SOUTHERN INNOVATION AND REVERSE KNOWLEDGE SPILLOVERS: A DYNAMIC FDI MODEL[*]

YIN HE AND KEITH E. MASKUS[1]

Abstract

We develop a general-equilibrium model of endogenous innovation and foreign direct investment (FDI). In the benchmark model, Northern firms innovate with the help of localized spillovers and a share of new products is transferred to Southern production via FDI. An increase in Southern imitation risk reduces this share. In the extended model we permit higher-cost Southern innovation, which yields inefficient specialization in both regions and reduces global growth. However, it generates a U-shaped relationship between FDI and local imitation. We also allow for "reverse" spillovers in knowledge to Northern innovation, which partially restore global efficiency and growth.

Keywords: Innovation; learning-by-doing; patents; multinational investment; growth

JEL classification: F12; F23; O31; O34

Running head: Innovation and Reverse Spillovers

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1. INTRODUCTION

The massive expansion of foreign direct investment (FDI) in recent years to such emerging countries as China, India and Brazil has increasingly been accompanied by growth in innovation by local firms in those markets (OECD, 2005: WIPO, 2007). It seems likely that these trends are jointly related in that more inward FDI permits additional domestic imitation and learning, from which innovation springs. Moreover, the expanded innovation in developing economies sets up the possibility of *reverse spillovers*: firms in developed countries may learn from inspecting new products and technologies imported from the developing world.

The evolution of optical storage media in audio and video systems illustrates this process. The earliest technology was the audio compact disc (CD), available in Western countries by the early 1980s. In 1993, Wanyan Electronics, a Chinese firm, invented the more affordable video compact disc (VCD) and VCD players, which quickly became popular in mainland China but were rarely known in the Western world (Xu, 2006). This invention was made possible through inspecting the technology sold by C-Cube Microsystems (an American company, which combined the CD with the MPEG-1 standard) and learning the production process of firms producing compact disks in China's special economic zones. However, Wanyan Electronics failed to patent their products, which were duplicated by domestic and international firms (Xu, 2006). Among these were such Japanese and European companies as Sony and Philips, which have international patents covering VCD standards (Linden, 2003). These companies, along with the US innovator of the MPEG-2 standard, later jointly invented the Digital Video Disc (DVD) technology.

This history illustrates the possibility we analyze here: a global technology is imported into an emerging economy, where it is imitated and then improved through local innovation. The new product, in turn, is learned by companies in the developed world and serves as the basis for further innovation. In essence, we develop the first product-cycle model in which there are two-way innovation and technology transfers in equilibrium.

For this purpose, we set out a dynamic, general-equilibrium model in which FDI (or imports), imitation, learning-by-doing (LBD) and innovation are jointly determined and ultimately affect economic growth. The model combines elements of those in Baldwin, Braconier and Forslid (BBF, 2005) and Lai (1998) but extends both. In BBF, firms in two symmetric developed countries perform R&D to generate new knowledge, subject to spillovers from the general knowledge pool and local LBD. We extend their analysis by permitting different learning productivities between a developed nation (the North) and a developing economy (the South) and higher-cost innovation in the latter. Lai introduced FDI into an endogenous North-South model but did not permit innovation in the developing country, nor did he consider LBD, both of which exist here.

In our benchmark model, after new knowledge is developed Northern firms choose the physical location of their production between the North and South. Firms in the South learn from observing the operations of multinational firms, imitate some of the new varieties, and compete in these varieties. In our extension, Southern firms are able to invent new products based on the local technology pool and LBD spillovers. Finally and most importantly, Southern new knowledge also spills over back to the North to reduce the unit cost of innovation there. To our knowledge this is the first model to study Southern innovation and reverse knowledge spillovers in a general-equilibrium, endogenous product-cycle model.

Within this framework we analyze how changes in intellectual property protection (IPP) in the South, indexed by the imitation rate, affect these processes. In the benchmark model, without the possibility of innovation in the South, a rise in imitation reduces inward FDI in equilibrium. This tends to reduce global growth in new products because less labor is allocated to innovation in the North. When the South is able to learn from FDI and develop its own products, innovation without reverse spillovers restricts FDI flows compared to the benchmark. Since Southern innovation efficiency is lower than its Northern counterpart, the equilibrium growth rate is lower than the benchmark rate at each given imitation rate. However, the relationship between imitation and multinationalization exhibits a U-shape because increases in the former first reduce FDI directly but ultimately increase it through a competition effect arising from the expansion of Southern new varieties. Finally, with a significant reverse spillover the enhanced innovation possibilities in the North generate more rapid growth than in the case without such learning. As a consequence, the growth rate is also U-shaped in imitation and may exceed its benchmark value without Southern innovation.

To motivate our work we offer stylized facts and briefly survey relevant literature in Section 2. We develop our benchmark model, where the South imitates multinational varieties without engaging in R&D or generating new knowledge, in Section 3. In Section 4 we introduce Southern innovation and reverse knowledge spillovers into the model. We perform extensive simulation analysis in Section 5 to compare models with and without Southern innovation and determine how the extent of reverse spillovers affects other key variables, including steady-state growth. We conclude in the final section.

2. MOTIVATION AND RELEVANT LITERATURE

There are two novelties in this paper: permitting Southern innovation in response to inward knowledge flows and the possibility of reverse flows of this innovation to the North. To motivate this work we first discuss basic evidence of these phenomena and then place our analysis into the broader literature.

2.1 Stylized Facts

Our story, in essence, is that countries in the South receive inward technology transfer (TT), learn to use incoming technologies through imitation and learning, and then build on this knowledge to become innovators themselves, with the potential for reverse TT to the North. As will become evident in the model, this dynamic is most likely to occur in developing nations that are both large and have a significant capacity for absorbing and improving technical information. Thus, we should expect to see stylized evidence of this evolution in data for such countries as Argentina, Brazil, Mexico, China, India and the Republic of Korea.

The three columns in the top panel of Table 1 list basic figures in 1995 for these countries in the three canonical forms of inward TT: high-technology imports (measured as a share of total manufacturing imports), foreign direct investment (measured as the position of U.S. multinational enterprises), and licensing (measured by royalties and license fees paid for patents, trademarks, brands and other forms of intellectual property).[2] In 1995 each of these nations had a significant share of manufactured imports arrive in high-technology items, which include pharmaceuticals, electrical machinery, scientific and controlling instruments, and aerospace goods. These shares ranged from around 10 percent in Mexico and Korea to over 20 percent in Brazil and China. Further, by 1995 U.S. multinationals had established significant FDI positions in Mexico and Brazil but those positions exceeded one billion dollars in China and Korea also. Finally, each nation paid far more in royalties and license fees than it earned (compare the payments column to the 1995 receipts in the fifth column of the bottom panel), with those payments ranging from $90 million in India to $2.4 billion in Korea. Chinese payments in the year 2000 approached $1.3 billion.

[Table 1 here]

The figures in the eight columns in the bottom panel strongly suggest that these inward TT flows were followed by significant increases in technological knowledge generated in this set of countries. Thus, each country experienced a rise in the share of high-technology products in its manufacturing exports from 1995 to 2005. There were particularly large increases in Argentina, Brazil, China and Korea. Next, by 2000 firms headquartered in Brazil, Mexico and Korea had established FDI positions in manufacturing in the United States, though positions from the other countries were negligible. By 2005, however, all except Argentina had become significant investors in U.S. manufacturing plants, raising prospects for FDI-mediated reverse spillovers. There were also substantial increases in current-dollar royalties and license fees, suggesting that

[2] Keller (2010) reviews evidence regarding trade and FDI as means of technology transfer and their resulting spillovers into higher local productivity. On licensing see Maskus (2004).

Korean, Chinese, Indian and Mexican brands and technologies were penetrating global markets. Finally, each nation saw growth in its share of patent applications at the United States Patent and Trademark Office and the European Patent Office. These increases were registered in a period of massive expansion of applications in both of these offices, implying major growth in the numbers of applications from the developing world. The growth in China's share from 0.05 percent to 1.01 percent was remarkable, as were the expansions from India and Korea. The latter nation now accounts for over five percent of applications at these two major authorities.

These stylized facts cannot demonstrate causality. However, they do suggest that the story we tell here is consistent with actual data. Thus, larger developing countries with emerging technical capacities to imitate, absorb, and improve upon international technologies ultimately become sources of new information that finds its way to the developed world. Our model is aimed at capturing this process.

2.2 Literature

The notion of a product cycle with one-way TT arising from international trade or FDI stems from Vernon (1966). It received initial analytical treatment by Krugman (1979) in a model with exogenous innovation and imitation. Early general-equilibrium models (Grossman and Helpman 1991a, Helpman 1993, Segerstrom, et al. 1990) of product-cycle dynamics with North-South TT retained exogenous imitation activity. More significantly for our model, they did not include knowledge spillovers, so that multinational corporations (MNCs) played no direct role in determining the growth rate. Later models, such as Lai (1998) and Glass and Saggi (2002), began to fill the latter gap by assuming that the efficiency of Northern innovation depends on the stock of existing knowledge. However, these models mostly assumed that knowledge contributes the same to further innovation regardless of its location and characteristics, which is not consistent with empirical studies. For example, Jaffe, et al. (1993), Sjöholm (1996), and Keller (2002) showed that the scale of spillover effects from knowledge transfers is geographically limited and the scope of technology diffusion is severely limited by distance.

BBF (2005) is the first study that distinguished among channels of cross-border knowledge spillovers in a theoretical FDI model. In their model, innovators fully understand domestic knowledge but can only partially make use of foreign knowledge. The spillover from LBD to innovation is introduced into a symmetric North-North framework, where innovators become more efficient as they observe more local production processes. FDI activities promote innovation and growth in both regions, since innovators everywhere become more efficient by learning the production processes of increasing varieties.

