Dynamic Analysis of Innovation and Licensing: the Effects of Intellectual Property Rights Protection*

Hitoshi Tanaka† Tatsuro Iwaisako‡
Koichi Futagami§

August 31, 2005

Abstract

Licensing is one of the major sources of international technology transfer to developing countries. This paper clarifies how strengthening intellectual property rights (IPRs) affect innovation and licensing by making use of a quality-ladder type of dynamic general equilibrium model. We explore not only the long-run effects but also the short-run effects of the policy by fully examining the dynamic characteristics of the model. The model shows that stronger IPRs promote innovation and technology transfers in both the long run and the short run if IPR protection greatly reduces the negotiation cost of licensing.

Keywords: Licensing; Innovation; Intellectual property rights; North–South; Technology transfer

JEL classification: F43; O33; O34;

---

*The authors are grateful to Yukiko Abe, Tetsugen Haruyama, Ryo Horii, Jun-ichi Itaya, Noritaka Kudoh, Kazuo Mino, and seminar participants at Hokkaido University and Kansai Macroeconomic Workshop for their helpful comments and useful discussion. This study was partly supported by the Grant-in-Aid for Young Scientists (No.16730104) from the Ministry of Education, Culture, Sports, and Technology. Any remaining errors are the authors' responsibility.

†Graduate School of Economics, Osaka University, 1-7 Machikaneyama, Toyonaka, Osaka 560-0043, Japan. E-mail: cg039th@srv.econ.osaka-u.ac.jp

‡Faculty of Economics, Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu, Shiga 525-8577, Japan. E-mail: tiwai@ec.ritsumei.ac.jp

§Faculty of Economics, Osaka University, 1-7 Machikaneyama, Toyonaka, Osaka 560-0043, Japan. E-mail: futagami@econ.osaka-u.ac.jp

1 Introduction

Advanced technologies possessed by firms in developed countries are necessary for the industrialization of developing countries. Many countries that are now developed have imported advanced technologies from other countries. For example, European countries and the US imported many technologies from Britain. Japan and South Korea also acquired technologies from Western countries. As these examples show, technology acquisition is indispensable for development. There are several ways in which advanced foreign technologies are transferred. Foreign direct investment (FDI), licensing, trade, and illegal imitation are typical examples. Japan and South Korea preferred licensing to FDI, especially in the early stages of their development after World War II.[1] Therefore, in this paper, we focus on licensing and investigate how strengthening intellectual property rights (IPRs) affects innovation and technology transfer by making use of a dynamic general equilibrium model constructed by Grossman and Helpman (1991).

Some studies have questioned whether strengthening IPRs promotes innovation and technology transfer to developing countries. By constructing a dynamic model in which Northern firms innovate and Southern firms imitate, Helpman (1993) investigated this issue and showed that although stronger IPRs raise the Northern innovation in the short run, they diminish it in the long run.[2] More recently, exploiting a dynamic North–South model with scale-invariant growth, Dinopoulos and Segerstrom (2005) concluded that stronger IPR protection is detrimental to innovation in the short run, but it has no effect in the long run.[3] On the other hand, some studies incorporated FDI into their models. Lai (1998) showed that the effects of stronger IPRs depend on whether the channel of technology transfer is FDI or imitation. He found that strengthening Southern IPRs raises

[1] See Peck (1976), Ozawa (1980), and Enos and Park (1988). See also Pack and Saggi (1997).

[2] Arnold (2002) indicated that Helpman's (1993) result on the long-run effect no longer holds when inflexibility in the Northern labor market is high.

[3] In order to remove scale effects, Dinopoulos and Segerstrom (2005) assumed that the difficulty of R&D increases with innovation (and imitation) in the same way as did Segerstrom (1998) and Li (2001). Moreover, Sener (2004) extended the scale-invariant growth model of Dinopoulos and Syropoulos (2001), which includes rent protection activities, into a North–South product-cycle model and showed that stronger IPR protection decreases the rate of innovation.

innovation and technology transfers when FDI is the channel of transfer, but reduces such transfers when imitation is the channel of transfer. In contrast, Glass and Saggi (2002b) showed that stronger IPRs decrease the level of innovation and technology transfer in a dynamic model in which both imitation and FDI are the channels of production transfer. Although these analyses explored the effects of stronger IPRs, they did not examine how stronger IPRs affect innovation and technology transfers under licensing.[4]

Yang and Maskus (2001) initially investigated this issue based on a product-cycle model developed by Grossman and Helpman when the channel of technology transfer is licensing. They showed that stronger IPRs raise innovation and technology transfer through reductions of licensing costs and improvements in the licensor's share of rents. Their conclusions have important implications for developing countries that are eager to learn from the experiences of Japan and South Korea, as both countries tended to adopt the purchase of foreign advanced technologies, that is, licensing.

Although Yang and Maskus' analysis has some interesting findings and makes a contribution to the theory of technology transfer, their analysis can be enhanced in two respects. First, in their model, the North, which has advanced technologies, uses its resources for licensing activities. However, as Peck (1976), Ozawa (1980), and Enos and Park (1988) stated, most licensing efforts are undertaken by recipient countries, as occurred in the case of Japan and South Korea.[5] Therefore, we modify Yang and Maskus' model in the following way: the parties who must make the effort to gain licenses are firms in the recipient country (the South), and they must use the resources of the recipient country. Second, and theoretically more importantly, Yang and Maskus analyze only the steady state and, consequently, they do not explore the dynamic nature of their model. With the exception of Helpman, the other papers mentioned above also focus only on the steady state. This can be allowed as a first approach if the dynamic system has stable equilib-

[4]Glass and Saggi (2002a) examined a dynamic general equilibrium model in which firms can choose the mode of technology transfer (FDI or licensing). However, in contrast to our study, and other studies mentioned above, they assumed the two countries were identical.

[5]A famous episode is the 'pilgrimage to Montecatini'. Many Japanese firms visited Montecatini — an Italian company that succeeded in converting propylene into a fiber-forming polypropylene — in order to obtain a licensing agreement. See Ozawa (1980).

rium paths to the steady state. However, in Yang and Maskus' setting (where the North, which has advanced technologies, uses its resources for licensing activities), the dynamic system becomes totally unstable.[6] In consequence, their model has no equilibrium path converging to the steady state. On the contrary, in the present setting, (where firms in the recipient country must make the effort to gain licenses and use the resources of the recipient country), there exists a stable equilibrium path, that is, a stable saddle path.

Based on the present dynamic analysis, we explore not only the long-run effects of stronger IPRs, but also the short-run effects of the policy by fully examining the dynamic characteristics of the model. This is an advantage in our analysis because many studies, including Yang and Maskus (2001), analyzed only the steady state and were not able to investigate the short-run effects of an IPR-strengthening policy.[7] The short-run effects of the policy are well deserving of consideration because there is a possibility that they will run in the counter direction to the long-run effects. Following Yang and Maskus (2001), this paper assumes that stronger IPRs reduce the cost of licensing negotiation and raise the rent share of licensors. Under these settings, we show that stronger IPRs raise innovation in the North and the level of licensing activities both in the long run and in the short run if tightening IPRs greatly reduces the cost of licensing negotiation. Consequently, stronger IPRs increase the number of goods produced in the South in such a situation. Conversely, we show that strengthening IPRs may suppress innovation and licensing activities in both the long run and the short run if stronger IPRs significantly raise the rent share of licensors or, in other words, significantly decrease the rent share of licensees. In addition, it is shown that stronger IPRs can raise the wage rate in the South. Although it is difficult to determine the effects of stronger IPRs on the relative wage, we present some numerical examples showing that strengthening IPRs tends to increase the Southern relative wage unless strengthening IPRs affects the rent distribution between licensors and licensees. That is, stronger IPRs may improve the welfare of the South when the rent distribution is not affected.

The rest of the paper is structured as follows. Section 2 describes the model. In

[6] Proof is available from the authors on request.

[7] Dinopoulos and Segerstrom (2005) examined the short-run effects on innovation. However, like many other studies, they conducted only comparative statics.

section 3, we derive the equilibrium path of the model and show that there exists a unique equilibrium path converging to the steady state. In section 4, we consider the short-run and long-run effects of stronger IPRs on the equilibrium path. Section 5 provides concluding remarks.

2 The Model

We develop a dynamic general equilibrium model such that licensing is introduced into the quality-ladder model as a means of international technical diffusion, based on Yang and Maskus (2001). Our model has the same basic structure as Grossman and Helpman (1991, ch.12).[8]

Consider an economy consisting of two regions, North and South, which are denoted by N and S, respectively. There is a continuum of goods, indexed by $\omega \in [0, 1]$, that are produced in the North or the South. Each product is classified by a countable infinite number of qualities $j = 0, 1, \cdots$ and its quality improves if innovation occurs in the industry. Product ω of quality j can be produced after the jth innovation in the industry ω and 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, this process of climbing the quality ladder requires research and development by firms. We choose our units appropriately so that the quality at time $t = 0$ is equal to unity in all industries.

Consumers living in both regions have identical preferences, as follows:

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

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

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

[8] Although the 'scale effect' remains in our model, as in Grossman and Helpman (1991), we follow Yang and Maskus (2001) in not attempting to remove it. Regarding the scale-effect problem, Temple (2003) concluded that it is unlikely the debate will be resolved empirically.

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

$$\int_0^\infty e^{-\int_0^t r(s)ds} E(t)dt = A(0),$$

where $r(t)$ is the interest rate which 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 of quality j at time t.

As is well established, this consumer's utility maximization problem can be solved in two stages. In the first stage, the consumer allocates his or her spending $E(t)$ to maximize $\log u(t)$, given prices at time t. To solve this static problem, the consumer allots identical expenditure shares to all products. Then, for each product, the consumer chooses the single quality $j = J_t(\omega)$ that carries the lowest quality-adjusted price $p_{j,t}(\omega)/q_{j,t}(\omega)$. This implies the following 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 stage, the consumer chooses the time pattern of spending to maximize his or her utility (1). This intertemporal utility maximization requires that $\dot{E}(t)/E(t) = r(t) - \rho$. By taking the aggregate spending as the numeraire, we normalize $E(t) = 1$ for all t so that interest rate $r(t)$ always corresponds to the subjective discount rate ρ.[9]

Turning to the production side, we assume that the each economy has a single primary production factor, labor. The amount of total labor supply is constant in each country but varies between countries. We assume that one unit of output requires one unit of labor input. In addition, research activities and licensing negotiations to win a license from a patent holder require labor inputs, as we shall discuss further below.

[9] This normalization is a convenient method for examining the dynamic behavior of the economy. See Grossman and Helpman (1991, ch.12).

Firms are separated into two types, 'leaders' and 'followers'. Leaders are firms with the ability to produce goods at the highest level of quality currently available, whereas all other firms are followers. A general feature of this kind of model is that industrial leaders do not intend to invest in further research and development of their products as long as the products are not imitated. In this model, we assume no imitation occurs in the equilibrium, so that industrial leaders have no incentive to invest in further R&D. Therefore, whenever innovation takes place in the industry, the incumbent leader must have been overtaken by a follower in terms of product quality.

Firms are distinguished in terms of their location, that is, whether they are in the North or in the South. We assume that Northern firms only have the ability to conduct R&D and bring state-of-the-art products into the market. Hence, only Northern followers drive quality improvements. The Northern firms that succeed in innovating and becoming the quality leader acquire the patent in the North. In addition, they can export their goods to the South without facing any transportation costs or tariffs.

Southern firms can offer a Northern leader a license contract such that they acquire the rights to produce and sell the invention of the Northern firm in exchange for royalty payments. When granted the license, the Southern firm receives the blueprint of the highest-quality product and acquires sufficient knowledge to manufacture it. Moreover, the firm can sell the product to the entire world legally. However, Southern licensees must pay a part of the rents from the sale of the product to their licensors as a license fee, until the product is replaced by a new product of higher quality. We assume that Southern licensee receives an exogenously determined share of the rent from sales, which reflects the bargaining power between licensees and licensors. Southern firms that possess greater bargaining power can retain a greater fraction of the rent. Moreover, we consider that the level of IPR protection in the South affects this rent distribution. The contracts between Northern and Southern firms forbid every Southern firm from breaking the agreement, and close monitoring ensures that this does not occur.

