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Abstract

This paper examines the long-run effects of intellectual property rights (IPR) protection and industrial policies on innovation and technology transfer using a North–South quality ladder model where licensing is the main mode of technology transfer to developing countries. We show that the governments of developing countries can promote innovation and technology transfer by strengthening IPR protection, which is enforced by restricting the imitation of products. Moreover, the results also imply that subsidies on the cost of license negotiation can promote innovation and technology transfer, whereas subsidies on the cost of R&D have no effect.

Keywords: Licensing; Imitation; Innovation; Intellectual property rights;
JEL classification: F43; O33; O34;

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1 Introduction

For developing countries with only limited knowledge of advanced technology, absorption from abroad is usually essential to promoting economic growth. Historically, for instance, the Japanese economy following World War II was able to experience high economic growth by importing knowledge of advanced technologies from the United States and Western Europe. Today, as technologies are continually improved by research and development efforts, the absorption of advanced knowledge from abroad has become increasingly important for developing countries to catch up with technological progress. For this reason, how developing countries smoothly absorb this knowledge and attain high economic performance has been a major concern in the field of economic growth theory for at least the past two decades.

Generally speaking, advanced knowledge is considered to be transferred from developed countries to developing countries through various channels. For example, importing machines and equipment enables firms in developing countries to access the general knowledge and information embodied in them.[1] On the other hand, multinational firms in developed countries often contribute to the conveyance of knowledge of their refined manufacturing techniques through their subsidiaries and affiliated partners.[2]

Local firms in developing countries also play an important role in diffusing knowledge of advanced technologies in two major ways. First, some local firms aim to make licensing contracts with patent holders to use their ideas and designs legally or to learn know-how.[3] In particular, firms in Japan and Korea made many licensing contracts to help absorb advanced technologies in the national development process after World War II.[4] Second, other

[1] See Coe et al. (1997).

[2] Lai (1998) investigated the long-term effects of intellectual property rights protection in developing countries on the rate of innovation, the rate of international production transfer and world income distribution when multinational firms transferred their technologies through foreign direct investment.

[3] A famous example is the 'pilgrimage to Montecattini' where a number of Japanese firms visited Montecattini in Italy—an Italian company that succeeded in converting propylene into a fiber-forming propylene—in order to obtain a licensing agreement. Other examples of international licensing involving firms of developed and developing countries are given in Park and Lippoldt (2005, Tables 7 and 8).

[4] See Peck (1976), Ozawa (1980), and Enos and Park (1988). One of the reasons why firms in those countries made many licensing contracts is that their governments desired the development of domestic firms

firms often sell products by copying ideas and technologies without the permission of patent holders in developed countries. These imitation activities are widely observed in developing countries owing to the weak protection of intellectual property rights (IPR) and are one of the major ways of disseminating advanced knowledge to developing countries.[5]

However, excessive risks of imitation induced by weak IPR protection are likely to decrease technology transference through other legal channels, because patent holders feel apprehensive about the imitation of their products and ideas. Indeed, some empirical studies demonstrate that the strength of IPR protection in the recipient country is a significant determinant of technology transfer toward that country. For example, Yang and Maskus (2001a) found that U.S. receipts of royalties and license fees from unaffiliated firms positively responded to a strengthening of patent rights protection in the recipient country. Likewise, Smith (2001) simultaneously analyzed the effect of patent rights in foreign countries on U.S. exports, affiliate sales, and licenses. The results indicated that strengthening foreign patent rights increased U.S. affiliate sales and licensing if the recipient country had strong imitative abilities. More recently, using U.S. firm-level data sets, Park and Lippoldt (2005) explored how royalty and licensing fee payments from unaffiliated firms in foreign countries to U.S. firms were influenced by four IPR indexes of the recipient countries: patent rights, copyrights, trademark rights, and enforcement effectiveness. They concluded that IPR strength as a whole has statistically significant positive influences on licensing receipts. The results of these studies imply that stronger IPR protection leading to the restriction of imitation promotes international technology licensing across countries.

This paper provides a theoretical framework to analyze how strengthening IPR protection, implemented by restricting imitation, affects international technology licensing. We

rather than depending on foreign firms. In addition, Japanese government authorities also feared the outflow of rents abroad. In fact, the Japanese government restricted foreign direct investment through a law established in 1950 (the Foreign Capital Law).

[5]Helpman (1993) explored how strengthening IPR in developing countries affected welfare using a dynamic general equilibrium model, such that technological innovation takes place in developed countries while an invented product faces the risk of imitation in developing countries at a constant probability through time.

construct a product-life-cycle general equilibrium model where local firms in developing countries pay efforts to win license contracts under circumstances of prevailing imitation. A key feature of our model is that we explicitly take account of copies of products' ideas, in addition to licensing activities, as a means of technology diffusion in developing countries, and regard the frequency of imitation as a measure of the strength of IPR protection.

By using this model, we investigate the influence of strengthening IPR in developing countries, the influence of the introduction of subsidies on licensing and R&D processes, and the influence of changing the rent distribution between licensors and licensees. As a consequence, we show three main results: (i) strengthening IPR through restricting imitation unambiguously increases technology transfer and innovation—this is consistent with the empirical results presented earlier; (ii) introducing subsidies for licensing activities promotes technology transfer and innovation, while subsidizing R&D activities has no effect; and (iii) an increase in the rate of license fees paid to the licensors is an obstacle, not only to technology transfer, but also to R&D activity.

In spite of the importance of licensing activities in technology transfer, only a few studies have incorporated it into a general equilibrium model. Yang and Maskus (2001b) initially addressed this issue using a 'quality ladder'-type product-cycle model developed by Grossman and Helpman (1991, Ch. 12). They concluded that stronger IPR promotes innovation and technology transfer. They also considered that strengthening IPR protection decreases the cost of licensing (the size effect), and increases the rent distribution of licensor firms that have patents on advanced technologies (the distribution effect), both of which work positively on technology transfer and innovation. However, because they assumed that firms in developed countries use their resources to make licensing contracts, their model does not suit the Japanese and Korean experience well. In addition, the steady state of their model is dynamically unstable, so that the model has a problem when the economy cannot approach the steady state.[6] Tanaka, Iwaisako, and Futagami (2007) later modified this point

[6] A proof is available from the authors on request.

and constructed a technology licensing model. In their model, firms in developing countries are assumed to use their own resources to win licensing contracts. However, they did not examine the effects of IPR protection policies.

Our study extends the models of both Yang and Maskus (2001b) and Tanaka, Iwaisako, and Futagami (2007) by formalizing the possibility that the design of a licensed product is copied by another firm. This extension is meaningful in the following three respects. First, our model better reflects actual observations on technology diffusion than either of the above studies. This is because the imitation of products is fairly prevalent in developing countries, and, as stated previously, is one of the main channels of technology diffusion. Second, our model better describes the trade-off that a patent holder faces by granting a license to an outside firm located in a low-wage country with weak IPR protection: the patented idea or product is exposed to a greater risk of imitation in exchange for the income accruing from license fees.

Third, and most importantly, our setting enables us to obtain richer implications for the policy of IPR protection. Yang and Maskus (2001b), for example, abstracted away the notion of the length and the breadth of patents and the procedures used for enforcement of IPR protection policy with the intention of analytical simplicity. As a result, they did not specify how government authorities control the strength of IPR protection. Instead, they indirectly analyzed the effects of stronger IPR protection by assuming that a fall in licensing costs and an increase in the licensor's share of rents are a consequence of strengthening IPR protection policy. However, it is likely to be difficult to derive the direct implications of such a practical policy as the strict enforcement of IPR protection through the restriction of imitation without some additional settings. This is because the model leaves unformulated the connection between IPR protection policy and both licensing costs and rent shares. In contrast, our model can directly draw conclusions about a restrictive policy on imitation since we explicitly introduce imitation into the model with an index of the degree of IPR protection. Moreover, our results give support to the global tide of intellectual property reform in the direction of strict protection following the World Trade Organization's (WTO) Trade-Related Aspects of Intellectual Property Rights Agreement in terms of promoting innovation and technology transfer.

The remainder of this paper is structured as follows. Section 2 introduces the model where both licensing and imitation coexist. Section 3 shows that a unique steady state exists. Section 4 conducts comparative statics of the steady state. Section 5 provides some concluding remarks.

2 The Model

This paper constructs a quality ladder-type dynamic North–South model in which licensing is the main mode of technology transfer to a developing country in order to examine the effects of governmental policies on innovation and technology transfer. In this model, we consider that imitation of products prevails in the developing country because of incomplete IPR protection. We regard this speed of imitation as an index reflecting the level of IPR protection in the developing country. Our model is mainly based on work by Yang and Maskus (2001b) and Tanaka, Iwaisako, and Futagami (2007).

Consider an economy consisting of two regions, North and South, labeled N and S, respectively. A continuum of goods indexed by $\omega \in [0, 1]$ exists in the economy and goods are produced in either the North or the South. Each product ω is classified by a countable infinite number of qualities $j = 0, 1, \cdots$. The product with one-grade higher quality than the current top-of-the-line quality of the product becomes available if innovation occurs in the industry. Therefore, product ω with quality j can be produced after the jth innovation in the industry ω. We assume that the quality is provided by $q_j(\omega) = \lambda^j$, where the increment of quality, $\lambda > 1$, is identical for all products. As described below, research and development conducted by firms brings this quality improvement. We choose units appropriately so that the quality at time $t = 0$ is equal to unity in all industries.

2.1 Consumer's Optimization

Consumers living in both regions have identical preferences:

$$U = \int_0^\infty e^{-\rho t} \log u(t) dt, \tag{1}$$

where ρ is a common subjective discount rate and $\log u(t)$ represents instantaneous utility at time t. We specify the instantaneous utility function in Cobb-Douglas form as:

$$\log u(t) = \int_0^1 \log \left[\sum_j q_j(\omega) d_{j,t}(\omega) \right] d\omega,$$

where $d_{j,t}(\omega)$ denotes consumption of good ω with quality j at time t. The representative consumer maximizes his or her utility (1) under an intertemporal budget constraint:

$$\int_0^\infty e^{-\int_0^t r(s) ds} E_t dt = A_0,$$

where r_t is the interest rate consumers in both countries face at time t and A_0 is the sum of initial asset holdings and discounted total labor income. The term E_t represents the flow of spending at time t, namely:

$$E_t = \int_0^1 \left[\sum_j p_{j,t}(\omega) d_{j,t}(\omega) \right] d\omega,$$

where $p_{j,t}(\omega)$ is the price of product ω with quality j at time t.

