ( MC_2^{(a-1)/a} - 1 ) + 1 - q^{(1-a)/a} ] + q^{(1-a)/a} \}$$

,

$$x_{1k_a} = \frac{X_1}{J} = D W_2 q^{k_{1a}(1-a)/a} q^{-1/a} [ I ( MC_2^{-1/a} - 1 ) + 1 ], \text{ and}$$

$$x_{2k_a} = \frac{X_2}{J} = (1 - D) W_2 q^{k_{2a}(1-a)/a},$$

where  $L_i = L_i A_i^{1/a} \left[ \frac{1-a}{q} \right]^{1/a}$ ,  $W_2 = [ L_1 A_1^{1/a} + L_2 A_2^{1/a} ( \frac{MC_2}{MC_1} )^{1/a} ] (1-a)^{1/a}$ , and

$q^{k_{ia}(1-a)/a} = \frac{Q_i}{J}$ . These budget constraints can be used to find expressions for the probabilities of innovation and imitation:

$$(15) \quad p_{Ik_{1a}} = z_{Ik_{1a}} \mathbf{f}_I(k_{1a}) \mathbf{J}_{k_{1a}} = (y_{1a} - x_{1a} - c_{1a}) q^{k_{1a}(a-1)/a} \frac{\mathbf{b}_I}{\mathbf{z}_{11}}$$

$$p_{Ck_{1a}} = z_{Ck_{1a}} \mathbf{f}_C(k_{1a}) \mathbf{J}_{k_{2a}} = (y_{2a} - x_{2a} - c_{2a}) q^{k_{1a}(a-1)/a} \frac{\mathbf{b}_C}{\mathbf{z}_{C2}(e^{-w} + 1)} \hat{Q}^{1-s} q$$

Notice that the proportion of intermediate goods sectors with production in the North,  $D$ , is equal to one minus the probability that the average Northern sector's technology has been imitated:

$$(16) \quad D = 1 - p_{Ck_{1a}}.$$

Substituting in  $\hat{Q} = I$ , the expressions from (14), and (16) into (15) yields

$$(17) \quad p_{Ik_{1a}} = \frac{\mathbf{b}_I}{\mathbf{z}_{11}} \{ (1 - p_{Ck_{1a}})(\hat{Q}\mathbf{y} + B) - \mathbf{c}_1 + \mathbf{L}_1 \}, \text{ and}$$

$$p_{Ck_{1a}} = \frac{\hat{Q}\mathbf{L}_2(1 - MC_2^{(1-a)/a}) + E + \mathbf{L}_2(qMC_2)^{(1-a)/a} - 1 - \mathbf{c}_2}{\frac{\mathbf{z}_{C2}(e^{-w} + 1)}{\mathbf{b}_C} \hat{Q}^{s-1} + \hat{Q}\mathbf{L}_2(1 - MC_2^{(1-a)/a}) + E}$$

where  $\mathbf{c}_i = \frac{C_i}{Q_i} = \frac{c_i}{q^{k_{ia}(1-a)/a}}$  and the remaining notation involves only parameters

$$\mathbf{y} = \mathbf{L}_1(MC_2^{(a-1)/a} - 1) - q^{-1/a}\mathbf{W}_2(MC_2^{-1/a} - 1)$$

$$B = \mathbf{L}_1(1 - q^{(1-a)/a}) - q^{-1/a}\mathbf{W}_2$$

$$E = \mathbf{L}_2MC_2^{(1-a)/a}(1 - q^{(1-a)/a}) + \mathbf{W}_2.$$

Given the probabilities of innovation and imitation in (17), the growth rate for the South/North Technology ratio is

$$(18) \quad \frac{\dot{\hat{Q}}}{\hat{Q}} = \frac{\dot{Q}_2}{Q_2} - \frac{\dot{Q}_1}{Q_1} = (q^{(1-a)/a} - 1)(p_{Ck_{1a}} - p_{Ik_{1a}}).$$