Whether FDI exists in equilibrium in BBF is determined by comparing two exogenous parameters: the trade cost and the fixed-cost premium when setting up a firm abroad. The rate of multinationalization is undetermined and the authors "take it as determined by factors outside of the model". Therefore, although the share of domestic varieties transferred abroad is crucial to the efficiency of innovation and growth in both regions, the equilibrium level of this share is left unexplained.

An exogenous rate of multinationalization as in BBF is questionable in a North-South model. Bringing knowledge to the South to take advantage of the low wage rate is the incentive for many firms in the North to engage in FDI. At the same time, transferring production to the South would alter the wage differential between the host and home countries, thereby changing firms' incentives for FDI. Thus, the multinationalization rate, investment in Northern innovation, the growth rate, and the wage gap should be made endogenous in a fuller model.

These variables were endogenized in various specifications by dynamic North-South FDI models, such as Helpman (1993), Lai (1998) and Glass and Saggi (2002), but Northern innovation in these models depends only on local R&D investments. An interesting additional question posed in those articles is the effect of more rigorous regulation in IPP in the South on the rate of Northern innovation and global growth. Helpman showed that in the presence of FDI a fall in the imitation rate would cause the South to suffer from both a deterioration of its terms of trade and higher prices paid for a larger fraction of products. Lai found that a lower rate of imitation encourages the North to increase the rate of both innovation and multinationalization, which raises the growth rate of the South. However, Glass and Saggi observed that a lower imitation rate exposes both MNCs and Northern firms to less risk, producing larger monopoly profits in production and thereby reducing both FDI and innovation. These papers generated numerous insights but did not consider the possibility of induced Southern innovation and what we call reverse spillovers.

There are models of induced Southern innovation that help inform our results. Chen and Puttitanun (2005) set out a static oligopoly model in which firms in developing countries in two sectors could imitate a foreign variety, imitate a domestic variety, or invest in a new variety. These decisions depended on the rigor of local IPP, providing a policy tradeoff for the authorities. They showed that there is a U-shaped relationship between optimal patent strength and a country's level of economic development, consistent with the empirical fact first highlighted by Maskus and Penubarti (1995).

A closer antecedent to our work is the paper by Chui, et al. (2001). They set out a model in which Northern firms always innovate high-technology goods, while the Southern location passes through four stages as potential steady-state equilibria: (1) specializing in a traditional good; (2) copying the high-technology goods; (3) copying and innovating jointly; (4) specializing in innovation. These outcomes arise in various configurations of three exogenous asymmetries. The South is less efficient at adopting technologies, the diffusion rate from North to South is slow while it is instantaneous in the other direction, and the South has a lower endowment of skilled labor. Stronger values of Southern patent protection move firms in that location through these stages. Their full model has no closed-form solution and they rely on simulation, as we do here. Our model is more general in that it considers the crucial role of FDI as the channel of gradual technology transfer, solves for endogenous multinationalization decisions, and permits within-region and across-region learning at different rates. In particular, the degree of

South-to-North technology spillovers, which Chui, et al. take to be infinite and instantaneous, is a critical determinant of impacts of imitation on multinationalization and growth.

Finally, Glass and Wu (2007) presented a dynamic model in which innovative firms in the North choose between vertical quality gains and horizontal variety increases. Followers can imitate or innovate against either type, which are transferred via costless FDI. Southern imitation raises Northern innovation and FDI in quality gains but reduces them in variety expansion. There is no learning-by-doing or Southern innovation.

Thus, in this paper we develop an endogenous product-cycle model that extends the existing literature significantly The multinationalization rate is endogenous to imitation and other factors but variations in this rate subsequently affect the growth rate. We distinguish among channels of knowledge spillovers by assuming that the extent of spillovers depends on the geographic location and ownership of general knowledge and the location of production processes. Finally, we analyze three scenarios regarding Southern innovation, where the imitation rate has different impacts on growth.

3. BENCHMARK MODEL WITH COSTLY IMITATION IN THE SOUTH

We begin with a North-South model of MNCs with endogenous knowledge innovation in the North based on different knowledge spillover effects. The theory combines and builds on those of Grossman and Helpman (1991b), Lai (1998) and BBF (2005).

There are two final goods, with Y the homogeneous good and X the manufacturing good with differentiated varieties. The market for the homogeneous product is perfectly competitive, while that for the manufacturing good is monopolistically competitive. There is only one factor, labor. That is, no physical capital is necessary for setting up a firm on producing either X or Y. However, some labor must be allocated to innovating a new technology before any variety of X can be produced. For now we assume that Southern labor has sufficiently lower skill than its Northern counterpart that only Northern labor has the capacity to innovate. Without inward FDI, firms in the South can only produce the homogeneous product. Let the Southern wage be normalized to unity and define the endogenous Northern wage to be *w*, which is greater than one. This implies that the North would produce only the differentiated product since it has a cost disadvantage in the homogeneous sector. Thus, the two regions would engage in complete specialization if no MNCs existed.

However, MNCs emerge in this model due to the wage gap between North and South. All innovation activities take place in the North by investing part of the Northern labor in R&D. When an element of new knowledge is generated and ready for industrial application, one unit of labor is needed for producing each unit of the new variety. Thus, firms in the North can choose to keep all production at home and serve the Southern market by exports. For simplicity we normalize constant unit trade costs to be zero. However, because of the lower wage rate, firms in the North might want to transfer the technology to the South, establish and produce in a subsidiary there, and export back to the North. The disadvantage of being a multinational lies in both the one-time cost of setting up a plant and the risk of being imitated, reducing its monopoly power and profits.

It is possible, as suggested by Lai (1998), that the physical appearance of production in MNCs in the host country permits Southern imitators to learn production processes more easily by inspection than by reverse engineering imported goods. There are also empirical studies showing that technology spillovers from inward FDI are larger than those from imports (Keller and Yeaple 2009). Therefore, for simplicity in the benchmark case, we assume that exports from the North to the South are free from the risk of imitation, but local production within MNCs is not. However, in an extension described later we consider the impact of also permitting imitation of imported goods.

Imitation by Southern firms takes time. To capture this possibility we model the duration between the time of an MNC setting up its plant in the South and the time of successful imitation as a random variable with a Poisson arrival rate. We assume that if the technology is imitated the South sets up a firm with no physical cost and produces for both markets the same variety it imitated from the targeted MNC, which exits production.

We acknowledge that our assumption of exogenous imitation risk, while common in the literature (e.g., Helpman 1993, Lai 1998), limits the potential richness of the outcomes we may explore. In particular, while imitation affects innovation in our model, the reverse feedback is absent. If imitation were endogenous, faster innovation could reduce the gains from imitation as new varieties are introduced more rapidly. Unfortunately, introducing this channel into the model would make the analysis considerably more complex.

3.1 Consumption

Consumers have identical and homothetic preferences over the two final goods. The intertemporal utility function at time τ is assumed to be:

$$(1) \qquad U_\tau = \int e^{-\rho(t-\tau)} \ln\left[(C_X)^\phi (C_Y)^{1-\phi}\right] dt$$

$$C_X \equiv \ln\left\{\int_0^{n+m+b} (c_h)^{1-1/\varepsilon} dh\right\}^{\frac{1}{1-1/\varepsilon}}$$

where $\rho > 0$ measures the time preference of consumers, $\varepsilon > 1$ is the elasticity of substitution between varieties of *X*, and c_h is the consumption of variety *h*. Letters *n*, *m*, and *b* represent the number of Northern, multinational, and Southern imitated varieties, respectively. There is one firm per variety.

The utility maximization problem yields a standard instantaneous CES demand function of variety *h*:

$$(2) \qquad c_h = \frac{p_h^{-\varepsilon}}{\int_0^{n+m+b} p_j^{1-\varepsilon} dj} \cdot \phi \cdot E = \eta_h \cdot \frac{\phi \cdot E}{p_h}$$

The consumption share of variety h is $\eta_h \equiv p_h c_h / \phi \cdot E = \left(p_h / P_X\right)^{1-\varepsilon}$, where

$P_X = \left(\int_0^{n+m+b} p_h{}^{1-\varepsilon} dh \right)^{1/(1-\varepsilon)}$ is the price index for manufacturing good X, E is global expenditure, and p_h is the price for variety h. Because varieties are assumed to be imperfect substitutes, goods with higher prices would have smaller market shares.

3.2 Production, Innovation and FDI

The market for good Y is perfectly competitive while that for good X is monopolistically competitive with product differentiation. The production of either type requires only one unit of labor *(L)*, regardless of the location and ownership of the firm. However, knowledge *(K)* is required before the manufacturing goods are produced and the knowledge is generated by investing labor in R&D.

The Northern innovation sector performs all R&D. Each unit of new knowledge is produced with a_I^N units of Northern labor. Following BBF (2005), we assume that

(3) $$a_I^N = \frac{1}{K^N + K^M + \mu n} \qquad (\mu \geq 0)$$

Here, K^N and K^M are the cumulated knowledge stock owned by Northern firms and MNCs, respectively, with their sum constituting the world stock. This innovation function exhibits two types of spillovers from existing knowledge.[3] The first comes from the global knowledge pool. Northern innovators have complete access to knowledge held by Northern and multinational firms, since all knowledge is originally invented in the North. The second type of spillover is LBD in the North. We assume that LBD is governed by parameter μ, which determines the ability to learn from existing local varieties in developing new goods. Thus, the efficiency of

[3] In this model, as in BBF, Northern knowledge is the same as the number of Northern varieties but we permit two means by which this knowledge spills over into reduced innovation costs. The stock of multinationals' knowledge is more than the number of their varieties due to the cost of engaging in FDI.

innovation is positively proportional to the number of varieties produced in the North. Note that the cost of innovation is then $\Omega = wa_I^N$.

