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Intellectual Property Rights and Technological Openness*

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Abstract

This paper examines the effects of intellectual property rights (IPR) protection on technological openness and innovation in a North–South product-cycle model. In this model, firms choose between a defensive technology and an open technology. In contrast to the monotonic relationships described by earlier models, the analysis shows that there is an inverted U-shaped relationship between IPR protection in developing countries and the rate of global innovation. As this suggests that very strong and very weak IPR policies decrease innovation, a more balanced approach to IPR protection is called for.

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1 Introduction

Intellectual property rights (IPR) protection is a critical issue in international relations between developed and developing countries, as reflected in the Trade-Related Aspects of Intellectual Property (TRIPs) agreement signed in the Uruguay round. Generally, the enforcement of intellectual property laws is expected to encourage technology transfer and innovation globally. However, this view remains highly controversial in at least some ways. For instance, in the current Doha round developing countries have called for a review of the TRIPs agreement counter to the position typically held by developed countries.[1] The same goes for international economists with the literature displaying two diametrically opposed views on IPR policy. Previous studies have individually identified either the positive or negative influence of IPR protection with a range of important factors (e.g., multinationals, licensing).[2] Nevertheless, the pros and cons of IPR protection in developing countries have never been comprehensively explained by a single factor in a unified setup.

We focus on technological openness as a missing link in explaining the complex relationship between IPR protection and innovation. In an increasingly digitalized economy, firms have more and more incentive to increase the sharing of tacit knowledge and create difficulties in copying[3] to reduce openness and informational spillover to buyers and outside competitors. Such "defensive" innovation has been highlighted in the theory of economic development and is widely debated among firm managers and in the business literature (see Thoenig and Verdier, 2005). In this paper, we allow for the possibility of firms lessening the threat of imitation at the cost of a carefully crafted, and thereby costly, method of production. Until now, IPR policies in developing countries and technological openness have been intensively, though separately, investigated in the literature.

We show that in a North–South setting, the effect of strengthening IPR policies in the developing South on innovation in the developed North differs

[1] See, for example, the "Declaration of the Group of 77 and China on the Fourth WTO Ministerial Conference at Doha, Qatar" issued on October 22, 2001.

[2] See Helpman (1993), Lai (1998), Yang and Maskus (2001), Glass and Saggi (2002), and Glass and Wu (2007).

[3] The obvious examples are DVDs, authorized software, and copy-protected CDs.

for two cases: stronger IPR policies encourage innovation by stimulating technological openness when the technologies are partly opened, whereas the opposite occurs when they are fully opened. These cases are associated with weaker and stronger IPR protection respectively. Consequently, and in contrast to previous findings, the relationship between innovation and the degree of IPR protection in the South is *peaked*; its shape is that of an inverted "U."

2 The Model

This section describes a basic model based on Helpman (1993). Helpman (1993) constructs a continuous-time two-region variety expansion model with exogenous imitation. Our model differs in that we allow for endogenous technological openness.

Two regions exist, the innovative North and the imitative South. There is a continuum of differentiated consumption products, indexed by j. The number of products available is n_t, and these increase over time because of innovations in the North.

The two regions differ in their technological capabilities. While the North endogenously innovates and monopolistically supplies new products, the South imitates Northern products at a rate m and competitively supplies the imitated products. Denote by n^i the number of region-i products, $i = N$, S; $n = n^N + n^S$.

2.1 Technological Openness and Innovation

There is a research sector in the North, where many R&D firms sell their innovations as exclusive licenses to firms in the consumption good sector. Each innovation introduces a production technology for manufacturing a new consumption good; the flow of date-t innovation is $\dot{n}_t$. Innovating a new technology/product requires b/n_t units of labor as inputs, where the knowledge externality is assumed to be the same as in standard endogenous growth models. Each innovator earns a discounted flow of monopoly profits.

Two types of technologies exist, a defensive technology and an open (non-defensive) technology. Innovators consider a trade-off in the technology selection. If an innovator adopts an open technology, he/she faces the threat of imitation from the South, but the production cost is smaller. Producing a unit of product requires $\lambda < 1$ units of labor, whereas the market power held by the innovator disappears at the next time point of the hazard rate, m. Alternatively, if an innovator adopts a crafted, defensive technology, he/she is safe from imitation (market power never disappears), but pays an additional cost for incorporating a copy protection mechanism into each product. Incorporating the copy protection mechanism requires $1 - \lambda$ units of labor per product; the defensive technology converts a unit of labor into a unit of product.

Let us denote by V and $\hat{V}$ the intertemporal values of the defensive and open innovators. From the above discussion, we have the following Bellman equations (see Thoenig and Verdier, 2005):

$$r_t V_t = \pi_t + \dot{V}_t, \qquad r_t \hat{V}_t = \hat{\pi}_t + \dot{\hat{V}}_t - m_t \hat{V}_t, \tag{1}$$

where r_t denotes the interest rate and π_t and $\hat{\pi}_t$ denote the profits from the defensive and open technologies. At any date innovators face the problem of technology selection; $\max\{V_t, \hat{V}_t\}$.