This is the first differential equation. Next, we want to derive differential equations for  $\mathbf{c}_1$  and  $\mathbf{c}_2$ , which will be constant in steady-state. Since  $\mathbf{c}_i = C_i/Q_i$ , we need to know the growth rate of consumption in each country, as well as the growth rate of Northern technology. Infinitely lived households maximize the following constant intertemporal elasticity of substitution (CIES) utility function, subject to the standard household budget constraint:

$$(19) \quad U_i = \int_0^{\infty} e^{-rt} \left[ \frac{c_i^{1-q} - 1}{1-q} \right] dt, \quad r > 0, q > 0,$$

where  $r$  is the subjective discount rate and  $1/q$  is the constant intertemporal elasticity of substitution in both countries. This leads to the standard first order condition,  $\frac{\dot{c}_i}{c_i} = \frac{1}{q}(r_i - r)$ . With no population growth this also equals the growth rate for aggregate

consumption. Hence,

$$(20) \quad \frac{\dot{c}_i}{c_i} = \frac{\dot{C}_i}{C_i} - \frac{\dot{Q}_i}{Q_i} = \frac{1}{q}(r_i - r) - (q^{(1-a)/a} - 1)p_{Ik_{1a}}.$$

From (20) we see that there will be interest rate equalization across the two countries in steady state. So even though there are no international capital flows, the diffusion of technology is sufficient to yield interest rate equalization.

Substituting equations (11) and (12) for  $r_2$  and  $r_1$  into (20) yields

$$(21) \quad \frac{\dot{c}_2}{c_2} = \frac{1}{q} \left[ (s-1) \frac{\dot{Q}}{Q} + \frac{b_C}{z_{C2}(e^{-w} + 1)} \hat{Q}^{1-s} q (MC_1 - MC_2) W_2 - p_{Ik_{1a}} - r \right] - (q^{(1-a)/a} - 1) p_{Ik_{1a}}$$

$$\frac{\dot{c}_1}{c_1} = \frac{1}{q} \left[ \frac{b_I}{z_{I1}} MC_1 (1 - q^{-1}) W_2 (\hat{Q} D + 1) - p_{Ik_{1a+1}} - p_{Ck_{1a+1}} + p_{Ik_{1a+1}} p_{Ck_{1a+1}} - \frac{\dot{Q}}{Q} \left[ \frac{\hat{Q}}{\hat{Q} + D} \right] - r \right] - (q^{(1-a)/a} - 1) p_{Ik_{1a}}$$

Equations (18) and (21) represent the system of autonomous differential equations in the variables,  $\hat{Q}$ ,  $C_1$  and  $C_2$  which describe the transition paths for the North and the South.

While these are analytical solutions to the model, it is difficult to visualize in three dimensions what is happening. To better understand the workings of the model, I have solved it numerically for reasonable parameter values. The benchmark parameter values presented here were chosen based on theoretical and empirical priors. Table 1 describes the choice of parameter values. Further, sensitivity analysis shows that a wide range of

parameter values yield similar stable saddle paths to steady-state, differing principally in terms of the steady-state levels of  $\hat{Q}$ ,  $p$ ,  $c_1$  and  $c_2$  to which they approach.

Consider the transition path for the South as it moves from being completely closed to imports of intermediate goods ( $M=0 \Rightarrow w=0$ ) to opening up to the average level of openness in LDCs ( $w=.13$ ).<sup>25</sup> Figure 1 shows that both the probability of imitation and innovation immediately jump up when  $w$  increases from 0 to .13.<sup>26</sup> The probability of imitation in the average Southern industry initially rises more than that of innovation in the average Northern industry, but falls more rapidly than innovation towards their new higher steady-state value of .089. Consequently,  $\hat{Q}$  is increasing, but at a decreasing rate until the new steady-state is reached when Southern technology is about 64 percent of that in the North. The fact that the probability of innovation initially increases but then falls during the transition implies that the growth rate of output per worker in both countries jumps up initially and then gradually decreases to its new higher steady state level of 1.68 percent. We also observe an immediate drop in  $c_2$ , reflecting a drop in consumption in the South as resources are shifted into imitative research. Still during the transition  $c_2$  recovers, finally reaching a new slightly higher steady-state level. Overall, greater interaction with the North, brought about through greater Southern openness to imports of intermediate goods, leads both to a higher  $\hat{Q}^*$  and to a higher world growth rate (see Table 2). While both countries benefit from the increased growth, the increased rate of innovation which fuels this growth is paid for by Northern firms trying to keep ahead of Southern imitators.