Once a blueprint (i.e., a new variety of *X*) is invented in the North, firms have the choice of either producing domestically or doing so abroad. If the firm chooses to transfer the technology to the South, it faces fixed costs to set up the plant. That is, if MNCs want to use one unit of knowledge for production in the South, they need to take *(1+Γ)* units of knowledge since the proportion *Γ* would need to be expended during the transfer process to cover contracting problems, language differences and the like.

Finally, Southern firms imitate varieties introduced by MNCs with some time lag. Following Lai (1998), define the Poisson arrival rate as the change in varieties produced by Southern firms as a proportion of the available multinational ones: $i = \Delta b / m$ $(1 \geq i \geq 0)$. The rate *i* is also the probability that any variety produced by MNCs is imitated by the South in each instant, which depends on the strength of IPP and the imitation ability of workers in the South. The higher is the imitation capacity and the weaker the strength of IPP, the sooner knowledge will diffuse from MNCs to Southern imitators. The number of imitated varieties per time period by the South is then $\Delta b = im$. Once the variety is copied, only the Southern firm produces it, which drives the price down to its marginal cost.

The profit-maximization price for Northern varieties is $p = w/\alpha$ and that for multinational varieties is $p = 1/\alpha$, where $0 < \alpha = 1 - 1/\varepsilon < 1$. The price index of the differentiated products is then $P_X = \int_0^{n+m+b} p_j^{\,1-\varepsilon} dj = \left(\frac{w}{\alpha}\right)^{1-\varepsilon} n + \left(\frac{1}{\alpha}\right)^{1-\varepsilon} (m - im) + im$. The instantaneous profit functions for (unimitated) multinational firms and Northern firms are, respectively,

$$\pi^M = \left(\frac{1}{\alpha} - 1\right) c^M = \frac{(1-\alpha)\phi E}{w^{1-\varepsilon} n + m - im + im\alpha^{1-\varepsilon}} \tag{4}$$

$$\pi^N = \left(\frac{w}{\alpha} - w\right)c^N = \frac{(1-\alpha)w^{1-\varepsilon}\phi E}{w^{1-\varepsilon}n + m - im + im\alpha^{1-\varepsilon}}$$

As noted above, Southern profits are zero.

Assume that the North invests L_I^N units of Northern labor in R&D. The amount of new knowledge generated in each instant is

$$\Delta K = \frac{L_I^N}{a_I^N} = L_I^N\left(K^N + K^M + \mu n\right) \tag{5}$$

In this model we study the steady-state equilibrium. In any equilibrium there is only one knowledge share of multinationals. Thus, the growth rates of knowledge held by Northern firms and multinationals are the same and both equal the growth rate of world knowledge

$$g = g^N = g^M = \frac{\Delta K}{K^N + K^M} = L_I^N[1 + \mu(1 - \Sigma^M)] \tag{6}$$

where $\Sigma^M = K^M/(K^N + K^M)$ is the share of knowledge owned by MNCs in all technology innovated in the North, which is between zero and one. Note that, although the growth rate in equation (6) is written in terms of endogenous variable L_I^N and Σ^M, these two variables can be expressed by exogenous parameters at the steady state so that the growth rate is also time-invariant in equilibrium. Also define $\Sigma^N = K^N/(K^N + K^M) = 1 - \Sigma^M$ to be the share of knowledge held by Northern firms. Since the South imitates existing multinational varieties at rate *i* at each instant, it grows at the same rate *g* as the North.

The discounted operating profit of a Northern firm at time τ is $\Pi^N \equiv \int_{t=\tau}^{\infty} e^{-r(t-\tau)}\pi_t^N dt$. Note that a higher interest rate reduces discounted profits. Further, the faster new varieties are innovated (i.e. the faster the growth rate), the lower the expected future profit for each variety. Therefore, the expected profit of a Northern firm is

(7) $$\Pi^N = \frac{\pi^N}{\rho + g}$$

A multinational firm can only enjoy its monopolistic profit before its variety is imitated. Therefore, the expected profit for MNCs is $\Pi^M = \int_{t=\tau}^{\infty} \left[\left(\int_{\delta=0}^{\tau} \pi^M e^{-r\delta} d\delta \right) \cdot prob(\delta = \tau) d\delta \right] dt$, where $prob(\delta = \tau)$ is the probability that a variety produced by any MNC has been copied at time τ. With the standard Poisson arrival rate, the duration τ between the time of an MNC setting up in the South and the time of imitation follows the probability density function $prob(t = \tau) = e^{-i\tau}$ where i is the Poisson arrival rate at which a variety would be imitated in the next instant under the condition that it has not yet happened. Thus, the expected profit function for an MNC is $\Pi^M = \int_{t=\tau}^{\infty} \left(\int_{\delta=0}^{\tau} \pi^M e^{-r\delta} d\delta \right) \cdot e^{-i\tau} dt$. Again, the interest rate and the growth rate of new varieties need to be accounted for, as does imitation risk. The multinational's expected profits become

(8) $$\Pi^M = \frac{\pi^M}{\rho + i + g}$$

3.3 Equilibrium Choice of FDI

Northern firms choose their production location after the new technology is innovated. In equilibrium, the choice between being an MNC or a Northern firm is based on the following equation with complementary slackness.

(9) $$\Sigma^M (1 - \Sigma^M) \left[\frac{\Pi^N}{\Omega} - \frac{\Pi^M}{\Omega(1+\Gamma)} \right] = 0$$

Equation (9) shows that, after successfully inventing the new variety, firms in the North compare the ratio of the expected operating profits and setup costs in order to choose location.

Plug equations (7) and (8) into equation (9) and rewrite the equation with complementary slackness as follows:

(10) $$\Sigma^M = 1 \text{ and } \frac{\pi^M}{(\rho + i + g)(1+\Gamma)\Omega} \geq \frac{\pi^N}{(\rho + g)\Omega}.$$

$$\Sigma^M = 0 \text{ and } \frac{\pi^M}{(\rho + i + g)(1+\Gamma)\Omega} \leq \frac{\pi^N}{(\rho + g)\Omega}$$

$$0 < \Sigma^M < 1 \text{ and } \frac{\pi^M}{(\rho + i + g)(1+\Gamma)\Omega} = \frac{\pi^N}{(\rho + g)\Omega}$$

The first equation states that all firms in the North would move their production to the South ($\Sigma^M = 1$) if the expected profits of being a multinational are higher than those of being a Northern firm. The second indicates that all firms would remain in the North ($\Sigma^M = 0$) if the opposite happens. The final condition states that firms are indifferent among locations ($1 > \Sigma^M > 0$) if the discounted returns of the two types of firms are the same.

3.4 Market-clearing Conditions

The instantaneous expenditure of the South simply equals the labor income of the whole economy, which also equals the total population of the South since the Southern wage is one. Northern workers get labor income and we assume that all profits are earned by the owners of active firms. Thus, the North enjoys the profits from both Northern firms and MNCs remaining in operation. However, part of this income stream needs to be allocated to generating new knowledge. The extra cost that MNCs pay to set up the plant in the South does not show up explicitly in the expenditure function but is embodied in their profit. Therefore, the instantaneous expenditure function for each region is the following.[4]

$$E^S = L^S \tag{11}$$

$$E^N = wL^N + \pi^N n + \pi^M (m - im) - wL_I^N \tag{12}$$

$$E = E^S + E^N \tag{13}$$

where L^S and L^N are the population in the South and North, respectively.

The labor endowment in the North is used in R&D and the production of Northern varieties and the Southern labor endowment is utilized in producing multinational varieties not yet imitated, imitated varieties *(B)*, and the homogeneous product. Thus, the labor market clearing conditions are as follows.

$$L^S = L_Y + (m - im) \cdot x^M + im \cdot x^B \tag{14}$$

$$L^N = L_I^N + n \cdot x^N \tag{15}$$

In these equations, *x* refers to production of a differentiated variety, which also equals consumption in equilibrium.

3.5 Dynamic Equilibrium

In our model, the monopolistic-competition framework implies free entry in the differentiated-products sector. Thus, the expected operating profits of Northern firms and multinationals, if they exist, should exactly cover their costs of acquiring the technology and other costs before production takes place in dynamic equilibrium. We therefore have

$$\frac{\Pi^N}{\Omega} = 1 = \frac{\Pi^M}{(1+\Gamma)\Omega} \tag{16}$$

[4]As in BBF (2005), we assume there is no population growth. Thus, when the number of varieties increases in the presence of a fixed labor force, the quantity of consumption for each variety would decrease to balance the labor market.

Comparing this to the inequality conditions in (10) on FDI choices we find that if all firms choose to be Northern firms (Σ^M =0) or all decide to be multinationals (Σ^M =1), either Northern firms or multinationals are making long-term positive profits and dynamic equilibrium is not possible. Therefore, we exclude those two inequality conditions and analyze only the equation stating that Northern and multinational firms should coexist.[5] It is illuminating to rewrite that condition as

(17) $$\frac{1}{\{\rho + L_I^N[1+\mu(1-\Sigma^M)] + i\}(1+\Gamma)} = \frac{w^{1-\varepsilon}}{\rho + L_I^N[1+\mu(1-\Sigma^M)]} \quad \text{(for } 0 < \Sigma^M < 1\text{)}$$

This condition shows that an increase in the imitation rate *(i)* or Southern relative cost premium *(Γ)* makes MNCs less profitable, *ceteris paribus*; while an increase in the Northern LBD spillover *(μ)* has the opposite effect.

