SUSTAINING THE GOOSE THAT LAYS THE GOLDEN EGG: A CONTINUOUS TREATMENT OF TECHNOLOGICAL TRANSFER

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ABSTRACT

This paper proposes a simple model of the trade-offs perceived by innovating firms when investing in countries with limited intellectual property rights (IPR). The model allows for a continuous treatment of technology transfer and production cost gains occurring through FDI. While it does not consider possible changes in rates of innovation caused by changes in IPR in developing countries, it allows one to uncover a potentially non-monotonic relationship between welfare and IPR in the recipient country.

I INTRODUCTION

What is the optimal enforcement of intellectual property rights (IPR) in a small and developing open economy? Is it no enforcement? Is it complete enforcement? Does the optimal level depend on other factors? The answers to these questions are crucially important to the growth and development of less developed economies.

Technology adoption indisputably contributes to output growth. The majority of innovations (as measured by patents) occur in five countries in the world. Without international technological diffusion these would be the few countries to experience positive growth rates. Yet, the majority of countries in the world do experience positive growth rates. This suggests that if technological advance is a primary determinant of growth, international diffusion of technology must be the driving force of growth in the vast majority of countries in the world.[1] Consistent with this conclusion is the evidence that, relative to developed countries (DC), less developed countries (LDC) rely more heavily on technological diffusion from abroad than on domestic innovations to sustain their productivity growth [Connolly (2003) and Lee (1995)].[2]

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[1] Eaton and Kortum (1996) show that even within OECD countries only the US benefits more from domestic than foreign productivity growth.

[2] Connolly (2003) finds that while imports of high technology goods is important to the diffusion of technology in both developed and developing countries, the magnitude of this effect is greater for developing countries. Moreover, the importance of high technology imports in domestic production is greater for LDC than DC, as is the importance of domestic innovation. Both results suggest that LDC rely more heavily than DC on trade and domestic R&D as

While the importance of international diffusion of technology is undisputed, the specific mechanisms that regulate it – and the associated policy implications – are not yet fully understood. With increasingly open markets, in particular, understanding how IPR interact with alternative forms of technological diffusion is very important.

This paper proposes a simple model of the trade-offs perceived by innovating firms when investing in countries with limited IPR. Namely, we develop a model which allows for a continuous treatment of technology transfer and production cost gains occurring through FDI. The model does not consider possible changes in rates of innovation caused by changes in IPR in developing countries. It does, however, allow one to uncover the potentially non-monotonic relationship between welfare and IPR in the recipient country.

II LITERATURE REVIEW

Maskus (2005) provides an exhaustive review of the theoretical and empirical literature on the interaction between IPR and FDI and technology transfer. Here, we focus on the empirical papers that study the link between IPR and levels and types of FDI, technology transfer, and licensing, since these are the mechanisms that we attempt to model.

While some papers such as Ferrantino (1993), Mansfield (1993), Maskus and Eby-Konan (1994) have not been able to find significant effects of domestic IPR on FDI within a country, more recent work [Maskus (1998), Lee and Mansfield (1996), Javorcik (2004)] suggests that there is a positive effect of IPR on FDI. Maskus (1998) considers a panel of 46 destination countries, using annual data from 1989 to 1992. His results suggest that a 1% increase in patent protection would lead to a 0.45% increase in the stock of US investments in that country. Lee and Mansfield (1996) find evidence suggesting that perceptions of US firms of the strength of a given country's IPR positively affect the volume and composition of US FDI in those countries. In particular, Lee and Mansfield find that FDI is more heavily biased towards sales and distribution or rudimentary production and assembly facilities when the recipient country is perceived to have weak IPR. Javorcik (2004) looks at transition economies in the 1990s. She finds that among sectors that traditionally rely heavily on IPR, countries with weak IPR experience reduced FDI. Moreover, across all sectors, she finds that IPR affect the composition of FDI. Specifically, weak IPR deter FDI in high-tech sectors and generally tilt the focus from local production towards distribution of imported goods. Both the Javorcik (2004) and the Lee and Mansfield (1996) studies, therefore, suggest that, ceteris paribus, not only the quantity, but also the quality of foreign investments improve in countries with stronger IPR.

