ENDOGENOUS IMITATION AND TECHNOLOGY ABSORPTION IN A MODEL OF NORTH-SOUTH TRADE

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Abstract

This paper considers the transfer of technology from the North to the South that occurs through trade in high-technology goods and explicitly models the "reverse-engineering" process that allows the South to assimilate new technologies. A key finding of this study is that the South's rate of growth is dictated by the size of the country's human capital, which determines its absorptive capacity and its ability to assimilate knowledge from the North. We find that while a Southern country that is poor in human capital can only imitate, Southern countries that possess sufficiently large human capital endowments, beyond a certain threshold, signal the onset of innovation. We also find that the North enjoys a higher rate of innovation and growth with trade than without. North's gains are the highest when it trades with a human-capital "poor" South, because imitation increases South's demand for Northern intermediates. But trade with the Southern countries that are human capital rich (and therefore involved in innovation), dampens their demand for Northern imports, adversely affecting North's growth. The model predicts growth convergence between the North and a South that is well passed the threshold for innovation.

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1. INTRODUCTION

Imports of technology-intensive goods from advanced countries, provide an avenue for developing countries to improve their lot through the use of improved inputs in production and more significantly through reverse engineering of these goods. This contributes to their domestic imitation capacity and improved technological know-how. Since the early 1990s an increasing number of countries, such as India, Brazil, and Mexico, have shifted away from an import-substituting model of growth to greater openness and liberalized trade regimes, thus providing themselves greater access to new technologies and goods invented abroad. This paper considers the transfer of technology from the North to the South that occurs through trade in high-technology goods and explicitly models the "reverse-engineering" process that allows the South to assimilate new technologies. In doing so, we also show that, while imitation allows the South to grow faster than before, the *rate* of growth is dictated by the country's human capital which determines its absorptive capacity and its ability to assimilate knowledge from the North.

Diffusion of knowledge has been a central factor in the economic growth of countries across the world. Studies have shown that economic integration between similar, innovating countries leads to a higher overall rate of innovation and growth (e.g. Rivera-Batiz and Romer 1991 a, b). In a North-South open economy context, diffusion of knowledge through *imitation*, from a technologically superior North to a less developed South (Vernon, 1966; Krugman, 1979; Dollar, 1986 and Grossman and Helpman, 1991 a, b) is shown to be equally crucial for technological catch-up. Following the traditional North-South models[1], more recent studies address the issue of transition from imitation to innovation (van Elkan 1996; Currie et. al 1999) and even switching of leadership roles (Brezis, Krugman and Tsiddon 1993). In the former studies, transition from imitation to innovation is determined by the rate of knowledge spillovers and the ease of imitation. South switches to innovation when the knowledge gap between the North and South becomes small and imitation becomes too costly. In the latter models, also described as "leapfrogging" models, a lagging country's ability to adopt a new technology before the traditional leader (sometimes due to its unwillingness to give up a successful older technology), can lead to a switch in leadership roles.

While the mechanism of innovation in the North is by now well understood, the process by which imitation occurs is not so clear. In particular, Paul Romer's (1990) seminal work shows that innovation is the consequence of the allocation of human capital to profit driven research. This notion is then extended by Rivera-Batiz and Romer (1991 a, b), to the case of trade and knowledge sharing between symmetrically innovating countries. However, in the North-South models where the North *innovates* and the South *imitates*, this symmetry breaks down. Due to the complexity that the absence of symmetry creates, most North-South models (cf. Grossman and Helpman 1991 a,b; van Elkan 1996; Currie et. al. 1999; Lin, 2002) have had to sacrifice the microeconomic specificity of the knowledge transfer and accumulation mechanism, assuming instead, that innovation and imitation occur through some exogenous macroeconomic process. An implicit underlying assumption of this approach is that knowledge is a *public good* that can be freely appropriated by producers anywhere. Integration into the international economy provides a country the necessary access to this "knowledge base". The leapfrogging models also tend to abstract away from the *mechanism* of technology transfer, assuming instead that productivity differences between two countries determines who adopts a new technology first. Yet, Keller

[1] In the traditional models exogenous differences between countries are assumed that results in innovation by the North and imitation by the South, but not both.

(1996), points out that mere *access* to this “knowledge base”, which is *public*, is not sufficient for technological catch-up. In particular, skill levels of domestic workers constrain a country’s ability to absorb and implement technologies invented abroad.

Several empirical studies have considered trade in goods and services as the instrument of technology diffusion (Coe and Helpman 1995; Coe, Helpman and Hoffmaister 1997; Keller 1998; Papaconstantinou, Sakurai and Wyckoff, 1998). Coe, Helpman and Hoffmaister (1997) in particular, consider *imports of machine and equipment* (intermediate goods) as the source of knowledge used in the process of imitation (reverse-engineering) by the South. Yet, despite this empirical evidence, little analytical research exists to show *how* imitation by the South actually occurs.

The present research is an effort to address this gap in the literature. To do this, we explicitly model the mechanism of technology transfer by *endogenizing* the reverse engineering process and integrating it in a North-South innovation-imitation framework, consistent with the empirical evidence. We show how the South “decodes” technology embedded in its imports from the North through this mechanism. We also show the role human capital plays in the assimilation and *absorption* of knowledge in the South. These constitute the main contribution of this paper[2]. Although our model focuses on the process of imitation in the South, it goes further to show the conditions for the *onset* of innovation in the South. Our findings bear some similarity to a recent paper by Currie et. al. (1999), that characterizes the “*phases”* of imitation and innovation in the South. But that paper is based on an *exogenously* parameterized rate of absorption of knowledge.

As stated, Keller (1996) has argued for the key role of domestic skills in the assimilation of imported knowledge. Likewise, in our model South’s human capital plays a crucial role in the

[2] Taylor's (1993) paper is closest to ours in formulating reverse engineering and the accumulation of South’s knowledge capital as a function of the imported northern product. The paper however, focuses on intellectual property rights (IPR) issues in North-South trade and considers the effects of “masquing” (efforts to make copying more difficult) by the North and the laxity of the South's patent protection, on the knowledge capital.

reverse engineering sector. It is, in fact, the size of human capital that determines the South's absorptive capacity and its ability to assimilate knowledge from the North. One key finding from the numerical simulation of the model is that for human capital levels below a certain 'threshold' level, South's comparative advantage lies in imitation. In this range, human capital and imported technology (source of imitation knowledge), are *complements* in the production of designs, indicating reliance on imitation. However, for southern countries with human capital endowment *above* the critical 'threshold,' *substitution* between human-capital and imported intermediate goods sets in. This lowers the South's dependence on imports in the creation of new designs, indicating the *onset of innovation*. This key finding is in fact consistent with the role that human capital plays in the paper by Keller (1996).

In what follows, Section 2 presents the theoretical framework and the basic model for the North and the South. Section 3 derives the balanced growth path solutions for the two regions. Section 4 presents the numerical solutions and their implications. Section 5 concludes.

2. THEORETICAL FRAMEWORK & BASIC MODEL

Consider innovation, imitation and trade in a global economy comprising of two regions, an advanced "North" and a less developed "South." North is at the frontier of the world technology set, and possesses the knowledge base and the skill level that allow it to innovate. By contrast, South, which possesses lower levels of human capital, is in the interior of the world technology set and relies on imitating North's technologies.