As described in Baldwin and Forslid (2000), analyzing dynamic models of this kind requires choice of the state variable, numeraire and solution methodology. In a product-innovation model like ours, investment determines the rate of knowledge accumulation, which in turn determines the rate of growth. Thus, the natural state variable is the amount of resources devoted to investment. Since our model has only one primary factor, labor, it naturally becomes the numeraire and investment in Northern innovation *(* L_I^N *)* is the natural state variable.

Use equations (11) to (15) to express Σ^M, *w*, *E*, E^N and E^S in terms of the state variable L_I^N and parameters *(Γ, i, μ, φ, ε, ρ,* L^N and L^S *)* and substitute these variables into equation (16). Then the equilibrium level of investment in Northern innovation can be solved with equation (17)

[5] It is interesting to note that in the “corner solutions” in which there is either full Northern production or full technology transfer of varieties to the South, the rate of multinationalization has no impact on innovation or growth.

satisfied for $0 < \Sigma^M < 1$. The equilibrium growth rate g can also be solved by substituting Northern R&D investment (L_I^N) and the multinationalization rate (Σ^M) into equation (6).

With appropriate substitutions, all other endogenous variables may be determined as a function of the wage differential, exogenous parameters and state variables. However, the fundamental equation has the form $aw + bw^{-\varepsilon} + cw^{1-\varepsilon} = 0$, which has no general solution.[6] In turn, the primary solution cannot be used to compute comparative-static effects of parameter changes on central endogenous variables. Thus, after next presenting our extended model, we engage in simulation analysis in Section 5 to examine these relationships.

4. SOUTHERN INNOVATION AND REVERSE KNOWLEDGE SPILLOVERS

Next we extend the model to permit investments in R&D by Southern firms. The introduction of Southern innovation and reverse knowledge spillovers alters the innovation sector directly. In addition to its own knowledge pool and LBD from the number of varieties produced locally, the North also absorbs knowledge from the South. The more knowledge the South creates and the more easily it flows to the North, the lower would be the unit labor cost for Northern innovation.

Like their Northern counterparts, Southern innovators learn from two sources, general knowledge and LBD. However, since the South is less developed, we assume its innovators are less productive in using knowledge, so that innovation functions are asymmetric. Specifically, we assume that Southern innovators cannot access Northern general knowledge, either because it is too difficult to reverse engineer or the IP protection in the North is too strong. Put differently, Southern innovators only use knowledge from the local pool, which consists of existing Southern inventions and knowledge that leaked out from MNCs to domestic imitators. As for LBD, we assume that Southern firms learn from production methods of Southern imitators and innovators

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6 In a technical appendix, which is available on request, we present the primary solution, which is a complex expression in the wage. We also discuss why there is no analytical solution for the wage gap for general values of the elasticity of substitution.

only. That is, MNCs are capable of disguising their processes sufficiently to preclude that form of spillover directly to Southern rivals. Thus, LBD comes from the number of varieties the South previously invented and is producing *(s)* and the number of varieties it imitates from MNCs *(im)*.

Collecting ideas, the unit labor cost of Northern innovation (a_I^N) and Southern innovation (a_I^S) are as follows.

(18) $$a_I^N = \frac{1}{K^N + K^M + \lambda K^S + \mu n} \qquad (0 \leq \lambda \leq 1 \,\&\, \mu \geq 0)$$

(19) $$a_I^S = \frac{1}{K^S + \dfrac{K^M}{1+\Gamma} + \theta(im + s)} \qquad (\mu \geq \theta \geq 0)$$

Southern knowledge is defined to be only Southern-innovated varieties and not the ones imitated from MNCs. Parameter λ is the reverse knowledge spillover parameter that measures how easy it is for Northern innovators to observe and absorb Southern new knowledge. The Southern LBD spillover parameter *(θ)* is similar to the Northern LBD spillover parameter *(μ)* and measures the extent that innovators learn from watching local production processes.

The rates of knowledge accumulation for the North *(g^N)* and South *(g^S)* depend on R&D investment levels in each region, the unit labor costs of innovation, and the initial knowledge stocks. Define the South-North knowledge stock ratio to be $\Sigma^S = \dfrac{K^S}{K^N + K^M}$. The regional growth rates become

(20) $$g^N = g^M = \frac{\Delta(K^N + K^M)}{K^N + K^M} = L_I^N [1 + \lambda \Sigma^S + \mu(1 - \Sigma^M)]$$

(21) $$g^S = \frac{\Delta K^S}{K^S} = \frac{L_I^S \left[\dfrac{K^M}{1+\Gamma} + K^S + \theta(im + s) \right]}{K^S} = \frac{L_I^S \left[\Sigma^M (1 + i\theta) + (1+\Gamma)\Sigma^S (1+\theta) \right]}{(1+\Gamma)\Sigma^S}$$

Again, although the growth rates are written in endogenous variables, these variables can be expressed by exogenous parameters at the steady-state equilibrium so that the growth rates are time-invariant.

Consumption behavior is the same as in the benchmark model except that consumers also access unimitated Southern-innovated varieties and imitated Southern varieties. Accordingly, the global price index of the differentiated-goods sector now takes into account Southern goods.

$$P_X = \int_0^{n+m+b+s} p_j^{\,1-\varepsilon} dj = \left(\frac{w}{\alpha}\right)^{1-\varepsilon} n + \left(\frac{1}{\alpha}\right)^{1-\varepsilon} (m - im) + im + \left(\frac{1}{\alpha}\right)^{1-\varepsilon} (s - is) + is \tag{22}$$

The only difference in production lies in the South, which, in addition to multinational and imitated varieties, also produces its own innovated varieties. These enjoy the same instantaneous monopolistic profit as unimitated multinational varieties. Instantaneous profit for firms producing Northern *(N)*, unimitated multinational *(M)*, and unimitated Southern-innovated *(S)* varieties are as follows.

$$\pi^N = \left(\frac{w}{\alpha} - w\right) x^N = \left(\frac{1-\alpha}{\alpha}\right) \frac{w^{1-\varepsilon} \phi(E^N + E^S)}{\alpha^{-\varepsilon} \cdot P_X} \tag{23}$$

$$\pi^S = \pi^M = \left(\frac{1}{\alpha} - 1\right) x^M = \left(\frac{1-\alpha}{\alpha}\right) \frac{\phi(E^N + E^S)}{\alpha^{-\varepsilon} \cdot P_X} \tag{24}$$

The FDI choice of firms in the North is based on the same condition as in the benchmark model (equation (9)).

The market-clearing conditions include two equations in each of the goods markets and labor markets. The amount of income in the South that can be spent in consumption is the sum of Southern workers' labor income and monopolistic profits of unimitated Southern innovative firms, excluding R&D investment. Spendable income in the North is the sum of Northern workers' labor income and monopolistic profits of Northern and unimitated multinational firms, excluding R&D expenditure. Northern labor is used to invest in R&D and produce Northern varieties, while Southern labor is now allocated to R&D as well as production of homogeneous products, unimitated multinational varieties, imitated varieties, and Southern varieties.

(25) $$E^S = L^S + \pi^S (s - is) - L_I^S$$

(26) $$E^N = wL^N + \pi^N n + \pi^M (m - im) - wL_I^N$$

(27) $$L^N = L_I^N + n \cdot x^N$$

(28) $$L^S = L_Y + (m - im) \cdot x^M + (s - is) \cdot x^S + (im + is) \cdot x^B + L_I^S$$

Finally, applying the free-entry condition, the expected operating profits of firms need to be the same as the cost of innovating a new variety.

$$\frac{\Pi^N}{wa_I^N} = \frac{\Pi^M}{(1+\Gamma)wa_I^N} = 1 = \frac{\Pi^S}{a_I^S}$$

The question remaining is how to discount the expected profits (Π^M , Π^N and Π^S). All variables in the instantaneous operating profit functions (23) and (24) are time-invariant in steady-state equilibrium except for Σ^S and $(K^N + K^M)$. The Northern knowledge stock grows at a constant rate g^N at the dynamic equilibrium as before. Therefore, the system is solvable only when Σ^S is also time-invariant at the steady-state equilibrium. This implies that the growth rates of Southern and Northern knowledge are equal to each other in the steady-state equilibrium.

(29) $$\frac{g^S}{g^N} = 1 \Rightarrow \frac{L_I^S \left[\Sigma^M (1 + i\theta) + (1+\Gamma)\Sigma^S (1+\theta)\right]}{(1+\Gamma)\Sigma^S} = L_I^N [1 + \lambda\Sigma^S + \mu(1 - \Sigma^M)]$$

In addition, since both multinational firms and innovative firms producing in the South suffer the risk of imitation in the local market, the free-entry conditions for multinational and Southern firms become

(30) $$\frac{\dfrac{\pi^{M}}{\rho+g+i}}{(1+\Gamma)wa_{I}^{N}}=1$$

(31) $$\frac{\dfrac{\pi^{S}}{\rho+g+i}}{a_{I}^{S}}=1$$

Note that the instantaneous profits for multinational and Southern firms are the same and they face the same risk of imitation. It immediately follows that

$$\frac{1}{a_{I}^{S}}=\frac{1}{(1+\Gamma)wa_{I}^{N}}$$

Because setting up a firm in a foreign (developing) country is more costly than doing so in the domestic (developed) country the setup cost premium (Γ) is positive. Thus, the unit cost of innovation in the South (a_{I}^{S}) is always larger than that in the North (wa_{I}^{N}) in an equilibrium with FDI. This inefficiency means that expanded innovation in the South bears the potential to reduce growth.

Finally, expected profits must be discounted and the FDI choice of Northern firms is again characterized by the system (10). Now the following equation must hold for an interior solution of the multinationalization rate.