In order to focus on the progress of licensing, we make the following two assumptions. First, no imitation by Southern followers occurs in the equilibrium. We posit that Northern firms maintain confidentiality when manufacturing their state-of-the-art products in the North. Therefore, even if IPR protection is not enforced perfectly in the South, it is economically and technologically impractical for the Southern firms to copy the Northern firms' products being manufactured in the North. On the other hand, weaker IPR protection in the South might not prevent Southern followers from imitating a state-of-the-art product that is licensed to a Southern firm.[10] However, assuming that unauthorized imitators are obliged to compete with the rightful licensee in the Bertrand fashion, they earn no positive profits as both types of firm face the same marginal costs. This implies that imitators can never pay the imitation costs as long as they are strictly positive. Therefore, no imitator intends to enter the market. The second assumption is that inward FDI is banned by the Southern government authorities or is infeasible.[11] Hence, licensing is the unique means of international technology transfer from the North to the South.

For tractability, we assume that the second-highest-quality product is always in the public domain and that its specifications are freely available. This means that, at any time, the nearest rivals of the leaders are the Southern firms with the ability to produce goods of the second-highest quality. These products are competitive despite the lower quality because the equilibrium wage in the South is lower than in the North. Then, to exclude the rivals, every leader charges the same limit price, as follows:

$$p = \lambda w^S, \tag{2}$$

where w^S is the wage rate in the South.

In the equilibrium, there exist two possible types of market activity: either the Southern licensee produces the highest-quality good under a license; or the Northern leader alone produces the state-of-the-art variety of goods. Following Yang and Maskus (2001), we refer to the former as the licensed South technology (S) market and the latter as the original North technology (N) market. Assuming that a licensor is obliged to compete with its licensee in the Bertrand fashion if it enters the product market, no licensor has

[10]Grossman and Lai (2004) have explored the reason why IPRs tend to be more weakly protected in the South than in the North, and also examined methods of efficient patent protection in the global economy.

[11]The Japanese authorities adopted a restrictive policy towards FDI in the early stages of the development process after World War II in order to encourage foreign firms to license advanced technology to Japanese firms. See Hoekman, Maskus, and Saggi (2004).

an incentive to continuing producing the good for him or herself in equilibrium. That is, once a license contract has been made, the Southern licensee supplies the product monopolistically in both the Northern and Southern markets. Whenever a Northern follower succeeds in innovation and produces a new higher quality product, the market would become an N, which is independent of whether the targeted market is N or S. Therefore, the research efforts of entrepreneurs range over all ω indiscriminately because the expected gains from innovation are equal between industries, provided that the leaders in each market are symmetrical, that is, provided that all leaders are equally exposed to the danger of replacement by next higher-quality product and that all Northern leaders equally succeed in reaching an agreement on licensing..

Under the pricing strategy (2), Northern leaders and Southern licensees make different profits because their costs differ. The price setting of each leader yields a demand per product of $E/\lambda w^S$. Therefore, each Northern leader earns a flow of profits as follows:

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

whereas each Southern licensee earns the following:

$$\pi_L = (\lambda w^S - w^S)\frac{1}{\lambda w^S} = 1 - \frac{1}{\lambda},$$

where w^N is the wage rate in the North, which must be restricted to be below λw^S so that the Northern leaders can earn a strictly positive profit.

We assume that the R&D process is modeled as a Poisson process, following Grossman and Helpman (1991). If a Northern firm i uses $a_I \tilde{I}_i$ units of the labor input in research for a time interval of length dt, it succeeds in innovation with a probability of $\tilde{I}_i dt$, where a_I is a parameter. The variable $\tilde{I}_i$, which is the Poisson arrival rate at which new technology will be innovated in the next instant, is the intensity of R&D chosen endogenously by entrepreneurs. As usual, we assume that the success of R&D depends, not on the cumulated resources that have been spent in the former period, but only on the current spending resources. We let $V_{I,t}$ denote the market value of representative leaders operating in the North at time t, i.e., the leaders that belong to the N market. As successful innovators attain this market value, each entrepreneur maximizes the expected net benefit,

$V_{I,t}\tilde{I}_i dt - w_t^N a_I \tilde{I}_i dt$. In equilibrium with a finite size of R&D investment, we must have:

$$V_{I,t} \leq w_t^N a_I \quad \text{with equality whenever } \tilde{I}_i > 0. \tag{3}$$

Similarly, the formation of a license contract follows a Poisson process. The negotiations leading to the agreement of a new license contract between the licensor and the licensee may be time consuming, as are adaptations to a new technique. However, the lengths of time involved may be uncertain. In this model, we take licensing negotiation to be costly and assume that a Southern firm i that wishes to be licensed must input $a_L\tilde{\iota}_i/\kappa$ units of labor per unit of time in order to attain success with an instantaneous probability of $\tilde{\iota}_i$. Let a_L be a parameter, while $\tilde{\iota}_i$ denotes the intensity of labor inputs required when the Southern firm undertakes a negotiation to obtain a license.[12] Following Yang and Maskus (1991), we let κ be a parameter that is related positively to the strength of IPR protection in the South. That is, the more tightly IPRs are enforced in the South, the higher κ becomes. This means that the more strongly patent protection is enforced, the easier it is to conclude a license contract. This reflects the effect that strengthening patent protection in the recipient country may ease the patent holder's fear of imitation by other firms and facilitate the overtures for a license.[13]

If a Northern firm and a Southern firm agree on a license, they split the stock market value of an imaginary representative firm in the S market, $V_{L,t}$. The Southern firm i, which undertakes licensing negotiations at the intensity $\tilde{\iota}_i dt$ for a time interval dt, receives an expected gain of $(1-\delta)V_{L,t}\tilde{\iota}_i dt$, where $0 < \delta < 1$ denotes the Northern licensor's exogenously determined share. As the rent distribution between licensors and licensees may be influenced by the degree of IPR protection in the recipient countries, we consider that δ depends on the level of IPR protection in the South, following Yang and Maskus (2001). Hence, a Southern firm under licensing negotiations decides on an intensity of labor inputs $\tilde{\iota}_i$ to maximize its expected payoff, $(1-\delta)V_{L,t}\tilde{\iota}_i dt - w_t^S(a_L/\kappa)\tilde{\iota}_i dt$. In equilibrium,

[12] In Yang and Maskus (2001), Northern leaders spend their resources in order to transfer the technology to the South. However, as stated in the introduction, our setting seems more realistic at least in the cases of Japan and South Korea.

[13] See Yang and Maskus (2001).

the Southern firm's decision requires the zero-profit condition, as follows:

$$V_{L,t} \leq w_t^S \frac{a_L/\kappa}{1-\delta} \quad \text{with equality whenever } \tilde{\iota}_i > 0. \tag{4}$$

On the other hand, a Northern patent holder that has not yet granted a license may refuse a Southern firm's offer. If a Northern firm obtains a smaller expected market value from granting a license than it obtains by continuing to operate in the North on its own account, then the Northern will prefer not to grant a license. Therefore, for a license contract to take place at time t, a Northern licensor's rent share must exceed a nonlicensing Northern firm's stock value; that is:

$$V_{I,t} \leq \delta V_{L,t}. \tag{5}$$

The measures of products that belong to the S market at time t, n_t^S, change over time. A measure of the inflow into the S market is equal to the measure of newly licensed industries into the N market at time t, whereas the outflow out of the S market is equal to the measure of industries in the S market where innovation at time t produces the next newly-invented higher-quality products. As in Grossman and Helpman (1991), we focus only on the symmetric equilibrium. In the equilibrium, every leader in the N market reaches a licensing agreement at the same aggregate intensity $\iota_t = \sum_i \tilde{\iota}_i$, and every incumbent leader in the economy is exposed to the danger of being replaced by the invention of a higher quality product at the same aggregate intensity $I_t = \sum_i \tilde{I}_i$. During a time interval dt, a new agreement is made about licensing in $\iota_t n_t^N dt$ industries of the N market, where $n_t^N \equiv 1 - n_t^S$ is a measure of the N market. In addition, innovation occurs in $I_t n_t^S dt$ industries of the S market and $I_t n_t^N dt$ industries of the N market in the same time interval. Therefore, n_t^S must follow the following equation of motion:

$$\dot{n}_t^S = \iota_t n_t^N - I_t n_t^S. \tag{6}$$

Now, we consider how the market value of each firm varies over time. Shareholders of a firm in the S market earn dividends $\pi_L dt$ and capital gains $\dot{V}_L dt$ over a time interval of length dt if no follower succeeds in innovating a new state-of-the-art product in the industry. However, the stock of each firm becomes worthless if the product is replaced by a higher-quality product during the interval dt. The probability that this occurs is equal to the innovation intensity targeted at the industry during the time interval, $I_t dt$. Provided that these idiosyncratic risks are shared by all investors properly, a stock should yield exactly the same expected rate of return as the risk-free interest rate, $r(t)$. Then, the no-arbitrage condition between the stock of a firm in the S market and a riskless asset is:

$$r(t)V_{L,t} = \pi_{L,t} + \dot{V}_{L,t} - I_t V_{L,t}. \tag{7}$$

The no-arbitrage condition for the stock of Northern leaders in the N market is a little complex. The shareholders of a leader in the N market earn dividends $\pi_I dt$ and capital gains $\dot{V}_I dt$ if no innovation occurs in the industry, while suffering a total capital loss of amount V_I with a probability of $I_t dt$. In addition, the stock value transforms into δV_L if the firm succeeds in reaching an agreement with a Southern firm about licensing during dt, the probability of which corresponds to $\iota_t dt$. Northern leaders in the N market take the instantaneous probability ι_t as given, notwithstanding its endogeneity, because it is selected by Southern followers. The sum of these risky returns must be identical to the risk-free interest rate. Therefore, we obtain the no-arbitrage condition between the stock of a leader in the N market and a riskless asset, as follows:

$$r(t)V_{I,t} = \pi_{I,t} + \dot{V}_{I,t} - I_t V_{I,t} + \iota_t(\delta V_{L,t} - V_{I,t}) \quad \text{if } \iota_t > 0. \tag{8}$$

Finally, we close the model by describing the labor-market-clearing conditions. Let the labor supply be L^N and L^S in the North and South, respectively, where both are exogenously given. The total manufacturing employment in the South equals $n_t^S E(t)/(\lambda w_t^S)$, whereas in the North it equals $n_t^N E(t)/(\lambda w_t^S)$. The R&D sector in the North employs $a_I I_t(n_t^S + n_t^N)$ units of labor. Labor-market clearing in the Northern market requires that:

$$\frac{1}{\lambda w_t^S} n_t^N + a_I I_t(n_t^S + n_t^N) = L^N. \tag{9}$$

On the other hand, the labor input for licensing negotiations by Southern follower firms is equal to $(a_L/\kappa)\iota_t n_t^N$. Hence, the Southern labor-market-clearing condition becomes:

$$\frac{1}{\lambda w_t^S} n_t^S + \frac{a_L}{\kappa}\iota_t n_t^N = L^S. \tag{10}$$

3 The Equilibrium Path

Now, we derive the equilibrium path of the economy. First, we compute the R&D and licensing intensity in the equilibrium. Substituting the zero-profit condition in licensing (4) into the Northern labor-market-clearing condition (9), we have:

$$I_t = \frac{L^N}{a_I} - \frac{a_L/\kappa}{a_I(1-\delta)\lambda}\frac{1-n_t^S}{V_{L,t}} \quad \text{whenever } \ I_t > 0 \text{ and } \iota_t > 0. \tag{11}$$

Similarly, from the zero-profit condition in licensing (4) and the Southern labor-market-clearing condition (10), we obtain:

$$\iota_t = \frac{1}{1-n_t^S}\left[\frac{L^S}{a_L/\kappa} - \frac{1}{(1-\delta)\lambda}\frac{n_t^S}{V_{L,t}}\right] \quad \text{whenever } \ \iota_t > 0. \tag{12}$$

Note that both R&D and licensing intensity depend only on the two endogenous variables, n_t^S and $V_{L,t}$. No innovation ($I_t = 0$) and no licensing ($\iota_t = 0$) take place when the right-hand sides of (11) and (12), respectively, become negative. However, we focus our attention on the region where both $I_t > 0$ and $\iota_t > 0$.