2.2 Imitation

The rate of imitation is composed of two parts: $m = \mu K$, as in Lai (1998). $\mu > 0$ is a policy parameter determined by the Southern government, while K is determined by the technologies. Following the literature,[4] we interpret a strengthening of IPR protection as a decline in μ.

Departing from Lai (1998), we endogenize K by the relative knowledge stock of the South. In a standard manner, the technological levels K^S and K^N are taken to equal n^S and n and then $m = \mu n^S / n$. The evolution of n^S can be written as:

$$\dot{n}^S = m \cdot \alpha n^N = \mu(1 - \hat{n}^N)\alpha n^N, \tag{2}$$

where α is the fraction of products manufactured with the open technology in the North, which we associate with the rate of openness, and $\hat{n}^N = n^N / n$ is the fraction of Northern products.

[4]See Helpman (1993), Lai (1998), and Furukawa (2007), for example.

2.3 Equilibrium

The remainder of the model is identical to Helpman (1993). Identical individuals choose consumption and saving so as to maximize: $U = \int_0^\infty e^{-\rho t} \ln u_t dt$, where ρ denotes the discount rate. The instantaneous utility takes the form of constant elasticity of substitution (CES) with elasticity $\sigma > 1$. Following Helpman (1993), we assume that financial capital does not flow between the two regions.

Because of the CES preferences, and as is well known, open and defensive innovators set monopolistic prices to $\lambda\sigma w^N/(\sigma-1)$ and $\sigma w^N/(\sigma-1)$, where w^i is the wage in region i. Imitated products are competitively priced to λw^S. We can also derive per-variety consumption $x^i(j)$ and profits π and $\hat{\pi}$ (see Akiyama and Furukawa, 2008).

Denote by L^i the labor force of region i. The labor market conditions are:

$$\lambda x^S n^S = L^S \ , \qquad x^N(1-\alpha)n^N + \lambda\hat{x}^N\alpha n^N + bg = L^N, \tag{3}$$

where $g = \dot{n}/n$ is the rate of innovation.

We consider two cases where $\hat{V} = V$ and $\hat{V} > V$.[5] In the former case, *only* some innovators are defensive ($0 < \alpha < 1$), whereas *all* innovators open their technology ($\alpha = 1$) in the case of the latter. We then can express the free-entry condition as:

$$V \leq \hat{V} = bw^N/n. \tag{4}$$

2.4 Balanced Growth Paths

In a balanced growth path (BGP), n, n^i, w^i, and E^i grow at a constant rate. The analysis of a BGP is straightforward: we can prove the following theorem from equations (1)–(4). The proof appears in Akiyama and Furukawa (2008).

Theorem 1 *The BGP is unique, saddle-path stable, and characterized by:*

$$g^* = \frac{\hat{\lambda}\mu L^N/b - \rho(\sigma-1)(\hat{\lambda}\mu-\rho)}{\rho+\sigma(\hat{\lambda}\mu-\rho)}, \ \alpha^* = \frac{g^*(\rho+\sigma(\hat{\lambda}\mu-\rho))/\mu}{-L^N/b+\sigma(\hat{\lambda}\mu-\rho)} < 1, \tag{5}$$

[5] $\hat{V} < V$ is inconsistent with the existence of balanced growth paths, where every innovator is defensive and no imitation can take place ($\dot{n}^S = 0$).

for the partially open case ($\hat{V} = V$) and:

$$g^{**} = \frac{\mu L^N/b}{\sigma\mu + (\sigma - 1)\rho}, \; \alpha^{**} = 1, \tag{6}$$

for the fully open case ($\hat{V} < V$), in which $\hat{\lambda} \equiv (\lambda^{1-\sigma} - 1)^{-1}$.

3 Protection of Intellectual Property Rights

This section examines the effects of a tightening of IPR protection in the developing South (i.e., a reduction in μ) by calculating the result for Theorem 1. Let us first investigate the effect on technological openness. The story is simple; stronger IPR protection makes open innovators safer from imitation, stimulating technological openness ($\partial\alpha^*/\partial\mu < 0$). However, because of the upper bound $\alpha \leq 1$, there is a threshold level of μ, denoted by $\hat{\mu}$,[6] below which all the innovators adopt the open technology (see Figure 1).

We then investigate the effects on the rate of innovation. As shown, a tightening of IPR protection initially increases the rate of technological openness. The enhanced openness saves Northern resources used for copy protection development and increases the average efficiency of Northern manufacturing. This is because adopting the defensive technology requires an additional labor input for incorporating the copy protection mechanism into the product. It thus expands the *pie of resources* available for the North and opens up more resources for innovation. Consequently, the rate of innovation increases with a strengthening of IPR protection in the South ($\partial g^*/\partial\mu < 0$).

However, for much stronger IPR protection, such as $\mu < \hat{\mu}$, the effect differs. As the rate of openness α^{**} is fixed (at unity), there is no longer a technology selection element (open or defensive) for the model. Hence, no mechanism exists where stronger IPR protection enhances openness and relaxes resource scarcity. This results in a situation much closer to Helpman's (1993) economy. Therefore, we can apply Helpman's discussion to this case: that is, tighter IPR protection depresses technology transfer through reduced imitation. Because of this, more production remains in the North and fewer resources are devoted to innovation. Finally, as in Helpman

[6] Akiyama and Furukawa (2008) provide a formal derivation of $\hat{\mu}$.

