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Abstract

This paper develops a quality-ladder type dynamic general equilibrium model with endogenous innovation and technology licensing as a major source of international technology transfer in developing countries. Examining the dynamic characteristics of the model fully, we explore the short- and long-run effects of both an improvement in the probability of reaching a licensing agreement with a given effort and an increase in the license fee rate. The model shows that the former promotes innovation and technology transfers in both the long and short run, while the latter discourages them.

Keywords: Innovation; Licensing; Technology transfer

JEL classification: F43; O33

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1 Introduction

Advanced technologies possessed by firms in developed countries are necessary for the industrialization of developing countries. Many countries that are now developed benefited from imported advanced technologies. For example, countries in Europe and the US imported many technologies from Britain, while Japan and Korea acquired technologies from Western economies. As these examples show, technology acquisition is indispensable for development.

Advanced foreign technologies are transferred with licensing, foreign direct investment (FDI), illegal imitation and trade as typical examples. Japan and Korea preferred licensing to FDI, especially in the early stages of their development following World War II.[1] In this paper, we construct a quality-ladder type dynamic general equilibrium model with endogenous innovation and technology licensing to investigate the international transfer of technology through licensing activities.

Based on the product-cycle model developed by Grossman and Helpman (1991), Yang and Maskus (2001) have already constructed a dynamic general equilibrium model in which the channel of technology transfer is licensing. Yang and Maskus (2001) explored how strengthening intellectual property rights (IPR) protection affects innovation and technology transfer through licensing. They showed that stronger IPR raise innovation and technology transfer through the reduction 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 Korea, as both 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, we further enhance their analysis in two respects. First, differently to Yang and Maskus, we consider the situation where the effort of firms that

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

aim to be granted a license is important in reaching agreement on the license. In Yang and Maskus' model, it is assumed that the North, which possesses advanced technologies, uses its resources for licensing activities. However, Peck (1976), Ozawa (1980), and Enos and Park (1988) argue that most licensing efforts are undertaken by recipient countries, as occurred in the case of Japan and Korea.[2] Therefore, to ensure the model matches better with the experiences of these countries, we modify Yang and Maskus' model in the following way: the parties who must make the effort to reach license agreement are firms in the recipient country (the South), and they must use the resources of the recipient country.

Second, and theoretically more importantly, we analyze not only the steady state but also the transitional dynamics of the model. Yang and Maskus analyzed only the steady state and consequently did not explore the dynamic nature of their model. With the exception of Helpman (1993) and Arnold (2002), other studies on international technology transfer also often focus only on the steady state. To focus on the steady state can be allowed as a first approach if the dynamic system of the model has a stable equilibrium path to the steady state. However, the dynamic system actually becomes totally unstable in Yang and Maskus' setting (where the North, which has advanced technologies, uses its resources for licensing activities).[3] As a result, their model has no equilibrium path converging to the steady state. By contrast, we show that there exists a stable equilibrium path; that is, a stable saddle path in our setting (where firms in the recipient country must make the effort to gain licenses and use the resources of the recipient country). Thus, our setting where firms in the recipient country make the effort not only corresponds to actual experience but also appears reasonable from the viewpoint of macroeconomic theory.

Because the instability of the steady state in Yang and Maskus' model implies that the economy never leads to the steady state analyzed in their work, we reexamine their policy

[2] 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).

[3] The proof is available from the authors on request.

analysis using a model with a stable equilibrium path, as developed in this paper. By reinterpreting their model somewhat, we separately explore the effects of the following changes: namely, an improvement in the "smoothness" of the licensing negotiation, which is represented by an increase in the probability of reaching license agreement with a given negotiation effort, and a rise in the license fee rate. Both are regarded by Yang and Maskus as a consequence of strengthening IPR protection. Based on the dynamic analysis of the model, we explore both the long- and short-run effects. Examining the short-run effect is one advantage of our approach because many studies, including Yang and Maskus, analyzed only the steady state representing the long-run state of the economy.[4]

The short-run effects are well deserving of consideration for at least two reasons. First, there is the possibility that the short-run effects will run in the opposite direction to the long-run effects. If a policy has opposite effects in the long run and in the short run, the policy must be assessed more carefully.[5] Second, the speed of convergence suggested by endogenous growth models may be slow.[6] The low speed of convergence is also supported empirically. For example, in the context of convergence across regions in some countries, Barro and Sala-i-Martin (2004) conclude that "it takes 25–35 years to eliminate one-half of an initial gap in per capita incomes" (p.496). The low speed of adjustment after a policy change implies that the short-run effects of the change can be more important than the long-run effects.[7] Thus, the analyses of the short-run effects are quite meaningful to economists and policy makers.