We can solve this representative consumer's problem in two steps. In the first step, we think of the intratemporal maximization problem by computing the allocation of spending E_t to maximize $\log u(t)$ given prices at time t. As a result of the static maximization, the consumer allots identical expenditure shares to all products and chooses a single quality $j = J_t(\omega)$ of each product that carries the lowest quality-adjusted price $p_{j,t}(\omega)/q_{j,t}(\omega)$. This implies the static demand function:

$$d_{j,t}(\omega) = \begin{cases} E_t/p_{j,t}(\omega) & \text{for } j = J_t(\omega), \\ 0 & \text{otherwise.} \end{cases}$$

In the second step, we compute the time pattern of spending to maximize the consumer's utility (1) subject to the dynamic budget constraint. This intertemporal utility maximization requires $\dot{E}_t/E_t = r_t - \rho$. By taking the aggregate spending as the numeraire, we normalize $E_t = 1$ for all t so that the interest rate r_t is always equal to the subjective discount rate ρ.

2.2 Production

We now consider the production side. We assume that each economy has a single primary production factor, labor. The total labor supply is assumed constant and depends on the country. We also assume that one unit of output requires one unit of labor input. In addition, research activities and license negotiations to win a license from a patent holder also require labor inputs, while imitation is assumed to progress exogenously without any labor, described below.

Two types of firm are assumed to exist in the economy, 'leaders' and 'followers'. Leaders are firms that have the ability to produce the current highest quality of each good, while followers are the remaining firms. As a general feature of this kind of model, industrial leaders are assumed not to intend to further research their products until the products are copied. Therefore, the quality gap between leaders and their closest rivals never exceeds one step.

A firm is also distinguished in terms of its location; that is, whether it is in the North or in the South. We assume that only Northern firms have the ability to conduct R&D and bring state-of-the-art products to the market. When succeeding in innovation, a Northern firm can acquire the patent on the design of a product in the North. In addition, the firm can also export the good to the South without any transportation costs or tariffs.

On the other hand, to acquire the exclusive rights to produce and sell a Northern firm's product that has not yet been imitated, a Southern firm must propose a license contract to the Northern patent holder. Granted the license, the Southern firm can receive the blueprint of the product and acquire enough knowledge to manufacture it. Moreover, the firm can legally make a monopoly of the product in the entire world. However, Southern licensees must keep paying a part of the rents from the sale to their licensors as a license fee, until the products are imitated or replaced by the next highest quality product. We assume that Southern licensees pay the exogenously determined share proportion of profits $\delta \in (0, 1)$, which reflects the bargaining power between a licensee and a licensor.[7] All Southern licensees are forbidden by their licensors to copy the blueprint and to break the license contracts so as to avoid paying the license fee.

When a product license is granted to a Southern firm, the design of the product becomes the target of imitation by other Southern firms.[8] For tractability, we assume that imitation occurs exogenously and that every licensee firm operating in the developing country is equally exposed to the threat of imitation.[9] In more detail, we assume that in an infinitesimal time interval dt, imitation occurs randomly in each industry with probability $m\gamma dt$, where m is an exogenous parameter determined by imitation technology or other factors such as cultural climate, while $0 \leq \gamma \leq 1$ is a policy parameter that reflects the degree of IPR protection chosen by the Southern authority. Smaller γ therefore means stronger IPR protection in the South: when γ is equal to zero, patent enforcement in the South is perfect so that no imita-

[7]It may be more natural to consider that the rent sharing between licensors and licensees is determined endogenously according to their bargaining power. We can endogenize rent sharing, if we assume that licensors and licensees decide the rent share δ through Nash bargaining. However, to simplify the analysis, we regard share proportion δ as exogenously given, following Yang and Maskus (2001b) and Tanaka, Iwaisako, and Futagami (2007).

[8]We exclude the possibility that Northern follower firms imitate a patented product by assuming perfect protection of IPR in the North. In equilibrium where the Southern wage rate is lower than the Northern wage rate, even if a Northern follower firm were to copy a licensed product, the Northern firm could not operate because of the limit-pricing strategy of the Southern official licensee. Therefore, in equilibrium, a Northern follower firm would not engage in imitation activities of a licensed product.

[9]The assumption of exogenous imitation following the technology transfer is also found in Lai (1998).

tion occurs; when γ is equal to one, IPR are not protected in the South at all. Throughout this paper, we assume that $m\gamma > \rho/(1-\delta)$ to ensure the local stability of the steady state.

The exogenous imitation rate $m\gamma$ can be also interpreted from another point of view. In the above formulation, the average time up to imitation after licensing in an industry is a random variable that follows the exponential distribution with parameter $m\gamma$, whose expectation is given by the reciprocal of the parameter, $1/(m\gamma)$. Hence, one can regard $1/(m\gamma)$ as the expected patent life in the South. Namely, in this model, the patent of a licensed product 'expires' in the South after a time interval of length $1/(m\gamma)$ on average.[10] According to this interpretation, a smaller γ corresponds to longer patent protection in the recipient country of the technology license.

Once imitation occurs in an industry, perfect competition prevails in the industry and the product is sold at unit cost w^S, where w^S is the wage rate in the South. Therefore, the Southern licensee loses its monopoly rent and its stock becomes of no value in the market. In addition, the Northern licensor can no longer receive the license fee. On the other hand, we posit state-of-the-art products manufactured in the North possess confidentiality, so that for follower firms, they are technologically or economically impractical to copy. Namely, we assume that no imitation occurs in an industry where the Northern leader firm manufactures the product in the North.

To maximize profits, each leader firm whose product has not yet been imitated sets prices at the upper limit to exclude rival firms from the market. Assuming that the patents of all products whose qualities are inferior to each state-of-the-art product are in the public domain, and that the Southern wage rate is less than the Northern wage rate, the strongest rivals of each leader firm whose product has not yet been imitated are always Southern followers who have the ability to produce the second-highest quality of each product. As a leader firm can exclude rival firms by setting the lowest quality-adjusted price on its prod-

[10] A similar interpretation of the expected value of patent protection length in the South is also used in Kwan and Lai (2003) and Grinols and Lin (2006).

uct, the optimal price setting of each Northern producer and each Southern licensee is the marginal cost of the strongest rival firm multiplied by the increment in quality:

$$p = \lambda w^S.$$

The price setting of each leader then yields a demand per product of $1/(\lambda w^S)$. Hence, each Northern patent holder earns a flow of profits:

$$\pi_N = (\lambda w^S - w^N)\frac{1}{\lambda w^S} = 1 - \frac{w^N}{\lambda w^S}, \tag{2}$$

where w^N is the wage rate in the North, which must be restricted below λw^S so that the Northern leaders can earn strictly positive profits. On the other hand, the profits of Southern licensees are:

$$\pi_L = (\lambda w^S - w^S)\frac{1}{\lambda w^S} = 1 - \frac{1}{\lambda}. \tag{3}$$

2.3 Research Activities and License Negotiations

We describe the random success of innovation as a Poisson process. That is, $a_N \tilde{I}_i$ units of labor input into research activities during an infinitesimal time interval dt lead an entrepreneur i to success of innovation with probability $\tilde{I}_i dt$, where a_N is a parameter. We assume the productivity of research a_N is the same in all firms, so that follower firms can compete with the incumbent leaders in regard to research and development of the next-higher-quality product. Let V_N be the market value of a Northern leader, which is the reward for innovation. In any moment, each entrepreneur decides the labor input to maximize his or her instantaneous profit: $(V_N - w^N a_N)\tilde{I}_i$. Hence, the following zero-profit condition in research activities is satisfied:

$$V_{N,t} \leq w_t^N a_N \quad \text{with equality if } \tilde{I}_i > 0. \tag{4}$$

Similarly, we assume that a Southern firm and a Northern patent holder can stochastically reach agreement on a license contract according to the degree of negotiation effort by the Southern firm. We assume that the Southern firm i hoping to reach a licensing agreement with instantaneous probability $\tilde{\iota}_i$ must throw $a_L\tilde{\iota}_i$ units of labor per unit of time into negotiation activities, where a_L is a parameter that satisfies $a_L < a_N$.[11] Let V_L denote the expected present value of profits earned by an incumbent licensee firm. For Southern firms, the expected gain obtained by winning a license is equal to $(1-\delta)V_L$. Therefore, such firms optimally choose the intensity of license negotiation in order to maximize their instantaneous profit $[(1-\delta)V_L - w^S a_L]\tilde{\iota}_i$. In the equilibrium, since the level of license negotiation must be positive but finite, the following zero-profit condition in the license negotiation is satisfied:

$$V_{L,t} \leq w_t^S \frac{a_L}{1-\delta} \quad \text{with equality if } \tilde{\iota}_i > 0. \tag{5}$$

While we posit in the above that patent holders are always willing to comply with the offer of license contracts, we need to consider the possibility that patent holders may refuse these offers. Northern patent holders will allow Southern firms to manufacture their products only when the market value after licensing exceeds the current value, $V_{N,t}$; otherwise they will not admit licensing. Reaching agreement on a license, the Northern patent holder acquires a claim on a fraction of the Southern licensee's profit as the license fee. Since a Northern licensor can receive $100 \times \delta$ percent of the licensee's profit in any moment, the expected value of that claim is expressed as $\delta V_{L,t}$. Assuming that a licensor is obliged to compete with its licensee in a Bertrand fashion if it also produces the product, no licensor has an incentive in equilibrium to continue to sell the product after the license agreement. Therefore, the market value of a licensor firm is also $\delta V_{L,t}$. As a result, the equilibrium with

[11] In our setting, Southern firms only incur license negotiation costs and Northern firms enjoy the benefit of licensing agreements without any effort. Perhaps, it may be more realistic to assume that not only the Southern firms but also the Northern firms incur negotiation costs. However, to make the analysis tractable and more contrastive to existing studies, we assume that only Southern firms throw their resources into license negotiation and bear all of the negotiation cost.

positive licensing requires the condition:

$$\delta V_{L,t} \geq V_{N,t}.$$

2.4 Equilibrium Conditions

In the equilibrium, there exist three possible categories of industry in the market: (i) the Northern patent holder produces the state-of-the-art variety; (ii) the Southern licensee produces the highest-quality product under a license; and (iii) Southern imitators produce the highest-quality product under perfect competition. We represent the measure of industries belonging to each category by $n_{N,t},\ n_{L,t}$, and $n_{M,t}$, respectively. Because the measure of all industries is unity, we have $n_{N,t} + n_{L,t} + n_{M,t} = 1$. In the following part of this paper, we focus only on the symmetric equilibrium such that all industries in the same category are symmetric.