In terms of technology transfers and licensing fees, both Yang and Maskus (2001) and Branstetter et al. (2006) provide evidence of a positive role of IPR in

sources of productivity growth. Lee (1995) finds that the ratio of imported to domestically produced capital goods in investment positively affects growth of income per capita in a cross-section of countries from 1960 to 1985. When considering OECD and non-OECD countries separately, Lee finds that this effect is greater for developing countries.

the determination of technology transfer and licensing. Yang and Maskus (2001) use panel data for 23 countries in 1985, 1990, and 1995. They find that in countries above a certain critical initial threshold of patent protection, further strengthening of patent laws positively affect US receipts of unaffiliated royalties and license fees (in both absolute terms and relative to trade volume). They are unfortunately unable to distinguish between licensing quantities and values. Branstetter *et al*. (2006) look at firm level data for US multinationals in 16 countries from 1982 to 1999. They observe that reforms strengthening IPR led to increased royalty payments for technology transfers, increased affiliate R&D expenditures, and increased foreign patent applications. The increase in royalty payments and R&D expenditures were seen primarily by affiliates of parent companies that before the reforms had used US patents extensively. Royalty payments increased over 30% for this subgroup of affiliates. Similarly to Yang and Maskus (2001) the increase in royalty payments observed by Branstetter *et al*. could be the result of increases either in the value or in the quantity of licenses, or both.

III   THE MODEL

Final producers

The model's relevant action takes place in the South. Accordingly we focus on that country without loss of generality. The South produces a homogeneous final good with the aggregate production function

$$Y = AL^{\alpha} \sum_{k=1}^{K} x_k^{1-\alpha}, \tag{1}$$

where A is a productivity parameter and L is labor (which in equilibrium equals population since we abstract from labor-leisure choice). The market for the Y good is perfectly competitive. We take the price of this good as the numeraire, i.e., $P_Y \equiv 1$.

Technology is embodied in the variety of intermediate goods, K. Output growth in the South then relies on the availability of new intermediate goods. Innovation takes place in the North. From there, intermediate goods can reach the South in different ways: direct exports, foreign direct investment, licensing, imitation. The goal of our model is to investigate which mode prevails in a simple, tractable way.

We begin by observing that given price $P_Y \equiv 1$ for the final good and price P_k for intermediate good k, demand for intermediate good k is

$$x_k = \left[AL^{\alpha}(1-\alpha) \frac{1}{P_k} \right]^{\frac{1}{\alpha}}. \tag{2}$$

The supplier of this good is a (local) monopolist in the South and prices the good at a mark-up over marginal cost. The demand function (2) yields

$$P_k = \frac{1}{1-\alpha} MC_k. \tag{3}$$

The main ingredient of our model is the characterization of the marginal cost MC_k. This depends on how the Northern innovator chooses to serve the Southern market in light of the perceived costs and benefits of direct exporting, local production (FDI), and licensing.

Supply of intermediate goods in the South

The simplest way to capture the costs and benefits of different ways of serving the local Southern market is to posit a linear technology that transforms MC_k units of final output into one unit of intermediate good. Conceptually, that means that the marginal cost depends on which country produces the intermediate good.

To achieve tractability, we model the marginal cost as a continuous function of the level of technology transfer chosen by the Northern innovator. Specifically, the expected profit of a Northern innovator that sells a new intermediate good k to Southern final producers is

$$\pi_{N_k} = \frac{\alpha}{1 - \alpha} MC_k(T)[1 - p_{C_k}(T, \delta, z)]x_k, \tag{4}$$

where $p_C \in [0, 1]$ is the probability of a Southern firm successfully imitating the intermediate good, T is the degree of technological transfer occurring from the North to the South when production of intermediate goods takes place in the South, δ is the degree of IPR enforcement in the South, and z is the imitative effort of Southern firms. Since the functions $MC(T)$ and $p_C(T, \delta, z)$ play crucial roles in our analysis, it is worthwhile to discuss their properties in detail.

The Northern producer decides the optimal amount of technology transfer, T, with $T \in [0, 1]$. $T = 0$ means that the Northern firm chooses to produce the intermediate good in the North, incurring marginal cost MC_N and directly exporting the good.[3] If the Northern firm chooses to produce the intermediate good in the South some technological transfer is necessary, $T > 0$. This foreign direct investment can imply different levels of outsourcing, involving transference of anything from basic blueprints to complete technical specifications, including process technologies. In turn, this can be supported by multiple options concerning the intensity of human capital flows or the delocalization of research departments. The more pervasive this transfer process is, the more the Northern firm may take advantage of lower production costs in the South. At the same time, the transfer process increases the potential for spillovers to occur, thereby enhancing the likelihood of imitation by Southern firms. $T = 1$ implies that the Northern firm has chosen to license production of the good to a Southern firm against payment of a fee. The marginal production cost is then the lowest possible but, all else equal, the risk of imitation is also highest. From the preceding observations, it follows that $MC'(T) < 0$. Assuming decreasing marginal benefits in the transfer process for the Northern firms provides the