Each region is characterized by three sectors: a research sector (involved in either innovation or imitation), an intermediate goods sector, and a final goods sector. In the North, the *research* sector creates new designs for intermediate goods and is therefore an innovator. The *intermediate* sector uses these designs to produce capital goods - part of which is sold domestically to the final goods sector, and the rest is exported to the South's intermediate and final goods sectors. The *manufacturing goods* sector in the North uses labor, human capital and intermediate goods to produce the final output, which is consumed domestically. Thus, the North's model is similar to Romer's (1990) with the major difference that the market structure of the intermediate goods sector now entails the dynamics of trade with the South.

Our key contribution lies in modeling the South's economy and in particular the *imitation* mechanism. Imitation represents the stylized facts of a Southern country that lacks the ability to conduct basic research[3], but has the capacity to emulate North's technologies. To do this, the South initially imports technology intensive intermediate goods from the North (e.g., a "new" generation of computers.) The *intermediate goods sector* then employs human capital to undertake "reverse engineering" in order to unravel the technology embodied in the Northern good, and thus create new "imitated designs." These designs are used to produce *clones*. The South's *final goods* sector uses the locally copied intermediate goods along with imports of Northern intermediate goods (not yet copied) and combines them with unskilled labor to produce final goods. Finally, to close the model, the manufacturing sector sells part of its output domestically and exports the rest to the North.

In our model, Southern imitators use their cost advantage to capture the domestic market for copied intermediate goods from imports. However, we assume that these imitators do not directly enter the Northern intermediate goods market. This is especially true of developing countries with large domestic markets such as India: capital goods (e.g. computers) from India hardly find their way into the U.S., yet the market for domestically produced "clones" is quite large[4]. Different factors are responsible for such behavior. Imitation generally occurs with a lag. By the time southern producers successfully imitate and produce the clones, northern consumers could have moved up the "quality ladder" e.g. a new generation of computers (Grossman and Helpman, 1991 b). Further, the cost of entering northern markets, such as the cost of advertising, often poses a significant barrier to entry. Finally, in some instances intellectual property rights in the North may

[3] Abramovitz (1986) describes this as the lack of "social capability".
[4] The total sales of the fast growing PC market in India, was estimated at 1,808,553 in 2001 by IDC, India, with a 52% growth over the previous year (Dataquest, 2001).

pose yet another barrier to entry. While there may be some generality gained by allowing Southern cloned intermediate goods to enter the North, the above caveats serve to justify, to a large extent, why we have abstracted from this particular channel.[5]

2.1 Basic Model for the North

With the exception of the market structure in intermediate goods sector, discussed later, North's model follows Romer's (1990) framework and is therefore only summarized here: The manufacturing sector produces final goods (Y_n) using human capital (H_{Yn}), labor (L_n) and a set *x(i)* of differentiated intermediate goods where i indexes the types of capital goods. This sector is perfectly competitive, both domestically and internationally, forcing the price be the same in both countries. Consequently the price of final goods is treated as *numeraire*. The production technology is represented by a constant returns to scale Cobb-Douglas technology,

$$Y_n = H_{Yn}{}^{\alpha} L_n{}^{\beta} \int_0^A x_n{}^N (i)^{1-\alpha-\beta} di \qquad (1)$$

where A is the index of the most recently invented good, representing the stock of knowledge. Technological progress is represented by an *expanding variety* of capital goods, taken from Dixit and Stiglitz (1977). Total stock of capital is given by $K = \int_0^A x_n(i) di$. Aggregating K becomes possible since all durable goods are produced according to the same production technology. K is measured in the units of consumption goods foregone, or $\dot{K}(t) = Y(t) - C(t)$.

The research sector relies on the existing stock of knowledge to produce new designs for producer durables using the balance of human capital H_{An} (so that $H_N = H_{An} + H_{Yn}$ where H_N is the total stock of human capital in the North). That is:

[5] We note a majority of goods finding their way to the US markets from China are either final goods, or intermediate goods that are the outcome of outsourcing arrangement by US based firms, rather than exports of *cloned* intermediate goods by *independent* Chinese firms.

$$\dot{A} = \delta_n H_{A\,n}\; A, \tag{2}$$

This knowledge is a *non-rival* public good, and therefore available to all. Note also that in (2) the productivity of research is linearly related to the existing knowledge stock and to human capital.

The intermediate goods sector buys the newly produced designs at a price P_A to produce capital goods, which it sells to the final goods sector *and* also exports to the South's intermediate and final goods sectors. The intermediate sector, which is both the innovator and producer of capital goods, is monopolistically competitive, appropriating the returns from R&D. However, given the distinct nature of the two markets (South and North) that it serves, this sector additionally *price-discriminates* between the two (see Section 3.2). This aspect differs from Romer (1990).

2.2 Basic Model for the South

The manufacturing sector in the South produces final goods. The technology to produce these goods is assumed to be labor-intensive, using low-skilled labor *(L_s)*. It also uses *indigenously* produced intermediate goods through reverse engineering *(x_s)* as well as directly *imported* intermediate goods (x_{nY}^{S}).

$$Y_s = L_s^{\theta} \int_0^I \left[x_s(i) + x_{nY}^{S}(i)\right]^{1-\theta} di \quad + \quad L_s^{\theta} \int_I^{I^*} \left[x_{nY}^{S}(i^*)\right]^{1-\theta} di^* \tag{3}$$

The South's knowledge base, say I is based on its ability to "reverse engineer" (or imitate) Northern goods, as we shall see later. To that extent, it is a subset of the knowledge-base available to the North, say A, which is the index of the most recently invented good by the North and represents the stock of world knowledge. Thus, $I < A$. As equation (3) suggests, a producer of final goods in the South can make use of three types of intermediate goods. In the range $0 \le i \le I$, it can choose between the *imports* of Northern intermediate goods (x_n) or the *domestically* produced clones of the same (x_s). For $I \le i^* \le I^*$, x_n represents the subset of *imported* intermediate goods that have not yet been imitated by the South. Further, $I^* < A$ as there are some Northern intermediates that may not be bought by the South. These may be state-of-art northern products that are too expensive for the South to buy or they are simply goods that are not traded.

As noted previously, a key innovation of this paper is the *explicit* modeling of the imitation process through reverse engineering: This process consists of (a) creation of "blueprints" (copied designs), and (b) additions to the South's body of imitation knowledge. Each new copied design is produced by combining the stock of South's human capital, H_s, with the knowledge embodied in the northern intermediate good, $x_n^S(i)$ to produce indigenous intermediate goods, $x_s(i)$. This is given by the following technology:

$$x_s(i) = H_s^{\phi} x_n^{S}(i)^{1-\phi} \qquad (\phi < 1) \tag{4}$$

where the process of 'reverse engineering' is assumed to be subject to constant returns to scale. New cloned designs add to the catalogue of South's knowledge, indexed by I, such that:

$$\dot{I} = \delta_s \int_0^I x_s(i)\ di \tag{5}$$

Substituting from (4), equation (5) can be represented as,

$$\dot{I} = \delta_s H_s^{\phi} \int_0^I x_{nI}^{S}(i)^{1-\phi}\ di \tag{6}$$

Equation (6) summarizes how knowledge, acquired through imitation, is accumulated in the South (δ_s is an efficiency factor): South's knowledge base, I, increases cumulatively with the number of Northern intermediate goods imported and subsequently imitated by the South.[6] Note that A, which represents the world knowledge base, a public good, is also available to the South. However initially, South lacks the know-how and resources to *process A*, which is in the form of

[6] Note that human capital accumulation is another avenue through which South can improve its knowledge base as shown by a recent working paper by Papageorgiou and Perez-Sebastian (2002). However, human capital endowments are treated as exogenous to keep the model tractable. Instead we explore this path in our numerical solutions by considering the effect of the level of South's human capital on its ability to imitate/innovate. This approach is consistent with the existing view that high human capital is what allows for the assimilation of technology (Keller, 1996).