Next, we compute the evolution of variables n_t^S and $V_{L,t}$. Substituting equations (11) and (12) into (6), we can rewrite the equation of motion for n_t^S as follows:

$$\dot{n}_t^S = \frac{L^S}{a_L/\kappa} - \left\{\frac{L^N}{a_I} + \frac{1}{(1-\delta)\lambda V_{L,t}}\left[1 - \frac{a_L/\kappa}{a_I}(1-n_t^S)\right]\right\} n_t^S. \tag{13}$$

In addition, using $r(t) = \rho$ for all t and combining (7) with (11), we derive the equation of motion for $V_{L,t}$ as follows:

$$\dot{V}_{L,t} = \left(\rho + \frac{L^N}{a_I}\right)V_{L,t} - \left[\frac{a_L/\kappa}{a_I(1-\delta)\lambda}(1-n_t^S) + \left(1 - \frac{1}{\lambda}\right)\right]. \tag{14}$$

Equations (13) and (14) form an autonomous system of two differential equations in n_t^S and $V_{L,t}$. Therefore, we can examine the dynamic behavior of these two variables separately from the other variables. In this system, n_t^S is a state variable, whereas $V_{L,t}$ is a jump variable.

Figure 1 depicts the phase diagram for this system on the (n^S, V_L) plane. The intersection of the two curves $\dot{n}_t^S = 0$ and $\dot{V}_{L,t} = 0$ at point A is the fixed point of this system. The shaded area represents a region in which neither research nor licensing occur. Recalling equations (11) and (12), we focus on the region where the following two inequalities are satisfied:

$$V_{L,t} > \frac{a_L/\kappa}{(1-\delta)\lambda L^N}(1-n_t^S), \tag{15}$$

and

$$V_{L,t} > \frac{a_L/\kappa}{(1-\delta)\lambda L^S} n_t^S. \tag{16}$$

The equation for the $\dot{n}_t^S = 0$-locus is represented by:

$$V_L = \frac{(a_L/\kappa)}{(1-\delta)\lambda} \frac{\left\{(a_L/\kappa)n^S + [a_I - (a_L/\kappa)]\right\} n^S}{a_I L^S - (a_L/\kappa)L^N n^S}, \tag{17}$$

whereas the equation for the $\dot{V}_{L,t} = 0$-locus is given by:

$$V_L = \frac{1}{\lambda(L^N + a_I\rho)} \left[\frac{a_L/\kappa}{1-\delta} + a_I(\lambda - 1)\right] - \frac{a_L/\kappa}{(1-\delta)\lambda(L^N + a_I\rho)} n^S. \tag{18}$$

The $\dot{n}_t^S = 0$-locus is upward sloping and remains in a finite region provided that innovation requires more labor inputs than licensing does in order to attain a certain probability of success and that the South is endowed with relatively abundant labor. In more detail, the condition is:

$$\frac{a_L}{\kappa} < a_I \quad \text{and} \quad \frac{a_L/\kappa}{a_I} L^N \leq L^S. \tag{19}$$

Furthermore, to ensure that two loci cross once, we assume that:

$$(a_L/\kappa)(L^N + a_I\rho) - (1-\delta)(\lambda-1)[a_I L^S - (a_L/\kappa)L^N] > 0. \tag{20}$$

The inequality is the condition such that the V_L coordinate of the $\dot{n}_t^S = 0$-locus exceeds that of the $\dot{V}_{L,t} = 0$-locus at $n^S = 1$. As the $\dot{V}_{L,t} = 0$-locus lies above the $\dot{n}_t^S = 0$-locus at $n^S = 0$, the two loci cross at least once if the restriction is fulfilled. Then, this economy may have a steady state that is a saddle point under appropriate additional assumptions. Moreover, in the steady state, a strictly positive fraction of products is under license and manufactured in the South.

To characterize the economy completely and seek out the steady state, we must investigate the evolution of the third variable, $V_{I,t}$. Imposing $I_t > 0$ and $\iota_t > 0$, from equations

(3), (4), (8), (11), and (12), we obtain the equation of motion for $V_{I,t}$, as follows:

$$\dot{V}_{I,t} = \left[\left(\rho + \frac{L^N}{a_I} \right) + \frac{n_t^S}{(1-\delta)\lambda V_{L,t}} \left(\frac{a_L/\kappa}{a_I} - \frac{1}{1-n_t^S} \right) + \frac{L^S}{a_L/\kappa} \frac{1}{1-n_t^S} \right] V_{I,t} - 1 - \frac{\delta L^S}{a_L/\kappa} \frac{V_{L,t}}{1-n_t^S} + \frac{\delta}{(1-\delta)\lambda} \frac{n_t^S}{1-n_t^S}. \tag{21}$$

Using the three variables, $n_t^S, V_{L,t}$, and $V_{I,t}$, we state some conditions under which a feasible steady state of the economy exists. Let $\bar{n}^S,\ \bar{V}_L, and\ \bar{V}_I$ denote the values of the fixed points in the differential equation system composed of (13), (14), and (21). In addition, the condition (5) must be imposed on $\bar{V}_L$ and $\bar{V}_I$ so that the steady state is attainable. Moreover, in the equilibrium, the Southern wage must be less than the Northern one, while the Northern wage cannot exceed the Southern one multiplied by λ, i.e., $w_t^S < w_t^N < \lambda w_t^S$. Under the assumptions that $I_t > 0$ and $\iota_t > 0$, from equations (3) and (4), the condition is described as follows:

$$\frac{a_I(1-\delta)}{a_L/\kappa} V_{L,t} < V_{I,t} < \frac{a_I(1-\delta)\lambda}{a_L/\kappa} V_{L,t}. \tag{22}$$

In addition, in order that both innovation and licensing take place in the steady state, $\bar{n}^S$ and $\bar{V}_L$ must take values that satisfy (15) and (16). This restriction corresponds to intersection A in figure 1 falling outside the shaded area because the point represents the coordinate of $(\bar{n}^S, \bar{V}_L)$. If $n_t^S, V_{L,t}$, and $V_{I,t}$ satisfy all of those conditions and the steady state is attainable, it is a saddle point (see the Appendix). These results are stated as the following proposition:

Proposition 1: *Suppose that parameters are under conditions (19) and (20). Then, the economy has a steady state with positive innovation and licensing if the steady state values $\bar{n}^S$, $\bar{V}_L$, and $\bar{V}_I$ satisfy all of the conditions (5), (15), (16), and (22). Moreover, the steady state is a saddle point.*

A numerical example of parameters in which the steady state exists is provided in the next section. As n_t^S is a state variable, the saddle path converging to the steady state is the equilibrium trajectory. Along this saddle path, the fraction of licensed products increases over time when the economy is below its steady-state value.

4 The Effects of Tightening IPRs

In this section, we investigate the effects of strengthening IPR protection in the South on the endogenous variables. As we have assumed κ and δ are dependent on the degree of IPR protection, we can distinguish two effects: first, the negotiation costs that licensees must pay in order to win a license contract are reduced; and second, the rent distribution between licensors and licensees changes. Let us call the former effect, the 'cost reducing effect' and the latter, the 'distribution effect'. In the first part of this section, we analyze these two effects individually. Later, we integrate the effects and explore the overall effect of tightening IPRs.

4.1 The cost-reducing effect

The cost-reducing effect of tighter IPRs is expressed by a rise of κ. First, we examine the long-run cost-reducing effect on innovation and licensing by conducting comparative statics. Combining equations (17) and (18), we derive $\bar{n}^S$ as a positive solution of the following equation:

$$a_L^2 \rho (\bar{n}^S)^2 + B\bar{n}^S - C = 0, \tag{23}$$

where:

$$B \equiv a_L \kappa \left\{ L^S + a_I \rho + L^N [\lambda - (\lambda - 1)\delta] \right\} - a_L^2 \rho > 0,$$
$$C \equiv \kappa L^S \left[a_L + a_I (1 - \delta) \kappa (\lambda - 1) \right] > 0.$$

Taking a total differential of the equation (23), we obtain:

$$\frac{\partial \bar{n}^S}{\partial \kappa} = \frac{1}{2a_L^2 \rho \bar{n}^S + B} \left(\frac{\partial C}{\partial \kappa} - \frac{\partial B}{\partial \kappa} \bar{n}^S \right). \tag{24}$$

This equation shows that a rise of κ increases the fraction of licensed products as long as $(\partial B/\partial \kappa)\bar{n}^S < \partial C/\partial \kappa$. Noting that $\partial B/\partial \kappa = (B + a_L^2 \rho)/\kappa$ and $\partial C/\partial \kappa = (C/\kappa) + a_I(1 - \delta)\kappa(\lambda - 1)L^S$, from the condition on parameters and equation (23), we can verify that $\partial C/\partial \kappa - (\partial B/\partial \kappa)\bar{n}^S$ is greater than $(a_L/\kappa)[(1-\delta)\kappa(\lambda-1)L^N - a_L\rho(1-\bar{n}^S)]$. Exploiting condition (15), which is necessary for the steady state with positive innovation, and equation (18) representing the $\dot{V}_L = 0$-locus, we obtain $(1 - \delta)\kappa(\lambda - 1)L^N - a_L\rho(1 - \bar{n}^S) > 0$. Hence, $\partial C/\partial \kappa$ is always larger than $(\partial B/\partial \kappa)\bar{n}^S$; that is, $\partial \bar{n}^S/\partial \kappa > 0$ in any case.

The cost-reducing effect on the value of $\bar{V}_L$ is computed by using the effect on $\bar{n}^S$. As the fixed point of the system is located on the $\dot{V}_{L,t} = 0$-locus, $\bar{V}_L$ is related to $\bar{n}^S$ by equation (18). Therefore, the long-run response of $V_{L,t}$ to changes of κ is given by:

$$\frac{\partial \bar{V}_L}{\partial \kappa} = -\frac{a_L/\kappa}{(1-\delta)\lambda(L^N + a_I\rho)} \left(\frac{1-\bar{n}^S}{\kappa} + \frac{\partial \bar{n}^S}{\partial \kappa} \right) < 0. \tag{25}$$

Exploiting the above result, we can examine how a rise of κ affects the other variables. First, we calculate the long-run cost-reducing effect on innovation. As the innovation intensity at time t satisfies (11), taking the derivative of $\bar{I}$ with respect to κ, we derive the following:

$$\frac{\partial \bar{I}}{\partial \kappa} = \frac{a_L/\kappa}{a_I(1-\delta)\lambda \bar{V}_L} \left(\frac{\partial \bar{n}^S}{\partial \kappa} + \frac{1-\bar{n}^S}{\kappa} + \frac{1-\bar{n}^S}{\bar{V}_L}\frac{\partial \bar{V}_L}{\partial \kappa} \right). \tag{26}$$

The above equation shows that the change of κ affects $\bar{I}$ through three channels: through the change of $\bar{n}^S$, the direct effect, and the change of $\bar{V}_L$. These effects are competing because whereas the first two effects encourage the innovation, the last effect weakens the incentive for innovation. However, using equations (18) and (25), we can immediately confirm that $\partial \bar{I}/\partial \kappa > 0$. That is, the first two positive effects dominate the last negative effect and the cost-reducing effect induces more innovation in the long run.

Intuitively, a rise of κ has two effects, which lead to a decrease in the Northern labor employed in the production sector. First, more products are manufactured in the South under license. This is because Southern firms are more eager to engage in license negotiations because they require less labor to attain a unit probability of successfully achieving a license agreement. This first effect is expressed by the first term in the parentheses of equation (26). Second, there is less demand for each product and, therefore, less demand for labor from each incumbent leader. The reductions in demand occur because the stronger incentives to undertake licensing negotiations caused by the rise of κ lead to a rise in the Southern wage, as is verified later. A boost in the Southern wage involves higher prices for products as each leader adopts a limit-pricing strategy to compete with the Southern closest rivals. This second effect is expressed by the second and the third terms in the parentheses of equation (26). These two effects decrease the labor demand from Northern incumbent leaders and, consequently, increase the labor input for innovation activities in the steady state.

In addition, a rise of κ positively affects in licensing intensity in the long run. As equation (6) implies that $\bar{\iota} = \bar{I}\bar{n}^S/(1-\bar{n}^S)$ in the steady state, the effect of the change on κ is given by:

$$\frac{\partial \bar{\iota}}{\partial \kappa} = \frac{\bar{n}^S}{1-\bar{n}^S}\frac{\partial \bar{I}}{\partial \kappa} + \frac{\bar{I}}{(1-\bar{n}^S)^2}\frac{\partial \bar{n}^S}{\partial \kappa} > 0.$$

In addition, the aggregate amount of licenses, $\bar{n}^N\bar{\iota}$, is positively related to κ. We can summarize the above analysis as the following proposition:

Proposition 2: *The cost-reducing effect caused by strengthening IPRs in the South promotes both innovation and licensing in the long run.*

Although this result is similar to Yang and Maskus (2001), our model can answer another related and important question, which is: does the cost-reducing effect encourage innovation and licensing in the short run as well as the long run? Yang and Maskus (2001) were unable to answer this question because their study focused only on the steady state, which was totally unstable. In contrast, our analysis enables us to examine the short-run effect because it fully describes the progress of the economy. In that respect, our analysis extends that of Yang and Maskus.