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[3] This marginal cost is the product of the number of units of the final goods required times the price of the final good in the North. In our analysis, however, we do not need to separate out the components since we take the price of the final good in the North as given.
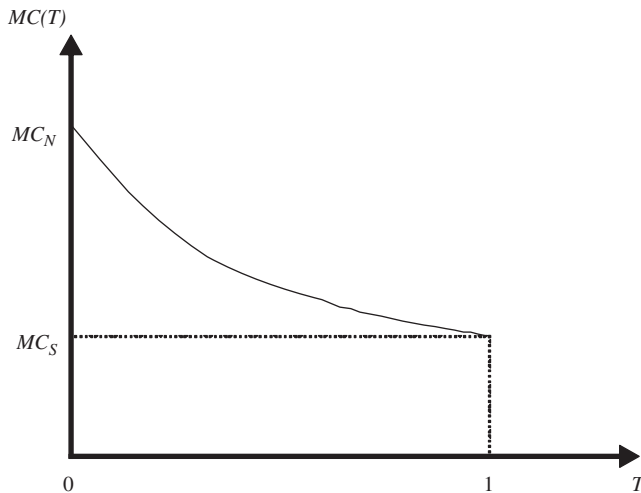
Figure 1. Marginal cost and technological transfer.

restriction $MC''(T) > 0$. This function is represented in Figure 1, where MC_S can be normalized to one for convenience.

The next item to discuss is the probability of imitation $p_{C_k}(T, \delta, z)$. We impose the following restrictions:

$$\frac{dp_C(\cdot)}{dT} > 0, \tag{5}$$

$$\frac{dp_C(\cdot)}{d\delta} < 0, \tag{6}$$

$$\frac{dp_C(\cdot)}{dz} > 0. \tag{7}$$

We think of imitation as a costly activity that allows Southern agents to bypass (legally) the IPR of Northern firms. As δ increases the South moves from no IPR enforcement to full IPR enforcement. Importantly, no IPR enforcement does not mean that imitation necessarily occurs, since that depends on the imitative effort (measured by z) and the availability of information concerning the original intermediate good (measured by T). To achieve tractability, we embed the marginal cost function in the imitation likelihood function through the following monotonic transformation:

$$p_C(T, \delta, z) = \frac{1}{\delta} MC(T)^{-\delta} f(z), \tag{8}$$

where $\delta > 1$. $f(z)$ is a continuous and differentiable function such that $0 < f(z) < 1$, $\forall z$. In addition, $f'(z) > 0$ and $f''(z) < 0$, reflecting decreasing marginal gains from investments in imitation. The underlying assumption is that reductions in marginal production costs (as a result of technological transfer) necessarily entail the

availability of more information, which can in turn leak to potential imitators. This implies a positive relationship between the imitation probability and the amount of technological transfer to Southern firms.[4] IPR decrease the benefit to imitators from technological transfer and thereby the likelihood of imitation.

Substituting the price in equation (3) into the demand in equation (2), and then substituting this into the profit function (4), results in

$$\pi_{N_k} = \theta MC(T)^{\frac{\alpha-1}{\alpha}}[1 - p_{C_k}(T,\delta,z)], \tag{9}$$

where

$$\theta \equiv \frac{\alpha\left[A_S(1-\alpha)^2\right]^{\frac{1}{\alpha}}L_S}{1-\alpha}. \tag{10}$$

The first-order condition with respect to T is

$$MC(T) = \left[\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}f(z)\right]^{\frac{1}{\delta}}. \tag{11}$$

See the Appendix A, for a discussion of the second-order condition. This yields the implicit solution for the optimal level of technological transfer, T, given the imitative effort of Southern firms, z. The intuition here is that the Northern firm internalizes the direct effect of T on the probability of imitation, while taking as given the amount of research carried out by imitators.

If we focus on the interior solution, we can show (see the Appendix A) that higher investment in imitation or weaker IPR lead to lower technological transfer. The probability of infringement behaves differently in each case, however. Substituting the solution defined by equation (11) into (8) yields

$$p_C(\delta) = \frac{1-\alpha}{1-\alpha(1-\delta)}, \tag{12}$$

which does not depend on z because our simplifying assumption (8) basically allows Northern innovators to choose the probability of imitation by choosing the degree of technology transfer, T. Specifically, investment in imitation increases Southern firms' chances to successfully enter the market. However, Northern firms understand this and accordingly reduce their technology transfer to the South. This reduces the spillovers for potential imitators, offsetting any gains afforded by their additional research effort. Conversely, stronger enforcement of IPR has a positive impact on technology transfer because it reduces the likelihood of infringement. This dominates the benefits to imitators from the additional pool of information made available to them so that the equilibrium value of p_C decreases.