In the symmetric equilibrium, the intensities of innovation and licensing are common to all industries. Let I denote this aggregate innovation intensity in each industry, namely, $I = \sum_i \tilde{I}_i$. Then, investment to innovation targeted at any industries yields the same expected payoff because the patents of a second-highest-quality product are always in the public domain. As a consequence, the research efforts of entrepreneurs range over all ω equally and innovation occurs in every industry with equal probability. Meanwhile, Southern firms negotiate license contracts with Northern state-of-the-art patent holders whose products are neither licensed nor imitated. In the symmetric equilibrium, Southern firms choose equal efforts of negotiation among the industries. As a result, each Northern leader firm whose product is neither licensed nor imitated receives such offers with equal intensity in the equilibrium. Let ι denote the aggregate intensity of license negotiation targeting at each industry, namely, $\iota = \sum_i \tilde{\iota}_i$.

How does the measure of products in each category change over time? In an infinitesimal time interval of length dt, Northern entrepreneurs succeed in upgrading $I_t(n_{L,t} + n_{M,t})dt$

products that Southern licensees or imitators manufacture, whereas $\iota_t n_{N,t} dt$ products are newly licensed and come to be manufactured in the South (see figure 1). Therefore, the measure of products manufactured in the North follows the equation of motion:

$$\dot{n}_{N,t} = I_t(n_{L,t} + n_{M,t}) - \iota_t n_{N,t}. \tag{6}$$

On the other hand, measure $m\gamma n_{L,t} dt$ licensed products are newly copied in the time interval, while $I_t n_{M,t} dt$ imitated products revert to Northern leaders because of success in innovation. Hence, we obtain the following equation of motion for the measure of imitated products:

$$\dot{n}_{M,t} = m\gamma n_{L,t} - I_t n_{M,t}. \tag{7}$$

Because $n_{N,t} + n_{L,t} + n_{M,t} = 1$, the measure of licensed products changes over time according to the following equation:

$$\dot{n}_{L,t} = -\dot{n}_{N,t} - \dot{n}_{M,t}.$$

Now we consider how the market value of each firm varies over time. First, we consider the stock of a Northern patent holder that has not yet achieved a license for its product. During an infinitesimal time interval of length dt, each Northern incumbent leader is exposed to the hazard of replacement by a higher-quality product with probability $I_t dt$. If innovation occurs, the incumbent Northern patent holder suffers capital loss $V_{N,t}$. In the same time interval, the patent holder can reach a license agreement with a Southern firm with probability $\iota_t dt$. The Northern leader then acquires $\delta V_{L,t}$ instead of the current market value $V_{N,t}$. If neither innovation nor licensing occurs in the industry during the time interval, the patent holder can earn the profits $\pi_{N,t} dt$ and capital gain $\dot{V}_{N,t} dt$. The total sum is the expected earnings of the shareholders in a Northern leader firm. Provided that the idiosyncratic risks arising from holding a stock are diversified away by all investors, a stock should yield exactly the same expected rate of return as the risk-free interest rate, r_t. The no-arbitrage condition between the stock and a risk-free asset is then:

$$r_t V_{N,t} = \pi_{N,t} + \dot{V}_{N,t} - I_t V_{N,t} + \iota_t(\delta V_{L,t} - V_{N,t}). \tag{8}$$

In the same manner, we can consider the total market value of a Southern firm operating under license. A Southern licensee suffers a capital loss $V_{L,t}$ if innovation occurs in the industry. In addition, a licensee firm is also faced with the risk of imitation by other Southern firms. Since a product is imitated by follower firms with instantaneous probability $m\gamma$, a Southern licensee loses the monopolistic position with probability $(I_t + m\gamma)dt$ in the infinitesimal time interval of length dt. If neither innovation nor imitation occurs in the industry during the time interval, the licensee firm can earn profits $\pi_{L,t}dt$ and capital gain $\dot{V}_{L,t}dt$. Since the sum of these risky rates of returns must be identical to the risk-free interest rate, we obtain the following no-arbitrage condition:

$$r_t V_{L,t} = \pi_{L,t} + \dot{V}_{L,t} - (I_t + m\gamma)V_{L,t}. \tag{9}$$

We finally consider the labor market equilibrium conditions. Let L^N and L^S denote the fixed labor supply in the North and the South, respectively. For analytical tractability, we assume that L^S is equal to or greater than $(a_L/a_N)L^N$. On the demand side, entrepreneurs who make an effort in R&D and Northern leader firms require labor in the North, while firms under negotiation with a Northern patent holder and Southern manufacturers (licensees and competitive firms) demand labor in the South. Entrepreneurs in the North conduct R&D at the same aggregate intensity I_t over all industries, so they employ $a_N I_t(n_{N,t} + n_{L,t} + n_{M,t})$ units of labor at each moment. In addition, each manufacturing firm in the North sells $1/(\lambda w_t^S)$ units of the product at time t, so that Northern manufactures employ $n_{N,t}/(\lambda w_t^S)$

units of labor at the time. Thus, the labor market-clearing condition in the North is:

$$a_N I_t(n_{N,t} + n_{L,t} + n_{M,t}) + \frac{1}{\lambda w_t^S} n_{N,t} = L^N. \tag{10}$$

In the South, follower firms employ $a_L \iota_t n_{N,t}$ units of labor for license negotiation at time t. Moreover, for production, licensee firms require $n_{L,t}/(\lambda w_t^S)$ units of labor, while competitive firms that manufacture imitated products need $n_{M,t}/w_t^S$ units of labor. In consequence, the labor market-clearing condition in the South is:

$$a_L \iota_t n_{N,t} + \frac{1}{\lambda w_t^S} n_{L,t} + \frac{1}{w_t^S} n_{M,t} = L^S. \tag{11}$$

3 Steady State Equilibrium

In the following part of this paper, we pay attention to only the steady state equilibrium in which innovation and licensing keep taking place at some constant speed over time.[12] In the steady state, the fraction of each type of industry, the market values of firms, and the wage rates of both regions are constant over time. Let variables with upper bar, e.g., $\bar{I}$, denote the steady state values of the corresponding variables.

In the steady state, the market value of a firm is equal to the expected present value of profits. From equations (3) and (9), the value of a licensee firm is given by:

$$\bar{V}_L = \frac{(\lambda - 1)/\lambda}{\bar{I} + m\gamma + \rho}. \tag{12}$$

Moreover, the zero-profit condition in licensing activities (5) implies that:

$$\bar{w}^S = \frac{(1-\delta)\bar{V}_L}{a_L}. \tag{13}$$

[12]We can verify that the equilibrium path converging to the steady state exists and is locally unique if the aggregate innovation intensity in the steady state, $\bar{I}$, satisfies the condition (19) as stated below. The proof is given in the appendix.

Similarly, using the relation that:

$$\bar{w}^N = \frac{\bar{V}_N}{a_N}, \tag{14}$$

which is derived from the zero-profit condition in innovation (4), together with equations (2), (8), and (13), we obtain:

$$\bar{V}_N = \frac{1 + \delta\bar{\iota}\bar{V}_L}{\bar{I} + \bar{\iota} + \rho + \frac{a_L}{a_N(1-\delta)\lambda}\frac{1}{\bar{V}_L}}. \tag{15}$$

For the sake of seeking the steady state values, we first rewrite the condition on the Northern labor market. Combining equations (10), (12), and (13), we can derive pairs of $\bar{I}$ and $\bar{n}_N$ that are consistent with Northern labor market clearing as follows:

$$\bar{n}_N = \frac{(1-\delta)(\lambda-1)}{a_L}\Phi(\bar{I};\gamma), \tag{16}$$

where $\Phi(\bar{I};\gamma) \equiv (L^N - a_N\bar{I})/(\bar{I} + m\gamma + \rho)$. This relationship is drawn as a downward-sloping curve on the $(\bar{I}, \bar{n}_N)$ plane (see figure 2). We name this curve NL. The NL curve means that the ratio of products manufactured in the North to all products must decrease with an increase in $\bar{I}$; otherwise the Northern labor market is never cleared owing to the excess demand for labor by incumbent leaders and firms researching higher-quality products.

To determine $\bar{I}$ and $\bar{n}_N$, we need another equation with respect to these variables. We can derive this relationship from the Southern labor market-clearing condition. First, from equations (6) and (7), the following relations are satisfied in the steady state:

$$\bar{\iota}\bar{n}_N = \bar{I}(1-\bar{n}_N),\ \bar{n}_L = \frac{\bar{I}}{\bar{I}+m\gamma}(1-\bar{n}_N),\ \text{and}\ \bar{n}_M = \frac{m\gamma}{\bar{I}+m\gamma}(1-\bar{n}_N). \tag{17}$$

Substituting (12), (13), and (17) into (11), we have:

$$\bar{n}_N = 1 - \frac{(1-\delta)(\lambda-1)L^S}{a_L}\Psi(\bar{I};\gamma), \tag{18}$$

where $\Psi(\bar{I};\gamma) \equiv (\bar{I}+m\gamma)/[(\bar{I}+m\gamma+\rho)(\bar{I}+m\gamma\lambda)+(1-\delta)(\lambda-1)\bar{I}(\bar{I}+m\gamma)]$. Note that the right-hand side of equation (18) is increasing with $\bar{I}$ under the assumption $m\gamma > \rho/(1-\delta)$. We describe the combinations of $\bar{I}$ and $\bar{n}_N$ that satisfy equation (18) by the SL curve in figure 2. The interpretation of the SL curve is similar to that of the NL curve. Namely, the proportion of products manufactured in the South to all products, $1 - \bar{n}_N$, must fall with a rise of $\bar{I}$, since the additional labor demand of leader firms manufacturing the products and of follower firms engaged in license negotiation prevent the Southern labor market clearing without such a reduction.

Since the SL curve is upward-sloping under the above assumptions, there is at most one crossing point of the two curves in the region where both $\bar{I}$ and $\bar{n}_N$ are positive. To ensure that the unique and attainable steady state and the locally unique equilibrium path converging to this steady state exist, we focus our attention on the case in which $\bar{I}$ satisfies the following inequality:

$$\max\left\{0,\ \lambda\left(\frac{L^S}{a_L} - m\gamma\right)\right\} < \bar{I} < \frac{L^N}{a_N}. \tag{19}$$

If both curves cross once in the first quadrant, $\bar{n}_N$ takes a value that is between zero and one. Then, $\bar{n}_L$, $\bar{n}_M$, and $\bar{\iota}$ are given by equations (17). Furthermore, $\bar{V}_L$, $\bar{V}_N$, $\bar{w}^S$, and $\bar{w}^N$ are determined by equations (12)–(15).