To investigate this short-run effect, we exploit the same approach as Helpman (1993).[14] For tractability, we restrict the analysis to an economy that initially stays in the steady state; namely, $n_0^S = \bar{n}^S$. Then, suppose that an unanticipated marginal increase in κ occurs at time 0 because of a slight improvement in the Southern IPR protection. We can calculate the first-order response of $(n_t^S, V_{L,t})$ to the marginal rise of κ from a linearized system of the differential equations (13) and (14) around the steady-state value. In the Appendix, we show that:

$$\left.\frac{\partial n_t^S}{\partial \kappa}\right|_{n_0^S=\bar{n}^S} = (1-e^{-xt})\frac{\partial \bar{n}^S}{\partial \kappa}, \tag{27}$$

and

$$\left.\frac{\partial V_{L,t}}{\partial \kappa}\right|_{n_0^S=\bar{n}^S} = \frac{\partial \bar{V}_L}{\partial \kappa} + \Lambda e^{-xt}\frac{\partial \bar{n}^S}{\partial \kappa}, \tag{28}$$

where x is the absolute value of the negative eigenvalue of the linearized coefficient matrix, and Λ, which represents the second element of the eigenvector associated with the negative

[14] Kwan and Lai (2003) have adopted the same method in their closed economy model.

eigenvalue, is positive as well. Because I_t follows equation (11), taking into consideration the initial condition $n_0^S = \bar{n}^S$ and the condition $\partial n_0^S/\partial\kappa = 0$, we derive the cost-reducing effect on the innovation intensity at time 0, as follows:

$$\left.\frac{\partial I_0}{\partial \kappa}\right|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L} = \frac{(a_L/\kappa)(1-\bar{n}^S)}{a_I(1-\delta)\kappa\lambda\bar{V}_L}\left(1+\frac{\kappa}{\bar{V}_L}\left.\frac{\partial V_{L,0}}{\partial\kappa}\right|_{n_0^S=\bar{n}^S}\right).$$

This equation suggests that the extent to which the innovation intensity responds to policy change depends on the elasticity of $V_{L,0}$ with respect to κ . If the elasticity exceeds -1, then $\partial I_0/\partial\kappa|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L}$ is positive; that is, innovation is stimulated by a rise of κ in the short term as well as the long term. To compute the elasticity, we must know the value of $\partial V_{L,0}/\partial\kappa$. However, equation (28) implies that $\partial V_{L,0}/\partial\kappa|_{n_0^S=\bar{n}^S}$ is greater than $\partial\bar{V}_L/\partial\kappa$. As we can verify that $(\kappa/\bar{V}_L)(\partial\bar{V}_L/\partial\kappa) > -1$ (see the Appendix), we conclude that the elasticity of $V_{L,0}$ with respect to κ evaluated at the steady-state value also exceeds -1. As a result, we show that $\partial I_0/\partial\kappa|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L} > 0$.

Similarly, using equation (12), we can compute the short-run cost-reducing effect on licensing as follows:

$$\left.\frac{\partial \iota_0}{\partial \kappa}\right|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L} = \frac{1}{1-\bar{n}^S}\left[\frac{L^S}{a_L}+\frac{\bar{n}^S}{(1-\delta)\lambda(\bar{V}_L)^2}\left.\frac{\partial V_{L,0}}{\partial\kappa}\right|_{n_0^S=\bar{n}^S}\right]. \qquad (29)$$

In addition, we can confirm that this $\partial\iota_0/\partial\kappa|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L}$ is greater than zero (see the Appendix). Thus, these results prove the following proposition.

Proposition 3: *The cost-reducing effect caused by strengthening IPRs in the South promotes both innovation and licensing in the short run as well as the long run.*

How are the wages in the both countries affected by a rise of κ in the steady state? As mentioned above, the Southern wage in the steady state rises unambiguously. Using equation (4), we obtain:

$$\frac{\partial\bar{w}^S}{\partial\kappa} = \frac{1-\delta}{a_L}\bar{V}_L + \frac{(1-\delta)\kappa}{a_L}\frac{\partial\bar{V}_L}{\partial\kappa} > 0. \qquad (30)$$

Turning to the relative wage between the North and the South, we have difficulty in computing the effect of strengthening IPRs because the effect on the Northern wage is unclear. Therefore, by using some numerical examples of parameters, we have examined the effect on the relative wage.[15] As a result, we have found that the relative wage of the South is monotonically increasing with a rise of κ for all parameter values that we have chosen.

4.2 The distribution effect

The distribution effect of tighter IPRs is represented by a change of δ. Therefore, in the first part of this subsection, we examine the comparative statics with respect to δ. Next, we show the short-run effect of tighter IPRs on innovation and licensing agreements by exploiting the same approach used in the previous subsection.

In order to derive the long-run distribution effect, we first compute the derivative of $\bar{n}^S$ and $\bar{V}_L$ with respect to δ. Totally differentiating equation (23) implies that:

$$\frac{\partial \bar{n}^S}{\partial \delta} = -\frac{\kappa(\lambda-1)(a_I \kappa L^S - a_L L^N \bar{n}^S)}{2a_L^2 \rho \bar{n}^S + B} < 0. \tag{31}$$

Furthermore, using the $\dot{V}_L = 0$-locus, we can derive the following:

$$\frac{\partial \bar{V}_L}{\partial \delta} = \frac{a_L/\kappa}{(1-\delta)\lambda(L^N + a_I \rho)} \left(\frac{1-\bar{n}^S}{1-\delta} - \frac{\partial \bar{n}^S}{\partial \delta} \right) > 0. \tag{32}$$

The first term of this expression represents the direct effect of a change in δ, whereas the second represents the indirect effect that occurs through the change of $\bar{n}^S$. These effects complement each other and shift $\bar{V}_L$ in the same direction. Consequently, $\bar{V}_L$ responds positively to a rise of the Northern rent share.

Using the above derivatives, we can compute $\partial \bar{I}/\partial \delta$ using the same method as in the previous subsection. The effects of a change in δ on innovation intensity in the steady state are:

$$\frac{\partial \bar{I}}{\partial \delta} = \frac{a_L/\kappa}{a_I(1-\delta)\lambda \bar{V}_L} \left(\frac{\partial \bar{n}^S}{\partial \delta} - \frac{1-\bar{n}^S}{1-\delta} + \frac{1-\bar{n}^S}{\bar{V}_L} \frac{\partial \bar{V}_L}{\partial \delta} \right) < 0. \tag{33}$$

The change of δ affects $\bar{I}$ through three channels: the change of $\bar{n}^S$, the direct effect, and the change of $\bar{V}_L$. The intuitive interpretation is as follows. First, as shown above, a higher

[15] Figure 2 is an output of the numerical calculation. In figure 2, we specify the parameters as $a_I = 7, a_L = 3.5, \lambda = 1.5, L^N = 1, L^S = 2$, and $\rho = 0.05$. Other examples are available from the authors upon request.

δ results in a lower $\bar{n}^S$; that is, more leaders come to operate in the North. The expansion of industries belonging to the N market creates additional Northern labor demand from incumbent leaders, which leads to a lower innovation intensity. The first term in the parentheses of (33) represents this first effect. Second, the higher δ discourages Southern followers from pursuing licensing efforts and reduces the Southern wage because of its lower return, other things remaining unchanged. The lower Southern wage obliges the incumbent leaders to charge a lower price and generates an additional product demand.

The second and the third terms in the parentheses of (33) represent this second effect. These two effects increase the labor demand from Northern incumbent leaders and, consequently, decrease $\bar{I}$.

The effects on licensing intensity $\bar{\iota}$ are computed in the same way as in the previous subsection. $\partial\bar{\iota}/\partial\delta$ is derived by:

$$\frac{\partial \bar{\iota}}{\partial \delta} = \frac{\bar{I}}{(1-\bar{n}^S)^2}\frac{\partial \bar{n}^S}{\partial \delta} + \frac{\bar{n}^S}{1-\bar{n}^S}\frac{\partial \bar{I}}{\partial \delta} < 0.$$

As both $\partial\bar{n}^S/\partial\delta$ and $\partial\bar{I}/\partial\delta$ are negative, $\partial\bar{\iota}/\partial\delta$ is also negative. Hence, a higher rent share for Northern licensors reduces the efforts of Southern followers to negotiate a license contract in the long run.

Next, we investigate the short-run effects of a change in rent sharing on innovation and licensing. By analogues of equations (27) and (28), we obtain: $\partial V_{L,0}/\partial\delta|_{n_0^S=\bar{n}^S} = (\partial\bar{V}_L/\partial\delta) + \Lambda(\partial\bar{n}^S/\partial\delta)$ and $\partial n_0^S/\partial\delta = 0$ for the economy that initially stays in the steady state. Hence, equations (11) and (12) imply that:

$$\left.\frac{\partial I_0}{\partial \delta}\right|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L} = \frac{(a_L/\kappa)(1-\bar{n}^S)}{a_I(1-\delta)\lambda\bar{V}_L}\left[-\frac{1}{1-\delta} + \frac{1}{\bar{V}_L}\left(\frac{\partial\bar{V}_L}{\partial\delta} + \Lambda\frac{\partial\bar{n}^S}{\partial\delta}\right)\right],$$

and

$$\left.\frac{\partial \iota_0}{\partial \delta}\right|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L} = \frac{\bar{n}^S}{(1-\delta)\lambda(1-\bar{n}^S)\bar{V}_L}\left[-\frac{1}{1-\delta} + \frac{1}{\bar{V}_L}\left(\frac{\partial\bar{V}_L}{\partial\delta} + \Lambda\frac{d\bar{n}^S}{d\delta}\right)\right].$$

Using equations (18), (31), and (32), and the definition of B, we can verify that $-[1/(1-\delta)] + (1/\bar{V}_L)(\partial\bar{V}_L/\partial\delta)$ is less than zero. Thus, both innovation and licensing intensity at time zero respond negatively to a rise of the Northern share of rent.

In addition, we examine the distribution effects on the Southern wage in the steady state. Equation (4) implies that:

$$\frac{\partial \bar{w}^S}{\partial \delta} = \frac{(1-\delta)\bar{V}_L}{a_L/\kappa}\left(-\frac{1}{1-\delta} + \frac{1}{\bar{V}_L}\frac{\partial \bar{V}_L}{\partial \delta}\right) < 0. \tag{34}$$

Therefore, a higher δ pushes the Southern wage down in the steady state. Moreover, we ascertain the tendency of the distribution effects on the Southern relative wage by using some numerical examples (see figure 2). From the results, we found that the relative wage of the South is monotonically decreasing with a rise of δ for reasonable values of parameters.

The above results are summarized as the following proposition.

Proposition 4: *A higher rent share for the licensor reduces both innovation and licensing in the long run and the short run.*

This proposition suggests that an excessively high rent share for Northern licensors results in low licensing efforts and interferes with the smooth transfer of production to the South. In addition, as the Southern wage diminishes with the rent share of Northern licensors, manufacturing per firm in the N market increases. These two effects lead to more production in the North, which discourages innovation through the decrease of labor input for research. As a result, less quality improvements take place and the expected duration of existing products increases.

4.3 Overall effects of strengthening IPRs

By incorporating the cost-reducing effect and the distribution effect, we can compute the overall effect of tighter IPRs. To do so, let us regard δ as a function of κ, namely, $\delta = \delta(\kappa)$. Moreover, we assume that δ is non-decreasing with κ, following Yang and Maskus (2001).[16] That is, we assume that tighter IPRs raise the rent share of Northern licensors. Then, we can consider parameter κ to be an index capturing the strength of IPRs in the South.

[16] Even if this assumption does not hold, the following analysis in this subsection is applicable. That is, if δ were decreasing with κ, the distribution effects would reinforce the cost-reducing effects, so that tightening IPRs would always promote both innovation and technology transfer.

Therefore, the long-run overall effects of tighter IPRs on innovation and licensing are computed as follows:

$$\text{long-run overall effect on innovation} = \frac{\partial \bar{I}}{\partial \kappa} + \delta'(\kappa)\frac{\partial \bar{I}}{\partial \delta},$$
$$\text{long-run overall effect on licensing} = \frac{\partial \bar{\iota}}{\partial \kappa} + \delta'(\kappa)\frac{\partial \bar{\iota}}{\partial \delta}.$$

These equations show that the overall long-run effects on innovation and licensing are positive if $\delta'(\kappa)$ is not so large — that is, if the cost-reducing effect caused by tightening IPRs in the South is relatively large. Conversely, the overall long-run effects on innovation and licensing are negative when $\delta'(\kappa)$ is large enough — that is, when the distribution effect dominates the cost-reducing effect.