(32) $$\frac{1}{\left\{\rho+L_{I}^{N}[1+\lambda\Sigma^{S}+\mu(1-\Sigma^{M})]+i\right\}(1+\Gamma)}=\frac{w^{1-\varepsilon}}{\rho+L_{I}^{N}[1+\lambda\Sigma^{S}+\mu(1-\Sigma^{M})]}$$

(for $0<\Sigma^{M}<1$)

This system of equations from (25) to (32) describes the steady-state equilibrium.

As with the benchmark case, the analytical solution of this extended model cannot be used to describe how parameter changes affect key variables. We therefore turn to simulation.

5. SIMULATION ANALYSIS

The commodity-markets and labor-markets clearing conditions (11) to (15), free-entry condition (16), global growth rate in (6) and the FDI-choice condition (17) are simulated as a system for the benchmark model. For the extended model with Southern innovation simulations of equations (25) to (32) describe the long-run, steady-state equilibrium.

We consider three cases for each simulation: the benchmark model, the situation in which Southern firms innovate but there is no reverse spillover $(\lambda = 0)$, and the case with partial reverse spillover $(\lambda < 1)$. We are interested in the impacts of Southern innovation on multinationalization choices and the global growth rate as other policy-related parameters change. These parameters include the imitation rate (i), which can be interpreted as a measure of the strength of Southern patents, relative investment barriers (Γ), the Northern LBD spillover (μ), and the Southern LBD spillover (θ). The benchmark values of these parameters and the range over which they vary are taken from the literature or calculated from available statistics. We describe these calculations in the appendix and the selected parameters are shown in Table 2.

[Table 2 here]

The fundamental difference between models with and without Southern innovation lies in the role of the South. In the benchmark model, Northern firms select innovation and the multinationalization rate in light of the imitation threat and cost parameters. In the extended model, both Northern and Southern firms choose R&D investment levels in response to available knowledge and production processes from which they learn. The relative labor demands and the rate of multinationalization are codetermined by the two regions. Specifically, Southern innovation increases domestic labor demand for both innovation and production of Southern varieties. Thus, *ceteris paribus*, the rate of multinationalization in the extended model will be lower than that in the benchmark model because there is less labor available for international firms.

5.1 Changes in the Imitation Rate

In the benchmark model, the North is the only innovator but MNCs are subject to imitation risk. When the Southern imitation rate decreases, either because local firms are less productive at imitation or there is stronger IPP, this risk diminishes, encouraging more firms in the North to move their production abroad. This rise in multinationalization is shown by the dotted line in Figure 1, reading from right to left.

The impact on growth is determined by two offsetting forces. On the one hand, diminished imitation risk raises the profits of Northern innovative firms, inducing a rise in R&D investment. On the other hand, the rise in the proportion of firms moving production abroad decreases innovation efficiency by having fewer local production processes in the North for LBD. The net impact on the knowledge growth rate is governed by Equation (6): $g = L_I^N[1+\mu(1-\Sigma^M)]$. This states that the overall effect depends on the relative strength of the increase in R&D investment *(* L_I^N *)* and the decrease in innovation efficiency from having diminished LBD *(1-* Σ^M *)*. Our simulation shows that, as depicted by the dotted line in Figure 2, the effect of the change in R&D dominates so that the growth rate increases as the Southern imitation rate goes down.[7] Put differently, higher rates of FDI activity are associated with higher global variety growth. This finding is consistent with Lai's (1998) result that, in the presence of FDI, stronger Southern IPP tends to attract more firms to become multinationals and also boosts innovation and growth.

Finally, the higher FDI activity raises Southern labor demand, resulting in a narrowing wage gap as imitation falls, as indicated by Figure 3. Thus, in this benchmark model, stronger IPP increases the relative Southern wage through the induced impact on FDI.

[Figures 1, 2 and 3 here]

Next, we introduce Southern innovation into the model without reverse spillover (*λ=0*). Focus initially on the impact of this change on multinationalization, holding Southern imitation

[7] In fact, simulations across many parameter values show that this result always holds for an interior multinationalization rate.

constant. Southern innovation will have two offsetting impacts. First, compared to the benchmark case, some Southern labor is allocated to innovation, squeezing out some multinationals and keeping more production in the North. This direct effect is offset by the fact that the appearance of new Southern varieties takes market share and profits from existing Northern varieties. This competition effect induces more Northern firms to become MNCs in order to exploit lower Southern production costs, raising the multinationalization rate.

Simulation shows that when the reverse spillover possibility is excluded the direct negative effect on FDI dominates so that the rate of multinationalization, shown by the connected-dot line in Figure 1, is lower than in the benchmark model for any imitation rate within the range depicted. It is possible, however, that at yet-higher imitation rates the competition effect would overwhelm the direct effect, generating a higher degree of multinational activity even with Southern innovation.

Note that there is a U-shaped relationship in Figure 1, where multinationalization first falls then rises with imitation. Higher imitation risk through, say, weaker IPP diminishes MNC profits and reduces the multinationalization rate, which dominates at lower imitation rates. On the other hand, an increase in the imitation rate also expands the Southern innovation ability through LBD and Southern varieties expand faster. This effect would erode the profits of existing varieties and, since Northern varieties have a higher price, they would suffer relatively larger reductions in market share and profits. In this sense, more firms in the North would want to be MNCs as the imitation rate goes up. This impact dominates at higher imitation rates and MNC activity expands. To our knowledge, this is the first model that generates this non-monotonic effect of imitation on MNCs through the operation of Southern innovation.

Turning to Figure 2, we find that the impact of Southern innovation is always to reduce global variety growth at any level of imitation risk. The fact that knowledge growth rates are lower than in the benchmark reflects the inefficient specialization permitted by Southern innovation. Specifically, where there is reduced MNC activity, more labor is used in production in the North, decreasing R&D there. In this sense, some Southern labor is allocated to innovation and additional Northern labor to production. This substitution of labor in both regions expands activities in which each has a comparative disadvantage. As a consequence, global knowledge accumulates at a lower rate. Interestingly, even where there is increased multinationalization at higher imitation rates the net effect is still to reduce global growth.[8]

Next, the introduction of Southern innovation increases local labor demand but this is more than offset by squeezing out MNCs, which raises labor demand in the North. Thus, the North-South wage gap becomes larger than that in the benchmark model, as noted by the connected-dot line in Figure 3.

We are also interested in how changes in the imitation rate affect Southern R&D investment, measured here by labor allocated to innovation. As shown by the connected-dot curve in Figure 4, the impact of higher imitation risk (weaker IPP) is non-monotonic: investment in Southern R&D first rises and then falls. This reflects the balance between changes in multinational activity and the growing numbers of imitated varieties. In fact, there are multiple processes in operation. First, a rise in imitation risk reduces (raises) MNC activity in the lower (higher) range of imitation rates. In turn, there is a fall (rise) in knowledge available to spill over to Southern innovation, reducing (raising) Southern R&D. Second, increases in i expand the efficiency of imitation, generating more imitated varieties per unit of both new MNC and Southern varieties. One impact is to generate more LBD, which expands Southern R&D investment. At the same time, however, greater imitation efficiency pushes more Southern labor into production of imitated varieties, which reduces labor available for R&D. Third, the higher imitation risk, which reflects weaker patent protection, would reduce the rents paid to new Southern-owned varieties. This would also limit investments in innovation in the South. This inverted-U relationship between patent rights and local innovation has been noted in other

8 Note that the global innovation curves converge at higher degrees of imitation.

theoretical contexts (Park 2008) but only in single-country models. It arises in our North-South model from a novel mix of imitation and innovation in the current framework.

[Figure 4 here]

Consider next a high degree of reverse spillover *(λ=2/3)*. In general, the same processes described above still hold. However, compared to the zero-spillover case, the new feature is that the South-North spillover increases innovation efficiency in the latter region. The immediate impact is that more new varieties would be generated, which establishes a higher global innovation growth rate, as noted by the dashed curve in Figure 2. As noted by the corresponding curve in Figure 1, the result of more Northern innovation is a higher degree of multinationalization as firms migrate to take advantage of cheaper production costs. And in Figure 3 we find that the North-South wage ratio is lowest in this case since Southern labor is in high demand from MNC production in addition to its allocation to R&D.

To examine the impacts of changing imitation risk in this scenario, first consider Figure 4, in which the dashed curve depicts Southern labor invested in R&D. We again get an inverted-U shape: R&D first rises, then falls as patents get weaker and imitation rates rise. We now find that Southern R&D investment bends downward at a lower imitation rate and it drops faster than in the no-spillover case.[9] The intuition is that the reverse spillover is sufficiently significant that a greater proportion of new Southern varieties face more rapid competition from Northern innovation per unit of time. Further, the expansion of Northern innovation induces a greater FDI

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[9] In fact, in the simulation Southern innovation reaches zero at an imitation rate of approximately 0.25 and would become increasingly negative beyond that point. Negative innovation cannot be an equilibrium. Indeed, at this same point, the multinationalization rate would no longer be computed to lie within the interior solution range we consider in equation system (10). Beyond this rate of imitation, the remaining variables in Figures 1-3 are indeterminate with the high spillover. Note that the same cutoff would happen at a higher imitation rate (not shown) in the case of zero reverse spillover.

flow, reducing Southern labor available for innovation. In combination with the growing risk from higher imitation, Southern firms find it less profitable to invest in R&D.

We note one potential policy implication in Figure 4. If the Southern government is interested in expanding local investments in innovation, our analysis suggests that it can be fairly lax in its IPP in the absence of any reverse spillover. However, if new Southern varieties easily leak back to the North, the need for stronger patent rights becomes paramount in encouraging local R&D.