The catch up pattern we observe for the South may explain the experience of the newly industrialized countries (NICs) who had a fast initial rate of catch up which then slowed. Similarly, the fall in the rate of innovation in the developed country as the technology gap between the two countries decreases may explain the apparent slowdown

---

<sup>25</sup> The estimate for  $w$  is based on empirical work in Connolly (1998) which measures countries' levels of high technology imports as a share of GDP and communication and transportation infrastructure, and then estimates the elasticity of imitation with respect to these levels.

<sup>26</sup> To map out the transition paths I use a reverse shooting method as presented in Judd (1998). Hence the timing of the change in  $\omega$  in the figures is based on working backwards from the new steady-state to the original steady-state.

pointed out by Jones (1995) of measured total factor productivity growth in OECD countries over the last 30 years.

If, like Grossman and Helpman (1991a and 1991b), we compare only the steady-state growth rates, we would conclude that this increased openness to trade has improved welfare in both regions. However, when we consider the transitional dynamics we see that there are transition costs reflected in reduced growth rates for consumption per capita during the transition, borne principally by the North. Moreover, since the transition path lasts for a very long time, 711 periods (approximately 355 years), the welfare effects during the transition can easily dominate steady-state welfare effects. Table 3 presents the compensating variations for the North and the South. Following Lucas's (1987) methodology, these represent the percentage change in the equilibrium path of consumption under initial conditions necessary to make the household indifferent between  $w=0$  and  $w=.13$ . Despite some transition costs for the South, the South unambiguously benefits from this increased openness to Northern imports. Overall, the South would require a 20 percent increase in the equilibrium path of consumption under initial conditions to be willing to remain closed to imports of intermediate goods. However for the North, the costs of transition dominate the steady-state welfare gains. When these costs of transition are included, Northern welfare falls despite the higher future steady-state growth rate. The North would be willing to give up about 16 percent of their initial equilibrium consumption path to avoid this increased competition from Southern imitators.

So the fact that the transition is so long and the North bears most of the transition costs since they are fueling the increased rate of innovation, implies that the North faces lower welfare when the South increases its openness to imports of Northern intermediate goods. One might conclude that freer trade has benefited the developing nation, while harming the developed nation. However, the welfare loss to the North is not due to trade per se, but rather to the lack of internationally enforced intellectual property rights (IPRs). Essentially, there are positive spillovers from Northern innovation to Southern imitation, since each new innovation by Northern firms lowers the cost of Southern imitation. This is due to the fact that holding constant research experience, the cost of imitation depends negatively on the pool of goods left to be imitated, i.e. it depends positively on  $\hat{Q}$ .

Hence, if the South opened itself to imports of intermediate goods and through some licensing arrangement remunerated the Northern innovators for this spillover, then both countries would unambiguously benefit. To see this, consider the experiment where the South opens and begins enforcing a higher level of IPRs, causing Southern imitators pay a fee to Northern firms. This raises the fixed cost of imitative research,  $z_{C2}$ , and lowers the fixed cost of innovative research,  $z_{I1}$ . Figure 2 shows the evolution of the key variables during the transition to steady state. The main difference from the previous experiment is that the initial jumps in the probabilities of innovation and imitation are not quite as high and the consequent costs to consumption growth during the transition are smaller. As a result of imposing a fee on Southern imitators, aggregate Southern technology now only reaches about 62 (vs. 64) percent that of the North. Still, we see from Table 3 that the South has an even greater welfare gain when the liberalization of intermediate good trade coincides with increased IPRs. Now the South would require a 29 (vs. 20) percent increase in its initial equilibrium consumption path to be willing to remain closed to intermediate goods imports and avoid any IPRs. Moreover, we see that Northern welfare now increases. It would now require a 6 percent increase in the equilibrium path of consumption under initial conditions for the North to be indifferent to having the South increase its openness and impose a certain level of IPRs. As one would expect, it is also the case that the gain from increases in IPRs is greater for both regions, the greater the openness of the South to imports of Northern intermediate goods.

## V. Summary and 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 affects the diffusion of technology is modeled.

International trade with imitation leads to feedback effects between Southern imitators and Northern innovators who compete for the world market. Hence, both countries face transition paths dependent on the relative technologies in the two countries.