Our flexible formulation captures direct exporting and licensing, qualitatively different modes of serving the Southern market, as corner solutions of the optimal technology transfer problem. This is a conceptually interesting point: it

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[4] Without loss of generality, further restrictions could be imposed on the behavior of marginal gains for imitators as they access more information. This could be done by adjusting the primitive marginal cost function and the relationship between its first and second derivatives.

means that we can use a continuous and smooth profit function to capture the distinct microeconomic foundations supporting alternative contractual mechanisms. In other words, we can proxy a qualitatively discrete jump from a foreign direct investment outcome to a licensing outcome with a continuous variable, T, without sacrifice of microeconomic consistency. The following lemmas formalize this property.

Lemma 1. Northern firms license the technology to Southern firms ($T = 1$) when

$$\delta \geq (1 - \alpha)f(z)\{1 - \alpha[1 + f(z)]\}^{-1}.$$

Proof. See Appendix A. ■

Intuitively, stronger IPR (higher δ) raise the likelihood of licensing. Similarly, weaker imitative effort by Southern firms (lower z) increases the likelihood of licensing. When the Northern firm licenses production rights, the expected profit of the local Southern producer is

$$\pi_{S_K} = (P_k - MC_S - \phi)[1 - p_{C_k}(T, \delta, z)]x_k, \tag{13}$$

where ϕ is a per-unit licensing fee. If imitation occurs, the licensee does not produce and the Northern firm does not earn any revenues. Southern firms bid competitively for the right to license a new intermediate good. Accordingly,

$$(P_{x_k} - MC_S - \phi)[1 - p_{C_k}(T, \delta, z)]x_k = 0, \tag{14}$$

and the licensing fee becomes

$$\phi = \frac{\alpha}{1 - \alpha}MC_S. \tag{15}$$

Note that this equilibrium fee allows the Northern firm to extract all possible rents from the local market. In addition, the Northern profit function (4) converges also to the expected value of these rents when maximum technological transfer occurs.

Lemma 2. Northern firms resort to direct exports ($T = 0$) when

$$MC_N \leq \left\{ \left[\delta^{-1} + \alpha(1 - \alpha)^{-1} \right] f(z) \right\}^{\frac{1}{\delta}}.$$

Proof. See Appendix A. ■

This says that Northern firms choose to export whenever the differential between marginal costs in the North and the South, $MC_N - 1$, is sufficiently small. Similarly, a high risk of imitation (both because IPR are not strongly enforced or because investments in imitative research are large) may be enough to discourage FDI and technology transfer.

So far we have taken imitative effort in the South, z, as given. We now turn to the Southern firm's choice of imitative effort.

Imitation

Recall that p_C defines the probability that a Southern firm successfully imitates intermediate good k. The profit for the imitating firm is

$$\pi_{C_k} = (P_k - MC_S)x_k. \tag{16}$$

Substituting equations (2) and (3) for the quantity and price, respectively, yields

$$\pi_{C_k} = \theta MC_S^{\frac{\alpha-1}{\alpha}}, \tag{17}$$

where θ is defined by (10).

Southern firms decide how many resources (z) to devote to imitative research in a given sector. Free entry into imitative research ensures that resources continue to be applied to research until the expected flow of net profits equals zero. These resources are measured in units of the final good. Accordingly, the free entry condition is

$$z_k = \theta p_{C_k}(T, \delta, z) MC_S^{\frac{\alpha-1}{\alpha}}. \tag{18}$$

Using (12) for the probability of imitation, and normalizing $MC_S \equiv 1$, we have

$$z_k = \frac{\theta(1 - \alpha)}{1 - \alpha(1 - \delta)}. \tag{19}$$

Substituting this solution back into the implicit solution for the optimal technological transfer (11) yields the general equilibrium solution for the level of technological transfer

$$MC(T) = \left[\frac{1 - \alpha(1 - \delta)}{(1 - \alpha)\delta} f\left(\frac{\theta(1 - \alpha)}{1 - \alpha(1 - \delta)} \right) \right]^{\frac{1}{\delta}}. \tag{20}$$

This implicit equation implies that IPR enforcement and technology transfer are positively related.

Lemma 3. Stronger enforcement of IPR in the South generates higher technology transfer from Northern firms.

Proof. See Appendix A. ∎

IPR enforcement has a direct negative effect on the likelihood of competition from imitators; see (12). This creates the incentive for Northern innovators to increase technology transfer, since the expected gains associated to lower marginal production costs in the South and higher demand for intermediate goods are reinforced. As the likelihood of effective imitation falls, the incentives for firms to invest in imitative research declines; see (19). This mechanism reinforces the previous effects, encouraging again more technological transfer. Eventually, the marginal benefit attained in terms of production costs decreases and is outweighed by the positive impact of added technological transfer over the probability of imitation. Under appropriate restrictions (see Lemmas 1 and

2) this ensures that the incentives for continuous technological transfer dissipate, enabling a new equilibrium to be reached.