The short-run overall effects of tighter IPRs on innovation and licensing are given by:

$$\text{short-run overall effect on innovation} = \frac{\partial I_0}{\partial \kappa} + \delta'(\kappa)\frac{\partial I_0}{\partial \delta},$$
$$\text{short-run overall effect on licensing} = \frac{\partial \iota_0}{\partial \kappa} + \delta'(\kappa)\frac{\partial \iota_0}{\partial \delta}.$$

These equations show that the overall short-run effects on innovation and licensing are also positive as long as $\delta'(\kappa)$ is not so large, whereas they are negative if $\delta'(\kappa)$ is large enough (see table 1). Note that the signs of the short-run overall effects can be opposite to those of the long-run overall effects. Therefore, a policy of tightening IPR protection in the South may have different effects on innovation and technology transfer in the short run compared to the long run. We can summarize these results as follows:

Proposition 5: *Strengthening IPRs in the South promotes both innovation and licensing if rent distribution is not sensitive to a tightening of IPR protection, and vice versa.*

This proposition asserts that our conclusions about IPR protection policy do not always accord with Yang and Maskus' (2001) results. In Yang and Maskus' setting (2001), licensors take an active part in the technology transfer to developing countries. Therefore, in their setting, when tighter IPRs induce a higher rent share for licensors, more Northern leaders engage in license activities, which accelerates both licensing and innovation. In other words, in Yang and Maskus' setting, the distribution effects reinforce the cost-reducing effects (called the 'size effect' by Yang and Maskus) . By contrast, in our setting, distribution effects weaken the cost-reducing effects because tighter IPRs lead to lower rent shares for licensees, which means fewer Southern followers have incentives to engage in license negotiation. Consequently, our result on tighter IPRs does not correspond to that of Yang and Maskus (2001) if the distribution effects are sufficiently large to dominate the cost-reducing effects.

Finally, let us examine the overall effects on the Southern wage and on the relative wage. Equations (30) and (34) suggest that tightening IPR protection in the South raises the Southern wage when the rent distribution does not react strongly to the change. On the other hand, we treat the effects on the relative wage by using numerical examples because of the difficulty in computing the effects on the Northern wage. Figure 2 depicts the relative wage corresponding to each value of δ and κ. The figure shows that whether the relative wage w^S/w^N rises with tighter IPRs depends on the extent of the change in δ and κ . That is, strengthening IPRs brings about a higher relative wage w^S/w^N when δ is not affected by the policy change. Conversely, if the rent share of licensees deteriorates due to the policy modification, the change would enlarge the wage gap between the North and the South.

5 Concluding Remarks

An international technical diffusion advances through various channels, including licensing. This paper has presented a quality-ladder type of product-cycle model in which licensing is introduced as the channel of technology diffusion. In the model, we have supposed that firms in developing countries must incur costs and input resources in their efforts to win a license contract. In actuality, such licensed firms often play an important role in reducing technological backwardness in recipient countries. Examples include Japan and South Korea after World War II. Our model captures the activity of such recipient countries and shows the existence of the steady state in which positive innovation and licensing continue to take place. An important advantage of our analysis is that we fully explore the dynamic nature of the economy. As a result, we have succeeded in verifying that the steady state in the economy is a saddle point. Moreover, in fully analyzing the dynamic system, our study has yielded an advantage with respect to the short-run effects of an IPR protection policy. Although many existing studies compromise with such an analysis by drawing a conclusions about the long-run effect only, our analysis enables us to determine both short-run and long-run effects.

However, we have focused only on the analysis of licensing and excluded the other channels of technology diffusion. Consequently, our analysis is restricted in the following two ways. First, our model does not take into account imitation activities, although these are widely observed and constitute a major source of technology acquisition in an early developing stage. The effects of IPR protection on the technology transfer may depend on what is a means of technology acquisition, as indicated in Lai (1998). On that point, our result is likely to be applied to middle-income countries rather than the least-developed countries. Second, we have assumed that foreign direct investment is impractical. In reality, however, there are two types of middle-income developing country. One encourages domestic firms to learn advanced technologies through licensing from firms in the developed countries, whereas the other prefers FDI by multinational firms to licensing. Clearly, we take only the former countries as the object of our analysis and come to the conclusion that stronger IPRs can promote licensing and innovation. In contrast, Glass and Saggi (2002b) showed that tighter IPRs reduce FDI and innovation because of the increased difficulty of imitation. The difference between Glass and Saggi's (2002b) conclusion and ours suggests that an IPR protection policy even in the middle-income countries should be carefully designed according to the country's main channels of technology transfer. Hence, a topic for future study will be an examination of the effects of strengthening IPRs in the North–South context under the existence of both licensing and another mode of technology transfer. Nevertheless, the result obtained in this paper will assist in determining the right treatment of IPRs.

A Appendix

In this appendix, we derive the cost-reducing effect of tighter IPRs on innovation and licensing in the short run. To do so, we first compute the negative eigenvalue and the corresponding eigenvector of the system. The linearized system of (13), (14), and (21) is:

$$\begin{pmatrix} \dot{n}_t^S \\ \dot{V}_{L,t} \\ \dot{V}_{I,t} \end{pmatrix} = \begin{pmatrix} -b_{11} & b_{12} & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{pmatrix} \begin{pmatrix} n_t^S - \bar{n}^S \\ V_{L,t} - \bar{V}_L \\ V_{I,t} - \bar{V}_I \end{pmatrix}, \tag{35}$$

where

$$b_{11} = \frac{L^N}{a_I} + \frac{1}{(1-\delta)\lambda\bar{V}_L}\left[1 - \frac{a_L/\kappa}{a_I}(1-2\bar{n}^S)\right] > 0,$$

$$b_{12} = \frac{\bar{n}^S}{(1-\delta)\lambda\bar{V}_L^2}\left[1 - \frac{a_L/\kappa}{a_I}(1-\bar{n}^S)\right] > 0,$$

$$b_{21} = \frac{a_L/\kappa}{a_I(1-\delta)\lambda} > 0,$$

$$b_{22} = \rho + \frac{L^N}{a_I} > 0,$$

and

$$b_{33} = \rho + \frac{L^N}{a_I(1-\bar{n}^S)} > 0,$$

while b_{31} and b_{32} are irrelevant to the analysis. The eigenequation associated with the coefficient matrix on the right-hand side is:

$$(\lambda - b_{33})[\lambda^2 + (b_{11} - b_{22})\lambda - b_{11}b_{22} - b_{12}b_{21}] = 0. \tag{36}$$

As the equation $\lambda^2 + (b_{11} - b_{22})\lambda - b_{11}b_{22} - b_{12}b_{21} = 0$ has one positive and one negative solution, the eigenequation (36) has two positive and one negative solution. Therefore, the steady state is a saddle point and there exists a stable saddle path converging to it. In addition, recalling that n_t^S is a state variable, while $V_{L,t}$ and $V_{I,t}$ are jump variables, the number of negative eigenvalues corresponds to that of the state variable.

Next, we compute the approximate saddle path around the steady state, using the linearized system of differential equations (35). In integrating the linearized differential equations, we have to base our choice of free integral constants on the conditions that a stable saddle path converges to the steady state and that n_t^S is a state variable whose initial value is historically given. This procedure yields the following expressions:

$$n_t^S = \bar{n}^S + (n_0^S - \bar{n}^S)e^{-xt}, \tag{37}$$

$$V_{L,t} = \bar{V}_L - \Lambda(n_0^S - \bar{n}^S)e^{-xt}, \tag{38}$$

where x is the absolute value of the negative eigenvalue, and Λ, which represents the absolute value of the second element of an eigenvector associated with the negative eigenvalue, is also positive. The definition of an eigenvalue and an eigenvector implies the following:

$$x = \frac{1}{2}(D + b_{11} - b_{22}), \qquad \Lambda = \frac{1}{b_{12}}(x - b_{11}) = \frac{1}{2b_{12}}(D - b_{11} - b_{22}),$$

where $D \equiv [(b_{22} - b_{11})^2 + 4(b_{11}b_{22} + b_{12}b_{21})]^{1/2} > b_{11} + b_{22}$. Because equations (37) and (38), of which the linearized stable saddle path consists, are consolidated into $V_{L,t} = -\Lambda n_t^S + (\bar{V}_L + \Lambda \bar{n}^S)$, the stable saddle path projecting on the (n^S, V_L) plane has a negative slope.

Third, we compute the change of n_t^S and $V_{L,t}$ to an unexpected marginal rise of κ. Differentiating (37) and (38) with respect to κ, we obtain:

$$\frac{\partial n_t^S}{\partial \kappa} = (1 - e^{-xt})\frac{\partial \bar{n}^S}{\partial \kappa} - (n_0^S - \bar{n}^S)te^{-xt}\frac{\partial x}{\partial \kappa}, \tag{39}$$

$$\frac{\partial V_{L,t}}{\partial \kappa} = \frac{\partial \bar{V}_L}{\partial \kappa} + \Lambda e^{-xt}\frac{\partial \bar{n}^S}{\partial \kappa} - (n_0^S - \bar{n}^S)e^{-xt}\frac{\partial \Lambda}{\partial \kappa} + \Lambda(n_0^S - \bar{n}^S)te^{-xt}\frac{\partial x}{\partial \kappa}. \tag{40}$$

As we consider that the economy initially stays in the steady state, namely, $n_0^S = \bar{n}^S$, the second term of (39) and the last two terms of (40) are equal to zero. Hence, the derivatives of n_t^S and $V_{L,t}$ with respect to κ on the steady state are given by (27) and (28) in the text. In particular, the size of the initial jump responding the policy change is derived as:

$$\left.\frac{\partial V_{L,0}}{\partial \kappa}\right|_{n_0^S = \bar{n}^S} = \frac{\partial \bar{V}_L}{\partial \kappa} + \Lambda \frac{\partial \bar{n}^S}{\partial \kappa}.$$

Figure 3 depicts the situation where κ rises. The figure indicates that $\partial V_{L,0}/\partial \kappa|_{n_0^S = \bar{n}^S}$ is greater than $\partial \bar{V}_L/\partial \kappa$ because the stable saddle path inclines negatively. Therefore, the elasticity of $V_{L,0}$ with respect to κ evaluating at the steady state value is larger than that of $\bar{V}_L$:

$$\frac{\kappa}{\bar{V}_L}\frac{\partial \bar{V}_L}{\partial \kappa} < \frac{\kappa}{\bar{V}_L}\left.\frac{\partial V_{L,0}}{\partial \kappa}\right|_{n_0^S = \bar{n}^S}.$$

Fourth, we show that $(\kappa/\bar{V}_L)(\partial \bar{V}_L/\partial \kappa)$ is greater than -1 in order to prove $\partial I_0/\partial \kappa|_{n_0^S = \bar{n}^S, V_{L,0} = \bar{V}_L} >$

0. First, substituting (24) into (25), we obtain:

$$\frac{\partial \bar{V}_L}{\partial \kappa} = -\frac{a_L/\kappa}{(2a_L^2\rho\bar{n}^S + B)(1-\delta)\lambda(L^N + a_I\rho)} \times \left[\frac{1}{\kappa}(2a_L^2\rho\bar{n}^S + B)(1-\bar{n}^S) + \frac{\partial C}{\partial \kappa} - \frac{\partial B}{\partial \kappa}\bar{n}^S\right].$$

Then, let us notice the content of the square bracket of this equation. Using the equation (23), we can easily verify that $(2a_L^2\rho\bar{n}^S+B)(1-\bar{n}^S) = (2a_L^2\rho+B)\bar{n}^S+(B-2C)$. In addition, from the definitions of B and C, $\partial B/\partial\kappa = (a_L^2\rho + B)/\kappa$ and $\partial C/\partial\kappa = -a_L L^S + 2C/\kappa$. Hence, we can rewrite $\partial\bar{V}_L/\partial\kappa$ as:

$$\frac{\partial \bar{V}_L}{\partial \kappa} = -\frac{a_L/\kappa}{(2a_L^2\rho\bar{n}^S + B)(1-\delta)\lambda(L^N + a_I\rho)}\left(\frac{a_L^2\rho}{\kappa}\bar{n}^S + \frac{B}{\kappa} - a_L L^S\right). \tag{41}$$

Therefore, exploiting (18) and (41), we obtain the following expression about the elasticity of $\bar{V}_L$ with respect to κ:

$$\frac{\kappa}{\bar{V}_L}\frac{\partial \bar{V}_L}{\partial \kappa} = -\frac{a_L(a_L^2\rho\bar{n}^S + B - a_L\kappa L^S)}{(2a_L^2\rho\bar{n}^S + B)\left[a_L(1-\bar{n}^S) + a_I(1-\delta)\kappa(\lambda-1)\right]}. \tag{42}$$

By using (23) we can show that the denominator on the right-hand side of equation (42) is greater than the numerator and, thus, we conclude that $(\kappa/\bar{V}_L)(\partial\bar{V}_L/\partial\kappa) > -1$ is true. Hence, innovation intensity at time zero responds positively to a tighter IPR protection.