However, we must impose two additional conditions on the parameters to assure the existence of the steady state. The first is a condition about the incentive of patent holders to license. As stated above, a patent holder has no incentive to grant a license of its product if the expected value of the license fee is below the current market value. Therefore, the steady state with strictly positive licensing requires $\delta\bar{V}_L \geq \bar{V}_N$. The second condition is concerned with the wage rates in both regions. Our analysis presumes that the Northern wage rate is higher than the Southern wage rate. Moreover, the Northern wage rate w^N is restricted below λw^S in the equilibrium; otherwise Northern leaders would cease to operate because of negative profits. From equations (13), (14), and (15), we can restate these conditions as:

$$\frac{a_N(1-\delta)}{a_L} < \frac{1+\delta\bar{\iota}\bar{V}_L}{(\bar{I}+\bar{\iota}+\rho)\bar{V}_L+\frac{a_L}{a_N(1-\delta)\lambda}} < \min\left\{\delta,\ \frac{a_N(1-\delta)\lambda}{a_L}\right\}.$$

4 Comparative Statics

In this section, we consider how the intensities of innovation and licensing are affected by the stronger protection of intellectual property rights, subsidy policies for license negotiation and research activities, and changes in the profit division rule.

4.1 Effects of Strengthening IPR Protection

In Section 2, we have assumed the imitation speed is affected by the IPR protection policy of the Southern authorities. That is, we have thought of γ as a policy parameter on IPR protection by the Southern government. Thus, in this subsection, we first conduct comparative statics with respect to γ.

First, totally differentiating equation (16), we obtain:

$$d\bar{n}_N = -\frac{(1-\delta)(\lambda-1)}{a_L(\bar{I}+m\gamma+\rho)^2}\left[(L^N+a_N m\gamma+a_N\rho)d\bar{I}+m(L^N-a_N\bar{I})d\gamma\right]. \tag{20}$$

Because $L^N - a_N\bar{I} > 0$ from equation (10), equation (20) means that $\bar{n}_N$ is required to increase with a fall of γ, if $\bar{I}$ were unchanged, in order to maintain equilibrium in the Northern labor market. In other words, the NL curve in figure 2 rotates clockwise in response to a fall in γ induced by tightening IPR protection. This is because, for any given $\bar{I}$ and $\bar{n}_N$, a lower γ raises the Southern wage rate through an increase in $\bar{V}_L$ (see equations (12) and (13)). The higher Southern wage rate enables each Northern patent holder to set a higher price. This leads to lower product demand, which thereby gives a lower each incumbent Northern leader's demand for Northern labor. Therefore, the Northern labor supply can afford to retain more producers in the North, that is, $\bar{n}_N$ must be higher than before to clear the excess labor supply, if the labor demand of the research sector, $a_N\bar{I}$, is unchanged by the Southern policy change.

Next, the total differential of equation (18) is expressed as follows:

$$d\bar{n}_N = \frac{(1-\delta)(\lambda-1)L^S\left[\Psi(\bar{I};\gamma)\right]^2}{a_L}\left(Ad\bar{I} + Bd\gamma\right), \tag{21}$$

where $A = \delta + \lambda(1-\delta) - \left[m\gamma\rho(\lambda-1)/(\bar{I}+m\gamma)^2\right] > 0$ and $B = m\left\{\lambda + \left[\bar{I}\rho(\lambda-1)/(\bar{I}+m\gamma)^2\right]\right\} > 0$. Equation (21) shows that $\bar{n}_N$ is required to decrease with a fall of γ, if $\bar{I}$ were unchanged, in order to maintain equilibrium in the Southern labor market. Thus, the SL curve in figure 2 moves downward with a decrease in γ.

Intuitively, if both $\bar{I}$ and $\bar{n}^N$ were unchanged, restrictions on imitation by the Southern government would decrease Southern labor engaging in manufacturing for two reasons. First, using the same argument as with Northern labor demand, the increase in the Southern wage rate through an increase in $\bar{V}_L$ due to a reduction in the threat of imitation decreases each incumbent leader's demand for Southern labor with the fall of γ. Second, from equation (17), a reduction of the proportion of imitated industries to licensed industries in the South, $\bar{n}_M/\bar{n}_L$, as induced by the policy modification, has a negative effect on labor demand in the South because licensee firms behaving as monopolists employ less Southern labor than a comparable competitive firm. The redundant labor originating from these two effects must be absorbed by follower firms under license negotiation to restore equilibrium to the Southern labor market. As a consequence, tightening IPR protection leads more Southern follower firms to reach an agreement of a license contract with a patent holder, which is described by an increase in $\bar{\iota}\bar{n}_N$, at each moment. From equation (17), this means that $\bar{n}_N$ must decrease with the strengthening of IPR protection for any given $\bar{I}$ in order for the Southern labor market to clear.

Because tightening IPR protection shifts both the NL and SL curves simultaneously upwards, modification of the IPR protection policy moves the intersection from E to E' in figure 2. Since the new intersection after the policy change is located rightward of the original, we can confirm that tightening IPR protection in the South unambiguously increases $\bar{I}$.

However, the figure provides no information about whether $\bar{n}_N$ increases or not. Therefore, we next compute $\partial\bar{n}_N/\partial\gamma$ to examine its sign. Using equations (20) and (21), we can eliminate the term $d\bar{I}$ and obtain:

$$\left[1+\frac{L^N+a_N m\gamma+a_N\rho}{L^S A(\bar{I}+m\gamma+\rho)^2\left[\Psi(\bar{I};\gamma)\right]^2}\right]d\bar{n}_N$$
$$=\frac{(1-\delta)(\lambda-1)}{Aa_L(\bar{I}+m\gamma+\rho)^2}\left[(L^N+a_N m\gamma+a_N\rho)B-m(L^N-a_N\bar{I})A\right]d\gamma. \qquad (22)$$

Because $(L^N+a_N m\gamma+a_N\rho)B-m(L^N-a_N\bar{I})A$ is positive, we can confirm that $\partial\bar{n}_N/\partial\gamma>0$ from equation (22). This result and equation (17) imply that both $\partial\bar{\iota}/\partial\gamma$ and $\partial(\bar{\iota}\bar{n}_N)/\partial\gamma$ are negative. In other words, license activities are stimulated by a strengthening IPR protection.

Hence, the above analysis is summarized in the next proposition.

Proposition 1 *Strengthening intellectual property rights protection through restrictions on imitation promotes innovation and technology licensing to developing countries.*

This proposition enhances Yang and Maskus' (2001b) result regarding the strengthening of IPR protection. Instead of assuming a policy parameter of the Southern government authorities, Yang and Maskus (2001b) have indirectly regarded both a rise in the probability of success in license negotiations under the same labor inputs (the cost-reducing effect) and a rise in royalty payments to the licensor (the distribution effect) as the effects of strengthening IPR protection. Based on such a formulation, they concluded that stronger IPR protection promotes innovation and licensing through two effects. In contrast, our model explicitly takes into account the possibility of imitation by other firms, and interprets the lower speed of exogenous imitation as the result of stronger IPR protection by the Southern government. As a result, we obtain proposition 1 which implies that the developing country's authority that aims to encourage licensing of state-of-the-art products should regulate copies targeting licensed products.[13]

We can also show that restrictions on imitation raise the Southern wage rate in the steady state. From equation (13), $\partial \bar{w}^S / \partial \gamma$ satisfies the following equation:

$$\frac{\partial \bar{w}^S}{\partial \gamma} = -\frac{(1-\delta)(\lambda - 1)}{a_L \lambda (\bar{I} + m\gamma + \rho)^2} \left(m + \frac{\partial \bar{I}}{\partial \gamma} \right) < 0. \tag{23}$$

To interpret this equation, recall that the Southern wage rate relates closely to profitability in the negotiation activities of the license because of free entry. This equation then shows that a rise of γ causes the Southern wage rate to change through two channels. First, tighter enforcement of IPR protection (a fall in γ) mitigates the threat of imitation by other firms, so that a licensee can enjoy the longer expected duration of the monopoly. This causes the stock value of a licensee firm that has a one-to-one correspondence to the Southern wage rate to increase directly. However, since strengthening IPR protection activates innovation in the North as stated in proposition 1, the higher frequency of innovation shortens the expected duration of the monopoly. In consequence, this second indirect effect induces the Southern wage rate to decrease and depresses the first effect. However, we can verify that the first positive effect dominates the second negative effect under restriction (19). Substituting equation (21) into (22) and rearranging the terms, we have:

$$\frac{\partial \bar{I}}{\partial \gamma} = -m \times \frac{(L^N - a_N \bar{I}) + L^S (B/m)(\bar{I} + m\gamma + \rho)^2 \left[\Psi(\bar{I};\gamma)\right]^2}{(L^N + a_N m\gamma + a_N \rho) + L^S A (\bar{I} + m\gamma + \rho)^2 \left[\Psi(\bar{I};\gamma)\right]^2}.$$

We can show that the numerator of the fraction on the right-hand side is smaller than the

[13]Another feature of our model is to confirm the local stability of the steady state. We prove in the appendix that the steady state of our model has a unique converging path. However, and as mentioned in the Introduction, the steady state in Yang and Maskus (2001b) is totally unstable.

denominator from condition (19), and $\partial \bar{I}/\partial \gamma$ is larger than $-m$. Thus, from equation (23), we can conclude that the Southern wage rate $\bar{w}^S$ is decreasing with γ (that is, increasing with the degree of IPR protection).

4.2 Effects of Subsidy Policies

In this subsection, we explore the effects of industrial policies through subsidies on R&D and technology transfer. In the previous subsection, we confirmed that the Southern government can encourage innovation and technology transfer by restricting imitation activities. In addition, government authorities are probably also concerned with subsidizing license negotiations and R&D for the sake of more directly promoting innovation and technology transfer. Hence, we examine whether or not governments can promote such activities by partly bearing the cost of license negotiations and R&D. Throughout the analysis in this section, the subsidies are assumed to be financed by lump-sum taxes.

4.2.1 Subsidies on license negotiation

We first consider the effects of subsidies on license negotiations by the Southern government. Let $s_L \in [0, 1)$ be the subsidy rate on the cost of license negotiations. The subsidy improves the profitability of Southern follower firms under license negotiation. That is, by engaging in license negotiations, a Southern follower firm i can earn the instantaneous expected profit $[(1-\delta)V_L - (1-s_L)w^S a_L]\tilde{\iota}_i$. Therefore, the introduction of subsidies modifies the zero-profit condition and yields the following relation:

$$\bar{w}^S = \frac{(1-\delta)\bar{V}_L}{(1-s_L)a_L}. \tag{24}$$

If s_L is equal to zero, this equation reduces to equation (13). Moreover, this equation shows that an increase in the rate of subsidy, other things being equal, pushes the Southern wage rate up because Southern follower firms wish to negotiate harder license contracts with the

Northern patent holder owing to a reduction in the cost of negotiation.