[4]Dinopoulos and Segerstrom (2006) examined the short-run effects of strengthening IPR protection on innovation, although they also only focused on the steady state.

[5]This is also true of Helpman's (1993) model. In that model, strengthening intellectual property rights protection enhances innovation in the short run but reduces innovation in the long run. Therefore Helpman (1993) fully examined the short-run effect.

[6]See, for example, Steger (2003). He examined the speed of convergence in the quality-ladder type endogenous growth model in Segerstrom (1998) and showed that the speed of convergence is low through calibration of the model. Our North–South growth model is also based on a quality-ladder model.

[7]Many theoretical studies of macroeconomics regarded the speed of convergence as important and examined it in the context of the various types of growth models. In particular, Ortigueira and Santos (1997) examined the speed of convergence in endogenous growth models with adjustment costs and showed that the speed of convergence may be slow. This result implies that it is necessary to examine the transitional dynamics as well as the steady states.

As a result of the analysis, we obtain two main conclusions. First, an improvement in the smoothness of licensing negotiation encourages innovation and technology transfer in both the long and short run. Second, an increase in the license fee rate is detrimental to innovation and technology transfer in both the long and short run. In addition, we show that an improvement in the smoothness of licensing negotiation increases the wage rate in the South, while the increase in the license fee rate reduces the wage rate. Because it is difficult to determine the effects on the relative wage rate, we present some numerical examples concerning the relationships between these changes and the relative wage rate.

Although we investigate technology transfer to developing countries through licensing, the present paper also relates to earlier studies that deal with the issue of innovation and technology transfer through channels other than licensing. For instance, Helpman (1993) constructed a dynamic general equilibrium model in which Northern firms innovate and Southern firms imitate. He showed that although stronger IPR increase Northern innovation in the short run, they reduce it in the longer run.[8] More recently, Dinopoulos and Segerstrom (2006) developed a dynamic North–South model with scale-invariant growth and endogenous imitation.[9] On the other hand, some studies incorporated FDI into their models. Lai (1998) showed that strengthening Southern IPR increases innovation and technology transfers when FDI is the channel of transfer but reduces such transfers when imitation is the channel of transfer. By contrast, Glass and Saggi (2002b) showed that stronger IPR decrease the level of innovation and technology transfer in a dynamic model where both imitation and FDI are the channels of production transfer. Because these models did not introduce licensing activities in their frameworks, our model will complement these studies and enable us to understand innovation and technology transfer better.[10]

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[8] Arnold (2002) suggests that Helpman's (1993) results concerning the long-run effect no longer hold when labor mobility among industries in the North is imperfect.

[9] In order to remove scale effects, Dinopoulos and Segerstrom (2006) assumed like Segerstrom (1998) and Li (2001) that the difficulty of R&D increases with innovation (and imitation). Moreover, Sener (2006) extended the scale-invariant growth model of Dinopoulos and Syropoulos (2006), which includes rent protection activities, into a North–South product-cycle model.

[10] Glass and Saggi (2002a) examined a dynamic general equilibrium model in which firms can choose the

The remainder of the paper is structured as follows. Section 2 describes the model. In 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- and long-run effects of a change in the smoothness of licensing negotiations and the license fee rate on the equilibrium path. In this section, we also compare the results with those in Yang and Maskus. In section 5, we make a comparison between our technology licensing model and the endogenous imitation models. Section 6 provides some concluding remarks.

2 The Model

We develop a dynamic general equilibrium model based on Yang and Maskus (2001), where licensing is introduced into a quality-ladder model as a means of international technical diffusion. Our model has the same basic structure as Grossman and Helpman (1991, ch.12).[11]

Consider an economy consisting of two regions, North and South, 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, the process of climbing the quality ladder requires research and development by firms. We choose our units appropriately so that the quality at time $t = 0$ equals unity in all industries.

mode of technology transfer (FDI or licensing). However, in contrast to our study and those discussed earlier, they assumed that the two countries were identical.