(1993), the strengthening of IPR protection in the South decreases innovation ($\partial g^{**}/\partial\mu > 0$).

[Insert Figure 1 about here]

As it turns out, stronger IPR protection in the South, by stimulating technological openness, increases innovation when IPR protection is weaker. The opposite occurs when IPR protection is so strong that everyone adopts the open technology. The following proposition summarizes our result:

Proposition 1 *There is an inverted U-shaped relationship between the South's IPR protection and innovation, as shown in Figure 1.*

Proposition 1 can help us understand both the positive and negative aspects of the South's IPR protection in a single setup: the key is endogenous technological openness. In contrast with previous studies, which have typically shown *monotonic* relations, our findings have a unique implication for the policy debate on IPR protection in developing countries. Put simply, very strong and very weak IPR policies in developing countries decrease innovation in developed countries; more moderate IPR policies are required.[7]

[7] See Bessen and Maskin (2008) for a balanced approach to IPR protection using evidence from a natural experiment in the software industry.

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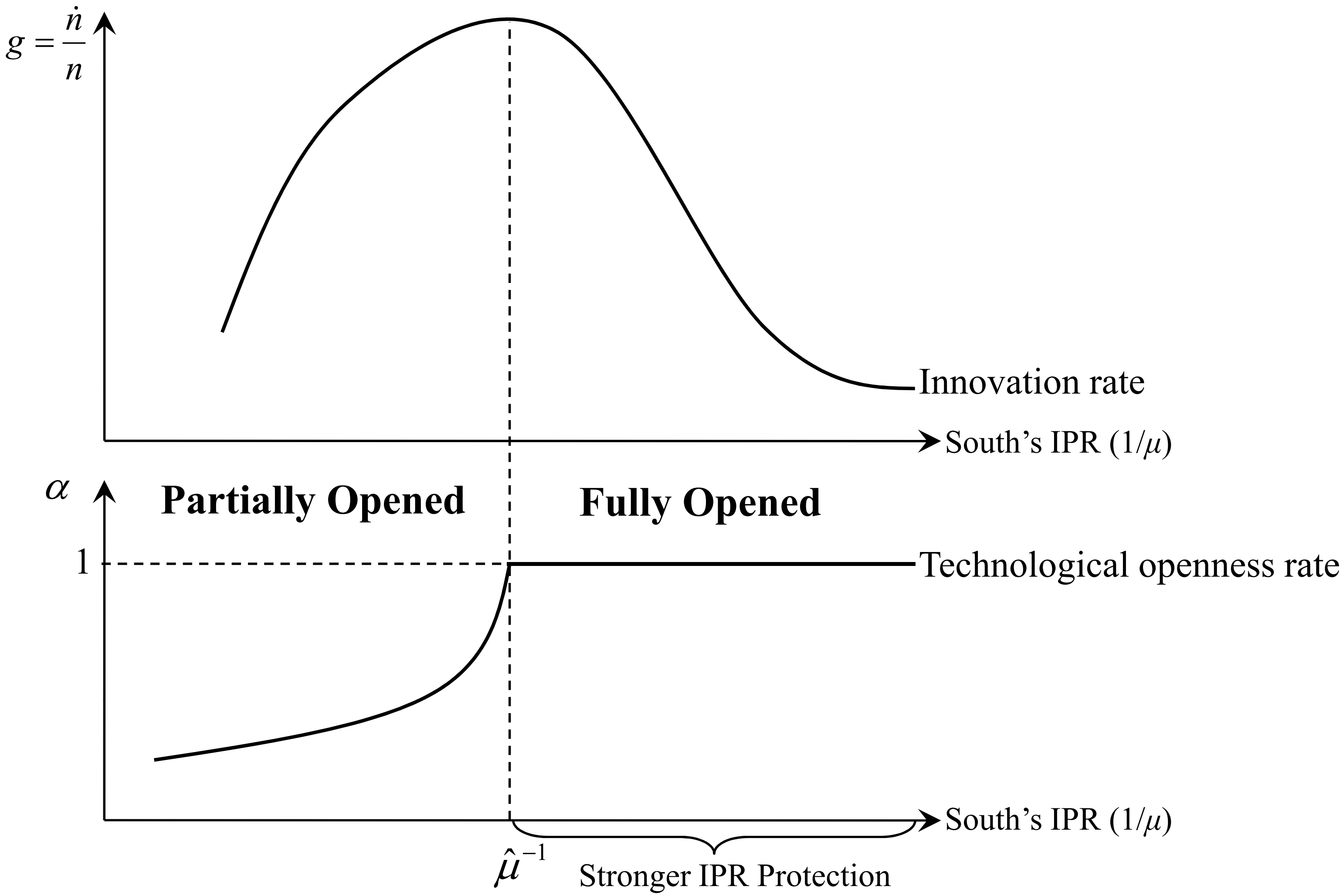

Figure 1. Intellectual Property Rights, Openness, and Innovation

Appendix to Intellectual Property Rights and Technological Openness

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This note shows a proof for Theorem 1 in Akiyama and Furukawa (2008).[1] The plan of the note is the following. Sections 1 and 2 analyze first order conditions of the problems of consumers and firms with equilibrium conditions. Section 3 derives and characterizes dynamic equilibria, in which Theorem 1 and Proposition 1 in Akiyama and Furukawa (2008) are proven. Section 4 presents some applications.