To determine a new pair of $\bar{I}$ and $\bar{n}_N$, we compute new NL and SL curves. From equations (10), (12), and (24), we have the following new NL curve:

$$\bar{n}_N = \frac{(1-\delta)(\lambda-1)}{a_L}\hat{\Phi}(\bar{I}; s_L), \tag{25}$$

where $\hat{\Phi}(\bar{I}; s_L) \equiv (L^N - a_N\bar{I})/[(1-s_L)(\bar{I}+m\gamma+\rho)]$. Similarly, substituting (12), (17), and (24) into (11), we obtain the new SL curve as follows:

$$\bar{n}_N = 1 - \frac{(1-\delta)(\lambda-1)L^S}{a_L}\hat{\Psi}(\bar{I}; s_L), \tag{26}$$

where $\hat{\Psi}(\bar{I}; s_L) \equiv (\bar{I}+m\gamma)/[(1-s_L)(\bar{I}+m\gamma+\rho)(\bar{I}+m\gamma\lambda)+(1-\delta)(\lambda-1)\bar{I}(\bar{I}+m\gamma)]$. The labor market clearing of both countries requires $\bar{I}$ and $\bar{n}_N$ to satisfy both equations (25) and (26).

Next, we totally differentiate equations (25) and (26) and examine the effects of the subsidies on license negotiation. Totally differentiating equation (25) implies that:

$$d\bar{n}_N = \frac{(1-\delta)(\lambda-1)}{a_L(1-s_L)}\left[-\frac{L^N + a_N m\gamma + a_N\rho}{(\bar{I}+m\gamma+\rho)^2}d\bar{I} + \hat{\Phi}(\bar{I}; s_L)ds_L\right]. \tag{27}$$

This equation shows that $\bar{n}_N$ must increase with an increase in the subsidy rate s_L for a given $\bar{I}$ to maintain equilibrium in the Northern labor market. Namely, the NL curve rotates clockwise with an increase in the subsidy rate as shown in figure 2. This is because an increase in s_L enables each Northern leader to set higher prices through the increase in the Southern wage rate and leads to lower labor demands by incumbent leaders for any given $\bar{I}$ and $\bar{n}_N$. As a result, $\bar{n}_N$ must be higher than before to clear the Northern labor market, if the labor demand of the R&D sector, $a_N\bar{I}$, is unchanged.

Meanwhile, from equation (26), we have:

$$d\bar{n}_N = \frac{(1-\delta)(\lambda-1)L^S\left[\hat{\Psi}(\bar{I};s_L)\right]^2}{a_L} \times \left\{[(1-s_L)A + s_L(1-\delta)(\lambda-1)]d\bar{I} - \frac{(\bar{I}+m\gamma+\rho)(\bar{I}+m\gamma\lambda)}{\bar{I}+m\gamma}ds_L\right\}. \quad (28)$$

This equation shows that $\bar{n}_N$ must decrease with an increase in the subsidy rate s_L for a given $\bar{I}$ to maintain equilibrium in the Southern labor market. Thus, the SL curve moves downwards as in figure 2. This is due to the same reasoning as shown in the Northern labor market: namely, an increase in s_L decreases the labor demands of incumbent producers through an increase in the Southern wage rate for any given $\bar{I}$ and $\bar{n}_N$, so that $\bar{\iota}\bar{n}_N$, which is equal to $\bar{I}(1-\bar{n}_N)$ from equation (17), must be higher than before. Therefore, $1-\bar{n}_N$ must increase with the increase in the subsidy rate in order to clear the Southern labor market if $\bar{I}$ is unchanged by the policy modification.

An increase in the subsidy rate moves the intersection in figure 2 from E to E'. As a consequence, we can immediately confirm that innovation intensity increases in the new steady state. However, whether $\bar{n}_N$ increases or not is again unclear from the figure, so we next compute $\partial\bar{n}_N/\partial s_L$. For tractability, we suppose that the initial subsidy rate is set equal to zero and examine the effect of a marginal increase in the rate. Substituting equation (28) into (27) and applying $s_L = 0$, we obtain:

$$\left[1 + \frac{L^N + a_N m\gamma + a_N\rho}{AL^S(\bar{I}+m\gamma+\rho)^2\left[\hat{\Psi}(\bar{I};0)\right]^2}\right]d\bar{n}_N = -\frac{(1-\delta)(\lambda-1)}{a_L}\left[\frac{(L^N+a_N m\gamma+a_N\rho)(\bar{I}+m\gamma\lambda)}{A(\bar{I}+m\gamma)(\bar{I}+m\gamma+\rho)} - \hat{\Phi}(\bar{I};0)\right]ds_L.$$

This equation implies that $\partial\bar{n}_N/\partial s_L|_{s_L=0} < 0$ because $(L^N+a_N m\gamma+a_N\rho)(\bar{I}+m\gamma\lambda)/[A(\bar{I}+m\gamma)(\bar{I}+m\gamma+\rho)] > \Phi(\bar{I};\gamma) = \hat{\Phi}(\bar{I};0)$ from condition (19) and from the assumption that $L^S \geq (a_L/a_N)L^N$. Thus, from equation (17), we can conclude that $\partial\bar{\iota}/\partial s_L|_{s_L=0}$ and

$\partial(\overline{\iota n}_N)/\partial s_L|_{s_L=0}$ are positive: that is, a marginal increase in the subsidies on license negotiation from zero can also promote licensing. These results are summarized as follows.

Proposition 2 *Suppose that the initial rate of a subsidy on license negotiation is zero. Then, a marginal subsidy on license negotiation can promote innovation and licensing.*

How does the subsidy on license negotiation affect the Southern wage rate $\bar{w}^S$? The subsidy has an effect on the Southern wage rate $\bar{w}^S$ through two channels:

$$\begin{aligned}\frac{\partial \bar{w}^S}{\partial s_L} &= \frac{1-\delta}{(1-s_L)^2 a_L}\bar{V}_L + \frac{1-\delta}{(1-s_L)a_L}\frac{\partial \bar{V}_L}{\partial s_L} \\ &= \frac{(1-\delta)(\lambda-1)}{(1-s_L)a_L\lambda(\bar{I}+m\gamma+\rho)^2}\left[\frac{\bar{I}+m\gamma+\rho}{1-s_L} - \frac{\partial \bar{I}}{\partial s_L}\right]. \end{aligned} \quad (29)$$

The first term represents a direct effect, whereas the second term is an indirect effect through $\bar{V}_L$. Since an increase in s_L, other things being equal, reduces negotiation costs, the Southern wage rate must be higher than before to attain zero profits in the negotiation activities. On the other hand, the higher s_L also raises innovation intensity $\bar{I}$, so that it lowers the stock value of licensee firms $\bar{V}_L$ through increasing the danger of being replaced by a higher-quality product. This second effect has a negative influence on the Southern wage rate.

Although the two effects have different signs to each other, the direct positive effect always dominates the indirect negative effect if the initial subsidy rate is zero and condition (19) is satisfied. Substituting (27) into (28) and applying $s_L = 0$, we have:

$$\left.\frac{\partial \bar{I}}{\partial s_L}\right|_{s_L=0} = \frac{(\bar{I}+m\gamma+\rho)\left\{(\bar{I}+m\gamma)(L^N - a_N\bar{I}) + L^S(\bar{I}+m\gamma\lambda)(\bar{I}+m\gamma+\rho)^2\left[\hat{\Psi}(\bar{I};0)\right]^2\right\}}{(\bar{I}+m\gamma)(L^N + a_N m\gamma + a_N\rho) + L^S A(\bar{I}+m\gamma)(\bar{I}+m\gamma+\rho)^2\left[\hat{\Psi}(\bar{I};0)\right]^2}.$$

Using this equation and condition (19), we can show that $\partial\bar{I}/\partial s_L|_{s_L=0} < \bar{I}+m\gamma+\rho$. Thus, from equation (29), $\partial\bar{w}^S/\partial s_L|_{s_L=0} > 0$, namely, the marginal rise of the subsidy rate from zero raises the Southern wage rate $\bar{w}^S$.

4.2.2 Subsidies on R&D

We now turn our analysis to the effects of subsidies on R&D by the Northern government. Let $s_R \in [0, 1)$ denote a subsidy rate on R&D chosen by the Northern government. As in the subsidies on license negotiation, subsidies on R&D improve the profitability of Northern firms engaging in R&D. Namely, a Northern follower firm i that undertakes R&D can earn the instantaneous expected profit $[V_N - (1 - s_R)w^N a_N]\tilde{I}_i$. Hence, introduction of subsidies alters the zero-profit condition and replaces equation (14) with the following:

$$\bar{w}^N = \frac{\bar{V}_N}{(1 - s_R)a_N}.$$

However, this modification does not bring any change in both the NL and SL curves because the labor market-clearing conditions in both countries are independent of the Northern wage rate (see equations (10) and (11)). Thus, neither $\bar{I}$ nor $\bar{\iota}$ are influenced at all by subsidies on R&D. We can summarize this result as the following proposition.

Proposition 3 *Subsidies on R&D have no influence on innovation and licensing.*

In addition, because innovation intensity is not influenced by the policy modification, the stock value of Southern licensee firms, $\bar{V}_L$, is also unchanged. As a result, a subsidy on the cost of R&D has no influence on the Southern wage rate. Hence, the subsidy policy on R&D, which is intended for promoting innovation in this model, can only affect the wage gap between the North and the South.

4.3 Effects of a Change in Profit Division

The determination of a profit division rule between a licensor and a licensee has been assumed to be dependent on the bargaining power between the licensor and a licensee. The bargaining power may be affected by a change in the contracting environment, for example, the revision of commercial law and a change in the enforcement of patent law. Hence, in this subsection, we examine how an alteration of the rate of license fee influences innovation and licensing.

Consider that the licensors' share of profit δ increases marginally from the initial value. Because the lower expected return induced by the higher license fee is insufficient to pay the negotiation cost, a higher licensors' share deteriorates the profitability of Southern firms engaging in negotiation. Therefore, to restore zero profits in negotiation activities, the Southern wage rate $\bar{w}^S$ must fall to a new equilibrium if $\bar{I}$ were to be left unchanged. Because of the limit-pricing strategy, the decrease of the Southern wage rate leads to higher labor demand by each incumbent leader. Hence, the improvement of licensors' share of profit makes the fraction of products manufactured in the North, $\bar{n}_N$, impossible to retain at the same level as before for a given $\bar{I}$, so the NL curve is pressured to rotate counterclockwise. In fact, by totally differentiating the NL curve (16), we obtain:

$$d\bar{n}_N = -\frac{\lambda - 1}{a_L}\left[\frac{(1-\delta)(L^N + a_N m\gamma + a_N\rho)}{(\bar{I} + m\gamma + \rho)^2}d\bar{I} + \Phi(\bar{I};\gamma)d\delta\right]. \tag{30}$$

From this relationship, we can confirm that $\bar{n}_N$ must fall with a rise of δ for any given $\bar{I}$ to be consistent with equilibrium in the Northern labor market.