IV WELFARE

The main advantage of out tractable formulation is that we now analyze the effects of IPR enforcement on welfare. We focus on the case of technology transfer, that is, we rule out direct exports of the intermediate good. For simplicity we also assume no trade in final goods.

The Southern aggregate resource constraint reflects the fact that final goods produced by the South (Y_S) can be consumed (C_S), used for research (Z_S), or transformed into intermediate goods (X_S):

$$Y_S = C_S + Z_S + X_S. \tag{21}$$

The level of aggregate output is obtained by substituting into equation (1) the demand for intermediate goods (2) and the price of intermediate goods (3). The latter depends on whether the intermediate good is produced by a Northern firm in the South (with probability $1 - p_C$ and marginal cost subject to the amount of technology transferred) or by a successful Southern imitator (with probability p_C, incurring marginal cost MC_S). Aggregating across intermediate goods yields

$$Y_S = \Lambda \sum_{k=1}^{K} \left\{ MC(T)^{-\frac{1-\alpha}{\alpha}}[1 - p_{C_k}(\cdot)] + MC_S^{-\frac{1-\alpha}{\alpha}} p_{C_k}(\cdot) \right\}, \tag{22}$$

where

$$\Lambda \equiv A_S^{\frac{1}{\alpha}} L_S MC_S^{\frac{1-\alpha}{\alpha}} (1 - \alpha)^{\frac{2(1-\alpha)}{\alpha}}. \tag{23}$$

Using (18), this can be rewritten as

$$Y_S = \Lambda \sum_{k=1}^{K} \left\{ MC(T)^{-\frac{1-\alpha}{\alpha}}[1 - p_{C_k}(\cdot)] + \frac{Z_S}{K\theta} \right\}, \tag{24}$$

where $\frac{Z_S}{K}$ is the average imitative effort in each sector.

Equations (2) and (3) yield

$$X_S = \Lambda (1 - \alpha)^2 MC_S \sum_{k=1}^{K} \left\{ MC(T)^{-\frac{1}{\alpha}}[1 - p_{C_k}(\cdot)] + \frac{Z_S}{MC_S K\theta} \right\}. \tag{25}$$

Assuming symmetry and substituting equations (24) and (25) into the resource constraint (21) yields the flow of consumption in the South,

$$C_S = \Lambda K[1 - p_C(\cdot)]MC(T)^{-\frac{1-\alpha}{\alpha}} \left[1 - (1 - \alpha)^2 \frac{MC_S}{MC(T)} \right]$$
$$+ Z_S \left[\frac{\Lambda \alpha (2 - \alpha)}{\theta} - 1 \right]. \tag{26}$$

Using equation (19) and $MC_S \equiv 1$ this becomes

$$C_S = K\Lambda\left\{ MC(T)^{-\frac{1-\alpha}{\alpha}}[1 - p_C(\cdot)]\left[1 - \frac{(1-\alpha)^2}{MC(T)}\right] + \frac{\alpha(1-\alpha)}{1 - \alpha(1-\delta)}\right\}.$$

(27)

Finally, using the equilibrium probability of imitation in equation (12) we have

$$C_S = K\Lambda\left\{\frac{\alpha\delta}{1 - \alpha(1-\delta)}\left(\Omega + \frac{1-\alpha}{\delta}\right)\right\},$$

(28)

where

$$\Omega \equiv MC(T)^{-\frac{1}{2}}\left[MC(T) - (1-\alpha)^2\right],$$

(29)

and $MC(T)$ is defined by equation (20).

How does the enforcement level of IPR in the South (the policy instrument in this model) affect welfare? The following proposition offers some insight on the answer.

Proposition 1. There is a critical level δ^* of IPR enforcement above which stronger enforcement of IPR raises Southern welfare. Below δ^* the effect of stronger enforcement of IPR on Southern welfare is theoretically ambiguous.