Rates of innovation and imitation are both falling in transition to steady-state and yet remain above that when the South is closed to intermediate goods imports. Increased interaction between the North and the South, through increased openness to imports of Northern intermediate goods, leads to higher world growth, demonstrating dynamic benefits to the South of increased trade with a more developed country. Northern welfare is lowered as a consequence of greater interaction with the South, despite increased world growth, because the transition to steady-state is very slow and entails transition costs borne principally by the North. However, these losses are attributable to the lack of internationally enforced intellectual property rights rather than trade liberalization per se. If the South increases intellectual property rights at the same time that it opens to imports of intermediate goods, then both regions will increase their welfare. For the South this welfare gain is greater than when opening to imports without imposing intellectual property rights.

The pattern of technological catch up presented in this model may explain the initially rapid but then slowing pattern of catch up experienced by the NICs. Similarly, the fall in the rate of innovation in the developed country as the developing country reduces the technology gap between the two countries may explain the apparent slowdown of measured total factor productivity growth in OECD countries over the last 30 years.

This paper thus provides a dynamic argument, especially from the point of view of developing nations, in favor of free trade. This is particularly relevant for sectors with high technology components. Unfortunately, these are often the very sectors which developing countries choose to protect using trade barriers in an attempt to foster industrialization in infant domestic industries. These results suggest that developing nations should not fear that 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 likely grow 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. Moreover, in a world where technology drives growth, and research in the South affects that in the North, it appears to be in the South's best interest to provide at least some degree of intellectual property rights to foreign firms.

**Table 1. Benchmark Parameters**

Parameter	Description	Notes
$r = .02$	subjective discount rate	A time period $\cong$ 6 months.
$q = 1$	$1/q$ = constant intertemporal elasticity of substitution	This gives log utility. Larger $q$ yield similar results.
$a = 0.7$	labor share in production	
$q = 1.5$	size of quality improvements with each innovation	Based on drastic innovations: $q > MC_1/MC_2$
$MC_2 = 0.7$	MC of production in South	$MC_1 = 1$
$w = .13$	Interaction Term	Based on average M/GDP and infrastructure levels for LDCs weighted by estimated elasticities of imitation with respect to these levels (for DCs $w = .352$ ). Estimates are from Connolly (1998).
$s = 1.45$	elasticity of the cost of imitation w.r.t. $\hat{Q}$	Based on theoretical specification that $s > 1$ .
$b_I = 0.8$	Learning to Learn Spillover from Innovation	Parameter values for $b$ , $z$ , and $s$ are based on Mansfield, Swartz, et al. finding that for U.S. industries the average cost of imitation is 65% that of the average cost of innovation. $w = .352$ (the estimate for DCs) was used since the Mansfield et al. results are for U.S. industries.
$b_C = 0.4$	Learning to Learn Spillover from Imitation	
$z_I = 10$	Fixed Cost of Innovation	
$z_C = 6.5$	Fixed Cost of Imitation	
$L_1 = 20$	Northern Work Force	Free parameters. These were chosen to yield $C_1 > C_2$ . Parameters yielding $C_1 < C_2$ give qualitatively similar results.
$L_2 = 23$	Southern Work Force	
$A_1 = 1.4$	Northern Productivity Parameter	
$A_2 = 0.6$	Southern Productivity Parameter	