A similar argument to the NL curve is also applied to the SL curve. Totally differentiating the SL curve (18) gives the following relation:

$$d\bar{n}_N = \frac{L^S(\lambda - 1)\left[\Psi(\bar{I};\gamma)\right]^2}{a_L}\left[(1-\delta)Ad\bar{I} + \frac{(\bar{I} + m\gamma + \rho)(\bar{I} + m\gamma\lambda)}{\bar{I} + m\gamma}d\delta\right]. \tag{31}$$

Because of the pricing rule, the fall of the Southern wage rate generates additional labor demand by each Southern firm to manufacture the product. Therefore, the rise of δ makes the fraction of products manufactured in the South, $\bar{n}_L + \bar{n}_M$, inevitably to decrease for a given $\bar{I}$. In consequence, the SL curve is required to shift upwards.

Figure 3 describes how a rise of δ affects the two curves and the intersection. As the figure shows, a rise in the rate of the license fee δ induces the intersection to move leftwards and the innovation intensity $\bar{I}$ to unambiguously decrease. However, figure 3 does not explain whether the change raises $\bar{n}_N$ or not. Therefore, we must compute $\partial \bar{n}_N / \partial \delta$ to determine the signs of $\partial \bar{\iota} / \partial \delta$ and $\partial (\bar{\iota} \bar{n}_N) / \partial \delta$.

Substituting equation (31) into (30) to eliminate the term of $d\bar{I}$, we have:

$$\left[1 + \frac{(L^N + a_N m\gamma + a_N \rho)}{AL^S(\bar{I} + m\gamma + \rho)^2 \left[\Psi(\bar{I}; \gamma) \right]^2} \right] d\bar{n}_N$$
$$= \frac{(\lambda - 1)}{a_L} \left[\frac{(L^N + a_N m\gamma + a_N \rho)(\bar{I} + m\gamma\lambda)}{A(\bar{I} + m\gamma)(\bar{I} + m\gamma + \rho)} - \Phi(\bar{I}; \gamma) \right] d\delta.$$

Recall that $(L^N + a_N m\gamma + a_N \rho)(\bar{I} + m\gamma\lambda)/[A(\bar{I} + m\gamma)(\bar{I} + m\gamma + \rho)] > \Phi(\bar{I}; \gamma)$ from condition (19) and from the assumption that $L^S \geq (a_L/a_N)L^N$. Hence, this equation implies that $\partial \bar{n}_N / \partial \delta > 0$. Moreover, from the result and equation (17), we obtain $\partial \bar{\iota} / \partial \delta < 0$ and $\partial \left(\bar{\iota} \bar{n}_N \right) / \partial \delta < 0$. Namely, a higher license fee rate δ reduces licensing activities.

We can summarize these results into the following proposition.

Proposition 4 *A higher rate of license fee becomes an obstacle to both innovation and the conclusion of license agreements.*

This proposition contains a seemingly counterintuitive assertion: that is, the higher licensor's share of profit deters not only licensing, but also innovation. However, in fact, the result is fairly natural in this model. A higher licensor's share of profit, other things being equal, raises the stock value of a Northern leader owing to an improvement in the expected payoff the leader can obtain by reaching license agreement. This effect on the stock value must be exactly offset by a change of the Northern wage rate since innovators always attain zero profits. However, these changes do not have any influence on the degree of innovation because innovation intensity depends neither on the stock value of a Northern leader nor on the Northern wage rate (see equation (10) and (11)). In addition, more Northern labor is devoted to manufacturing by incumbent leaders than before for two reasons. First, incumbent leaders become less likely to reach license agreement because of a reduction in negotiation efforts by Southern follower firms. In consequence, more leaders operate in the North than before. Second, a rise in δ forces the Southern wage rate down, as later verified. As pointed out earlier, a decrease in the Southern wage rate leads to higher labor demand by each incumbent leader. Thus, less labor can engage in R&D activities than before, and the economy incurs the situation of less innovation, despite the favorable change to the licensors.

We now examine how an increase in the licensor's profit share δ affects the Southern wage rate. As discussed previously, this change lowers the Southern wage rate. We compute the partial derivative of $\bar{w}^S$ with respect to δ to verify it:

$$\frac{\partial \bar{w}^S}{\partial \delta} = -\frac{\bar{V}_L}{a_L} + \frac{1-\delta}{a_L}\frac{\partial \bar{V}_L}{\partial \delta} = -\frac{(1-\delta)(\lambda-1)}{a_L \lambda (\bar{I} + m\gamma + \rho)^2}\left[\frac{\bar{I} + m\gamma + \rho}{1-\delta} + \frac{\partial \bar{I}}{\partial \delta}\right]. \tag{32}$$

This equation shows that an increase in δ brings about two effects on the profitability of license negotiation. First, other things being equal, higher δ directly impinges on licensees' profitability, which is expressed by the first term of equation (32). On the other hand, the indirect effect through the value of a licensee firm improves profitability, as represented by the second term. This is due to an increase in the licensee's stock value induced by the decrease in the risk of replacement by a new invention. As a result, increase in δ causes two conflicting effects. However, by computing $\partial \bar{I}/\partial \delta$, we can confirm that the second positive effect is insufficient to compensate for the first negative effect. Substituting (30) into (31) and eliminating the term $d\bar{n}_N$, we have:

$$\frac{\partial \bar{I}}{\partial \delta} = -\frac{\bar{I} + m\gamma + \rho}{1-\delta}\frac{(\bar{I} + m\gamma)(L^N - a_N \bar{I}) + L^S(\bar{I} + m\gamma\lambda)(\bar{I} + m\gamma + \rho)^2\left[\Psi(\bar{I};\gamma)\right]^2}{(\bar{I} + m\gamma)(L^N + a_N m\gamma + a_N \rho) + L^S A(\bar{I} + m\gamma)(\bar{I} + m\gamma + \rho)^2\left[\Psi(\bar{I};\gamma)\right]^2}.$$

Noting that $\hat{\Psi}(\bar{I};0) = \Psi(\bar{I};\gamma)$, we can show that $\partial \bar{I}/\partial \delta > -(\bar{I} + m\gamma + \rho)/(1-\delta)$ in the same way as the proof of $\partial \bar{I}/\partial s_L|_{s_L=0} < \bar{I} + m\gamma + \rho$. Thus, we can conclude that the Southern wage rate is decreasing with the profit share of licensors from equation (32), that is, $\partial \bar{w}^S/\partial \delta < 0$.

5 Concluding Remarks

Licensing of patents has played an important role in the introduction of high technologies and development processes in Japan and Korea following World War II. In this paper, we constructed a dynamic North–South model to investigate the effects of governments' policies on innovation and technology transfer in an economy where the main channel of transfer is licensing activities. From the comparative statics analysis of the model, we obtained the following three results. First, the Southern government can promote innovation and technology transfer by restricting imitation activities. Second, an increase in subsidies on the cost of license negotiations also promotes innovation and technology transfer, while subsidies on the cost of R&D have no effect. Third, policy changes that induce higher license fee rates reduce innovation and technology transfer.

A key feature of our model is that the production of copies is assumed to prevail in the South because of the imperfect enforcement of IPR protection often observed in actual developing countries. As a result, the model well describes firms in developing countries that make an effort at negotiating licenses with patent holders in developed countries in an environment of imperfect IPR protection. This assumption enables us to draw richer implications concerning IPR protection policy as enforced by restricting imitation activities than existing studies because these simplified the IPR protection policy setting.

However, our model is constructed on the following two assumptions in order to maintain simplicity. First, imitation of products is assumed to be an exogenous process. However, it may be more realistic to consider copying as a profit-maximizing activity of follower firms.[14] Second, no alternative channel of technology transfer save licensing is incorporated in the model. In practice, not only licensing but also FDI is a primary channel of technology transfer to developing countries.[15] Therefore, one direction for future research would be to

[14]Glass and Saggi (2002b) pointed out that strengthening IPR protection in the South decreases FDI flows to the South using a model that endogenizes imitation activities as well as FDI.

[15]For example, Glass and Saggi (2002a) constructed a symmetric two-country model that includes the firm's choice of market mode: either establishing a local subsidiary company or licensing technology to a local firm.

develop a model that takes account of these limitations.

A Appendix: A Proof of Local Stability of the Steady State

In this appendix, we show that the steady state of the economy is a saddle point whose stable manifold is a hyperplane of dimension two. Because our model has two state variables (and two jump variables), it ensures the steady state to be saddle-point stable and the equilibrium path to be (locally) determinate.

To show it, we first derive an autonomous system of differential equations that describes the dynamics of the model. Because the system of this economy is completely described by four variables, $n_{N,t},\ n_{L,t},\ V_{L,t},\ V_{N,t}$, we compute dynamic equations with respect to those variables. Substituting equations (5), (10), and (11) into (6) yields the first differential equation with respect to $n_{N,t}$ as:

$$\dot{n}_{N,t} = -\frac{L^S}{a_L} + \frac{(\lambda-1)n_{M,t}}{(1-\delta)\lambda V_{L,t}} + \left[\frac{L^N}{a_N} + \frac{1}{(1-\delta)\lambda V_{L,t}}\left(1 - \frac{a_L}{a_N}n_{N,t}\right)\right](1-n_{N,t}). \quad (33)$$

Similarly, eliminating $n_{L,t}$ from equation (7) by using the relation $n_{N,t} + n_{L,t} + n_{M,t} = 1$ and substituting (5) and (10) into (7), we have the second differential equation with respect to $n_{M,t}$ as follows:

$$\dot{n}_{M,t} = m\gamma(1-n_{N,t}) - n_{M,t}\left[\frac{L^N}{a_N} - \frac{a_L n_{N,t}}{a_N(1-\delta)\lambda V_{L,t}} + m\gamma\right]. \quad (34)$$

These two variables are state variables since the measure of products belonging to each category, which is determined as a result of past innovation, licensing, and imitation, cannot adjust immediately.

The other two equations are derived from no-arbitrage conditions (8) and (9). From

Antràs (2005) developed a North–South model in which the Northern researcher can choose the mode of production between licensing and multinationalizing.

equations (3), (5), (9), and (10), and $r_t = \rho$, we obtain the third differential equation with respect to $V_{L,t}$:

$$\dot{V}_{L,t} = \left(\rho + m\gamma + \frac{L^N}{a_N}\right) V_{L,t} - \left[\frac{a_L n_{N,t}}{a_N(1-\delta)\lambda} + \left(1 - \frac{1}{\lambda}\right)\right]. \tag{35}$$

Moreover, substituting equations (2), (4), (5), and $r_t = \rho$ into (8), we have the last differential equation with respect to $V_{N,t}$:

$$\dot{V}_{N,t} = \left(\frac{a_L}{a_N(1-\delta)\lambda V_{L,t}} + I_t + \iota_t + \rho\right) V_{N,t} - 1 - \delta\iota_t V_{L,t}, \tag{36}$$

where I_t and ι_t are given by equations (10) and (11) according to the values of $n_{N,t}$, $n_{L,t}$, and $V_{L,t}$. Note that the stock values of firms, $V_{L,t}$ and $V_{N,t}$, are jumpable.