Proof. See Appendix A. ■

This proposition stresses the benefits arising from the enforcement of IPR. Welfare is proxied here by the flow of consumption goods in the Southern economy, as expressed by equation (28). This in turn is subject to the aggregate resource constraint (21). Consumption depends then on available income Y_S, which is determined by the amount of intermediate goods used in production activities. This quantity is constrained by the average price of such inputs. The impact of property rights upon the price of intermediate goods entails two effects. More protection reduces the likelihood of imitation, thus decreasing the share of inputs available at the lowest price. Conversely, higher protection encourages technological transfer, enabling lower marginal production costs (and prices) for an increasing fraction of inputs that are not imitated. Now, as the enforcement of property rights is strengthened, the marginal drop on the probability of imitation becomes smaller. Potential Southern imitators are benefiting from a concurrent gain since more information is transferred from Northern innovators. This lessens the negative effect on imitation and thus on the average price of intermediate goods. On the other hand, when the share of inputs produced by Northern firms (through foreign direct investment) increases, the marginal benefit yielded by lower production costs and prices is reinforced. Finally, the protection of IPR carries one last general equilibrium

effect on welfare. As investments on imitative research are discouraged, more resources are freed up to finance consumption.

The proof of Proposition 1 adds some information to these interactions. When Northern and Southern production costs are very similar, the price disadvantage of non-imitated inputs is smaller. Hence, the expected market share of non-imitated inputs increases, for a given level of IPR enforcement. This market share effect magnifies the marginal benefit generated by changes on marginal production costs, thus making it more likely that enforcement of property rights enhance welfare. From a different perspective, this also means that the potential for a negative effect on welfare requires that the initial share of intermediate goods produced by the North is sufficiently small, because of large cost and price differentials (in addition to high imitation probabilities). This is ignoring the costs of enforcing property rights, which could generate by themselves a new channel through which negative welfare outcomes might arise.

V Conclusion

This paper presents a North–South model of technological transfer. Innovating firms perceive a trade-off when evaluating the risks and benefits of foreign direct investment in countries with limited IPR. As more technology is transferred to the South, larger savings in production costs are obtained. However, since more information is made available in the South, the risk of imitation also increases. From a conceptual standpoint, the model displays one key feature. The transfer of technology is modeled through a continuous variable, capturing within its range direct export, different measures of foreign direct investment, and full licensing. Most importantly, the model is able to incorporate distinct microeconomic foundations for each of these results, while at the same time embedding them in one single and continuous profit function.

This approach can still be refined in future extensions. The Southern economy is studied here under general equilibrium conditions, but the model neglects possible changes in rates of innovation caused by adjustments in IPR in developing countries. Moreover, the particular choice by Northern firms of which activities to delocalize, the interaction of this mix with production costs, and the exact nature of the mechanisms supporting knowledge transfer certainly warrant further analytical exploration.

The main results offered by the model suggest the prevalence of a positive link between enforcement of IPR and welfare, though exceptions might be found when departing from weak protection ranges. Everything else constant, large cost differentials between imitated goods and their original Northern counterparts result in large market shares for imitated inputs. This weakens the impact of technological transfer through FDI, since the resulting change in prices affects only a small portion of the total inputs. This argument may discourage the enforcement of IPR in some developing countries, while missing the more evident benefits that obtain once deeper processes of technological transfer are explored.

<center>APPENDIX A</center>

Second-order condition for T

Using equation (11), the second order condition for this problem is

$$
-\theta\left[\frac{dMC(T)}{dT}\right]^2\left[\frac{\alpha-1}{\alpha^2}MC(T)^{-\left(\frac{1}{\alpha}+1\right)}\right.
$$
$$
-\left(\frac{\alpha-1}{\alpha}-\delta\right)\left(\frac{1}{\alpha}+\delta\right)MC(T)^{-\left(\frac{1}{\alpha}+1+\delta\right)}\frac{f(z)}{\delta}\right]
$$
$$
+\theta\frac{d^2MC(T)}{dT^2}\left[\frac{\alpha-1}{\alpha}MC(T)^{-\frac{1}{\alpha}}-\left(\frac{\alpha-1}{\alpha}-\delta\right)MC(T)^{-\left(\frac{1}{\alpha}+\delta\right)}\frac{f(z)}{\delta}\right]\le 0.
$$
$$
\text{(A1)}
$$

The first-order condition says that the last term is zero. Hence, the expression above reduces to

$$
\frac{\alpha-1}{\alpha^2}MC(T)^{-\left(\frac{1}{\alpha}+1\right)}-\left(\frac{\alpha-1}{\alpha}-\delta\right)\left(\frac{1}{\alpha}+\delta\right)MC(T)^{-\left(\frac{1}{\alpha}+1+\delta\right)}\frac{f(z)}{\delta}\ge 0. \quad \text{(A2)}
$$

Using equation (11) we have

$$
\frac{\alpha-1}{\alpha^2}+\frac{1-\alpha}{\alpha}\left(\frac{1}{\alpha}+\delta\right)\ge 0 \Rightarrow \frac{1-\alpha}{\alpha}\delta\ge 0. \quad\quad\quad\quad \text{(A3)}
$$

This condition always holds since $0<\alpha<1$ and $\delta\ge 1$.