1 The consumers:

Owing to the CES specification of temporary utility, static optimization of the consumers implies that the demand functions exhibit a constant price elasticity, $\sigma > 1$:

$$x(j) = p(j)^{-\sigma} \frac{E}{P^{1-\sigma}} , \qquad P = \left[\int_0^{n_t} p(j)^{1-\sigma} dj \right]^{\frac{1}{1-\sigma}} , \tag{1}$$

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where $p(j)$ denotes the price of product j, $E = \int_0^n p(j)x(j)dj$ denotes aggregate spending on differentiated products, and P is the price index for consumption goods. Using the instantaneous utility and (1), we have: $\ln u = \ln E - \ln P$. This equation implies that the instantaneous utility depends on real spending, E/P. It is well known that the dynamic optimization problem has a solution that yields the equation:

$$\frac{\dot{E}^N}{E^N} = r^N - \rho \ , \tag{2}$$

where E^N represents consumption spending of Northern consumers and r^N is the nominal rate of interest. The assumpetion of no financial capital movement implies $E^N = \int_{n^S}^n p(j)x(j)dj$. The South spends all of its income on consumption goods because there are no international capital flows and thus no investment takes place in the South: per capita expenditure on consumption in the South is equal to the Southern wage rate.

2 The producers:

Next, owing to the constant price elasticity $\sigma > 1$, a Northern innovator charges monopoly prices for the open technology (as long as the product has not been imitated) and for the defensive technology:

$$\hat{p}^N = \frac{\sigma\lambda}{\sigma - 1} w^N \ , \qquad\qquad p^N = \frac{\sigma}{\sigma - 1} w^N \ , \tag{3}$$

respectively. w^N represents the wage rate in the North, then the marginal cost for opened innovators is λw^N, and the marginal cost for defensive innovators is $w^N > \lambda w^N$. Clearly, $p^N = \hat{p}^N/\lambda > \hat{p}^N$ holds.

Assuming that imitated products are available to all Southern producers, imitated products are competitively produced in the South. In this event, the price of the remaining n^S products is equal to the marginal cost in the South:

$$p^S = \lambda w^S \ , \tag{4}$$

where w^S is the wage rate in the South. We assume that the wage rate is higher in the North.[2]

[2] This assumption ensures that imitated products are manufactured in the South.

From the demand functions, (1), and the prices in the North, (3), we have $\hat{x}^N = \lambda^{-\sigma} x^N$. Let $\hat{x}^N$ and x^N denote the per product consumption of a non-defensive, open product and of a defensive product. Using this relationship, we can express the temporary profits for both open and defensive products as: $\hat{\pi} = \lambda^{1-\sigma} p^N x^N / \sigma$ and $\pi = p^N x^N / \sigma$, respectively. Since $\lambda^{1-\sigma} > 1$, the profit for open products is higher than for defensive products: $\hat{\pi} > \pi$.

Note again that $\alpha_t \in [0, 1]$ denotes the proportion of products manufactured with the opened technology. It follows that $(1 - \alpha_t) n_t^N$ products are defensive (highly priced at p_t^N), and $\alpha_t n^N$ products are manufactured with the opened technology (lowly priced at $\hat{p}_t^N$). Using the above prices of products, we rewrite the condition for the lack of international capital mobility, $E^N = \int_{n^S}^{n} p(j) x(j) dj$, as:

$$E^N = (1 - \alpha) n^N p^N x^N + \alpha n^N \hat{p}^N \hat{x}^N = n^N p^N x^N \left[1 - \alpha + \lambda^{1-\sigma} \alpha \right] , \tag{5}$$

noting $\hat{x}^N = \lambda^{-\sigma} x^N$. From this equation, combined with the above profit functions, we can express the temporary profits in the North as follows:

$$\pi = \lambda^{\sigma-1} \hat{\pi} = \frac{E^N}{\sigma n^N \left[1 - \alpha + \lambda^{1-\sigma} \alpha \right]} . \tag{6}$$

Using (3), (5) and the free entry condition $(\max[V, \hat{V}] = b w^N / n)$, we can rewrite this labor market condition for the North in Eq. (3) in that paper as:

$$\frac{\sigma - 1}{\sigma} \frac{E^N}{nV} + g = \frac{L^N}{b} . \tag{7}$$

3 Market equilibrium:

In what follows, we show that there are two cases depending on the level of IPR protection. The BGP rate of technological openness is less than unity (partially opened, $\hat{V} = V$) when IPR protection is initially weak, whereas it is constant at unity when initially strong (fully opened, $\hat{V} > V$). We then determine the BGP values in both cases.