The four equations give an autonomous system of differential equations and completely characterize the dynamics of the model. The values of the other endogenous variables are determined from the four variables.

Next, we derive a characteristic equation associated with a Jacobian matrix of a system of equations linearized around the steady state. From equations (33) – (36), the system of linearized equations is given by:

$$\begin{pmatrix} \dot{n}_{N,t} \\ \dot{n}_{M,t} \\ \dot{V}_{L,t} \\ \dot{V}_{N,t} \end{pmatrix} = \begin{pmatrix} -J_{11} & J_{12} & -J_{13} & 0 \\ J_{21} & -J_{22} & -J_{23} & 0 \\ -J_{31} & 0 & J_{33} & 0 \\ J_{41} & J_{42} & J_{43} & J_{44} \end{pmatrix} \begin{pmatrix} n_{N,t} - \bar{n}_N \\ n_{M,t} - \bar{n}_M \\ V_{L,t} - \bar{V}_L \\ V_{N,t} - \bar{V}_N \end{pmatrix}, \tag{37}$$

where

$$J_{11} = -\frac{\partial \dot{n}_{N,t}}{\partial n_{N,t}} = \bar{I} + \frac{1}{(1-\delta)\lambda\bar{V}_L} + \frac{a_L(1-\bar{n}_N)}{a_N(1-\delta)\lambda\bar{V}_L} > 0,$$

$$J_{12} = \frac{\partial \dot{n}_{N,t}}{\partial n_{M,t}} = \frac{\lambda - 1}{(1-\delta)\lambda \bar{V}_L} > 0,$$

$$\begin{aligned} J_{13} = -\frac{\partial \dot{n}_{N,t}}{\partial V_{L,t}} &= \frac{(\lambda-1)\bar{n}_M}{(1-\delta)\lambda(\bar{V}_L)^2} + \frac{(1-\bar{n}_N)}{(1-\delta)\lambda(\bar{V}_L)^2}\left(1 - \frac{a_L}{a_N}\bar{n}_N\right) \\ &= \frac{1}{\bar{V}_L}\left[\frac{L^S}{a_L} - \frac{L^N}{a_N}(1-\bar{n}_N)\right] > 0, \end{aligned}$$

$$J_{21} = \frac{\partial \dot{n}_{M,t}}{\partial n_{N,t}} = \frac{a_L \bar{n}_M}{a_N(1-\delta)\lambda \bar{V}_L} - m\gamma,$$

$$J_{22} = -\frac{\partial \dot{n}_{M,t}}{\partial n_{M,t}} = \bar{I} + m\gamma > 0,$$

$$J_{23} = -\frac{\partial \dot{n}_{M,t}}{\partial V_{L,t}} = \frac{\bar{n}_M}{\bar{V}_L}\left(\frac{L^N}{a_N} - \bar{I}\right) > 0,$$

$$J_{31} = -\frac{\partial \dot{V}_{L,t}}{\partial n_{N,t}} = \frac{a_L}{a_N(1-\delta)\lambda} > 0,$$

$$J_{33} = \frac{\partial \dot{n}_{N,t}}{\partial n_{N,t}} = \frac{L^N}{a_N} + m\gamma + \rho > 0,$$

$$J_{44} = \frac{\partial \dot{n}_{N,t}}{\partial n_{N,t}} = \frac{a_L}{a_N(1-\delta)\lambda \bar{V}_L} + \bar{I} + \bar{\imath} + \rho > 0,$$

and J_{41}, J_{42}, and J_{43} are not relevant to the following analysis. Note that it is not clear whether J_{21} is positive or negative. Defining matrix J as:

$$J \equiv \begin{pmatrix} -J_{11} & J_{12} & -J_{13} \\ J_{21} & -J_{22} & -J_{23} \\ -J_{31} & 0 & J_{33} \end{pmatrix},$$

we obtain the characteristic equation of the coefficient matrix on the right-hand side of equation (37) as follows:

$$(J_{44} - x)(-x^3 + \text{Tr } J\ x^2 - \text{B } J\ x + \text{Det } J) = 0, \tag{38}$$

where

$$\text{Tr } J = -J_{11} - J_{22} + J_{33}, \tag{39}$$

$$\text{B } J = J_{11}J_{22} - J_{11}J_{33} - J_{12}J_{21} - J_{13}J_{31} - J_{22}J_{33}, \tag{40}$$

$$\text{Det } J = J_{11}J_{22}J_{33} + J_{12}J_{23}J_{31} + J_{13}J_{22}J_{31} - J_{12}J_{21}J_{33}. \tag{41}$$

Since J_{44} is positive, we must show that the polynomial:

$$-x^3 + \text{Tr } J\ x^2 - \text{B } J\ x + \text{Det } J = 0 \tag{42}$$

has one root with a positive real part and two roots with negative real parts in order to prove that the steady state has a stable manifold of dimension two.

To show this, we exploit the following application of 'Ruth's theorem' to a third-order polynomial as shown in Benhabib and Perli (1994).

Theorem (Benhabib and Perli, 1994) *The number of roots of the polynomial in (42) with positive real parts is equal to the number of variations of sign in the scheme:*

$$-1 \qquad Tr\ J \qquad -B\ J + \frac{Det\ J}{Tr\ J} \qquad Det\ J. \tag{43}$$

A proof of the more general version of Ruth's theorem is, for example, given by Gantmacher (1960, vol. 2, Ch. XV).

To make use of the theorem, and show that the scheme (43) has one variation of sign, we next verify that Det $J > 0$. From the components of the Jacobian matrix, each term on the right-hand side of (41) is:

$$\begin{aligned} J_{11}J_{22}J_{33} &= \left[\bar{I} + \frac{1}{(1-\delta)\lambda\bar{V}_L} + \frac{a_L(1-\bar{n}_N)}{a_N(1-\delta)\lambda\bar{V}_L}\right]\left(\bar{I}+m\gamma\right)\left(\frac{L^N}{a_N}+m\gamma+\rho\right) \\ &> \frac{a_L(1-\bar{n}_N)}{a_N(1-\delta)\lambda\bar{V}_L}\left(\bar{I}+m\gamma\right)\left(\bar{I}+m\gamma+\rho\right), \end{aligned}$$

$$\begin{aligned} J_{12}J_{23}J_{31} &= \left[\frac{\lambda-1}{(1-\delta)\lambda\bar{V}_L}\right] \times \frac{\bar{n}_M}{\bar{V}_L}\left(\frac{L^N}{a_N}-\bar{I}\right) \times \frac{a_L}{a_N(1-\delta)\lambda} \\ &= \frac{a_L m\gamma(1-\bar{n}_N)}{a_N(1-\delta)^2\lambda\bar{V}_L(\bar{I}+m\gamma)}\left(\bar{I}+m\gamma+\rho\right)\left(\frac{L^N}{a_N}-\bar{I}\right), \end{aligned}$$

$$\begin{aligned} J_{13}J_{22}J_{31} &= \left[\frac{(\lambda-1)\bar{n}_M}{(1-\delta)\lambda(\bar{V}_L)^2} + \frac{(1-\bar{n}_N)}{(1-\delta)\lambda(\bar{V}_L)^2}\left(1-\frac{a_L}{a_N}\bar{n}_N\right)\right] \times \left(\bar{I}+m\gamma\right) \times \frac{a_L}{a_N(1-\delta)\lambda} \\ &> \frac{a_L m\gamma(1-\bar{n}_N)}{a_N(1-\delta)^2\lambda\bar{V}_L}\left(\bar{I}+m\gamma+\rho\right), \end{aligned}$$

$$\begin{aligned} -J_{12}J_{21}J_{33} &= -\frac{\lambda-1}{(1-\delta)\lambda\bar{V}_L}\left[\frac{a_L\bar{n}_M}{a_N(1-\delta)\lambda\bar{V}_L}-m\gamma\right]\left(\frac{L^N}{a_N}+m\gamma+\rho\right) \\ &> -\frac{a_L m\gamma(1-\bar{n}_N)}{a_N(1-\delta)^2\lambda\bar{V}_L(\bar{I}+m\gamma)}\left(\bar{I}+m\gamma+\rho\right)\left(\frac{L^N}{a_N}+m\gamma+\rho\right). \end{aligned}$$

Therefore, we have the following inequality:

$$\text{Det } J > \frac{a_L(1-\bar{n}_N)(\bar{I}+m\gamma+\rho)}{a_N(1-\delta)^2\lambda\bar{V}_L(\bar{I}+m\gamma)}\left[(1-\delta)\left(\bar{I}+m\gamma\right)^2 - m\gamma\rho\right]. \tag{44}$$

Equation (44) together with the assumption that $m\gamma > \rho/(1-\delta)$ implies Det $J > 0$. Thus, we can conclude that the scheme (43) varies its sign an uneven number (one or three) times. To show that the number of variations is always one, we consider three cases according to the sign of Tr J: Tr $J < 0$, Tr $J = 0$, and Tr $J > 0$.

(i) **The case of** Tr $J < 0$

If Tr $J < 0$, then the scheme (43) must have only one variation of the sign regardless of the signs of $-$B $J +$ Det $J/$Tr J. Hence, in this case, the characteristic equation (38) has always two positive solutions and two solutions with negative real parts, so that the steady state is saddle-point stable and the equilibrium path is locally determinate.

(ii) **The case of** Tr $J = 0$

If Tr $J = 0$, then the sum of the three solutions of equation (42) is equal to zero. Because the product of the three solutions, which is equal to Det$J$, is strictly positive, it can occur only if equation (42) has one positive solution and two solutions with negative real parts. Thus, in the case of Tr $J = 0$, the characteristic equation (38) has two positive solutions and two solutions with negative real parts.

(iii) **The case of** Tr $J > 0$

Now suppose that Tr $J > 0$. In this case, we must verify that $-$B $J +$ Det $J/$Tr $J > 0$ to show that scheme (43) has one variation of signs. Since the sign of $-$B $J +$ Det $J/$Tr J coincides with that of $-$B JTr $J+$Det J, we prove below that $-$B JTr $J+$Det J is positive.