Proof of Lemma 1

A corner solution where $T=1$ occurs when $\left.\frac{\partial\pi_{N_k}}{\partial T}\right|_{T=1}\ge 0$. This condition implies

$$
\frac{\alpha-1}{\alpha}MC(1)^{-\frac{1}{\alpha}}\left.\frac{dMC(T)}{dT}\right|_{T=1}
$$
$$
-\left(\frac{\alpha-1}{\alpha}-\delta\right)MC(1)^{-\left(\frac{1}{\alpha}+\delta\right)}\frac{f(z)}{\delta}\left.\frac{dMC(T)}{dT}\right|_{T=1}\ge 0. \quad \text{(A4)}
$$

Since $MC(1)=MC_S=1$ (by normalization) and $\frac{dMC(T)}{dT}<0, \forall T$, the condition becomes

$$
\delta\ge\frac{(1-\alpha)f(z)}{1-\alpha[1+f(z)]}. \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \text{(A5)}
$$

<div align="right">■</div>

Proof of Lemma 2

A corner solution where $T = 0$ occurs when $\left.\frac{\partial \pi_{N_k}}{\partial T}\right|_{T=0} \le 0$. This condition implies

$$\frac{\alpha - 1}{\alpha} MC\,(N)^{-\frac{1}{\alpha}} \left.\frac{dMC(T)}{dT}\right|_{T=0}$$

$$- \left(\frac{\alpha - 1}{\alpha} - \delta\right) MC\,(N)^{-\left(\frac{1}{\alpha}+\delta\right)} \frac{f(z)}{\delta} \left.\frac{dMC(T)}{dT}\right|_{T=0} \le 0. \tag{A6}$$

Since $\frac{dMC(T)}{dT} < 0, \forall T$, the condition becomes

$$MC(N) \le \left[\left(\frac{1}{\delta} + \frac{\alpha}{1-\alpha}\right) f(z)\right]^{\frac{1}{\delta}}. \tag{A7}$$

∎

Partial equilibrium comparative statics

Using equation (11), the comparative statics with respect to z and δ, evaluated at the equilibrium point, imply

$$\frac{dMC(T)}{dT}\frac{\partial T}{\partial z} = \frac{1}{\delta}\left[\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}f(z)\right]^{\frac{1}{\delta}-1}\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}\frac{df(z)}{dz}, \tag{A8}$$

$$\frac{dMC(T)}{dT}\frac{\partial T}{\partial \delta} = \left\{-\frac{1}{\delta^2}\ln\left[\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}f(z)\right] - \frac{1-\alpha}{\delta^2[1-\alpha(1-\delta)]}\right\}$$

$$\times \left[\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}f(z)\right]^{\frac{1}{\delta}}. \tag{A9}$$

Since $\frac{dMC(T)}{dT} < 0$ and $\frac{\partial f(z)}{\partial z} > 0$, it must be the case that $\frac{\partial T}{\partial z} < 0$. Similarly, since $\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}f(z) > 1$ with an interior solution, it follows that $\frac{\partial T}{\partial \delta} > 0$.

Proof of Lemma 3

Differentiating equation (20) with respect to δ yields

$$\frac{dMC(T)}{dT}\frac{\partial T}{\partial \delta} = \left\{-\frac{\ln\left[\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}f\left(\frac{\theta(1-\alpha)}{1-\alpha(1-\delta)}\right)\right]}{\delta^2} + \Psi\right\}\Phi, \tag{A10}$$

where

$$\Psi = -\frac{1-\alpha}{\delta[1-\alpha(1-\delta)]}\left[\frac{1}{\delta} + \frac{\alpha\theta(1-\alpha)}{1-\alpha(1-\delta)}\frac{f'(\cdot)}{f(\cdot)}\right], \tag{A11}$$

and

$$\Phi = \left[\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}f\left(\frac{\theta(1-\alpha)}{1-\alpha(1-\delta)}\right)\right]^{\frac{1}{\delta}}. \tag{A12}$$

Since $f(\cdot)$ and $f'(\cdot)$ are positive, $\Psi < 0$. Φ corresponds to the equilibrium marginal cost value, which is positive. Since $MC(T) \geq 1$, the log argument in equation (A10) must not be <1. The right-hand side of this equation is then negative. Finally, $\frac{dMC(T)}{dT} < 0$ implies that $\frac{\partial T}{\partial \delta} > 0$. ∎

Proof of Proposition 1

This proof proceeds in several steps. From equation (28) it may be noted that

$$\frac{d\left[\dfrac{\alpha\delta}{1 - \alpha(1 - \delta)}\right]}{d\delta} = \frac{\alpha(1 - \alpha)}{[1 - \alpha(1 - \delta)]^2}. \tag{A13}$$

This derivative is always positive.