[11] Although a '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.

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 the instantaneous utility at time t. We specify the instantaneous utility function as:

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

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 that 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, the 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 the interest rate $r(t)$ always corresponds to the subjective discount rate ρ.[12]

Turning to the production side, we assume that each economy has a single primary production factor in the form of 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 discussed below.

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 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 to the market. Hence, only Northern followers drive quality improvements. The Northern firms that succeed in innovating and becoming quality leaders

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

acquire patents 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 an invention of a 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 legally sell the product to the entire world. 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 the Southern licensee receives an exogenously determined share of the rent from sales, which reflects the bargaining power between licensees and licensors. That is, Southern firms can retain a greater fraction of the rent if they possess greater bargaining power. The contracts between Northern and Southern firms forbid every Southern licensee from breaking the agreement and imitating the blueprints to avoid paying the license fee, 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 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 perfectly enforced in the South, it is economically and technologically impractical for Southern firms to copy the Northern firms' products manufactured in the North. On the other hand, weaker IPR protection in the South may not prevent Southern followers from imitating a state-of-the-art product that is licensed to a Southern firm.[13] However, assuming that unauthorized imitators are obliged to compete with the rightful licensee in a Bertrand fashion, they earn no positive profits as both types of firm face the same marginal costs. This implies that imitators can never pay imitation costs as long as they are strictly positive. Therefore, no imitator intends to enter the market. The

[13]Grossman and Lai (2004) explored the reason why IPR 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.

second assumption is that inward FDI is banned by the Southern governmental authorities or is unfeasible.[14] 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 Southern firms with the ability to produce goods of the second-highest quality. These products can potentially be competitive against the state-of-the-art products, despite the lower quality, because the equilibrium wage rate in the South is lower than in the North. Then, to exclude 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 equilibrium, two possible types of market activity exist: either the Southern licensee produces the highest-quality good under license, or the Northern leader 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 a Bertrand fashion if it enters the product market, no licensor has an incentive to continue producing the good for himself 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 N, which is independent of whether the targeted market is N or S. Therefore, the research efforts of entrepreneurs indiscriminately range over all ω because the expected gains from innovation are equal between industries, provided

[14] In practice, Japanese authorities adopted a restrictive policy towards FDI in the early stages of the development process following World War II in order to encourage foreign firms to license advanced technology to Japanese firms. See Hoekman, Maskus, and Saggi (2005) and Peck (1976).

that the leaders in each market are symmetrical; that is, provided that all leaders are equally exposed to the danger of replacement by the next higher-quality product and that all Northern leaders succeed equally in reaching agreement on licensing.

Under the pricing strategy (2), Northern leaders and Southern licensees make different profits because 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, 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:

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

Similarly, the formation of a license contract follows a Poisson process. The negotiations leading to agreement on a new license contract between the licensor and the licensee and adaptations to a new technique after the agreement are most likely time consuming. However, the lengths of time involved may be uncertain. Therefore, 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 a licensing agreement that is optimally chosen by the Southern firm.[15] We let κ be a parameter representing circumstances that influence the speed of negotiations and subsequent adaptations to a licensed technique. For example, the speed of progress in a license negotiation may depend on the degree of establishment of laws and regulations on the contract in the developing country. Moreover, strict enforcement of punishment on infringement of a contract may ease the patent holder's fear involved with licensing and thus enable swift agreement between the parties concerned. One possibility is that the educational level in the developing country may affect the ability to adapt an unknown technique. Hence, we regard κ as an index reflecting all of these factors and representing the "smoothness" of negotiations.