Using equations (39) – (41), we can rewrite $-$B JTr $J +$ Det J as follows:

$$\begin{aligned} -\text{B } J\text{Tr } J + \text{Det } J &= \text{Tr } J\left[J_{11}J_{33} + J_{13}J_{31} + J_{22}J_{33}\right] + J_{11}J_{22}\left(J_{11}+J_{22}\right) \\ &\quad + J_{31}\left(J_{12}J_{23} + J_{13}J_{22}\right) - J_{12}J_{21}\left(J_{11}+J_{22}\right). \end{aligned} \tag{45}$$

Recall that the sign of J_{21} is ambiguous, while the signs of J_{11}, J_{12}, J_{13}, J_{21}, J_{22}, J_{23}, J_{31}, and J_{33} are all positive. Equation (45) directly shows that $-\text{B } J\text{Tr } J + \text{Det } J$ is positive if J_{21} is negative or zero, so that scheme (43) varies its sign only once in that case.

On the other hand, $-\text{B } J\text{Tr } J + \text{Det } J$ is still positive, even if $J_{21} > 0$. To verify it, we again rewrite $-\text{B } J\text{Tr } J + \text{Det } J$ into:

$$\begin{aligned} -\text{B } J\text{Tr } J + \text{Det } J \;&=\; \text{Tr } J\left[J_{11}J_{33} + J_{12}J_{21} + J_{22}J_{33}\right] + J_{11}\left[J_{22}\left(J_{11} + J_{22}\right) - J_{13}J_{31}\right] \\ &\quad + J_{33}\left(J_{13}J_{31} - J_{12}J_{21}\right) + J_{12}J_{23}J_{31}. \end{aligned} \tag{46}$$

The second term on the right-hand side of equation (46) is positive because:

$$\begin{aligned} J_{22}\left(J_{11} + J_{22}\right) - J_{13}J_{31} \;&=\; \left(\bar{I} + m\gamma\right)\left[\bar{I} + \frac{a_L(1-\bar{n}_N)}{a_N(1-\delta)\lambda\bar{V}_L} + \left(\bar{I} + m\gamma\right)\right] \\ &\quad + \frac{1}{(1-\delta)\lambda\bar{V}_L}\left[\left(\bar{I} + m\gamma\right) - \frac{L^S}{a_N}\right] + \frac{a_L L^N(1-\bar{n}_N)}{(a_N)^2(1-\delta)\lambda\bar{V}_L}, \end{aligned}$$

where $(\bar{I} + m\gamma) - (L^S/a_N) > 0$ under condition (19). In addition, the third term on the right-hand side of equation (46) is also positive since:

$$J_{13}J_{31} - J_{12}J_{21} = \frac{a_L(1-\bar{n}_N)}{a_N(1-\delta)^2\lambda^2(\bar{V}_L)^2}\left(1 - \frac{a_L}{a_N}\bar{n}_N\right) + \frac{m\gamma(\lambda-1)}{(1-\delta)\lambda\bar{V}_L} > 0.$$

As a result, equation (46) implies that $-\text{B } J\text{Tr } J + \text{Det } J$ is positive even if $J_{21} > 0$, so that scheme (43) turns its signs only once in this case also. Therefore, in the case of Tr $J > 0$, two solutions of the characteristic equation (38) are positive real numbers and the other two solutions are complex numbers with negative real parts.

Thus, the proof to confirm saddle-point stability and local determinacy of the steady state has been completed.

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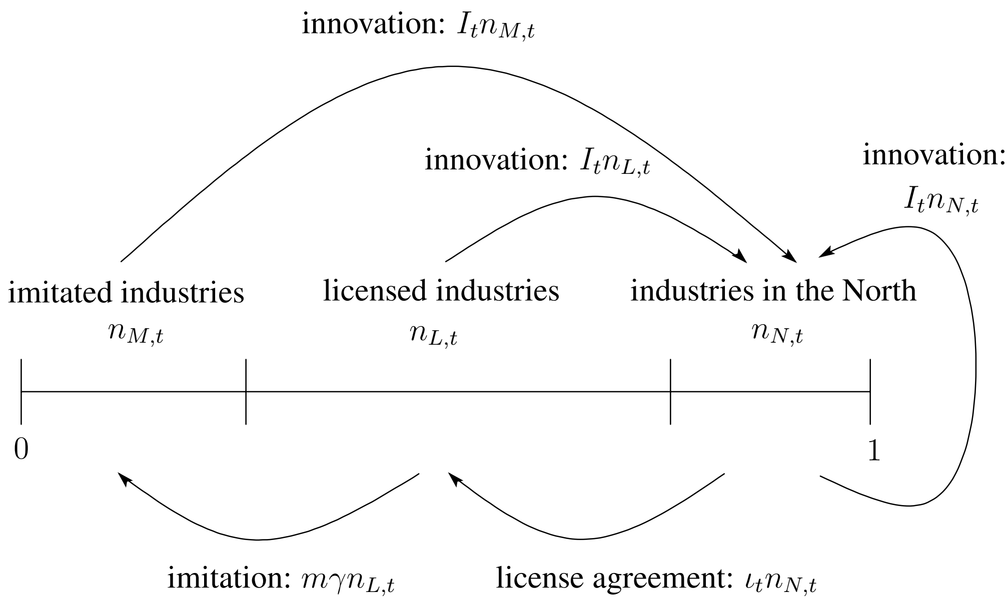

Figure 1: The structure of industries

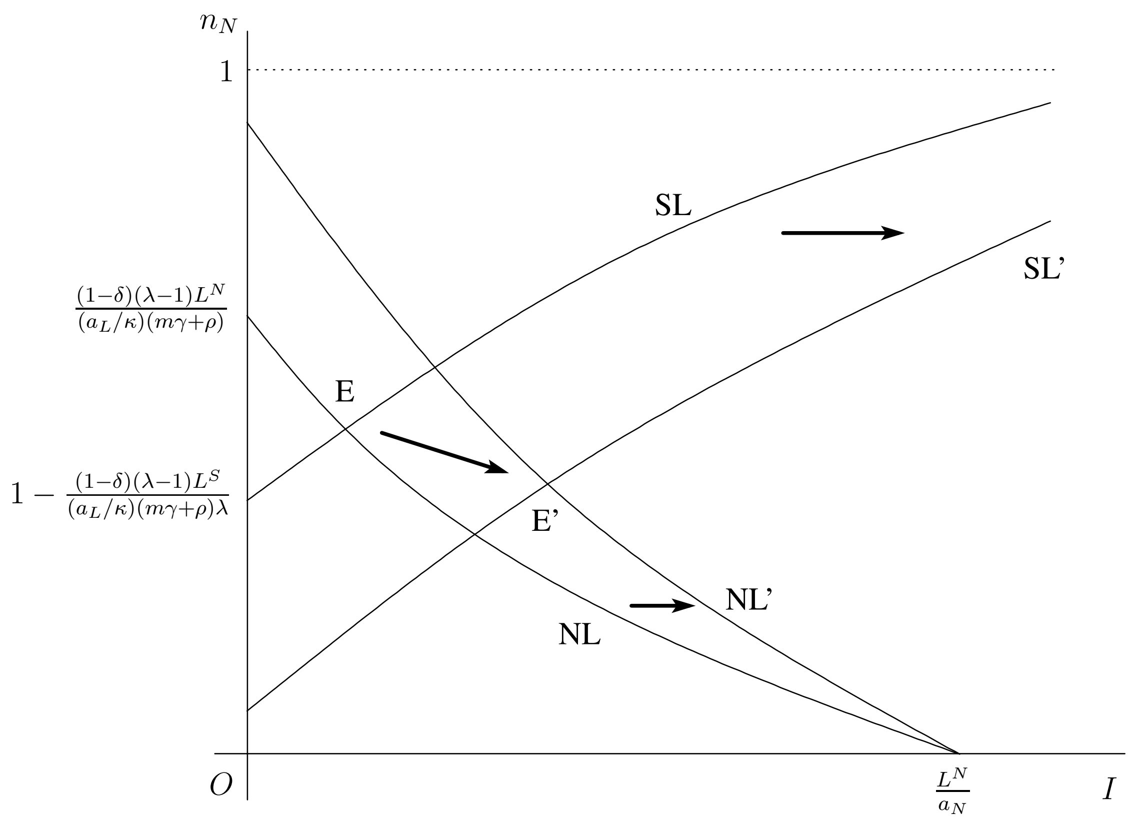

Figure 2: Determination of the steady state

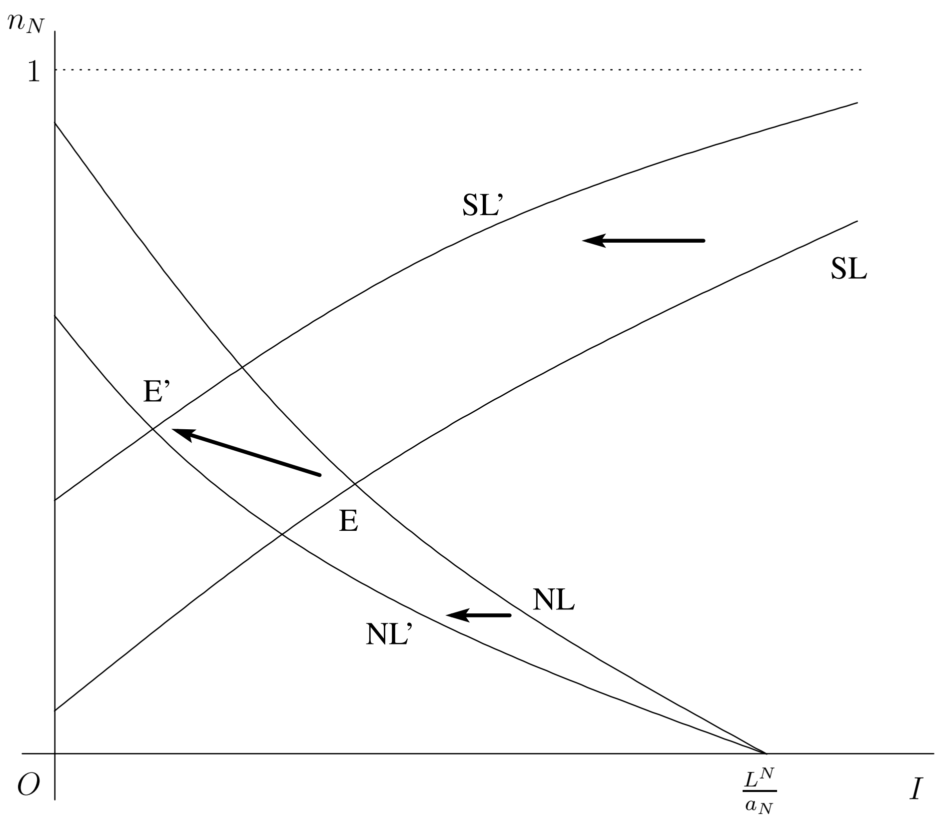

Figure 3: The effects of the rise of δ