abstract knowledge or basic scientific principles. Instead, it relies on copying product-specific information from goods already developed by the North. This approach reflects the existing view that skill level of domestic workers constrains the ability to assimilate new knowledge (Keller, 1996). The difference between the indexes *I* and *A* measures the North-South technology gap. It follows that $I < A$ since Northern technology is assumed to be more advanced than Southern technology, at least until the gap in technology levels is eliminated. It is this technology gap, which has been used by some as the driving force towards technology adoption – in the so-called catch-up models[7]. However, unlike in the present case, the process of catch-up is treated as *exogenous* in these models. Our numerical solution in section 4 shows that when the level of human capital in the South H_s, which is devoted entirely to the imitation process, is sufficiently large, South's dependence on northern imports x_n^S begins to decline, indicating the onset of innovation.[8]

The intermediate goods sector mass-produces clones for sale to the final goods sector in the South, based on the 'designs' that were created through the reverse engineering process, above. Finally, the fact that the South's intermediate goods sector commands both knowledge capital and the reproduction of imitated goods, allows this sector to be monopolistically competitive, as in the North, thereby allowing this sector to appropriate the benefits of imitation. Equations (4)-(6) constitute the key equations of the paper and will be used in the development of the North-South model.

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[7] See e.g Nelson and Phelps, (1996) and van Elkan (1996).

[8] Note that in equations (4) and (6), as the parameter ϕ rises, dependence of the South on Northern imports declines. At the limit when $\phi = 1$, intermediate goods x_s, are produced entirely with southern human capital and no imports from the North so that, equation (6) becomes, $\dot{I}_{\phi=1} = \delta_s H_s I$, which is essentially Romer's innovation equation. Our model however, does not address the very final stage of South's development as we rule out $\phi = 1$ because our manufacturing sector differs from the North's.

2.3 Preferences

Preferences in each country *i* are given by intertemporal utility function of the Ramsey type,

$$U_i = \int_0^\infty \frac{C_i^{1-\sigma_i}}{1-\sigma_i} e^{-\rho_i t} dt \qquad \text{where } i = N, S \qquad (7)$$

where ρ_i is the rate of time preference, σ_i is the elasticity of intertemporal substitution and C_i is final goods consumption. Preferences enter balanced growth path through the Euler solution to equation (7):

$$\dot{C}_i / C_i = (r_i - \rho_i) / \sigma_i \quad , \qquad (8)$$

where r_i is the market interest rate in region *i*. In the absence of capital movements, the rate of interest in the two regions need not equalize, *thereby allowing for the possibility that the two regions grow at different rates.*

3. SOLVING FOR BALANCED GROWTH

3.1 South

Given the nested nature of North's model, we first outline the model for the South. The South, which is human capital deficient relative to the North, uses all its human capital in the research sector. Although domestic clones and imported intermediates are perfect substitutes in the technology range (0, I), as is seen from equation 3, we assume that transaction costs (such as transportation costs, tariffs etc.) make the price of Northern intermediates higher relative to their Southern clones. Thus, as far as the Y sector is concerned only the Southern clones are profitable to use in the range, (*0, I*). However, in the range given by (*I, I**), only intermediate imports are available (and therefore used) regardless of their price. Based on this view, profit maximization by the perfectly competitive final goods producers is represented as:

$$\max_{x_s(j)}\left([\int_0^I L_s^\theta x_s(i)^{1-\theta} - P_s(i)x_s(i)]di + [\int_I^{I*} L_s^\theta x_{nY}^S(i*)^{1-\theta} - (1+\tau)P_n^S(i*)x_{nY}^S(i*)]di* - w_{Ls}L_s \right)$$

which yields the demand for *domestic* and *imported* capital goods $x_s(i)$ and $x_{nY}^S(i)$ respectively:

$$P_s(x_s) = (1-\theta)L_s^\theta x_s^{-\theta} \tag{9}$$

$$P_n^S(x_{nY}^S) = (1-\theta)L_s^\theta x_{nY}^{S\ -\theta} /(1+\tau) \tag{9'}$$

Producers of intermediate goods in the South are monopolistically competitive vis-à-vis the final demand sector and take the inverse demand function in (9) in their optimization decision. They engage in mass reproduction of intermediate goods, based on "blueprints" that are produced by the design sector and adapted to local conditions. The profits of each firm from sale of intermediate goods to final goods producers are:

$$\Pi_{x_s} = P_s(x_s)x_s - r_s x_s \tag{10}$$

where $r_s x_s$ represents the interest cost of capital. Maximizing (10) in x_s (using 9) yields the monopoly price of x_s as a mark-up over the marginal cost r_s,

$$P_s^* = r_s /(1-\theta)\,. \tag{11}$$

The flow of monopoly profits at this price is $\Pi_{x_s}^* = \theta P_s^* x_s^*$, where x_s^* is demand corresponding to P_s^*.

Next we determine P_I, the cost of "imitated" designs. Free entry in the design industry ensures that the cost or price of the southern 'blueprint' or design (P_I) equals the discounted *net* revenue stream, i.e., revenue minus variable cost, $P_I(t) = \int_t^\infty e^{-\int_t^\tau r_s(l)dl}\, \Pi_{x_s}(\tau)d\tau$ (see Romer, 1990).

Differentiating this equation in time yields,

$$\Pi_{x_s} = r_s P_I \tag{12}$$

Substituting for Π_{x_s} and subsequently for P_s* in the resulting equation, we find:

$$P_I = \frac{\Pi^*_{x_s}}{r_s} = \frac{\theta P^*_s x^*_s}{r_s} = \frac{\theta}{1-\theta} x^*_s \ , \tag{13}$$

Solving for x_s from (9) and (11) and substituting into (13) we get,

$$P_I = \frac{\theta(1-\theta)^{\frac{2-\theta}{\theta}}}{r_s^{\frac{1}{\theta}}} L_s \tag{13'}$$

In (13') notice that a higher interest rate in the South reduces P_I as it reduces the demand for such investments and thus their reservation cost.

We now determine South's demand for the 'technology-embodied' capital goods *imports* from the North (x^S_{nI}) for use in the imitation activity. To do so, we must solve optimization problem of the imitation activity carried out by the research or reverse engineering sector. Profits are given by,

$$\Pi_I = P_I x_s - w_{H_s} H_s - (1+\tau) P_n{}^S x_n{}^S \tag{14}$$

where τ is the tariff rate that South imposes on North's products ($\tau = 0$ under free trade).

Substituting for x_s from equation (4) and maximizing with respect to x^S_{nI} yields the expression for South's demand for x^S_{nI} as a function of P_I, $P_n{}^S$, and ϕ.

$$x^S_{nI} = \left[\frac{(1-\phi)\ H^\phi_s P_I}{(1+\tau)P^S_n}\right]^{\frac{1}{\phi}} \tag{15}$$

Thus, South's demand for Northern intermediate goods (x^S_{nI}) is inversely related to the import price ($P_n{}^S$) and positively related to the price of imitated intermediate goods in the South (P_I) , the latter because it increases importing firms profits, increasing their incentive to import. Substituting for P_I from (13') in (15) we find this demand to be:

$$x_{nI}^{S} = \left[\frac{(1-\phi)\theta \ (1-\theta)^{\frac{2-\theta}{\theta}} \ L_s H_s^{\phi}}{(1+\tau) \ r_s^{\frac{1}{\theta}} P_n^S} \right]^{\frac{1}{\phi}} \qquad (15')$$

Equation (15') can also be expressed in inverse demand form as $P_n^S(x_{nI}^S)$. The North's intermediate goods sector, in deciding its profit maximizing level of output, takes this as the export demand for x_n to augment its own domestic demand.