If a Northern firm and a Southern firm agree on a license, they split the expected present value of joint profits earned by the Southern firm, $V_{L,t}$. The Southern firm i, which undertakes licensing negotiations at the intensity $\tilde{\iota}_i$ during a time interval dt, receives an expected gain of $(1-\delta)V_{L,t}\tilde{\iota}_i dt$, where $0 < \delta < 1$ denotes the exogenously determined license fee rate. Hence, a Southern firm under licensing negotiations decides on an intensity $\tilde{\iota}_i$ 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, the Southern firm's decision requires a zero-profit condition as follows:

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

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

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 firm will prefer not to grant a license. Therefore, for a license contract to take place at time t, the stock value of a Northern licensor must exceed that of the Northern current leader that has not yet granted a license: 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 inflow into the S market is equal to the measure of newly licensed industries in 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 occurs at time t. 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 $I_t = \sum_i \tilde{I}_i$. For 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:

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

We now 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 probability that innovation succeeds in the industry in the time interval, $I_t dt$. Provided that these idiosyncratic risks are properly 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 of a firm in the S market and a riskless asset is then:

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

The no-arbitrage condition for the stock of Northern leaders in the N market is, however, more 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. 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

We now derive the equilibrium path of the economy. First, we compute innovation 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 innovation 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 remaining 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 both research and licensing do not 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 in order to attain a certain probability of success and that the South is endowed with relatively abundant labor. In greater detail, the conditions are:

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

Furthermore, to ensure that the 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. This economy may then 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:

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

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). The condition (5) must then be imposed on $\bar{V}_L$ and $\bar{V}_I$ so that the steady state is attainable. Moreover, in equilibrium, the Southern wage rate must be less than the Northern wage rate, while the Northern wage rate cannot exceed the Southern wage rate 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 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 where 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 Effects of Changes in the Smoothness of Negotiation and Rent Distribution

In this section, we investigate the effects of an improvement in the smoothness of license negotiation and an increase in the license fee rate. In the first part of this section, we analyze the long- and short-run effects of the improvement in the smoothness of license negotiation. Later, we examine the long- and short-run effects of higher license fee rates.

4.1 An improvement in the smoothness of license negotiation

The improvement in the smoothness of license negotiation is expressed by an increase in κ. First, we examine the long-run 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 an increase in 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 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 a change in 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, we can examine how an increase in κ affects the remaining variables. First, we calculate the long-run effect on innovation. As the innovation intensity at time t satisfies (11), taking the derivative of $\bar{I}$ with respect to κ, we obtain 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 in 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 innovation, the third 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 third negative effect, and the increase in κ induces greater innovation in the long run.

Intuitively, an increase in κ has two effects that lead to a decrease in 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 parentheses in equation (26). Second, there is less demand for each product and, therefore, less demand for labor from each incumbent leader. The reduction in demand occurs because the stronger incentives to undertake licensing negotiations caused by an increase in κ lead to a rise in the Southern wage rate, as verified later. An increase in the Southern wage rate 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 third terms in parentheses in equation (26). These two effects decrease labor demand from Northern incumbent leaders and, consequently, increase the labor input for R&D activities in the steady state.

In addition, an increase in κ positively affects 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 rise in κ on $\bar{\iota}$ is given by:

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

Moreover, 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: *An improvement in the smoothness of license negotiation promotes both innovation and licensing in the long run.*

Furthermore, our model can answer another related and important question: does the improvement encourage innovation and licensing in the short run as well as the long run? Many related studies are unable to respond to this kind of question because they focus only on the steady state. In contrast, our analysis enables us to examine the short-run effect because it fully describes the progress of the economy.

To investigate the short-run effect, we exploit the same approach as Helpman (1993).[16] 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. We can calculate the first-order response of $(n_t^S, V_{L,t})$ to the marginal increase in κ from a linearized system of the differential equations (13) and (14) around the steady-state value.

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

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 eigenvalue, is also positive. 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 can derive the effect on 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 the increase in κ 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 with an increase in κ in the short and 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 have the short-run effect on licensing intensity as follows:

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

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

Proposition 3: *The improvement in the smoothness of license negotiation promotes both innovation and licensing in the short run as in the long run.*

How are the wages in both countries affected by an increase in κ in the steady state? As discussed, the Southern wage rate in the steady state rises unambiguously. Using equation (4), we obtain:

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

Turning to the relative wage rate between the North and the South, we may have difficulty in computing the effect because the impact on the Northern wage rate is unclear. Therefore, by using some numerical examples of parameters, we have examined the effect on the relative wage rate (see figure 2).[17] As a result, we found that the relative wage rate of the South is monotonically increasing with an increase in κ for all parameter values chosen.