3.1 Partial Technological Openness with Weaker IPR Protection

3.1.1 Dynamic Equilibrium

We first focus on a situation whereby n^N Northern products are manufactured with both open and defensive techniques in the BGP: Northern innovators are indifferent on whether to open their technology or not ($\hat{V} = V$).

To analyze the dynamic equilibrium, it is useful to define a new variable, $v = E^N/(\sigma n V)$. From (6) and $\hat{V} = V$, the two Bellman equations in the paper can be reduced to a single expression:

$$1 - \alpha = \frac{1}{1 - \lambda^{\sigma-1}} - \frac{v}{\mu \hat{n}^N (1 - \hat{n}^N)} \ , \tag{8}$$

from which we have the dynamics of V and $\hat{n}^N$ as follows. Noting (6), $r^N - \dot{V}/V = \hat{\lambda}\mu(1 - \hat{n}^N)$, where we define $\hat{\lambda} = \lambda^{\sigma-1}/(1 - \lambda^{\sigma-1})$. Combined with (2) and (8), with Eq. (2) in the paper, we can derive from this equation the following law of motion for v and $\hat{n}^N$:

$$\frac{\dot{v}}{v} = \hat{\lambda}\mu(1 - \hat{n}^N) - (\rho + g), \qquad \frac{\dot{\hat{n}}^N}{\hat{n}^N} = \frac{g(1 - \hat{n}^N)}{\hat{n}^N} + \hat{\lambda}\mu(1 - \hat{n}^N) - \frac{v}{\hat{n}^N}, \tag{9}$$

where use has been made of $\dot{n}^N = \dot{n} - \dot{n}^S$. Finally, together with $v = E^N/(\sigma n V)$, the labor market condition for the North implies:

$$g = \frac{L^N}{b} - (\sigma - 1)v \ . \tag{10}$$

It follows that Eqs. (9) and (10) form an autonomous system of two differential equations in $(v, \hat{n}^N)$. In this system, $\hat{n}^N$ is a state variable, while v is a jumpable variable.[3]

[3] For simplicity, we assume that $L^S > b\sigma^\sigma \mu/[(1 - \lambda^{\sigma-1})(\sigma - 1)^{\sigma-1}]$ holds. This ensures that, for any point $(\hat{n}^N, v)$, the wage rate in the North is higher than in the South. The labor market condition for the North can derive the following expression: $x^N = (L^N - bg)/n^N[1 - \alpha + \lambda^{1-\sigma}\alpha]$. Together with $x^S = L^S/(\lambda n^S)$, (3), (4), (7), and (8), this equation implies:

$$\frac{w^N}{w^S} = \left[\frac{(\sigma - 1)^{\sigma-1}(1 - \lambda^{\sigma-1})L^S}{b\mu\sigma^\sigma(1 - \hat{n}^N)^2}\right]^{\frac{1}{\sigma}} \ .$$

This equation, together with the prices (3) and (4), implies that $w^N > w^S$ holds if and only if $L^S > b\sigma^\sigma\mu/[(1 - \lambda^{\sigma-1})(\sigma - 1)^{\sigma-1}]$ holds. While we can loosen this condition, we impose it for the sake of simplicity.

3.1.2 Balanced Growth Paths

Define BGP values of v and $\hat{n}^N$ as v^* and n^*, satisfying $\dot{v} = \dot{\hat{n}}^N = 0$. From (9)–(10), we can determine the BGP, (v^*, n^*), uniquely:

$$v^* = \frac{(L^N/b+\rho)(\hat{\lambda}\mu-\rho)}{\rho+\sigma(\hat{\lambda}\mu-\rho)}, \qquad n^* = \frac{-L^N/b+\sigma(\hat{\lambda}\mu-\rho)}{\rho+\sigma(\hat{\lambda}\mu-\rho)}. \tag{11}$$

Together with (10), this equation derives the BGP rate of innovation as:

$$g^* = \frac{\hat{\lambda}\mu L^N/b - \rho(\sigma-1)(\hat{\lambda}\mu-\rho)}{\rho+\sigma(\hat{\lambda}\mu-\rho)} \ . \tag{12}$$

This unique BGP, (v^*, n^*), is a saddle point. Its proof is as follows. We log-linearize the system of (9)–(10) around the BGP, (v^*, b^*), represented by (11):

$$\text{(S)} \qquad \begin{pmatrix} \dot{\zeta} \\ \dot{\eta} \end{pmatrix} = \begin{pmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{pmatrix} \begin{pmatrix} \zeta \\ \eta \end{pmatrix} \ ,$$

where $\zeta = \ln v - \ln v^*$, $\eta = \ln \hat{n}^N - \ln n^*$, $z_{11} = (\sigma-1)v^* > 0$, $z_{12} = -\hat{\lambda}\mu n^* < 0$, $z_{21} = (\sigma-1)v^* - (\sigma v^*)/n^* < 0$, and $z_{22} = -\hat{\lambda}\mu n^* + (\sigma v^*)/n^* - L^N/bn^*$. Using (15), the determinant of the coefficient matrix $Z = (z_{ij})$ can be represented by: $|Z| = L^N/b - \sigma(\hat{\lambda}\mu - \rho)$. The condition $\mu > \hat{\mu}$ implies that this determinant is negative: $|Z| < 0$. We can therefore conclude that it has one positive and one negative eigenvalue. This means that the dynamic system is saddle-path-stable. ‖