3.2 North

Producers of intermediate (capital) goods in the North must now serve *both* the North's own market and that of the South, which differentiates our model from the autarkic model of Romer (1990). Based on the evidence that is discussed extensively below, we assume that the two markets are separated from each other, not just by distance, but by various trade barriers, so that arbitrage will not be able to equalize prices across borders. With this, the price of North's capital goods in the Northern and the Southern market will differ, leading to price discriminating behavior on the part of Northern capital goods producers.

This view requires elaboration. For, in a world increasingly characterized by free trade arrangements and WTO rules or regional free trade arrangements, the notion that arbitrage may not be able to close price gaps, enabling market discrimination, appears paradoxical. However, evidence suggests that this is indeed the case. In the pharmaceutical industry, for example, price gaps between the US, Canada and the European Union for identical medicines persist despite attempt by private agents to purchase directly from the lowest priced market. Similar price differentials seem to also persist across borders for firms in the information technology (IT) industries. Both examples are indeed from R&D intensive industries, which are the focus of our study. The question as to why such patterns may persist, points to the role of differences in the regulatory environment and regulatory standards. This is shown by Danzon, P. and L. Chao 2000 for the case of the pharmaceutical industry and by the United States International Trade Commission (USITC) (1998), publication 3141, for the case of the IT industry. In fact, the latter states that, “As tariffs on information technology (IT) products have been reduced and face elimination in global markets, standards-related barriers have emerged as the most important obstacles to trade for IT producers.” In India, for instance, many “high technology” products such as electronic items used in computer systems are part of a "Restricted List" of items for import, qualifying them for additional restrictions such import licenses and “special items” lists. All these factors point to departures from free trade, promoting segmentation of national markets and enabling price discrimination behavior.

Combined with the customary assumption that these producers are monopolistically competitive, the relevant market structure that emerges in this sector is that of price discriminating monopolistic competition.

The first part of demand for North’s capital goods sector stems from the North’s own final goods sector. This part is standard (as in Romer, 1990) and is given by the maximization problem in the final good sector, conditional on human capital and unskilled labor in the North:

$$\max_{x} \int_{0}^{A} \left[H_{Y_n}^{\alpha} L_n{}^{\beta} x_n(i)^{1-\alpha-\beta} - P_n^N x_n^N(i) \right] di \tag{16}$$

Differentiating under the integral leads to the inverse derived demand for x_n from this sector:

$$P_n{}^N(x_n{}^N(i)) = (1-\alpha-\beta) H_{Y_n}^{\alpha} L_n^{\beta} x_n^N(i)^{-\alpha-\beta} \tag{17}$$

The second part of demand, which is new, originates from two sources in the South: Demand from the South’s final goods sector (x_{nY}^S) and the imitation sector (x_{nI}^S). Total demand for the South can be determined by adding up (x_{nY}^S) and (x_{nI}^S), per equations (9’) and (15’). In order to obtain a closed form solution for the system we make a simplifying assumption, namely that the productivity of the intermediate inputs in the South’s final goods is the *same* as that in the production of clones, implying that $\phi = \theta$. Note, however, that this assumption is *not* a necessary condition for the solution of the model but is made to keep the model tractable. The South's inverse demand for northern intermediate goods is then given by:

$$P_n^S = \left[\frac{(1-\theta)L_s^\theta}{(1+\tau)} + \frac{\theta(1-\theta)^{\frac{2}{\theta}} L_s H_s^\theta}{(1+\tau) r^{1/\theta}} \right] x_n^{S\ -\theta} \tag{18}$$

Total profits of the North's capital goods sector are based on both these sources of demand:

$$\Pi_{x_n} = P_n^N (x_n^N) x_n^N + P_n^S (x_n^S) x_n^S - r_n (x_n^N + x_n^S) \tag{19}$$

where superscript N and S are used to denote the two destinations of x_n at the two respective prices and $r_n x_n$ represents the interest cost on the units of x_n needed to produce the output. Equation (19) shows that trade enlarges the size of the market available to the intermediate producer in the North through sales to the South and thus increases the profit opportunity for the innovator. Substituting for (17) and (18), into equation (19) yields:

$$\Pi_{x_n} = \left[(1-\alpha-\beta) H_{Y_n}^\alpha L_n^\beta x_n^{N\ 1-\alpha-\beta} - r_n x_n^N \right] + \left[\pi L_s^\theta + (\Psi H_s^{\ \theta} L_s) x_n^{S\ 1-\theta} - r_n x_n^S \right] \tag{20}$$

where $\pi = \dfrac{1-\theta}{(1+\tau)}$ *and* $\Psi = \left[\dfrac{\theta\ (1-\theta)^{\frac{2}{\theta}}}{(1+\tau)\ r_s^{\frac{1}{\theta}}} \right]$.

Maximizing (20) in x_n^N and x_n^S yields the equilibrium prices for the two markets, with each price indicating a mark-up over marginal cost. These are given by:

$$P_n^{N^*} = r_n / (1-\alpha-\beta) \tag{21}$$

and,

$$P_n^{S^*} = r_n / (1-\theta) \tag{22}$$

To find the profit of the North's intermediate goods sector at these equilibrium prices, equation (20) must be expressed in terms of North's domestic price P_n^N and domestic sales x_n^N. Given the proportionality between prices, we substitute $P_n^S = \dfrac{(1-\alpha-\beta)}{(1-\theta)} P_n^N$ from (21) and (22) into (20).

The remaining challenge is to relate x_n^S to x_n^N. Here, we adopt a similar proportionality approach for quantities as for prices, namely,

$$x_n{}^S = mx_n{}^N \tag{23}$$

where m is an endogenous variable whose value remains to be determined. Incorporating the pair-wise proportionalities of quantities and prices into (20), North's intermediate sector profit level is expressed in terms of m, P_n^N and x_n^N (all endogenous) as:

$$\overline{\prod}_{x_n} = \left[(\alpha+\beta) + m\frac{\theta}{(1-\theta)}(1-\alpha-\beta)\right]P_n^N x_n^N\,, \tag{24}$$

The cost of innovated design in the North, P_A, is then determined as the present discounted value of the stream of monopoly profits, or:

$$P_A = \frac{\Pi^*_{x_n}}{r_n} = \frac{1}{r_n}\left[(\alpha+\beta) + m\frac{\theta}{(1-\theta)}(1-\alpha-\beta)\right](1-\alpha-\beta)H^{\alpha}_{Y_n}L^{\beta}_n x_n^{1-\alpha-\beta} \tag{25}$$

Next the allocation of human capital in the North is to be determined. This part is standard: Under free labor mobility, returns to human capital equalize between the research sector with and the manufacturing sector, yielding:

$$w_{H_n} = \delta_n AP_A = \alpha H^{\alpha-1}_{Yn} L^{\beta}_n A x_n^{1-\alpha-\beta} \tag{26}$$

Substituting for P_A from (25) into (26), and solving for (26) for H_{Yn} yields the equilibrium allocation of human capital in manufacturing, as a function of the variable m:

$$H_{Yn}(m) = \frac{1}{\delta_n}\frac{\alpha}{\Phi(m)(1-\alpha-\beta)}r_n \tag{27}$$

where, $$\Phi(m) = (\alpha+\beta) + m\frac{\theta}{(1-\theta)}(1-\alpha-\beta) \tag{28}$$

Note that if North exports nothing to the South, then $m=0$ and the second term in equation (28) disappears. In this case, H_{Yn} in (27) reduces to Romer's (1990) autarky value [i.e.,

$H_{Yn}(m=0) = H_{YRomer} = \frac{1}{\delta_n}\frac{\alpha}{(\alpha+\beta)(1-\alpha-\beta)} r_n$], verifying the consistency of the results. Note that in equation 27, $m>0$ (which holds by trade), $\partial H_{Yn}/\partial m < 0$. From the constraint, $H_{An} + H_{Yn} = H_N$, this implies that $\partial H_{An}/\partial m > 0$, yielding an important additional insight:

Result 1: Trade allows the North to reallocate human capital from manufacturing to research.