Note in Figure 1 that the U-shaped relationship remains and that multinationalization starts to rise at a lower imitation risk compared to the case with no spillover. This indicates that the competition effect we described above is stronger with the reverse spillover. The intuition is that more new Southern varieties leak back into the North, generating a higher innovation rate and raising the share of firms becoming multinationals to take advantage of lower production costs.

A new feature is that, as shown by the dashed line in Figure 2, there is now a U-shaped relationship between the rate of imitation and variety growth. The reason is that when the multinationalization rate increases with a rising imitation rate (Figure 1), Southern innovation efficiency expands (even as overall investment in R&D falls in Figure 4) because there are both a higher level of general knowledge brought to the South and a larger LBD spillover. Moreover, the Northern innovation efficiency benefits through the reverse spillover. Finally, these high rates of multinationalization and imitation imply that the North transfers a larger share of its varieties to the South. In consequence, both regions engage more in activities in which they have greater relative advantage. Thus, the global growth rate can rise with weaker Southern IPP and may even surpass the level in the benchmark model.

To summarize this section, if the South only imitates, a low imitation rate (strong IPP) attracts more FDI, expands global innovation and promotes Southern imitation, so that both regions grow at a higher speed. The novelty here is to consider the effects of endogenous Southern innovation, with and without the reverse spillover. Our model demonstrates that the relationship between the rate of imitation and multinationalization becomes U-shaped. The intuition is that a high imitation rate implies rapid learning in the South, which expands Southern varieties and raises FDI incentives through a competition effect.

Concerning innovation growth, we find the following. With no reverse spillover Southern innovation pushes labor in both regions to engage more in activities in which they have a comparative disadvantage. Thus, the growth rate is always lower than in the benchmark model. However, this impact can be reversed by a significant South-North spillover. In this case, the higher rate of multinationalization increases Southern innovation efficiency and also benefits Northern innovation. The result is to restore the efficiency loss from Southern innovation and generate higher knowledge growth.

5.2 Changes in other Parameters

We briefly describe the results of other policy simulations.[10] As may be expected, a reduction in the Southern FDI investment cost (Γ), which in this model is a pure resource cost, raises the rate of multinationalization for any fixed imitation rate. The proportion of firms that become MNCs is always lowest in the case where Southern firms innovate but there is no South-North spillover. It becomes highest when there is such a spillover and the setup cost falls to low levels. A reduction in the investment cost also raises global innovation in all cases and raises the Southern wage relative to the Northern wage.

Next, a rise in the Northern learning spillover (μ) directly increases innovation efficiency in the benchmark model and expands both multinationalization and growth. Where there is a significant South-North spillover these impacts are magnified as Northern LBD improves. In essence, this situation expands the learning gain from the reverse spillover. Finally, increases in the Southern learning parameter (θ) diminish multinationalization and growth in both cases of

[10] Precise results are available on request.

Southern innovation. However, the FDI proportion and global innovation growth remain higher in the situation with a significant reverse spillover.

5.3 Adding Imitation of Northern Exports

Our assumption that Southern imitation targets only products made in multinational firms is stark. We relax it here by permitting also imitation of goods imported from the North, which generates an additional channel of North-South technology transfer.[11] Prior literature (Lai 1998, Glass and Saggi 2002) suggests that it is easier for Southern imitators to learn production techniques from local MNCs than from Northern exporters due to geographic proximity, demonstration effects and the potential for technical personnel to migrate to imitative firms. Thus, following Lai (1998), we assume that it takes longer to imitate Northern exports, implying that the Poisson arrival rate in imitating such varieties (i^e) is smaller than that of multinational goods (i^m).

In this setup, note that once the Northern variety is imitated, the exporter would abandon production since the price is driven down to the Southern imitator's marginal cost. An important implication is that imitated export varieties no longer contribute to Northern innovation through LBD. Further, in our extended model these varieties contribute to Southern innovation in the forms of both general knowledge and LBD.

We simulate a new case in this situation with a benchmark value of the export imitation parameter equal to either 33 percent or 20 percent of the FDI imitation rate, holding other parameters unchanged. Rather than present all outcomes we show differences between our earlier and new results when there is both Southern innovation and the South-North technology transfer.[12]

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[11] Equations are available in a technical appendix on request.

[12] There are no qualitative differences to report in the first two cases (no Southern innovation and Southern innovation with no reverse spillover) except to note that both the multinationalization and growth rates

In Figure 5 the monotonically declining line (A1) is the same as our benchmark solution, with no Southern innovation and no export imitation. The lowest U-shaped curve (A2) repeats our scenario with Southern innovation and no reverse spillover, while the dashed curve (A3) repeats the situation with Southern innovation and a high rate of reverse spillover. The light-solid curve (A4) is the simulated result when we permit imitation to target both FDI and Northern exported goods with the 33 percent relative risk, while there is a significant reverse spillover (λ = 2/3). As may be seen, this scenario also generates a U-shaped relationship between multinationalization rates and imitation propensities, suggesting that our model is robust to this change. The dark-solid curve (A5) repeats the analysis for the goods-imitation rate set at 20 percent of the FDI-imitation rate.

[Figure 5 here]

The fact that multinationalization rates are now lower than in the FDI-only imitation case reflects a balance between two forces. First, the second imitation channel raises competition for all Northern varieties, tending to push more firms to become multinationals. Second, the additional imitation reduces the Southern labor force available for production within multinationals. The second effect dominates in this scenario and reduces the multinationalization rate.

Finally, we note that in this case the innovation growth rate retains its U shape with respect to imitation under our two channels.[13] However, the growth rates are smaller than in the case where imitation of exports is even less rapid (at 20 percent of the FDI imitation rate). This is broadly consistent with Lai's (1998) theoretical result that, with a sufficiently small export-imitation rate, a strengthened Southern patent regime raises Northern innovation.

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diminish marginally more rapidly as the imitation rate increases in the case of export-variety imitation threat.

[13] The diagram for these simulations is available on request.

6. CONCLUSION

We present a dynamic, general-equilibrium model in which the benchmark case permits endogenous FDI choice but there is no Southern innovation. In this case the more FDI activities that exist, the greater is the allocation of Southern labor to production and the greater is the allocation of Northern labor to innovation for any given imitation rate. This outcome represents an efficient allocation of labor in the two regions and generally maximizes the potential for global innovation growth. We find also in the model that as the Southern imitation rate declines there is an increase in multinationalization and higher global innovation. Thus, policy efforts in the South to reduce domestic imitation actually would expand international innovation.

When we next introduce the possibility of endogenous but high-cost Southern innovation a complex set of tradeoffs emerges. A primary result is that the more Southern labor allocated to innovation the slower is global growth because it implies relatively greater specialization by both regions in inefficient activities: the South in innovation and the North in production. In this case, however, there is a non-monotonic relationship between imitation and multinationalization. It is possible for increases in imitation risk (due perhaps to weaker patents) to expand MNC investment through a competition effect.

Next, a substantial spillover of Southern knowledge into improved Northern innovation implies at least partial reversal of the inefficient specialization. As a result, global innovation growth is intermediate between the no-spillover case and the benchmark case, and may exceed the latter at high rates of imitation. A similar relationship arises for the rate of multinationalization. It is interesting that the combination of endogenous Southern innovation and knowledge spillovers to the North expands both FDI and global innovation at higher rates of imitation. In this sense the learning from South to North helps restore an efficient international resource allocation. Finally, our results remain intact when we permit a second channel of imitation through exports arriving in the South.

We emphasize that these results emerge in a complex and stylized model. However, they do highlight a possibility that has not been recognized widely in the literature. Specifically, technology transfer through multinational investment tends to go up in an environment of lower imitation risk, perhaps due to strengthened intellectual property protection. This multinationalization may kick off a process in the South in which local imitation and learning-by-doing establish the possibility of domestic innovation as the costs of R&D fall. In equilibrium, however, Southern innovation and investment in multinational subsidiaries must pay the same economic return and cover both the innovation costs and the FDI setup cost. This fact implies that Southern innovation remains expensive relative to its Northern counterpart. As a result, inefficient specialization can reduce the extent of FDI and international knowledge accumulation. To counter this inefficiency a Southern policy of strengthening IPP and reducing the costs of inward investment can expand multinationalization and growth, an effect enhanced by the reverse spillover. As noted in Figure 2, global innovation is maximized under weak Southern imitation risk.

Our analysis turns up another novel feature, however. Beyond a certain range, increases in the Southern imitation rate may raise the arrival rate of multinational enterprises due to a competition effect arising from lower-cost Southern innovation and the reverse technology spillover. This factor can reverse the impact of inefficient specialization and ultimately increase global innovation growth. In this context, the relationship between growth and patent protection is U-shaped. Thus, in cases where the reverse spillover from South to North is sufficiently strong, world innovation may benefit from a relaxation in local IPP.

Yin He is Assistant Professor of Economics, *University of International Business and Economics, Beijing, China.*

Keith E. Maskus is Professor of Economics at the *University of Colorado, Boulder.*

APPENDIX: PARAMETER VALUES FOR SIMULATION

The reverse knowledge spillover from South to North *(λ)* may be measured by the geographic pattern of learning. Jaffe, et al. (1993) find that 60-75 percent of knowledge through citations of U.S. patent in the 1970s and 1980s is learned by domestic firms while 25-40 percent is absorbed by foreign firms. Thus, we take the value of our knowledge spillover parameter to be either 1/3 or 2/3.