Finally, we confirm that $\partial\iota_0/\partial\kappa|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L}$ is greater than zero. For the sake of the confirmation, we show that $(L^S/a_L)+[\bar{n}^S/(1-\delta)\lambda(\bar{V}_L)^2](\partial\bar{V}_L/\partial\kappa) > 0$. As $\partial V_{L,0}/\partial\kappa|_{n_0^S=\bar{n}^S}$ is larger than $\partial\bar{V}_L/\partial\kappa$, the inequality and equation (29) imply $\partial\iota_0/\partial\kappa|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L} > 0$. Using (18) and (41), together with the definition of B, we obtain:

$$\begin{aligned}
&\frac{L^S}{a_L} + \left[\frac{\bar{n}^S}{(1-\delta)\lambda(\bar{V}_L)^2}\right]\frac{\partial \bar{V}_L}{\partial \kappa} \\
&= \frac{(C - a_L\kappa L^S\bar{n}^S)}{(2a_L^2\rho\bar{n}^S + B)\left[a_L(1-\bar{n}^S) + a_I(1-\delta)\kappa(\lambda-1)\right]^2\kappa^2 L^S} \\
&\quad \times \left\{a_L\bar{n}^S\rho(C - a_L\kappa L^S\bar{n}^S) + \kappa(L^N + a_I\rho)(C - a_L\kappa L^S)\right. \\
&\quad \left. + C[(1-\delta)\kappa(\lambda-1)L^N - a_L\rho(1-\bar{n}^S)]\right\}.
\end{aligned}$$

Note that, from equations (15) and (18), the term $(1-\delta)\kappa(\lambda-1)L^N - a_L\rho(1-\bar{n}^S)$ is positive under the situation with positive innovation in the steady state. Therefore,

$L^S/a_L + [\bar{n}^S/(1-\delta)\lambda\bar{V}_L](\partial\bar{V}_L/\partial\kappa)$ is greater than zero. This result means that licensing intensity at time zero reacts positively to an increase of κ, that is, $\partial\iota_0/\partial\kappa|_{n_0^S=\bar{n}^S, V_{L,0}=\bar{V}_L} > 0$.

Thus, the proof of proposition 3 has been completed.

References

[1] Arnold, L. G., 2002, On the Growth Effects of North–South Trade: The Role of Labor Market Flexibility. *Journal of International Economics* 58 (2), 451–466.

[2] Dinopoulos, E., Segerstrom, P. S., 2005, A Theory of North–South Trade and Globalization. mimeo, University of Florida.

[3] Dinopoulos, E., Syropoulos, C., 2001, Innovation and Rent Protection in the Theory of Schumpeterian Growth. mimeo, University of Florida and Stockholm School of Economics.

[4] Enos, J. L., Park, W. H., 1988, *The Adoption and Diffusion of Imported Technology: The Case of Korea*. Croom Helm, New York.

[5] Glass, A. J., Saggi, K., 2002a, Licensing versus Direct Investment: Implications for Economic Growth. *Journal of International Economics* 56 (1), 131–153.

[6] Glass, A. J., Saggi, K., 2002b, Intellectual Property Rights and Foreign Direct Investment. *Journal of International Economics* 56 (2), 387–410.

[7] Grossman, G. M., Helpman, E., 1991, *Innovation and Growth in the Global Economy*. The MIT Press, Cambridge, MA.

[8] Grossman, G. M., Lai, E. L.-C., 2004, International Protection of Intellectual Property. *American Economic Review* 94 (5), 1635–1653.

[9] Helpman, E., 1993, Innovation, Imitation, and Intellectual Property Rights. *Econometrica* 61 (6), 1247–1280.

[10] Hoekman, B. M., Maskus, K. E., Saggi, K., 2004, Transfer of Technology to Developing Countries: Unilateral and Multilateral Policy Options. The World Bank, Policy Research Working Paper Series: No. 3332.

[11] Kwan, Y. K., Lai, E. L.-C., 2003, Intellectual Property Rights Protection and Endogenous Economic Growth. *Journal of Economic Dynamics and Control* 27 (5), 853–873.

[12] Lai, E. L.-C., 1998, International Intellectual Property Rights Protection and the Rate of Product Innovation. *Journal of Development Economics* 55 (1), 133–153.

[13] Li, C.-W., 2001, On the Policy Implications of Endogenous Technological Progress. *Economic Journal* 111 (471), C164–C179.

[14] Ozawa, T., 1980, Government Control over Technology Acquisition and Firms' Entry into New Sectors: The Experience of Japan's Synthetic-Fibre Industry. *Cambridge Journal of Economics* 4 (2), 133–146.

[15] Pack, H., Saggi, K., 1997, Inflows of Foreign Technology and Indigenous Technological Development. *Review of Development Economics* 1 (1), 81–98.

[16] Peck, M., 1976, Technology, in H. Patrick and H. Rosovsky, eds., *Asia's New Giant: How the Japanese Economy Works.* Brookings Institution Press, Washington.

[17] Segerstrom, P. S., 1998, Endogenous Growth without Scale Effects. *American Economic Review* 88 (5), 1290–1310.

[18] Sener, F., 2004, Intellectual Property Rights and Rent Protection in a North–South Product-Cycle Model. mimeo, Union College, New York.

[19] Temple, J., 2003, The Long-run Implications of Growth Theories. *Journal of Economic Surveys* 17 (3), 497–510.

[20] Yang, G., Maskus, K. E., 2001, Intellectual Property Rights, Licensing, and Innovation in an Endogenous Product-Cycle Model. *Journal of International Economics* 53 (1), 169–187.

Table 1: The effects of strengthening IPR protection on innovation and licensing

		cost-reducing effect (C.E.) ($\kappa \uparrow$)	distribution effect (D.E.) ($\delta \uparrow$)	overall effect	
				C.E. > D.E.	C.E. < D.E.
innovation	short run	+	−	+	−
	long run	+	−	+	−
licensing	short run	+	−	+	−
	long run	+	−	+	−