Result 1, occurs because trade expands North's capital goods to serve the South *and* the North. Below, we investigate what this means for the North's growth.

3.3 ***Balanced growth path for the North***

The steady-state growth path is given by,

$$g_n = \frac{\dot{C}}{C} = \frac{\dot{Y}_n}{Y_n} = \frac{\dot{K}}{K} = \frac{\dot{A}}{A} = \delta_n H_{An} = \delta_n (H_N - H_{Yn}) \tag{29}$$

Substituting for H_{Yn} from equation (27), we find:

$$g_n(m) = \delta_n H_N - \Gamma(m) r_n \tag{30}$$

where, $$\Gamma(m) \equiv \frac{\alpha}{\Phi(m)(1-\alpha-\beta)} = \frac{\alpha}{(1-\alpha-\beta)[(\alpha+\beta) + m\frac{\theta}{(1-\theta)}(1-\alpha-\beta)]} \tag{31}$$

The model is closed when we substitute for r_n in (30) from the preference structure (8), yielding:

$$g_n^*(m) = \frac{\delta_n H_N - \Gamma(m)\rho_n}{1+\Gamma(m)\sigma_n} \tag{32}$$

Equation (31) shows that $\partial g_n^*(m)/\partial m > 0$, since $\partial \Gamma(m)/\partial m < 0$. Notice that without trade, $m=0$

so that $\Gamma = \alpha/[(\alpha+\beta)(1-\alpha-\beta)]$ and g^*_n reduces to Romer's (1990) growth[9]. From (32) it can be seen that $g_n^* > g_{Romer}$ if $\Gamma < \Lambda$. In turn, this condition holds if and only if, $\theta = \phi < 1$ and $m > 0$; The first condition holds by (4) and the second by trade. In short, North's growth is higher under trade with the South than under autarky.

Result 2: Trade accelerates North's growth compared to autarky

What explains this result? Note that, $g_n^* > g_{Romer}$ is true if $H_{An} > H_{ARomer}$. In fact we saw in *Result 1* that trade allows North to reallocate its human capital to the research sector. This reallocation results in a higher rate of innovation and growth in the North, than under autarky.

A critical question is how does *m* evolve as the South grows and how does this impact innovation in the North. Because *m* is endogenous, the answer to this question awaits determining *m*, which will be done shortly. First, however, the South's growth rate is examined.

3.4 Balanced Growth Path for the South

As in the North, steady-state equilibrium and balanced growth for the South implies that all variables *I, K*, *C* and *Y* grow at the same constant rate. In particular, equation (6) implies that investments grow by,

$$\frac{\dot{I}}{I} = \delta_s H_s^{\phi} x_n^{S\,1-\phi} \tag{33}$$

I grows at a constant rate as the right hand side of (33) is time-independent: H_s, the South's total human capital stock, is exogenous; x_n^S, the South's unit measure of imitated design, while endogenous, is time-independent as can be seen from (15') and (22). Next, from (3), and given the discussion preceding equation (9), we have,

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9 In Romer's (1990) closed economy, $g_{Romer} = \frac{\delta H_N - \Lambda\rho}{1+\Lambda\sigma}$, where $\Lambda = \frac{\alpha}{(1-\alpha-\beta)(\alpha+\beta)}$.

$$Y_s = L_s^{\theta}\left[\int_o^I x_s(i)^{1-\theta}\,di + \int_o^I x_{nY}^S(i)^{1-\theta}\,di + \int_I^{I^*} x_{nY}^S(i^*)^{1-\theta}\,di^*\right]$$

$$\Rightarrow L_s^{\theta}\left[Ix_s(i)^{1-\theta} + Ix_{ny}^S(i)^{1-\theta} + (I^* - I)x_{nY}^S(i^*)^{1-\theta}\right] \tag{34}$$

To ensure steady state we assume that at any point in time the South imitates a fraction of the North's innovations. This implies that the distance from *0* to *I* is a constant fraction of the distance from *I* to *I**. Denoting this fraction by φ, we have $I = \varphi\,(I^*- I)$ where $\varphi \in (0, I)$. Since x_n^S and x_s are both time-independent (from 4), equation (34) implies that Y_s, I and $(I^*- I)$ will grow at the same rate. Finally, from the expression for South's capital stock, $K=\int_0^I x_s di = Ix_s$, K too grows at the same rate. Denoting this common rate by g_s, we have:

$$g_s = \delta_S H_s^{\phi} x_n^{S\,1-\phi} \tag{35}$$

Substituting for the demand function $x_n^s\,(P_n^s)$ from (15') and making use of the assumption that $\phi = \theta$ discussed earlier, this yields,

$$g_s = \delta_s \left[\frac{\theta(1-\theta)^{\frac{2}{\theta}}}{(1+\tau)P_n^S}\right]^{\frac{1-\theta}{\theta}} H_s L_s^{\frac{1-\theta}{\theta}} r_s^{-\frac{1-\theta}{\theta^2}} \tag{36}$$

Equation (36) summarizes the basic relationship between South's growth rate and discount rate via the technology-production channel. As in the North, the model is closed by relating g_s to the South's preference structure, i.e., $g_s = \dot{C}/C = (r_s - \rho_s)/\sigma_s$, and eliminating r_s. Solving the result for g_s yields:

$$g_s(\sigma_s\ g_s + \rho_s)^{\frac{1-\theta}{\theta^2}} = \delta_s\ \Omega^{\frac{1-\theta}{\vartheta}} H_s L_s^{\frac{1-\theta}{\theta}}\left[\frac{1}{P_n^S}\right]^{\frac{1-\theta}{\theta}} \tag{37}$$

where, $$\Omega \equiv \frac{\theta(1-\theta)^{\frac{2}{\theta}}}{(1+\tau)} \tag{37'}$$

Equation (37) shows that growth in the South is positively associated with the South's human capital and unskilled labor endowments and negatively with the price of intermediate imports P_n^s. This price, charged by the North's monopolistically competitive intermediate goods producers, is a function of the North's rate of return to capital r_n, as per equation (22). In turn, r_n is found by equating g_n from the technological side (equation 30) to that from the preference side. Thus, we have:

$$P_n^S = \frac{r_n}{(1-\theta)} = \left[\frac{\sigma_n \delta_n H_N + \rho_n}{1+\Gamma(m)\sigma_n}\right]\frac{1}{(1-\theta)} \tag{38}$$

Substituting P_n^S into (37) and setting South's total labor force to 1, $L_s = 1 - H_s$ and we find,

$$g_s(m)[\sigma_s \; g_s(m) + \rho_s]^{\frac{1-\theta}{\theta^2}} = \delta_s \; \Omega^{\frac{1-\theta}{\theta}} H_s (1-H_s)^{\frac{1-\theta}{\theta}} \left[\frac{(1-\theta)(1+\Gamma(m)\sigma_n)}{\sigma_n \delta_n H_N + \rho_n}\right]^{\frac{1-\theta}{\theta}} \tag{39}$$

where Ω and Γ(*m*) are defined by (37') and (31) respectively.