**Table 2. Comparing Steady-States Only**

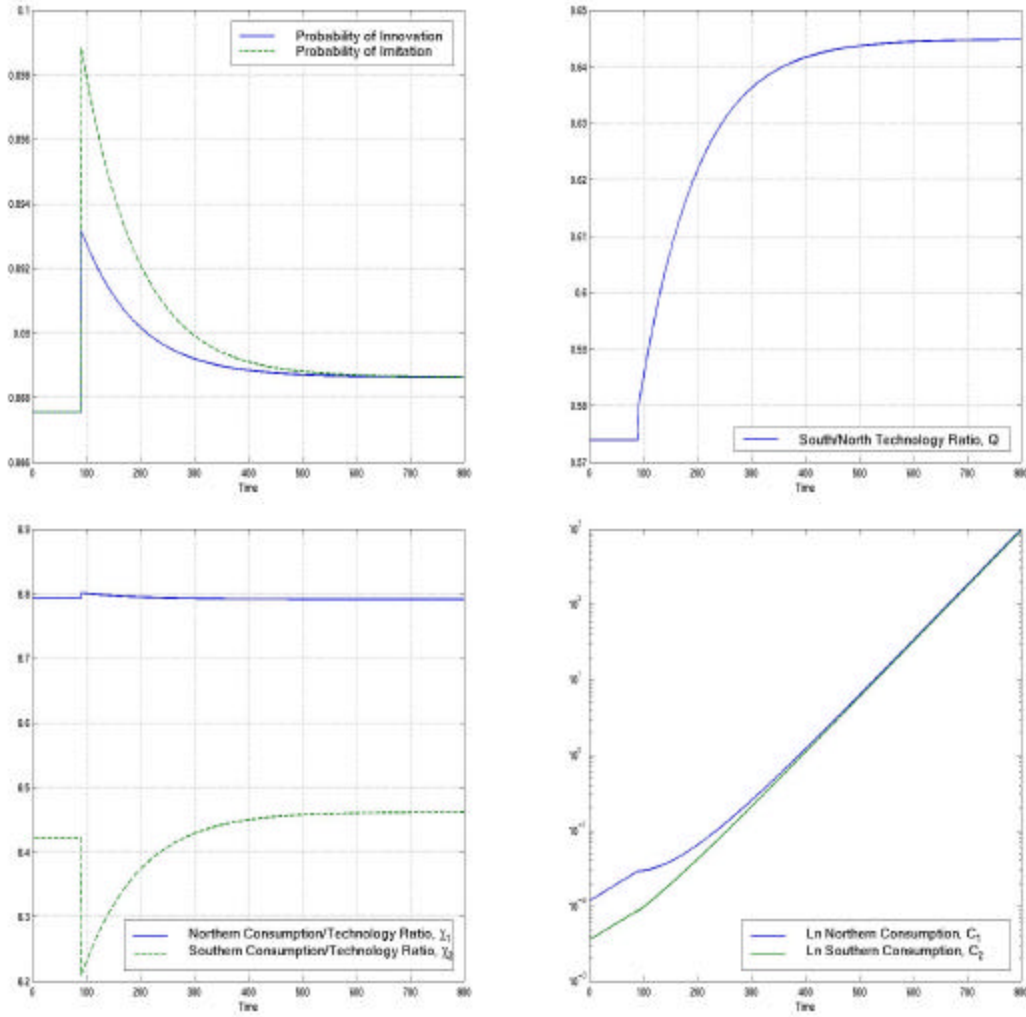
	<b>South Closed to Intermediate Good Imports</b>	<b>Increased Southern Openness</b>	<b>Increased Southern Openness Combined with Increased IPRs</b>
	Initial $w=0, z_I=10, z_C=6.5$	Final $w=.13, z_I=10, z_C=6.5$	Final $w=.13, z_I=9.9, z_C=6.6$
$\hat{Q}$	0.5739	0.6448	0.6158
$\chi_1$	8.7928	8.7919	8.7977
$\chi_2$	8.4228	8.4623	8.4352
Interest Rate	0.0366	0.0368	0.0369
Growth Rate	0.0166	0.0168	0.0169