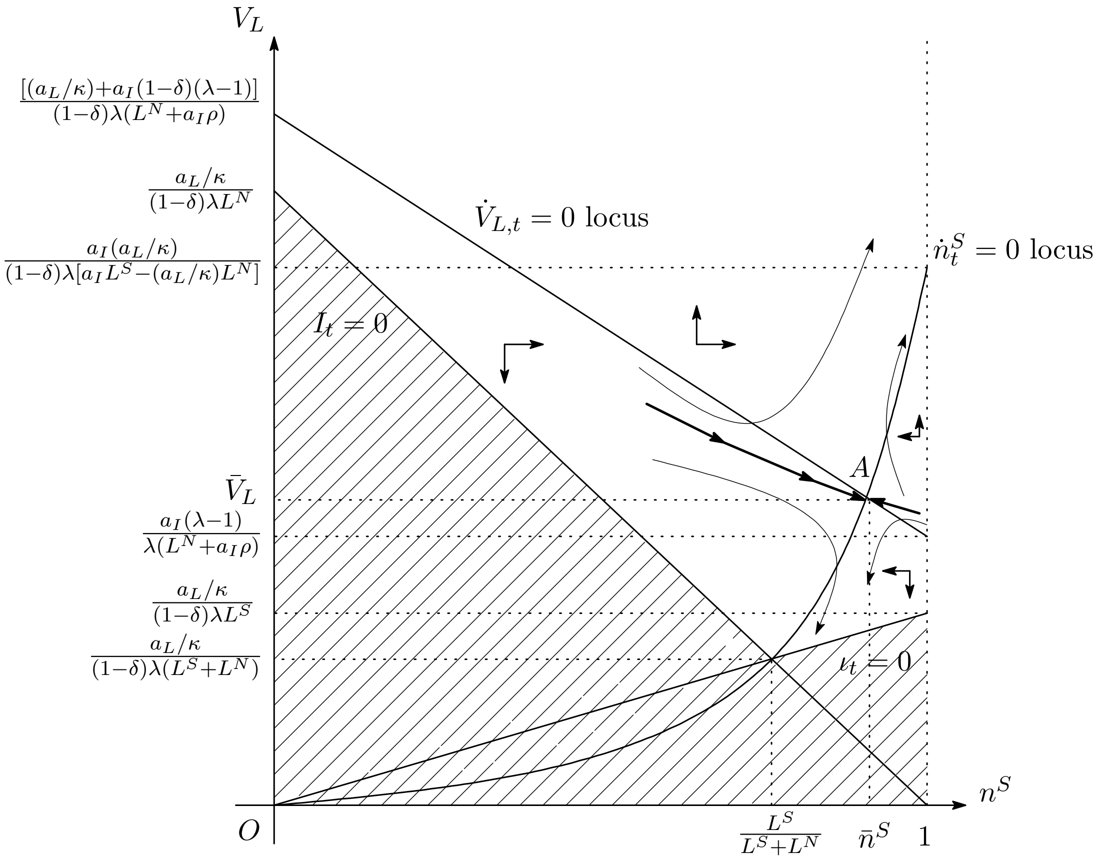

Figure 1: Phase diagram

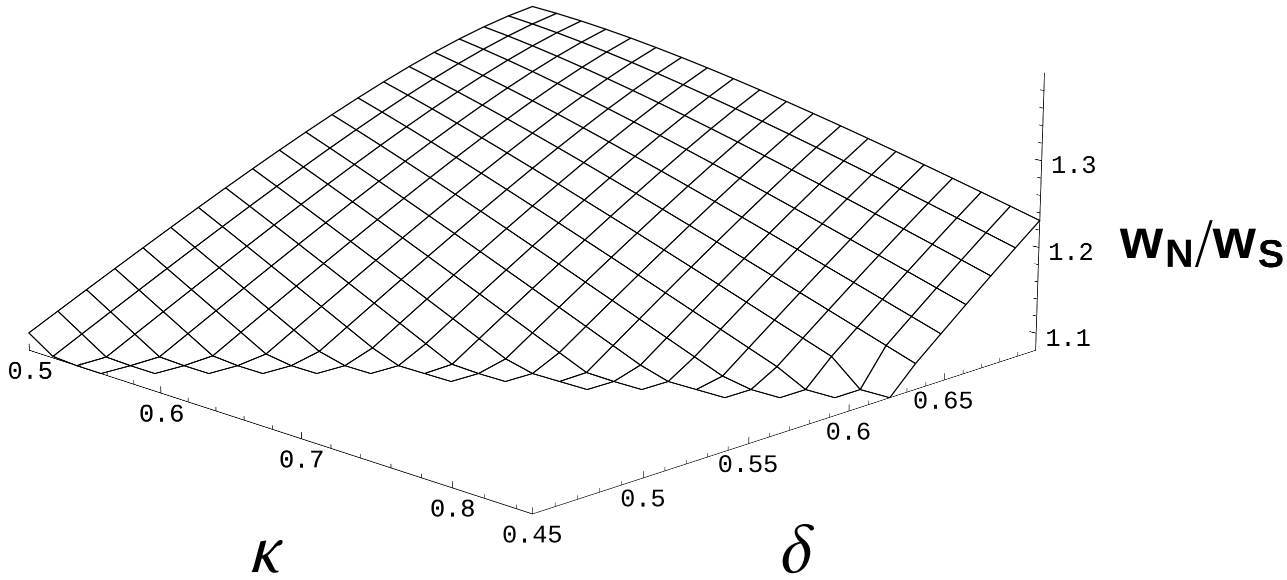

Figure 2: Relative wage corresponding to each value of δ and κ

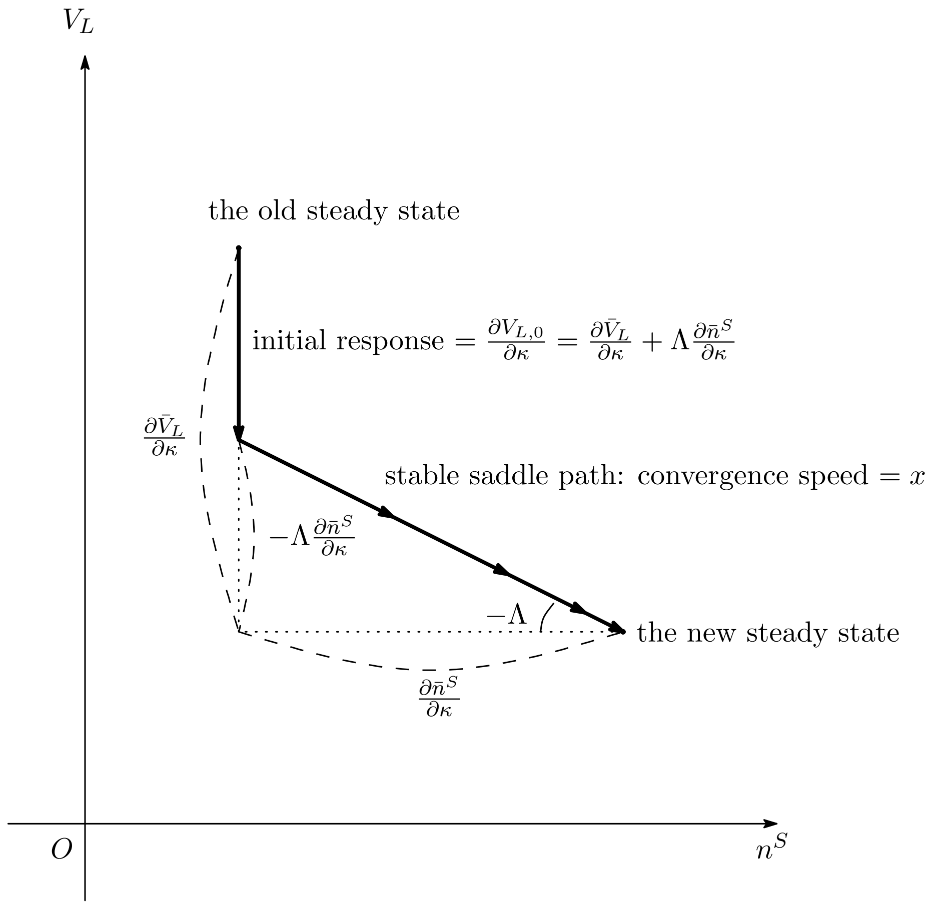

Figure 3: Response to a rise of κ at the initial time and in the long run

B Appendix: The Dynamics of the Yang–Maskus Model

This appendix examines the dynamics of the model of Yang and Maskus (2001) (hereafter Y–M). We show that the steady state of their model becomes totally unstable. As a result, because their model has one predetermined variable, the number of goods that are produced in the Southern market, or similarly the number of goods that are produced in the Northern market, the steady state analyzed in their model is never attained.

First, we construct the dynamic system of the Y–M model. The no-arbitrage condition between the stock of a leader firm in the Northern market and a riskless asset is given by [1]

$$\rho V_{I,t} = \max_{\iota_t} \left[\pi_{I,t} + \dot{V}_{I,t} - I_t V_{I,t} + \iota_t \left(\delta V_{L,t} - V_{I,t} - \frac{a_L}{\kappa} w_t^N \right) \right]. \tag{B1}$$

Note that each leader firm in the Northern market optimally chooses the instantaneous probability of success in licensing. If the level of licensing activities is positive but finite, profit maximization by each patent holder requires that:

$$\delta V_{L,t} = V_{I,t} + \frac{a_L}{\kappa} w_t^N. \tag{B2}$$

Because (B2) holds, (B1) becomes:

$$\rho V_{I,t} = \pi_{I,t} + \dot{V}_{I,t} - I_t V_{I,t}. \tag{B3}$$

On the other hand, the no-arbitrage condition between the stock of a licensor firm and a riskless asset is given by:

$$\rho V_{L,t} = \pi_{L,t} + \dot{V}_{L,t} - I_t V_{L,t}. \tag{B4}$$

Because leading firms in the Northern market undertake licensing activities in the Y–M model, the Northern labor-market-equilibrium condition becomes:

$$\frac{1}{\lambda w_t^S} n_t^N + a_I I_t (n_t^N + n_t^S) + \iota_t \frac{a_L}{\kappa} n_t^N = L^N. \tag{B5}$$

[1] In the Y–M model, the stock price of a leader firm in the Northern market does not contain the cost of licensing activities, $(a_L/\kappa)w_t^N$. However, this cost must be included in the arbitrage condition because firms that undertake licensing efforts must pay this cost at each instant of time.

The Southern labor-market-equilibrium condition is given by:

$$\frac{1}{\lambda w_t^S} n_t^S = L^S. \tag{B6}$$

Next, we derive the transition equation of goods between the Northern market and the Southern market. This equation is given by (6) in the text, that is:

$$\dot{n}_t^S = \iota_t n_t^N - I_t n_t^S, \tag{B7}$$

and $n_t^N = 1 - n_t^S$.

From (B3), the free-entry condition into the innovation race (3), $V_{I,t} = w_t^N a_I$, and the profit of the leader firms in the North market, $\pi_{I,t} = (1 - w_t^N/\lambda w_t^S)$ (see page 9), we obtain:

$$\frac{\dot{V}_{I,t}}{V_{I,t}} = \rho + I_t - \frac{1 - w_t^N/\lambda w_t^S}{w_t^N a_I}. \tag{B8}$$

On the other hand, substituting the zero-profit condition in the licensing activities, (B2), and the profit of a licensor firm in the Northern market, $\pi_{L,t} = (1 - 1/\lambda)$ (see page 9) into (B4) yields:

$$\frac{\dot{V}_{L,t}}{V_{L,t}} = \rho + I_t - \frac{\delta(1 - 1/\lambda)}{(a_I + a_L/\kappa)\, w_t^N}. \tag{B9}$$

Moreover, substituting the zero-profit condition into the licensing activities, (B2), and the free-entry condition into the innovation race (3), $V_{I,t} = w_t^N a_I$ results in $\delta V_{I,t} = (a_I + a_L/\kappa)\, w_t^N$. Thus, we obtain:

$$\frac{\dot{V}_{I,t}}{V_{I,t}} = \frac{\dot{V}_{L,t}}{V_{L,t}} = \frac{\dot{w}_t^N}{w_t^N}. \tag{B10}$$

Therefore, from (B8) and (B9), we obtain:

$$\frac{1 - w_t^N/\lambda w_t^S}{w_t^N a_I} = \frac{\delta(1 - 1/\lambda)}{(a_I + a_L/\kappa)\, w_t^N}.$$

This equation determines the relative wage, w_t^N/w_t^S, as follows:

$$\frac{w_t^N}{w_t^S} = \lambda\,(1 - \Phi)\,, \text{ where } \Phi \equiv \frac{(1 - 1/\lambda) a_I \delta}{(a_I + a_L/\kappa)}. \tag{B11}$$

From (B6), $w_t^S = n_t^S/\lambda L^S$. Substituting this into (B11), we obtain:

$$w_t^N = \frac{n_t^S}{L^S}(1-\Phi). \tag{B12}$$

Therefore, the following relation holds:

$$\frac{\dot{w}_t^N}{w_t^N} = \frac{\dot{n}_t^S}{n_t^S}. \tag{B13}$$

Moreover, from (B11) and (B12), we can calculate the following:

$$\frac{\pi_{I,t}}{V_{I,t}} = \frac{1 - w_t^N/\lambda w_t^S}{w_t^N a_I} = \frac{\Phi}{1-\Phi}\frac{L^S}{a_I n_t^S}. \tag{B14}$$

From (B8), (B10), (B13), and (B14), we obtain the following dynamics for n_t^S:

$$\frac{\dot{n}_t^S}{n_t^S} = \rho + I_t - \frac{\Phi}{1-\Phi}\frac{L^S}{a_I n_t^S}. \tag{B15}$$

By substituting the transition equation of n_t^S, (B7), into (B15), we obtain the following:

$$(\rho + 2I_t)n_t^S - \iota_t(1-n_t^S) - \frac{\Phi}{1-\Phi}\frac{L^S}{a_I} = 0.$$

By making use of (B5) and this equation, we can eliminate ι_t and obtain the following:

$$\left(2n_t^S + \frac{a_I}{a_L}\kappa\right) I_t = \frac{(L^N + L^S)\kappa}{a_L} + \frac{\Phi}{1-\Phi}\frac{L^S}{a_I} - \frac{L^S\kappa}{a_L}\frac{1}{n_t^S} - \rho n_t^S. \tag{B16}$$

This equation defines the innovation activity level, I_t, as a function of n_t^S. Consequently, substituting this function, $I(n_t^S)$, into (B15), we obtain the one-dimensional dynamics of n_t^S.

First, we consider the steady state of this dynamics of n_t^S. From (B15), at the steady state, the following holds:

$$\rho n^S + I n^S = \frac{\Phi}{1-\Phi}\frac{L^S}{a_I}, \tag{B17}$$

where n^S and I are the steady-state values of n_t^S and I_t, respectively. By using this, we can eliminate $I_t n_t^S$ from the left-hand side of (B16) and obtain:

$$2\left(\frac{\Phi}{1-\Phi}\frac{L^S}{a_I} - \rho n^S\right) + \frac{a_I}{a_L}\kappa I = \frac{(L^N + L^S)\kappa}{a_L} + \frac{\Phi}{1-\Phi}\frac{L^S}{a_I} - \frac{L^S\kappa}{a_L}\frac{1}{n^S} - \rho n^S.$$

By rearranging this expression, we obtain the following:

$$\frac{a_I}{a_L}\kappa I = \frac{(L^N + L^S)\kappa}{a_L} - \frac{\Phi}{1-\Phi}\frac{L^S}{a_I} - \frac{L^S\kappa}{a_L}\frac{1}{n^S} + \rho n^S. \tag{B18}$$

We can depict (B17) and (B18) as in Figure B-1. Equation (B17) can be drawn as the downward sloping curve and (B18) can be drawn as the upward sloping curve. Therefore, the unique steady state that Yang and Maskus examined exists. From (B16), we know that $\lim_{n_t^S \to 0} I(n_t^S) = -\infty$. Therefore, we can depict the dynamics of n_t^S, (B15) as in Figure B-2. It is obvious that the steady state is totally unstable. However, because the number of goods produced in the Southern market is not a jump variable, the economy cannot approach the steady state unless the economy is accidentally at the steady state at the start of the economy. This is almost certain not to occur. In sum, the steady state of the Y–M model cannot be attained.