Another important parameter is the Southern rate of imitation *(i)*. We calculate it from two components: the relative strength of IPP and the relative learning ability of the FDI-recipient country. The stronger are patent rights and the lower is the learning ability, the lower would be the imitation rate. The strength of IPP is calculated from the Ginarte-Park (GP) patent index in the year 2000 (Park and Wagh 2002). The average index in a selection of developing countries was 2.84 while that of developed regions was 4.05. Thus, the strength of IPP in developing regions was about 70 percent of the level in developed regions, suggesting an imitation margin of 30 percent. The learning ability of developing countries relative to developed nations is calculated from data on the education attainment of total population of age 25 and over in Barro and Lee (2001). The average years of schooling in developed nations was 9.4 and that in developing countries was 6.1. Using these data, workers in developing countries have about 65 percent of the learning ability of those in developed regions. Multiplying the relative imitation possibility from the weakness of IPP (0.3) and the relative average learning ability (0.65), developing countries are calibrated to have an imitation rate of 0.2 in the benchmark. Our lower bound for this parameter is 0.0, while we take 0.4 as the upper bound. These values are used also for the imitation rate of multinational varieties (i^m) in the extended model. The parameter τ, which captures the proportionately lower imitation rate for Northern exports than for multinationals ($i^e = \tau\, i^m$) , takes a benchmark value of 0.33 and we also consider 0.2 and 0.5.

The relative investment barrier in the South (Γ) is calculated from the investment cost index developed by Carr, et al. (2001). The index measures the cost of investing in a country by averaging several indexes of impediments to foreign operations as reported in the *World Competitiveness Report* published by the World Economic Forum. In our simulations, Γ is defined as the percentage difference in the average investment cost index in developing countries compared to that in developed countries. This difference suggested that the average additional investment cost was around 65 percent and we take our benchmark value to be 0.65. The minimum is set to zero and the maximum is set to 1.3, which doubles the benchmark value.

The value of the Northern LBD spillover parameter (μ) is taken from the literature. Irwin and Klenow (1994) estimate the LBD coefficient to be 0.2 in the semiconductor industry. Benkard (2000) concludes that if knowledge does not depreciate then the learning rate is roughly 18 percent in the commercial aircraft industry. Cooper and Johri (2002) present estimates of coefficients for LBD spillovers (measured by various output-based measures of organizational capital) ranging from 0.22 to 0.38 on the plant level. Therefore, we set our benchmark value of Northern LBD to 0.2 and allow it to change between 0.0 and 0.4.

The LBD spillover in the South (θ) reflects the learning ability of workers from watching local production processes. Recalling that workers in developing countries have about 65 percent of the learning ability of workers in developed countries, the benchmark value of the LBD spillover in the South is set to be 0.13, which is 65 percent of the benchmark value of the Northern LBD spillover. We permit the Southern parameter to range from 0.0 to 0.2, implying that the South could have no LBD or it could enjoy the same LBD as their Northern counterpart.

The remaining parameters do not have direct policy relevance and we simply fix them at a benchmark value. Based on Broda and Weinstein's (2006) finding that the mean elasticity of substitution at the SITC 5-digit level is 6.6, the elasticity of substitution between differentiated varieties (ε) is set to 6.5. The time preference parameter (ρ) is set to be 0.02, suggested by Barro and Sala-i-Martin (1995). The global expenditure share of manufacturing goods (Φ) is assumed to equal the value added of industrial goods divided by GDP. Taken from the 2007 *World Development Indicators* database of the World Bank, the value of this ratio for high-income and middle-income regions is calculated to be 0.3. Finally, define the "North" to be comprised of countries with ratios of gross enterprise R&D to GDP greater than 2.0 percent in 2007, taken from the OECD's *SourceOECD* online database. This amounts to a population of approximately 650 million in 2008, leaving a population in the "South" of around 6.51 billion. This ratio of 10 to 1 is not quite sufficient to support innovation, multinational production, and local production in the South in steady-state equilibrium. Thus, we raise the benchmark value of Southern population to 12 (with the Northern population at 1) to permit comparing the benchmark with extended models.

All of our parameter values are summarized in Table 2.

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TABLES AND FIGURES

TABLE 1

INDICATORS OF TECHNOLOGY TRANSFER

	High-Tech Imports %[a]	*US FDI Position Abroad $m*[c]	*Royalties & Fees Payments $m*	
Country	*1995*	*1995*	*1995*	
Argentina	13.8	3,289	392	
Brazil	22.3	17,385	529	
Mexico	9.7	10,580	484	
China	20.7	1,263	1,281[b]	
India	13.9	399	90	
Rep. Korea	10.3	2,083	2,385	

	High-Tech Exports %[a]		*FDI Position in US $m*[c]		*Royalties & Fees Receipts $m*		*Patent Application Shares in USPTO & EPO*	
Country	*1995*	*2005*	*2000*	*2005*	*1995*	*2005*	*1995*	*2005*
Argentina	3.5	6.5	neg	neg	12	51	0.03	0.04
Brazil	4.8	12.8	429	1,588	32	102	0.06	0.11
Mexico	15.1	19.6	3,448	5,674	114	171	0.04	0.05
China	10.5	30.6	neg	175	80[b]	157	0.07	1.01
India	4.3	4.7	neg	94	1	206	0.05	0.56
Rep. Korea	25.9	32.3	1,141	525	299	1,908	1.26	5.61

Notes: [a]Percentage of manufacturing imports or exports.
[b]Figures for 2000.
[c]FDI position in total manufacturing at historical cost.

Sources: Computed by authors from UN Comtrade; World Bank World Development Indicators; US Bureau of Economic Analysis; World Intellectual Property Organization

TABLE 2

PARAMETER VALUES FOR SIMULATION

	Benchmark	Low	High
Reverse spillover (λ)	-	0.33	0.67
Southern imitation (i)	0.2	0	0.4
Relative investment cost (Γ)	0.65	0	1.3
Northern LBD (μ)	0.2	0	0.4
Southern LBD (θ)	0.13	0	0.2
Relative imitation risk (τ)	0.33	0.2	0.5
Time preference (ρ)	0.02	-	-
Elasticity of substitution (ε)	6.5	-	-
Consumption share of differentiated goods (Φ)	0.3	-	-
Northern labor	1	-	-
Southern labor	12	-	-