Finally, from (8) and (11), we determine the equilibrium rate of technological openness endogenously;

$$\alpha^* = \frac{\hat{\lambda}\mu-\rho}{\mu}\frac{\rho+\sigma(\hat{\lambda}\mu-\rho)}{-L^N/b+\sigma(\hat{\lambda}\mu-\rho)} - \frac{\lambda^{\sigma-1}}{1-\lambda^{\sigma-1}} \ . \tag{13}$$

3.1.3 IPR Protection and Pattern of Technological Openness

Before we proceed, we should clearly characterize the partially opened case by the strength of IPR protection. In this case, the rate of technological openness, α, is less than unity in a BGP ($\hat{V} = V$).[4] The parameter values determine whether $\alpha^* < 1$ or $\alpha^* = 1$. From (13), we can easily show that the case of $\alpha^* < 1$ requires that μ is not too small. We define the threshold value of μ as $\hat{\mu}$.[5] The intuition is as follows. Tighter IPR protection reduces the cost of openning a technology by decreasing the threat of imitation. It follows that a reduction in μ stimulates an incentive to open a technology. Then for a sufficiently small μ, innovators will leave the defensive technology in place: there could exist a threshold value of μ below which all innovators choose to open their technologies. We can then associate the partially opened case ($\hat{V} = V$) with weaker IPR protection ($\mu > \hat{\mu}$).

Furthermore, we need two restrictions on the parameters to ensure the existence and feasibility of a non-trivial BGP. First, the following feasibility condition assures that $0 < n^* < 1$: $\mu > [L^N/b + \sigma\rho]/(\hat{\lambda}\sigma)$. If we assume that $\hat{\mu} > [L^N/b + \sigma\rho]/(\hat{\lambda}\sigma)$,[6] two restrictions on μ can be reduced to a single expression, $\mu > \hat{\mu}$. Second, the long-run rate of innovation, $g^* = L^N/b - (\sigma - 1)v^*$, needs to be positive for a non-trivial BGP, (v^*, n^*). Assume that the North innovates at a positive rate for any μ: $L^N/b > \rho(\sigma - 1)$. This restriction implies that the effective labor supply is sufficiently large to ensure

[4] Note that the case of and $V > \hat{V}$ and $\alpha = 0$ is not possible in a BGP. We will demonstrate that, under the assumption of positive growth imposed below ($L^N/b > \rho(\sigma - 1)$), $\alpha^* > 0$ necessarily holds. Using (8) and (11), $\alpha^* > 0$ implies $\rho(\sigma-1)(\hat{\lambda}\mu - \rho)/\hat{\lambda}\mu[\rho + \sigma(\hat{\lambda} - \rho)] < L^N/b[\rho + \sigma(\hat{\lambda} - \rho)]$, which implies $(\hat{\lambda}\mu - \rho)/\hat{\lambda}\mu < L^N/b\rho(\sigma - 1)$. This inequality is always satisfied because the positivity condition ($L^N/b > \rho(\sigma - 1)$) implies that $L^N/b\rho(\sigma - 1) > 1$, and $(\hat{\lambda}\mu - \rho)/\hat{\lambda}\mu < 1$.

[5] We prove here that there exists a threshold value of μ, $\hat{\mu}$, which satisfies $\alpha^* < 1$ for all $\mu > \hat{\mu}$. From (13), $\alpha^* < 1$ can be expressed as a quadratic function of μ:

$$\text{(m)} \qquad f(\mu) = a_1\mu^2 + a_2\mu - a_3 > 0 \ ,$$

where $a_1 = \hat{\lambda}\sigma$, $a_2 = \hat{\lambda}\rho(\sigma - 1) - \rho\sigma - L^N/b[1 - \lambda^{\sigma-1}$, and $a_3 = \rho^2(\sigma - 1)$. It is easy to verify that the function f is a convex function and then $f' = 0$ implies a minimum value of f: $-a_2/(2a_1)$ is a unique minimum point of f, which is assured to be positive by the positive growth condition. In addition, the minimum of f is negative; $f(-a_2/(2a_1)) < 0$, and f is an increasing function for $\mu > -a_2/(2a_1)$. It follows that if we define

$$\hat{\mu} = [-a_2 + (a_2^2 + 4a_1a_3)^{1/2}]/2a_1,$$

then the above inequality (m), or equivalently $\alpha^* < 1$, always holds for all μ that satisfy $\mu > \hat{\mu}$.

[6] While we maintain this assumption for simplicity, the implications of this paper are not altered without this simplification.