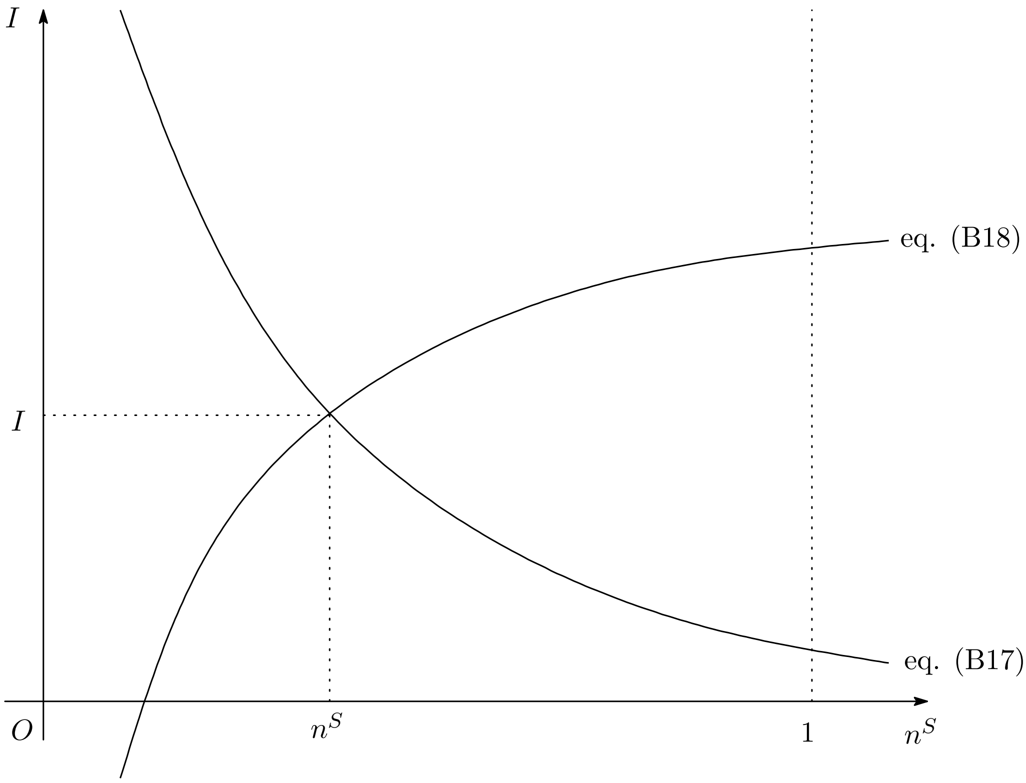

Figure B-1: Determination of the steady-state values of n_t^S and I_t

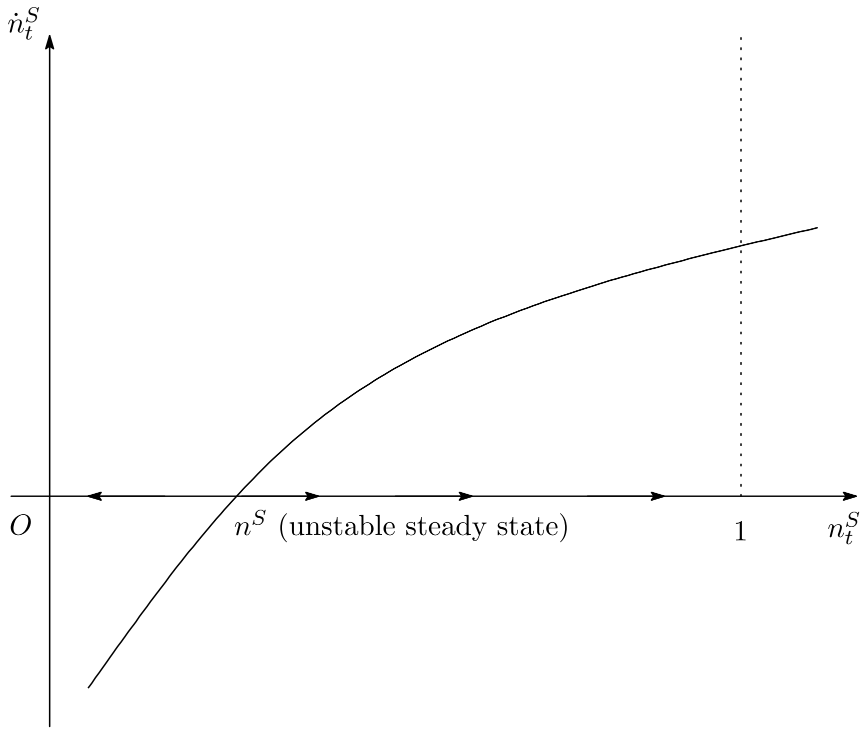

Figure B-2: The phase diagram of n_t^S in the Y–M model

C Appendix: Additional Numerical Examples

In this appendix, we present some additional results on the numerical calculation of the relative wage between the North and the South, which is mentioned in the text. First, figures C-1 and C-2 illustrate the relative wage for some available ranges of κ in various parameter examples. In all examples, we set the parameters as $a_L = 3.5, \delta = 0.6, \lambda = 1.5, L^N = 1$, and $\rho = 0.05$. The relative wage $\bar{w}^S/\bar{w}^N$ is monotonically increasing with a rise of κ in any case. This means that cost-reducing effect induced by a rise of κ tends to narrow the wage gap between the North and the South. Next, figures C-3 and C-4 plot the relative wages in some plausible range of δ. We set the parameters as $a_L = 3.5, \kappa = 0.51, \lambda = 1.5, L^N = 1$, and $\rho = 0.05$. The relative wage tends to be decreasing with a rise of δ in this case. This is partly due to the decreasing Northern wage with δ. The figures show that the distribution effects on the Southern relative wage are likely to be negative in a reasonable range of parameters. Thus, these results support the conclusion in the text about the effects on the relative wage of strengthening IPR protection.

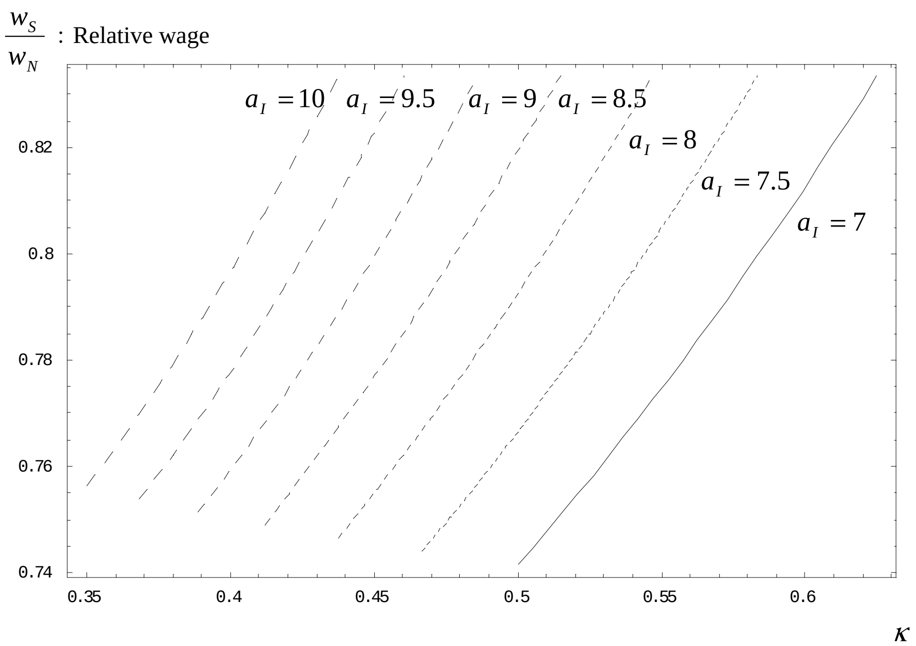

Figure C-1: Relative wage and change of κ for $L^S = 2$

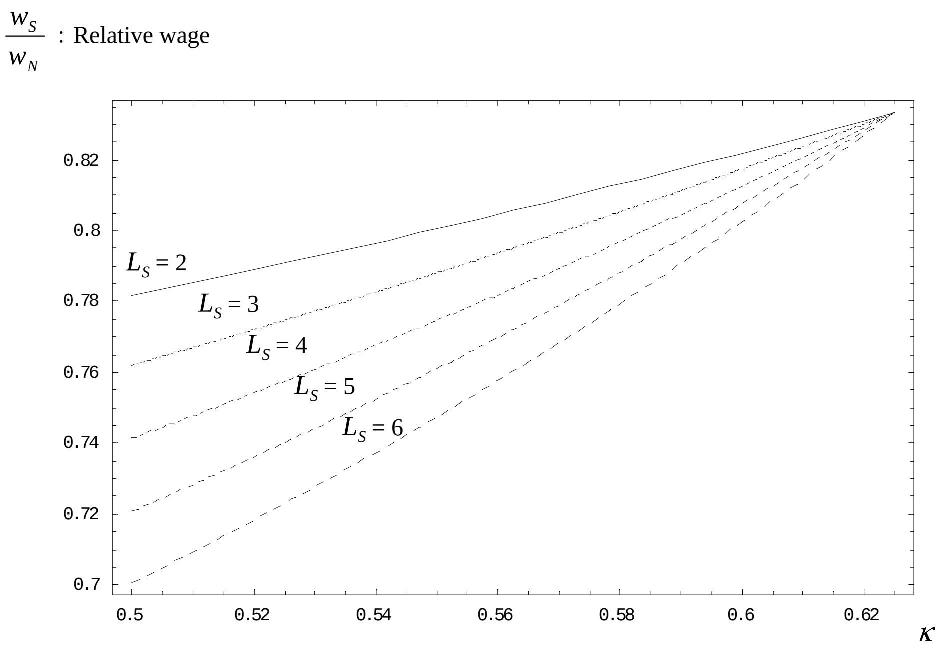

Figure C-2: Relative wage and change of κ for $a_I = 7$

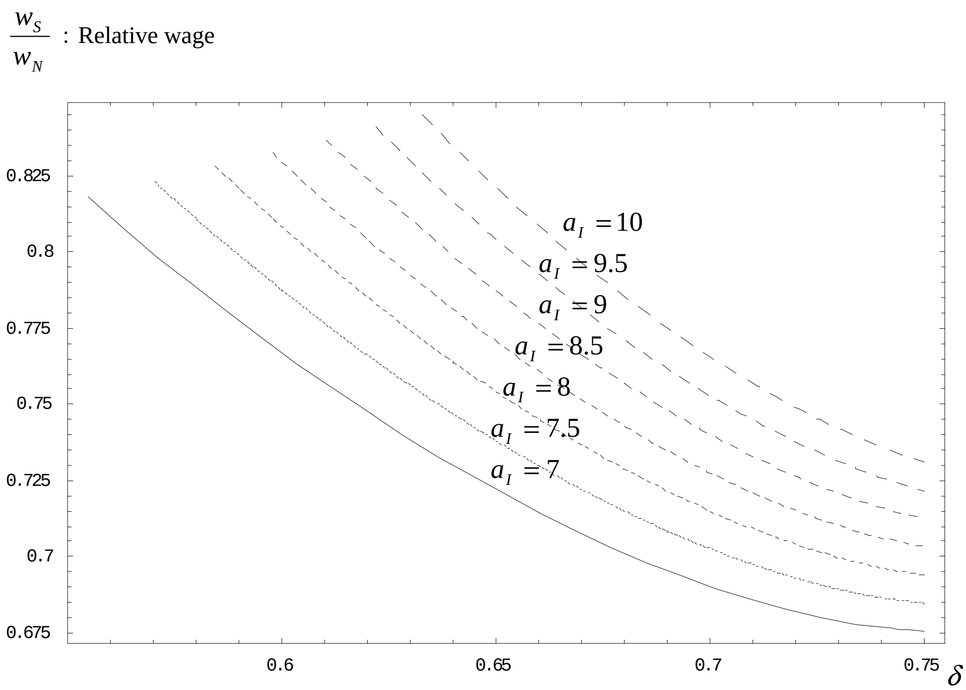

Figure C-3: Relative wage and rent share of licensors for $L^S = 3$

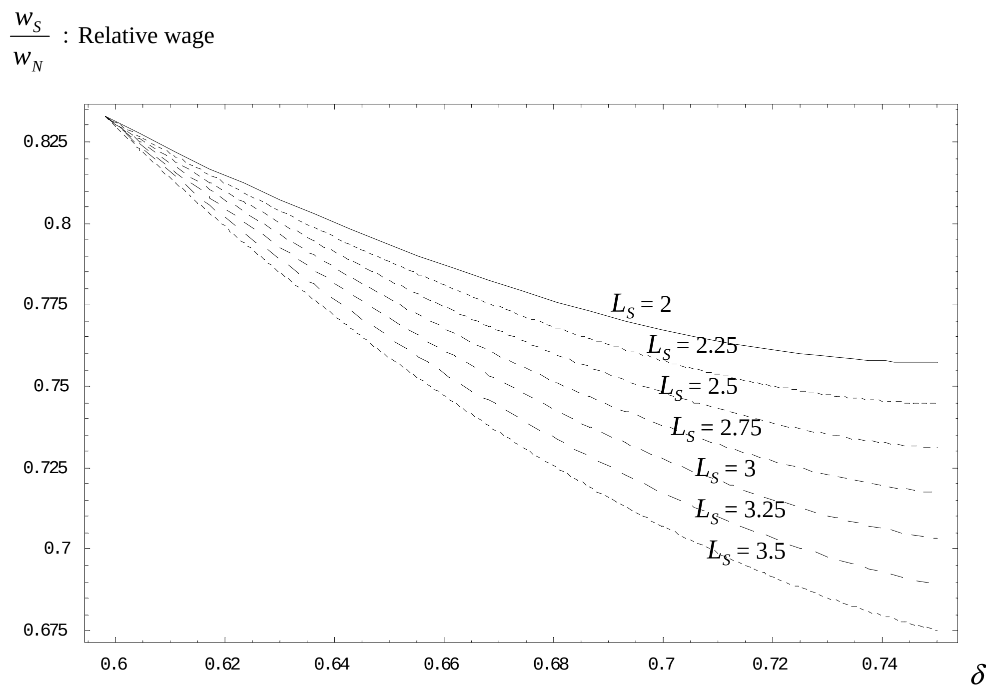

Figure C-4: Relative wage and rent share of licensors for $a_I = 8.5$