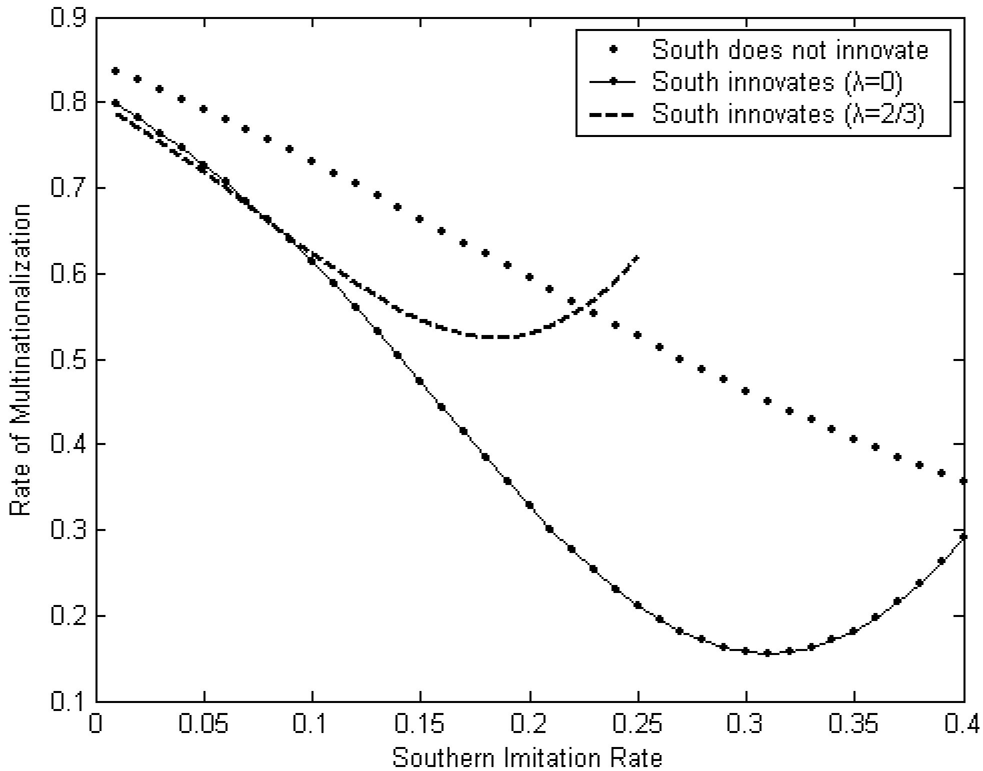


FIGURE 1: SOUTHERN IMITATION RATE AND THE RATE OF

MULTINATIONALIZATION

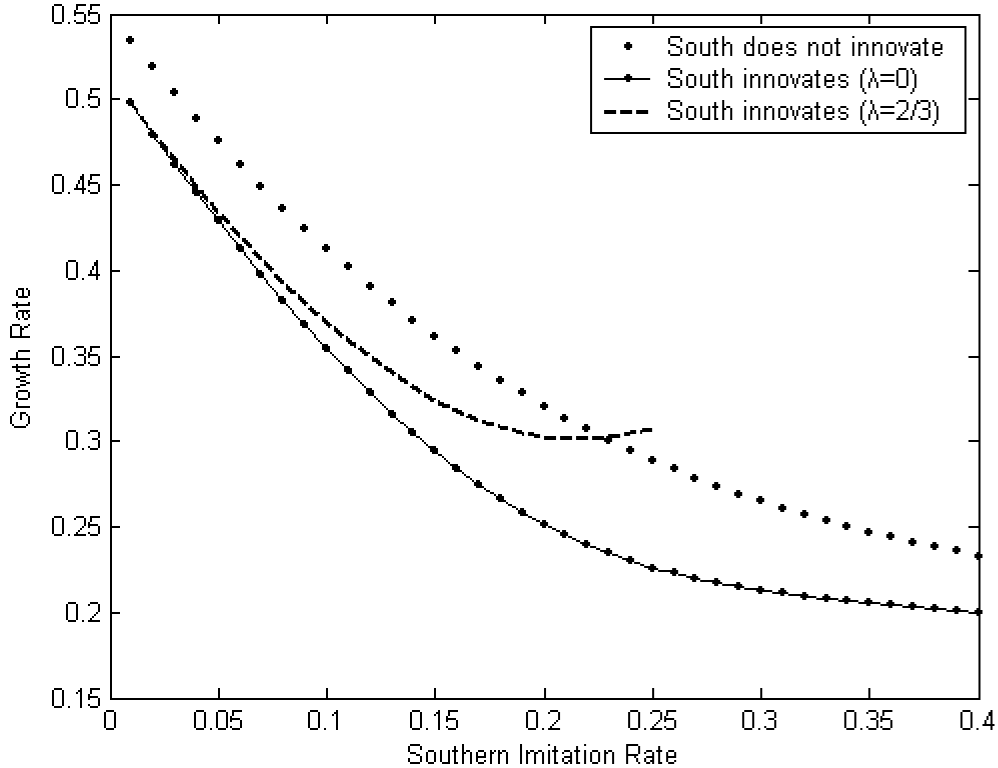


FIGURE 2: SOUTHERN IMITATION AND GROWTH

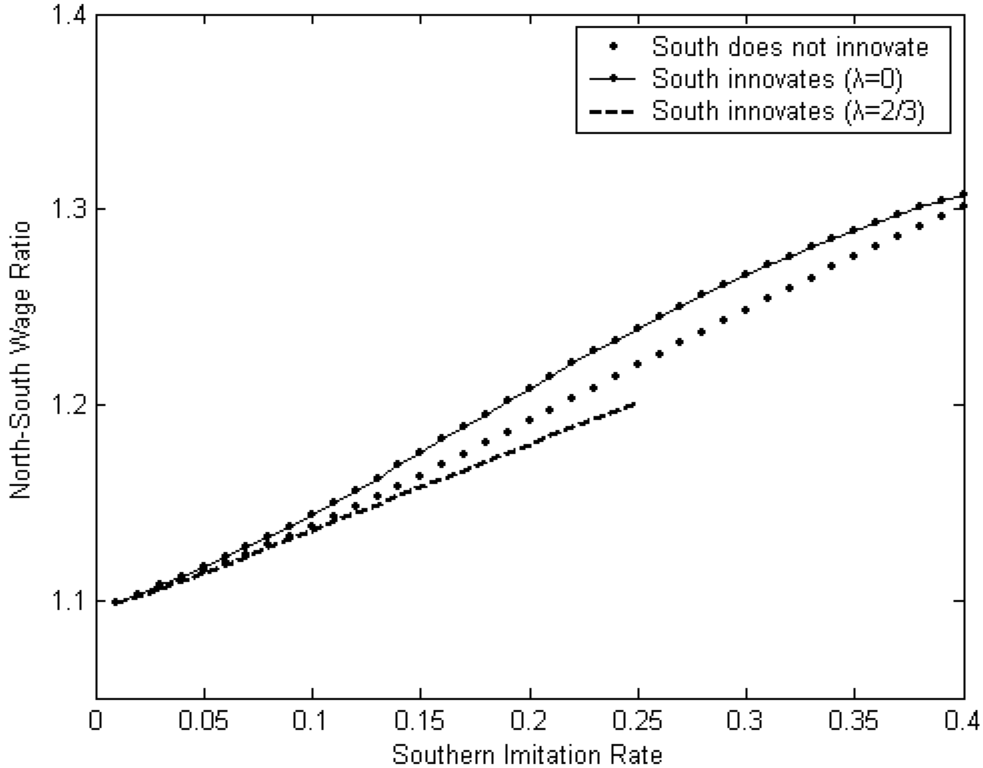


FIGURE 3: SOUTHERN IMITATION RATE AND NORTH-SOUTH WAGE RATIO

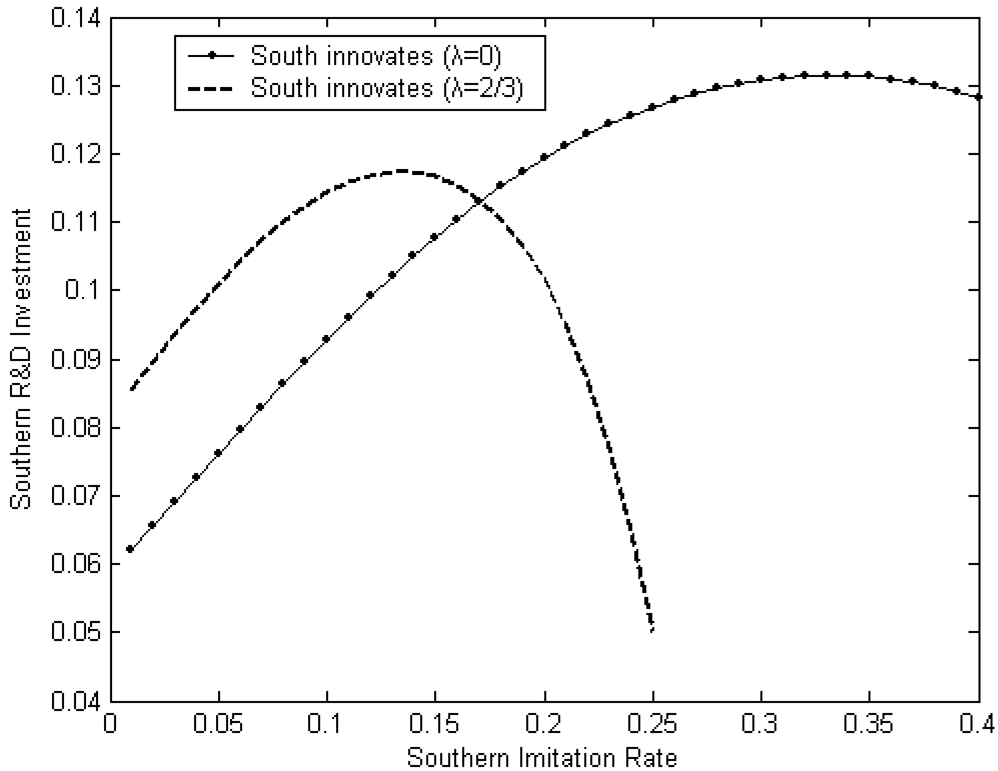
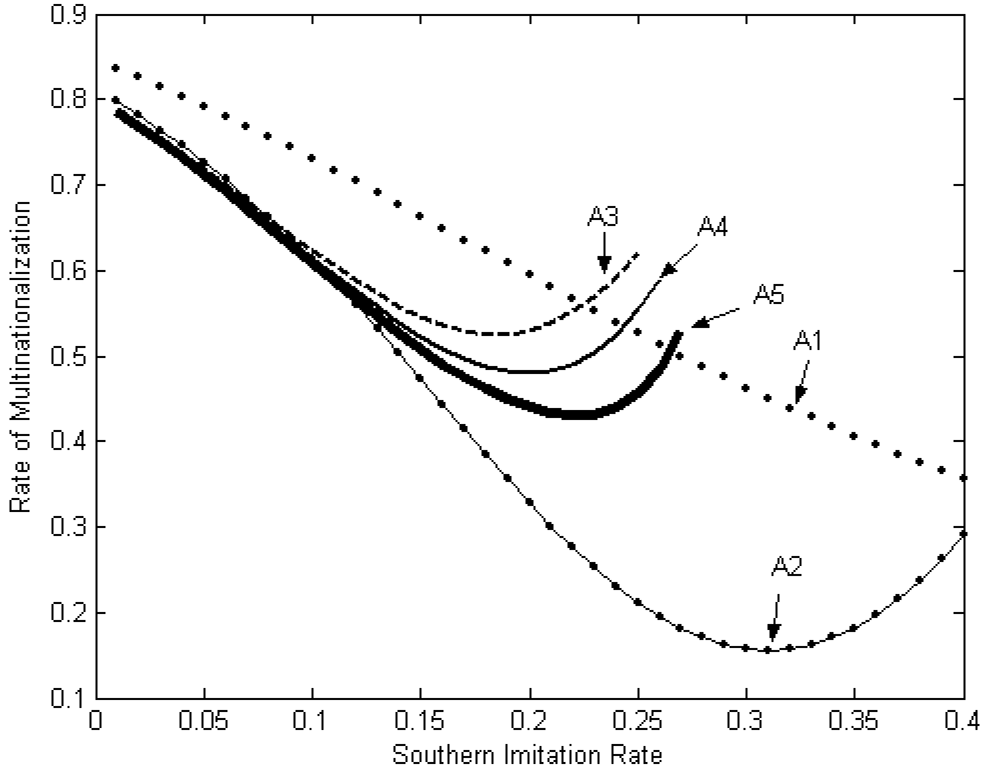


FIGURE 4: SOUTHERN IMITATION AND SOUTHERN R&D INVESTMENT



Note: Dotted line (A1): Benchmark, no export imitation
Dash-dot line (A2): No spillover, no export imitation
Dashed line (A3): High reverse spillover, no export imitation
Light-solid line (A4): High reverse spillover with low export imitation
Dark-solid line (A5): High reverse spillover with medium export imitation

FIGURE 5: MULTINATIONALIZATION RATE WITH EXPORT AND FDI IMITATION