Equation (39) expresses South's growth *implicitly* as a function of the variable *m*. A closed form solution to (39) could be found if the intertemporal rate of substitution in the South $\rho_{s,}$ were zero, but such an assumption is not realistic. Thus, we opt for a numerical approach to solving the implicit equation (39), for g_s. Most of the comparative dynamics, including the impact of H_s on the growth of North and South and on South's trade with the North, as well as the relation between the growth rates of North and South will await the result of this numerical solution.

3.4.1. H_n, Tariffs, Intellectual Property and South's growth

Before turning to the numerical analysis, one result that is readily available from (39) is the effect of an increase in North's human capital on the South's growth rate. In particular, (39) shows that $\partial g_s / \partial H_N < 0$, i.e.

Result 3: An increase in the level of North's human capital stock lowers South's growth

This finding is similar to what Grossman and Helpman (1991c, Ch.11, p 297) obtain. In our paper, the adverse link is explained by the terms of trade effect: First, a larger pool of human capital in the North increases the North's growth rate (eqn. 32). This increases the rate of interest r_n in the North via the equation, $r_n = \sigma_n g_n + \rho_n$. This in turn raises South's import price, given by $P_n^S = r_n/(1-\theta)$), thus dampening imitation and growth in the South. The terms of trade effect is clearly revealed in equation (37).

Another result that does not depend on the solution of the entire system is the role of tariffs. Tariffs adversely affect South's growth as seen in equation (37) and (37'). Thus,

Result 4: Lower Tariffs increase South's growth rate

The mechanism underlying result 4 is once again the terms of trade effect as is seen in (37). Equation (15') shows that this result comes about as lower tariffs increase imports of intermediate goods, which speeds up the rate of imitation and therefore South's growth rate.

The next question of interest is the role of intellectual property rights. As Taylor (1993) points out, stringent intellectual property protection increases the cost of imitation for Southern firms, while a lax patent policy is likely to speed up the process. In our model tighter intellectual property rights lower the efficiency of imitation. This is captured by δ_s in equation (6). Such a policy would also lower the rate of growth as per (37):

Result 5: Tighter Intellectual Property Rights reduce South's growth

This is consistent with the findings of Chin and Grossman (1988) and Helpman (1993), who find that Southern government's best policy is to look the other way while Southern firms infringe on Northern intellectual property. However, these results do not take into account the possible effect on North's R&D activity. In this context, for example, Taylor (1994) shows that failure to provide patent protection for foreign innovations reduces aggregate R&D activities worldwide, which lowers technology transfer across countries, and in turn lowers growth worldwide. A recent paper by Grinols and Lin (1998) also suggests that if innovation goods are regionally differentiated, Helpman's (1993) results may not apply. However, we do not consider such regional differentiation.

4. THE EQUATION SYSTEM AND NUMERICAL SOLUTION

The five variables of our model are, g_s, g_n, m, r_s, r_n. Recall that *m* is the ratio of the North's capital goods exports to the South, to its domestic sales ($m = x_n^S / x_n^N$). In turn, x_n^S is derived from the demand equation (15') and its corresponding equilibrium price, P_n^{S*} (equation 22), while x_n^N is found from the North's inverse demand equation (17) and its corresponding equilibrium price, P_n^{N*} (Eqn. 21). Making these substitutions yields:

$$m = \frac{\left[\dfrac{(1-\theta)\Omega(1-H_s)H_s^{\theta}}{r_n(m)r_s(m)^{\frac{1}{\theta}}}\right]^{\frac{1}{\theta}}}{\left[\dfrac{(1-\alpha-\beta)^2}{r_n(m)}\left(\dfrac{r_n(m)}{\delta_n\Gamma(m)}\right)^{\alpha} L_n^{\beta}\right]^{\frac{1}{\alpha+\beta}}} \tag{40}$$

where Ω and $\Gamma(m)$ are defined by (37') and (31) respectively. Equation (40) involves the rate of return functions $r_s(m)$ and $r_n(m)$. These are related to the growth rate via the preference structure:

$$r_s(m) = \sigma_s g_s(m) + \rho_s \tag{41}$$

$$r_n(m) = \sigma_n g_n(m) + \rho_n \tag{42}$$

In turn, the North and South's growth rates depend on *m*, and are given by equations (32) and (39), closing the system. Equations (32), (39), (40)-(42) constitute a system of five non-linear equations in the five variables, m, g_s, g_n, r_s *and* r_n. Given its implicit form, equation (40) is estimated using numerical methods[10]. The results of the simulations are reported in Figues 1-5.

4.1 The Role of H_s in Trade and Growth

Figures 1 and 2 reveal the relationship of g_s and g_n, and H_s for different values of μ, yielding some interesting insights: Higher levels of human capital in the South lead to higher rates of growth for the South, although the increases occur at a diminishing rate. On the other hand, North's growth rate responds positively to higher values of H_s only for very small values of H_s, but negatively thereafter.

Figures 1 and 2 go about here

4.1.1. Imitation, Innovation and Human Capital in the South

There are two channels that explain the patterns that we observe in figures 1 and 2; (a) the indirect effect of H_s on both growth rates via its effect on m, i.e., South's demand for intermediate imports from the North; (b) the direct effect of H_s on South's growth rate. The indirect effect, i.e., the effect of H_s on m is depicted in Figure 3. (See appendix for algebraic derivation). This figure shows that for smaller values of H_s the import ratio m rises with H_s, while for larger values of H_s, m declines with H_s.

Figure 3 goes about here

Thus for low levels of H_s in the South, a *complementarity* effect exists between South's human capital and imitation capital, embodied in the South's imports from the North. This represents human capital levels that are too small for the South to undertake innovation. Since South is solely dependent on imitation at this stage, higher levels of H_s are accompanied by higher m. However, for a southern country with large H_s, there exists a *substitution* effect

[10] Numerical solutions are based on the parameter values of $\alpha=0.37$, $\beta=0.49$, $\theta=0.4$. These values are taken from the estimates for non-oil countries (in Mankiw, Romer and Weil, 1992): Also, we assume $\delta_s=\delta_n=0.5$, $\sigma_s=\sigma_n=0.1$, $\tau=0$, $H_n=0.7$ *and* $L_s=1-H_s$, where H_s is allowed to vary exogenously (see below).

between the two forms of capital (human capital versus imitation capital), such that higher levels of H_s lower values of *m.* This suggests there is a threshold level of human capital for the south (around the value of H_s=0.3 from Figure 3) below which South is merely an imitator and above which innovation begins to occur. Thus,

Result 6: For low levels of human capital, South only imitates. In this range human capital and imitation capital are complements. For levels of human capital above a threshold level, South begins to innovate. In this range, human capital and imitation capital become substitutes.