$g^* > 0$.[7]

3.2 Full Technological Openness with Strong IPR Protection

3.2.1 Dynamic Equilibrium

In the case of full technological openness ($\hat{V} > V$), the time at which an innovator introduces his/her product into the market is the time at which he/she adopts the non-defensive, opened production technology. All Northern monopolists manufacture their products using the open technology ($\alpha^* = 1$). Taking into account the fact that $\dot{\hat{V}} = \dot{V}$ along the BGP, we can rewrite $\hat{V} > V$ using (6) and (1) in the paper as: $(1 - \lambda^{\sigma-1})v^*/n^* > \mu(1 - n^*)$, in which we redefine v as $v = E^N/\sigma n\hat{V}$. Under the assumption for positive growth, $L^N/b > \rho(\sigma - 1)$, $\hat{V} > V$ holds in a neighborhood of the BGP: all innovators make their technologies opened; $\alpha = 1$.

Two differential equations in the partially opened case in (9) must be changed in the fully opened case as follows. From (2) and (6), with (1) and (2) in the paper, we have:

$$\frac{\dot{v}}{v} = \frac{v}{\hat{n}^N} - [\mu(1 - \hat{n}^N) + \rho + g], \qquad \frac{\dot{\hat{n}}^N}{\hat{n}^N} = \frac{g(1 - \hat{n}^N)}{\hat{n}^N} - \mu(1 - \hat{n}^N),$$

reflecting $\alpha^* = 1$.

3.2.2 Balanced Growth Paths

These equations, together with $\dot{v} = \dot{\hat{n}}^N = 0$, determine BGP levels of g, $\hat{n}^N$, and v:

$$g^* = \mu n^* = \frac{\mu L^N/b}{\sigma\mu + (\sigma - 1)\rho}, \qquad n^* = \frac{L^N/b}{\sigma\mu + (\sigma - 1)\rho}, \qquad v^* = \frac{(\mu + \rho)L^N/b}{\sigma\mu + (\sigma - 1)\rho}. \tag{14}$$

[7] We formally check $n^* < 1$ using (11). Clearly, $n^* < 1$ if and only if $\rho + \sigma(\hat{\lambda}\mu - \rho) > 0$, which can be rewritten as $\mu > \rho(\sigma - 1)/(\hat{\lambda}\sigma)$. Next, we turn to the condition for $n^* > 0$. Taking account of $\mu > \rho(\sigma - 1)/(\hat{\lambda}\sigma)$, $n^* > 0$ implies $\mu > (L^N/b + \rho\sigma)/(\hat{\lambda}\sigma)$. We can reduce these two conditions to a single expression because $\rho(\sigma - 1) < L^N/b + \rho\sigma$. That is, it suffices to impose $\mu > (L^N/b + \rho\sigma)/(\hat{\lambda}\sigma)$ for $n^* \in (0, 1)$.

The condition for positive growth ($g^* > 0$, for any $\boldsymbol{\mu}$) is easy to be derived by using (12) and condition $\mu > \hat{\mu}$.

Clearly, the BGP rate of technological openness is constant at unity in this case; $\alpha^* = 1$. We can easily show that the BGP is also locally saddle-path-stable in the fully opened case with stronger IPR in the South $\mu < \hat{\mu}$.

3.2.3 IPR Protection and Pattern of Technological Openness

We here associate the fully opened case with stronger IPR protection. Using (14), the condition required for the current case ($\hat{V} > V$), shown in Section 3.2.1, can be rewritten by: $\mu < \hat{\mu}$, noting the definition of the threshold level of μ, $\hat{\mu}$. This associates this case with stronger IPR protection. In addition, we need to impose the following condition to ensure $n^* < 1$: $L^N/b < \rho(\sigma - 1) + \mu\sigma$. We assume that the parameters satisfy this condition and the positive growth condition ($L^N/b > \rho(\sigma - 1)$) to focus on both cases of weaker and stronger IPR protection.

3.3 Proof for Theorem 1

As is apparent from the preceding discussions, Eqs. (11), (12), and (14) prove Theorem 1 in the paper.

Theorem 1 *A BGP of the model is unique and a saddle, given by either*

$$g^* = \frac{\hat{\lambda}\mu L^N/b - \rho(\sigma-1)(\hat{\lambda}\mu - \rho)}{\rho + \sigma(\hat{\lambda}\mu - \rho)},\ n^* = \frac{-L^N/b + \sigma(\hat{\lambda}\mu - \rho)}{\rho + \sigma(\hat{\lambda}\mu - \rho)}\ ,$$

for the partially opened case ($\hat{V} = V$), or

$$g^* = \mu n^* = \frac{\mu L^N/b}{\sigma\mu + (\sigma-1)\rho}\ , n^* = \frac{L^N/b}{\sigma\mu + (\sigma-1)\rho}\ ,$$

for the fully opened case ($\hat{V} < V$).

From Theorem 1 (by differentiating g^* with respect to μ), we have established Proposition 1 in the paper.

Proposition 1 *There is an inverted-U relationship between South's IPR protection and innovation as shown in Figure 1.*

4 Some Applications

4.1 The Effect on Wage Inequality

Our remaining interest lies in the effect of IPR protection in the South on the relative wage of the South; w^S/w^N.