4.2 A higher license fee rate

An increase in the license fee rate is represented by an increase in δ. The higher license fee rate means that the Northern licensors can enjoy a larger monopolistic rent after the licenses, whereas the Southern licensees receive a smaller rent. In the first part of this subsection, we examine the comparative statics with respect to δ. Next, we show the short-run effect of the increase in δ on innovation and licensing agreements by exploiting the same approach as employed in the previous subsection.

In order to derive the long-run effects, we first compute the derivative of $\bar{n}^S$ and $\bar{V}_L$ with

[17]Figure 2 is an output of the numerical calculation. In the figure, 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.

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 an increase in share of Northern rents.

Using the above derivatives, we 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 in δ affects $\bar{I}$ through three channels: a change in $\bar{n}^S$, a direct effect, and a change in $\bar{V}_L$. An intuitive interpretation is as follows. First, as shown, a higher δ results in a lower $\bar{n}^S$; that is, more leaders begin 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 lower innovation intensity. The first term in parentheses in (33) represents this effect. Second, the higher δ discourages Southern followers from pursuing licensing efforts and reduces the Southern wage rate because of its lower return, all other things remaining unchanged. The lower Southern wage rate obliges the incumbent leaders to charge a lower price and generates additional product demand. As a result, Northern labor demand from each incumbent leader is also increasing with δ. The second and the third terms in parentheses in (33) represent the 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 license fee rate 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. Using 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 an increase in the license fee rate.

Finally, we examine the effect of an increase in δ on the Southern wage rate and the relative wage rate 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 rate down in the steady state. Moreover, we ascertain the tendency of the effects on the Southern relative wage rate by using some numerical examples (see figure 2). From the results, we found under reasonable ranges of parameters that the Southern relative wage rate is monotonically decreasing with δ.

The above results are summarized as the following proposition.

Proposition 4: *A higher license fee rate reduces both innovation and licensing in both the long and short run.*

This proposition suggests that an excessively high license fee rate results in low licensing efforts and interferes with the smooth transfer of production to the South. In addition, as the Southern wage rate falls with the license fee rate, manufacturing per firm in the N market increases. These two effects lead to greater production in the North, which discourages innovation through a decrease in labor inputs for research. As a result, lower quality improvements take place, and the expected duration of existing products increases.

4.3 Discussion

How can these results be compared with those of Yang and Maskus? Yang and Maskus have argued that strengthening IPR protection in the South promotes innovation and technology licensing in the long run. They do so by assuming that stronger IPR protection in the South has two influences: an increase in the probability of success in licensing for a given resource spending and an increase in the licensor's share of rents. Yang and Maskus named the former "the size effect" of strengthening IPR and the latter "the distribution effect". In addition, they concluded that "the size effect and the distribution effect would enhance each other in encouraging more licensing and more innovation in response to stronger Southern protection of intellectual property" (Yang and Maskus, 2001, p.182).

In comparison with Yang and Maskus, our analysis in section 4.1 shows that an improvement in the smoothness of licensing negotiation, corresponding to the size effect in Yang and Maskus' analysis, encourages innovation and licensing. Therefore, our analysis of proposition 2 can be interpreted as proof that Yang and Maskus' conclusion that the size effect of strengthening IPR encourages innovation and licensing in the long run holds, even if their model is modified to have a stable path converging to the steady state. Moreover, we obtain a richer conclusion on the short-run effects than Yang and Maskus. Thus, one can regard our analysis in section 4.1 as reinforcing and extending the Yang and Maskus argument on the size effect induced by stronger IPR protection.

In contrast, our analysis in section 4.2 shows that an increase in the license fee rate discourages innovation and licensing in the long run, as opposed to the analysis of the distribution effect in Yang and Maskus. We can interpret causes of this significant difference between our analysis and Yang and Maskus as follows: in a Yang and Maskus setting, Northern patent holders take an active part in the technology transfer to developing countries. Therefore, when tighter IPR induce a higher rent share for licensors, Northern leaders have more incentive to engage in license activities. This accelerates both licensing and innovation. On the other hand, in our setting, Southern firms that hope to be granted a license play an important role in the technology transfer. Because a higher license fee rate leads to a lower rent share for licensees, Southern followers have fewer incentives to engage in license negotiation activities under the higher license fee rate. This slows down both licensing and innovation. Consequently, our results concerning an increase in the license fee rate lie opposite to that in Yang and Maskus. Thus, from our analysis in section 4.2, one can draw the conclusion that Yang and Maskus' argument concerning the distribution effect is not robust and is crucially dependent on their assumption that patent holders themselves make an effort to license the Southern firms to sell the products. From this comparison between our model and that in Yang and Maskus, we can surmise that whether an increase in δ enhances technology transfer and innovation depends largely on who plays an important role in technology transfer. In order to obtain a more general result, we need to examine the effect of the licensing fee in a more general model where Northern firms, as well as Southern firms, devote their resources to licensing activities. Examination of such a general model remains an important task for future study. We provide a related discussion about this general model in the conclusion.