4.1.2. Size of H_s and North's growth

The effect of H_s on the *North's* growth rate can be entirely explained by the trade channel alone, as imports (*m*) are the only link between North's growth and South's human capital stock: When North trades with a human capital-poor South, H_s is small and additions to the stock of H_s by the South raises South's demand for the import of intermediate inputs from the North (the *complementarity* effect), raising North growth rate. However when it trades with a human capital-rich South, H_s is large and additions to the stock of H_s by the South *lowers* South's demand for the imports of intermediate inputs from the North (the *substitution* effect), reducing North growth rate. Thus an imitating South helps raise the rate of innovation and therefore growth in the North. On the other hand, increases in South's ability to innovate, lowers North's growth. To see this algebraically, totally differentiate equation (32). This yields the following equation which is entirely consistent with the finding in Figure 3.

$$\underset{(+/-)}{\frac{dg_n}{dH_s}} = \underset{(+)}{\frac{\partial g_n}{\partial m}} \cdot \underset{(+/-)}{\frac{dm}{dH_s}} \tag{43}$$

This is clearly evident from figures 3 and 2. Figure 2 shows that g_n is positive for small values H_s but negative for values of H_s above a critical level. Thus,

Result 7: North's growth rate is higher when it trades with a human capital poor South that only imitates. Growth in the North declines at higher levels of human capital in the South that allows the latter to innovate

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4.1.3. Size of H_s and South's Growth

The effect of H_s on the South's growth rate is more complex and includes the second mechanism, i.e., the direct effect of H_s. To study this effect, totally differentiate g_s in H_s:

$$\frac{dg_s}{dHs} = \frac{\partial g_s}{\partial Hs} + \frac{\partial g_s}{\partial m}\frac{\partial m}{\partial Hs} > 0 \tag{44}$$

where the direct effect is represented by the first partial derivative on the right of (=). The indirect effect is given by the second term, in the form of the product of the effect of H_s on South import propensity, m, and in turn, the effect of m on South's growth. Focusing on the product term first, implicit log-differentiation of (39) shows that

$$\frac{\partial g_s}{\partial m} < 0 \tag{45}$$

i.e. the higher is the import ratio, *ceteris paribus*, the lower is South's growth[11].

Moreover, figure 3 tells us that the last derivative in (44) $\partial m / \partial H_s$ is positive for small H_s and negative for large H_s.[12] Thus,

$$\frac{\partial m}{\partial Hs} > 0 \quad if \quad H_s \quad small; \qquad \frac{\partial m}{\partial Hs} < 0 \quad if\ H_s \quad large \tag{46}$$

To study the direct effect of H_s on the South's growth rate [$\partial g_s/\partial H_s$ in (44)], notice from the expression $H_s(1-H_s)^{(1-\theta)/\theta}$ in (39) that this effect results from the direct positive effect of H_s via the imitation technology (equation 4), and the negative effect of a smaller pool of unskilled labor

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[11] i.e., $[\frac{\theta}{1-\theta}.\frac{1}{g_s} + \theta\frac{\sigma_s}{\sigma_s g_s + \sigma_s}]\partial g_s / \partial m\Big|_{H_S} = \frac{\sigma_n \Gamma'(m)}{1+\sigma_n\Gamma(m)}$. Since Γ'(m)<0, we have $g_s'(m)|_{Hs} < 0$.

[12] Algebraically, the effect of H_s on *m* is derived in the appendix. However, the sign of this derivative cannot be established analytically, as explained in the appendix.

force in the final goods sector. Implicit partial differentiation of (39) in logarithmic form shows,[13]

$$\frac{\partial g_s}{\partial Hs} > 0 \; for \quad H_s < \theta \qquad \frac{\partial g_s}{\partial Hs} < 0 \; for \quad H_s > \theta \tag{47}$$

The intuition behind equation (47) is that as the pool of skilled workers (H_s) in the South rises, more and more workers are engaged in the *design* sector and less in final goods production. Initially, for high enough levels of H_s, this has a positive effect on growth due to the higher productivity of the *design* sector. However beyond a certain point, defined by the value θ, diminishing productivity in the *design* sector implies that more H_s actually leads to less growth for the South.

The signs of derivatives from (45)-(47) are combined in equation (44), constituting the total effect of H_s on South's growth. It is seen that when the South is human-capital poor (rich), this effect is the combination of a positive (negative) direct effect of H_s and a negative (positive) indirect effect of H_s, working via m. From these equations the overall effect would seem ambiguous. However, information from Figure 1 sheds further light on this issue. In particular, it suggests that *for small levels of human capital H_s in the South, the direct (positive) effect dominates. However, for larger levels of H_s, the indirect (positive) effect via import avoidance just cancels out the direct (now negative) effect via diminishing marginal productivity, resulting in the flat end segment of the curve.* We summarize this important finding:

Result 8: Higher levels of human capital in the South increases South's growth for most of its range before diminishing returns to H_s begins to dominate.

4.2 Will the South Catch up with the North?

Observe from functions $g_n(H_n,H_s)$ and $g_s(H_n,H_s)$, that the potential for the South to catch-up with the North depends, not only on how South's human capital policies, but *also* on the North's.

[13]This differentiation yields, $[\frac{1}{g_s} + \frac{1-\theta}{\theta^2}\frac{\sigma_s}{\sigma_s g_s + \sigma_s}]\partial g_s / \partial H_s = \frac{\theta - H_s}{\theta H_s (1-H_s)}$. The bracket on the left is positive so that the sign of the derivative depend on the size of H_s relative to ϕ.

Figure 4a and 4b (which in effect combine figures 2 and 3) explore this issue based on equations (32) and (39), and other equations of the system.

Figures 4a and 4b go about here

First, note that, not surprisingly, larger values of H_n shift g_n curve up, and the g_s curve down. In terms of growth convergence, the study provides some interesting results. For a sufficiently poor-human capital South that relies on imitation, gap in growth rates between the North and South actually increases with H_s (because South's import of knowledge goods rise with H_s in this range). For H_s values above this level, the gap in growth rates decreases with higher H_s. This story is consistent with the discussion around figure 3 that in the low H_s range (i.e. $0<H_s<0.3$ for our parameters) complementarity with *m* prevails so that more H_s induces further imports of intermediate goods as inputs to South's reverse engineering sector. Above this value substitution takes over, as the onset of innovation by the South succeeds in reducing the need to imported knowledge capital (*m* falls). Here, North's growth rate begins to fall with higher H_s moving toward rate-convergence with the South.

5. CONCLUSION

We develop an endogenous growth model where knowledge, accumulated through learning from imitation, and the level of human capital determine the South's ability to move from imitation towards innovation. We show explicitly, how transfer of knowledge from the North to the South occurs. The basic process is through trade in high-technology goods, where the South initially relies on reverse engineering to emulate the technology embedded in capital goods imported from the North. The South becomes a "quasi-innovator" only when it human capital (absorptive capacity) is higher than a certain threshold level.

North also enjoys higher growth with trade with the South than without, as trade releases human capital from the North's manufacturing to its research sector. North's gains are the highest, the more human-capital "poor" the South is, as in Grossman and Helpman's (1991,b) inefficient follower concept. This is because a human capital-poor South is more dependent on imitation and thus on imports of intermediate goods from the North. With higher levels of human capital in the South, such imports decline (South moves towards innovation) causing North's growth to be less than would otherwise be.

Can the South ever catch up with the North? As long as the North innovates and the South imitates, the two growth rates diverge. However, for sufficiently human capital-rich South, innovation becomes possible. This raises its growth rate and lowers that of the North, implying a move towards convergence[14]. South's per capita income, however, remains below the North, as long as it's relative advantage lies in imitation.

One of the paper's important implications, that is somewhat neglected in the literature, is that South's prospects for catching up with the North depend not only on South's own policies, but also the North's, thereby underscoring the interactive forces of the global economy.

The paper is developed within the framework of scale effects, a view originated with Romer, followed by many others, but criticized by Jones (1995) and others. The debate about the existence of scale promoting growth effects has not been settled. For example, a recent paper by Todo (2002) shows that scale effects are consistent with the evidence once one accounts for technology diffusion effects. Earlier papers also did verify the existence of more narrowly defined forms of scale effects. An example is the paper by Backus, et. al. (1992) in which such effects were found in the manufacturing sector.