The case of weaker IPR protection: The relative wage of the North, w^N/w^S, can be represented as follows (see footnote 3):

$$\frac{w^N}{w^S} = \left[\frac{(\sigma-1)^{\sigma-1}(1-\lambda^{\sigma-1})L^S}{b\mu\sigma^\sigma(1-\hat{n}^N)^2}\right]^{\frac{1}{\sigma}} , \tag{15}$$

which exceeds 1. Eq. (15) implies that the Northern relative wage, w^N/w^S, decreases as $\mu(1-n^*)^2$ increases along the BGP. Then we calculate: $\partial[\mu(1-n^*)^2]\partial\mu < 0$. From this expression, we can verify that the long-run response of w^N/w^S to μ is positive: that is, $\partial(w^N/w^S)/\partial\mu > 0$. It follows that the relative wage of the *South*, w^S/w^N, increases as a result of a tightening of IPR protection (a decrease in μ) in the case of partially opend technology.

The economic intuition behind this result is as follows. As shown in Proposition 1 in the paper, tighter IPR protection stimulates the incentive for Northern innovators to open their technologies, and thus encourages the international transfer of technology from the South to the North. The encouraged technology transfer implies an increase in the demand for labor in the South. As a consequence, the wage, or terms of trade, of the South increases when IPR protection is tightened.

The case of stronger IPR protection: From Eqs. (14) and (15), it is straightforward to determine the response of the relative wage: stronger IPR protection leads to a lower wage in the South relative to the North. Contrary to the case of weaker IPR protection ($\mu > \hat{\mu}$, $\hat{V} = V$), the mechanism of technology selection (either open or defensive) has little effect on economic performance, so that tighter IPR protection directly decreases the international transfer of technology from the South to the North. It follows that a decreased demand for Southern labor leads to a lower wage for the South. Then we can state:

Remark 2 *There is an inverted U-shaped relationship between the South's IPR protection and the relative wage of the South.*

4.2 Comparative statics for the stable saddle path

Solving the characteristic equation $|Z - \epsilon I| = 0$, the two eigenvalues are:

$$\epsilon_1 = \frac{1}{2}[(z_{11} + z_{22}) + B^{1/2}], \qquad \epsilon_2 = \frac{1}{2}[(z_{11} + z_{22}) - B^{1/2}],$$

where $B = (z_{11} + z_{22})^2 - 4|Z| > 0$, noting $|Z| < 0$. Since $|Z| < 0$ implies that the two eigenvalues are of opposite sign, $\epsilon_1 > 0$ and $\epsilon_2 < 0$ hold.

The general solution of the log-linearized system (S) can be represented as: $\zeta(t) = A_1\gamma_{11}e^{\epsilon_1 t} + A_2\gamma_{12}e^{\epsilon_2 t}$ and $\eta(t) = A_1\gamma_{21}e^{\epsilon_1 t} + A_2\gamma_{22}e^{\epsilon_2 t}$, where $\boldsymbol{\gamma}_1 = {}^t(\gamma_{11}, \gamma_{21})$ and $\boldsymbol{\gamma}_2 = {}^t(\gamma_{12}, \gamma_{22})$ are the eigenvectors corresponding to ϵ_1 and ϵ_2, respectively, and A_1 and A_2 are arbitrary constants, which are determined as the solution of the initial value problem. While η is a state variable, $\eta(0) = \eta_0$ is given as an initial condition. In addition, the transversality condition works as a boundary condition: $\eta(+\infty) = 0$ on the stable saddle path, or equivalently, $\hat{n}^N(+\infty) = n^*$.

Using these two conditions, we have the two arbitrary constants $A_1 = 0$, and $A_2 = \eta_0/\gamma_{22}$, reflecting the fact that $\epsilon_1 > 0$ and $\epsilon_2 < 0$ hold. By normalizing the eigenvector as $\gamma_{12} = \gamma$ and $\gamma_{22} = 1$, we can represent the particular solution as: $\zeta(t) = \eta_0\gamma e^{\epsilon_2 t}$ and $\eta(t) = \eta_0 e^{\epsilon_2 t}$.

We now turn to determination of the eigenvector, $(\gamma, 1)$. By definition,

$$\begin{pmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{pmatrix} \begin{pmatrix} \gamma \\ 1 \end{pmatrix} = \epsilon_2 \begin{pmatrix} \gamma \\ 1 \end{pmatrix} .$$

Then we determine γ as $\gamma = z_{12}/(\epsilon_2 - z_{11} = (\epsilon_2 - z_{22})/z_{21} > 0$, reflecting $z_{11} > 0$, $z_{12} < 0$, and $\epsilon_2 < 0$. We combine the particular solutions shown above to obtain the following policy function: $\zeta(\eta) = \gamma\eta$, from which we can easily show that, around the BGP, $\zeta'(\eta) = \gamma > 0$. By definition of ζ and η, we can establish that the stable saddle path is upward sloping; $v'(\hat{n}^N) = \gamma v^*(n^*)^{-\gamma}(\hat{n}^N)^{\gamma-1} > 0$.