**Table 3. Compensating Variations Including the Transition Path\***

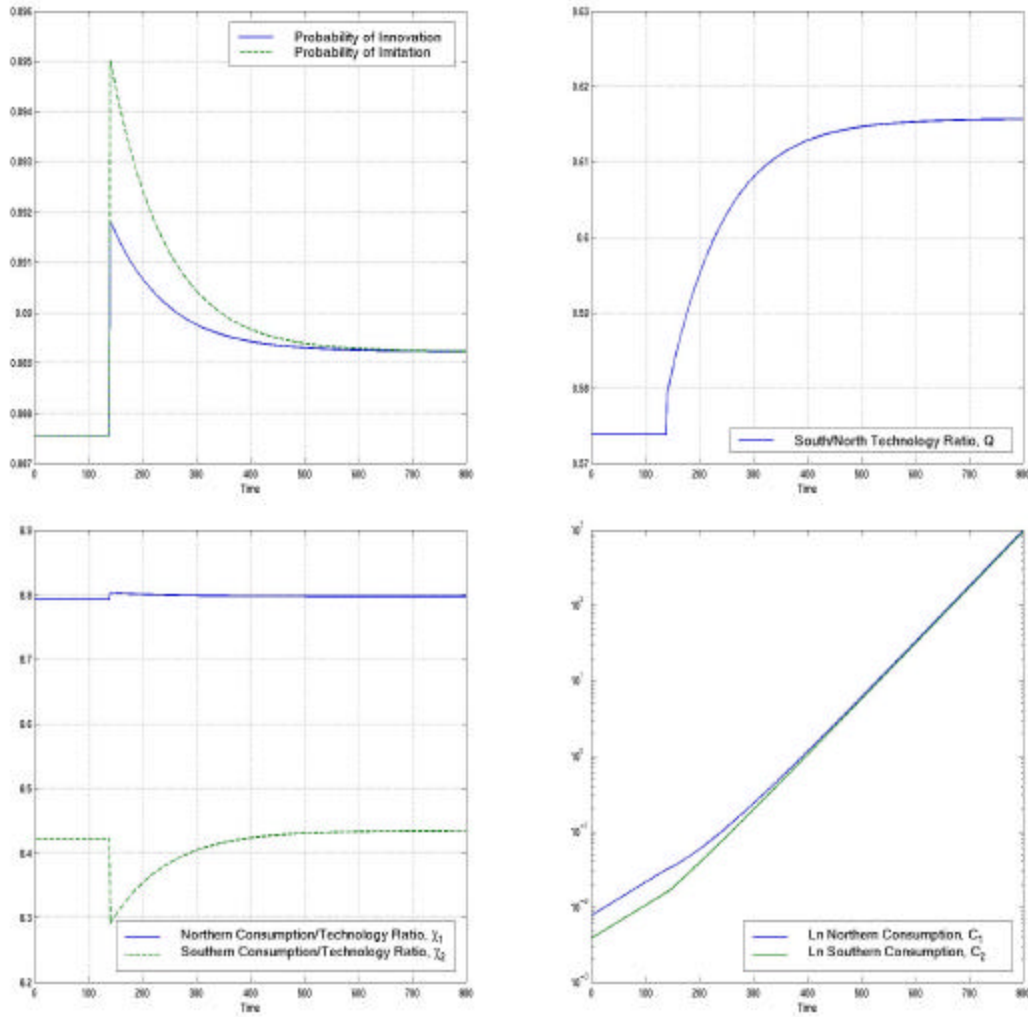
	<b>Increased Southern Openness</b>	<b>Increased Southern Openness Combined with Increased IPRs</b>
North	-0.1592	0.0578
South	0.2019	0.2939

\*Compensating variations measure the percentage increase in the equilibrium path of consumption under initial conditions necessary to make the household indifferent between pre- and post-policy conditions.

**Figure 1. As South moves from being closed to intermediate good imports to having the average LDC level of openness to these imports.  
(increasing  $\omega$  from 0 to .13)**



**Figure 2. Increased Southern openness to intermediate good imports, along with increased intellectual property rights.**  
 (increasing  $\omega$  from 0 to .13, reducing  $z_{II}$  from 10 to 9.9, increasing  $z_{C2}$  from 6.5 to 6.6)