Finally, what are the policy implications for the Southern country in this set up? Imitation is the ladder to innovation in the South. Lower tariff barriers or conversely import subsidies can increase the rate of imitation and thus enlarge the pool of accumulated knowledge in the South. However, more importantly, the stock of human capital in the South effectively constrains the ability to innovate. Therefore to achieve higher growth, South must also actively support human

[14] However, we do not address the limiting case of the South completely switching to innovation.

capital formation, otherwise it will be locked in the role of an imitator. This partly explains the difference in the growth experience of East Asian tigers versus laggards such as India and Brazil, as Keller (1996) has shown.

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APPENDIX: ***Relationship between H_s and m:***

The ratio *m* is given by equation (39). This ratio can be re-written as,

$$m = \frac{A}{B}\left[C + Dm\right]^{\frac{\alpha}{\alpha+\beta}} r_n(m)^{\frac{1-\alpha-\frac{1}{\theta}(\alpha+\beta)}{(\alpha+\beta)}} r_s(m)^{-\frac{1}{\theta^2}} H_s(1-H_s)^{\frac{1}{\theta}} \qquad (A1)$$

$$A \equiv \left((1-\theta)\Omega\right)^{\frac{1}{\theta}}, \; B \equiv \left[(1-\alpha-\beta)^2\left(\frac{\alpha}{\delta_n}\right)^{\alpha} L_n{}^{\beta}\right]^{\frac{1}{\alpha+\beta}}, \; C \equiv (\alpha+\beta)(1-\alpha-\beta),$$

$D \equiv m\dfrac{\theta}{1-\theta}(1-\alpha-\beta)^2$ Taking logs and differentiating *m* with respect to H_s, we get:

$$\frac{dm}{dH_s} = \frac{\dfrac{\theta(1-H_s)-1}{\theta(1-H_s)}\dfrac{1}{H_s} - \dfrac{1}{\theta^2}\dfrac{\partial r_s/\partial H_s}{r_s}}{\dfrac{1}{m} - \dfrac{\alpha}{\alpha+\beta}\dfrac{1}{\dfrac{1-\theta}{\theta}\dfrac{(\alpha+\beta)}{1-\alpha-\beta}+m} - \dfrac{1-\alpha-\dfrac{1}{\theta}(\alpha+\beta)}{(\alpha+\beta)}\dfrac{\partial r_n/\partial m}{r_n} + \dfrac{1}{\theta^2}\dfrac{\partial r_s/\partial m}{r_s}} \qquad (A2)$$

In the numerator, the first term is negative; the sign of $\partial r_s/\partial H_s$ in the second term depends on $\partial g_s/\partial H_s$ by (41). From (46), $\partial g_s/\partial H_s > 0$ for $H_s < \theta$ and < 0 for $H_s > \theta$. Thus, the numerator of *(A2)* is >0, or <0 for small H_s but unambiguously <0 for large H_s. In the denominator, the first two terms combined are positive; the third is positive [as $r'_n(m) > 0$ from (41) and (32)]; but the last is negative [from (45) and (41)]. The denominator's overall sign is likely positive, however, because a rise in South's imports adversely affects South by *less* than it benefits the North. This results from the fact that South's imitation technology is subject to diminishing returns to imitation knowledge, imbedded in its intermediate imports (eq. 4), whereas North's innovation technology is subject to constant returns to innovation knowledge (from eq. 2). To sum, the sign of *(A2)* likely obeys the numerator's: negative for large H_s, but negative or positive for small H_s. Figure 4 corroborates the high-H_s end of the result. In the low-H_s range, the ambiguity is resolved numerically as in the text.

Fig 1: Size of Hs and South's growth

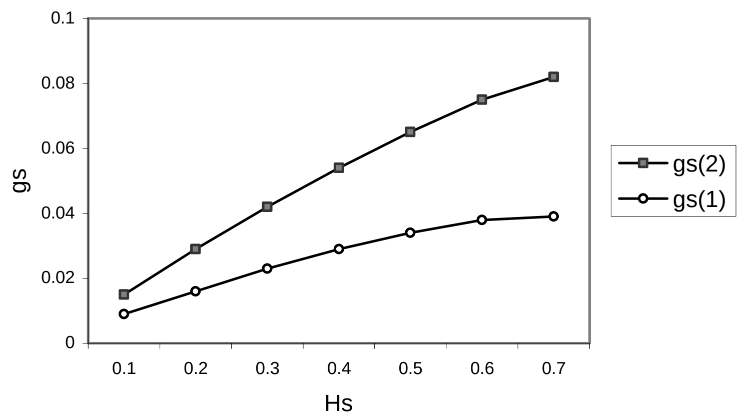
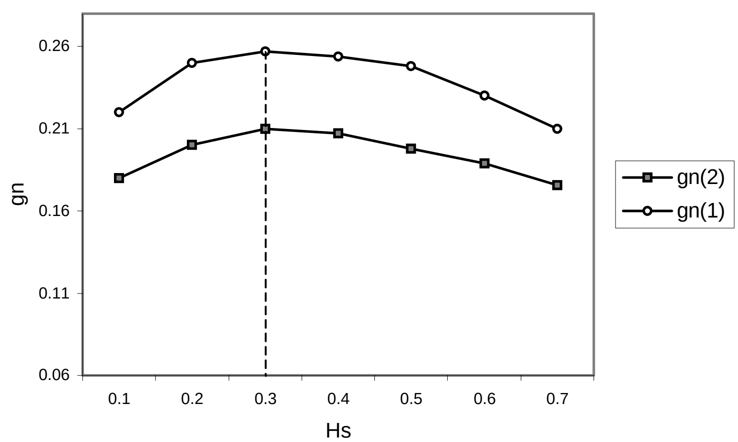


Fig 2 : Size of Hs and North's growth



Note: In figures 1 & 2, $g_s(1)$ and $g_s(2)$ [$g_n(1)$ and $g_n(2)$] correspond to θ=0.7 and θ=0.8, respectively.

Fig 3: South's human capital and imports
of Northern intermediates

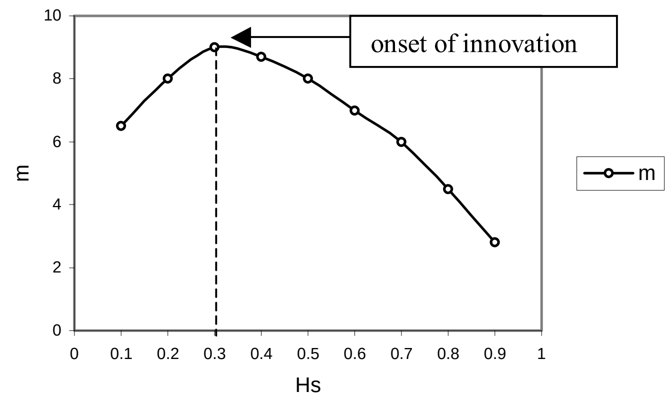


Fig. 4a: N-S growth and convergence
(Hn=0.9)

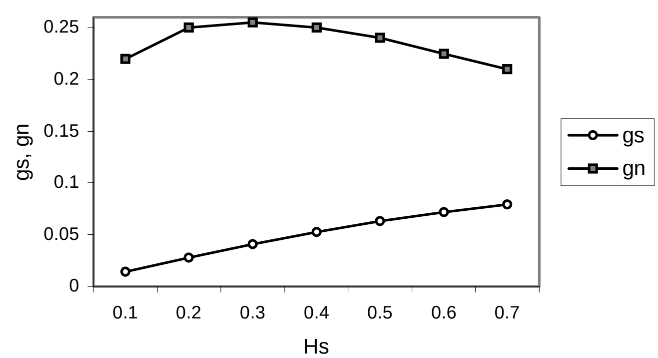


Fig. 4b: N-S growth and convergence
(Hn=0.7)