Next, consider the marginal effect on Ω, given by

$$\frac{\partial \Omega}{\partial \delta} = \frac{dMC(T)}{dT}\frac{\partial T}{\partial \delta} MC(T)^{-\frac{1}{\alpha}}\left\{\frac{(1 - \alpha)[1 - \alpha - MC(T)]}{\alpha MC(T)}\right\}. \tag{A14}$$

Since $\frac{dMC(T)}{dT} < 0$, $\frac{\partial T}{\partial \delta} > 0$, and $MC(T) \geq 1$, it follows that $\frac{\partial \Omega}{\partial \delta} > 0$.

Using equation (A14), we also have

$$\frac{\partial \left(\Omega + \frac{1-\alpha}{\delta}\right)}{\partial \delta} = \frac{dMC(T)}{dT}\frac{\partial T}{\partial \delta} MC(T)^{-\frac{1}{\alpha}}\left\{\frac{(1 - \alpha)[1 - \alpha - MC(T)]}{\alpha MC(T)}\right\} - \frac{1 - \alpha}{\delta^2}. \tag{A15}$$

The sign for this derivative is uncertain.

Substituting equation (A10) into equation (A15) yields

$$\frac{\partial \left(\Omega + \frac{1-\alpha}{\delta}\right)}{\partial \delta} = -\frac{1 - \alpha}{\delta^2}\left[\begin{array}{c}\left\{\dfrac{\ln\left[\dfrac{1 - \alpha(1 - \delta)}{(1 - \alpha)\delta}f\left(\dfrac{\theta(1 - \alpha)}{1 - \alpha(1 - \delta)}\right)\right]}{1 - \alpha} + \dfrac{\delta^2\Psi}{1 - \alpha}\right\} \\ \times \dfrac{MC(T)^{-\frac{1}{\alpha}}(1 - \alpha)[1 - \alpha - MC(T)]}{\alpha} + 1\end{array}\right]. \tag{A16}$$

The sign for this derivative is uncertain, as well.

Finally, using equations (28), (A13) and (A16),

$$\frac{\partial C_S}{\partial \delta} = K\Lambda\frac{\alpha(1 - \alpha)}{1 - \alpha(1 - \delta)}\left\{\Upsilon + \frac{\delta\Omega + 1 - \alpha}{\delta[1 - \alpha(1 - \delta)]}\right\}, \tag{A17}$$

where

$$\Upsilon = \left\{ \frac{\ln\left[\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}f\left(\frac{\theta(1-\alpha)}{1-\alpha(1-\delta)}\right)\right]}{1-\alpha} + \frac{\delta^2\Psi}{1-\alpha} \right\}$$

$$\times \frac{MC\,(T)^{-\frac{1}{\alpha}}(1-\alpha)[MC(T)-(1-\alpha)]}{\delta\alpha} - \frac{1}{\delta}. \tag{A18}$$

The sign of $\frac{\partial C_S}{\partial\delta}$ will then depend on the sign of

$$\Upsilon + \frac{\delta\Omega+1-\alpha}{\delta[1-\alpha(1-\delta)]} = \left\{ \frac{\ln\left[\frac{1-\alpha(1-\delta)}{(1-\alpha)\delta}f\left(\frac{\theta(1-\alpha)}{1-\alpha(1-\delta)}\right)\right]}{1-\alpha} + \frac{\delta^2\Psi}{1-\alpha} \right\}$$

$$\times \frac{MC\,(T)^{-\frac{1}{\alpha}}(1-\alpha)[MC(T)-(1-\alpha)]}{\delta\alpha}$$

$$+ \frac{\Omega-\alpha}{1-\alpha(1-\delta)}. \tag{A19}$$

Expression (A19) is positive as long as $\Omega \geq \alpha$. Since $\frac{\partial\Omega}{\partial\delta}>0$ [see equation (A14)] and $\max\Omega = \Omega|_{T=1} = \alpha(2-\alpha) > \alpha$, it follows that there is a δ^* such that $\frac{\partial C_S}{\partial\delta}>0, \forall\delta\geq\delta^*$.

It may not be guaranteed that $\min\Omega = \Omega|_{T=0} < \alpha$. However, since Ω is a decreasing function of $MC(T)$, a large enough value of MC_N may be sufficient to induce $\Omega<\alpha$. Such value exists, as it can be illustrated with the limit case where $\Omega|_{MC_N\to\infty} \to 0$. Conversely, for a sufficiently low value of MC_N, $\frac{\partial C_S}{\partial\delta}>0, \forall\delta$. ∎

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