## References

- Aghion, Philippe and Peter Howitt. "A Model of Growth Through Creative Destruction." *Econometrica*. 60, No. 2 (March 1992): 323-51.
- Barro, Robert and Xavier Sala-i-Martin. *Economic Growth*. New York: McGraw-Hill, Inc. (1995).
- \_\_\_\_\_. "Technological Diffusion, Convergence, and Growth." *Journal of Economic Growth*. 2 (1) (March 1997): 1-26.
- Ben-David, Dan. "Equalizing Exchange: Trade Liberalization and Income Convergence." *Quarterly Journal of Economics*. 108 (1993): 653-679.
- \_\_\_\_\_. "Trade and Convergence Among Countries." *Journal of International Economics*. 40 (1996): 279-98.
- Ben-David, Dan and A.K.M. Atiqur Rahman. "Technological Convergence and International Trade." working paper. University of Houston. (1996).
- Bolton, Michele K. "Imitation versus Innovation." *Organizational Dynamics*. (Winter 1993): 30-45.
- Coe, David T. and Elhanan Helpman. "International R&D Spillovers." *European Economic Review*. Vol. 39, no. 5 (May 1995): 859-87.
- Coe, David T., Elhanan Helpman, and Alexander W. Hoffmaister. "North-South R&D Spillovers." *Economic Journal*. 107 (January 1997): 134-49.
- Coe, David T., and Alexander W. Hoffmaister. "Are There International R&D Spillovers Among Randomly Matched Trade Partners? A Response to Keller" mimeo International Monetary Fund. (January 1999).
- Connolly, Michelle. "The Dual Nature of Trade: Measuring its Impact on Imitation and Growth." Duke University, Economics Department Working Paper, No. 97-34 (1998).
- Dollar, David. "Technological Innovation, Capital Mobility, and the Product Cycle in North-South Trade." *American Economic Review*. Vol. 76, No. 1 (March 1986): 177-90.
- Eaton, Jonathan and Samuel Kortum. "Trade in Ideas: Patenting and Productivity in the OECD." *Journal of International Economics*. 40 (3-4) (May 1996a): 251-78.
- \_\_\_\_\_. "Measuring Technology Diffusion and the International Sources of Growth." *Eastern Economic Journal*. 22 (4) (Fall 1996b): 401-410.
- Glass, Amy. "Product cycles and Market Penetration." *International Economic Review*. 38, 4 (November 1997): 865-91.
- Grossman, Gene and Elhanan Helpman. *Innovation and Growth in the Global Economy*. Cambridge, Massachusetts: MIT Press, 1991a.
- \_\_\_\_\_. "Quality Ladders and Product Cycles." *Quarterly Journal of Economics*. May (1991b): 557-86.
- Jones, Charles I. "R&D-Based Models of Economic Growth." *Journal of Political Economy*. 103, no.4

- (1995): 759-784.
- Judd, Kenneth. *Numerical Methods in Economics*. Cambridge, Massachusetts: MIT Press, 1998.
- Keller, Wolfgang. "Are International R&D Spillovers Trade-Related? Analyzing Spillovers Among Randomly Matched Trade Partners." *European Economic Review*. 42 (1998): 1469-1481.
- Krugman, Paul. "A Model of Innovation, Technology Transfer, and the World Distribution of Income." *Journal of Political Economy*. 87(April 1979): 253-266.
- Lesley, Robert. *History of the Portland Cement Industry in the United States*. Chicago, Illinois: International Trade Press, Inc., 1924.
- Lucas, Robert E. *Models of Business Cycles*. New York, NY: Basil Blackwell Inc., 1987.
- Mansfield, Edwin and Anthony Romeo. "Technology Transfer to Overseas Subsidiaries by U.S.-Based Firms," *Quarterly Journal of Economics*. (December 1980): 737-750.
- Mansfield, Edwin, Mark Swartz, and Samuel Wagner. "Imitation Costs and Patents: An Empirical Study." *Economic Journal*. 91 (December 1981): 907-918.
- Nelson, Richard R. and Edmund S. Phelps. "Investment in Humans, Technological Diffusion, and Economic Growth." *American Economic Review*. 56, No. 2 (May 1966), 69-75.
- Rivera-Batiz, Luis A. and Paul Romer. "Economic Integration and Endogenous Growth." *Quarterly Journal of Economics*. 106, 2 (May 1991): 531-55.
- Romer, Paul. "Endogenous Technological Change." *Journal of Political Economy*. 98, no. 5 (1990): S71-S102.
- Sokoloff, Kenneth L. "Inventive Activity in Early Industrial America: Evidence from Patent Records, 1790-1846." *Journal of Economic History*. 48 (December 1988): 813-50.
- Stokey, Nancy. "Learning by Doing and the Introduction of New Goods." *Journal of Political Economy*. 96, No. 4 (August 1988): 701(17).
- Thompson, Ross. "Learning by Selling and Invention: The Case of the Sewing Machine," *Journal of Economic History*, 55 (May 1992): 285-307.
- van Elkan, Rachel. "Catching Up and Slowing Down: Learning and Growth Patterns in an Open Economy." *Journal of International Economics*. 41 (August 1996): 95-111.
- Young, Alwyn. "Learning By Doing and the Dynamic Effects of International Trade." *Quarterly Journal of Economics*. (1991): 369-405.