5 A Comparison with Models with Imitation

In this subsection, in order to show the differences between licensing and imitation as alternative channels that transfer technology from the North to the South, we compare the characteristics and results of the present technology licensing model with such an imitation model as Grossman and Helpman (1991, ch.12).

The basic structure of our model is similar to the North–South quality-ladder model with endogenous innovation and imitation.[18] We can obtain a model where the channel of technology transfer is imitation by making a few changes in the present licensing model. Envisage that Southern follower firms in our model spend labor not to negotiate a licensing agreement with patent holders but to imitate products. We then interpret ι as the probability of success in imitation and interpret $w^S a_L/\kappa$ as the unit cost of imitation. In the case of technology transfer through imitation, a Southern firm can earn all of the monopoly profits without paying a license fee at each point of time if the firm succeeds in the technology transfer, while a Northern innovator cannot obtain profits after the success of imitation in the industry. If we set $\delta = 0$ in equations (4) and (8), we could consider the equations to be the zero-profit condition for the imitation activities and the no-arbitrage condition concerning the stocks of the Northern firms, respectively. Moreover, we note that our model can be regarded as a model with endogenous innovation and imitation by ignoring condition (5).

In fact, it is the existence of the license fee and the condition (5) that are a key feature in separating our technology licensing model from other endogenous imitation models. In the case that a Southern follower firm offers a Northern patent holder a license contract, we

[18]The similarity between licensing and imitation in our model was pointed out by an anonymous referee.

consider the possibility that the Northern patent holder refuses the offer as discussed above. For example, if the license fee rate δ were zero, a patent holder would never enter into a license contract. As a result, no equilibrium with positive licensing would exist in the case where the license fee rate is too low. To exclude this possibility and ensure a sufficiently high license fee rate, we imposed the condition (5). As long as this condition is satisfied, reaching license agreement is beneficial not only to the Southern firm granted the license but also to the Northern patent holder. Meanwhile, if a Southern firm imitates the design of a state-of-the-art product without the permission of the patent holder, then we do not have to take into account the possibility that the Southern firm fails in the imitation activity through the objections of the patent holder. Therefore we do not need to impose a condition corresponding to condition (5) in the technology licensing model. However, in the case of technology transfer through imitation, a Southern imitator benefits from succeeding in the imitation at the cost of the monopolistic rent of the Northern patent holder.

By utilizing the similarities between our technology licensing model and endogenous imitation models, and the results of sections 4.1 and 4.2, we can compare the effects of an increase in κ and δ in the case of licensing with those in the case of imitation that corresponds to the model where δ is set at 0 and condition (5) is not imposed.[19] Applying proposition 3 to the case of $\delta = 0$, we can show that a decrease in imitation cost (an increase in κ) promotes innovation and imitation in both the short and long run. Hence, it is concluded that whether the channel of technology transfer is licensing or imitation, a decrease in cost for technology transfer enhances not only technology transfer but also innovation. In addition, according to proposition 4, the intensities of innovation and licensing, $\bar{I}$ and $\bar{\iota}$, are decreasing functions of δ. Therefore the intensities are maximized at $\delta = 0$. This implies that innovation, as well as technology transfer, is more active when the channel of technology transfer is imitation than when the channel of technology transfer is licensing. It may be somewhat counterintuitive

[19]Though we can obtain the results concerning innovation and imitation by using this similarity, we cannot easily obtain results concerning the relative wage rate between the North and the South and welfare, because we need to examine the dynamics of $V_{I,t}$ to derive the relative wage rate and welfare on the equilibrium paths.

that more innovation occurs in the case of imitation than in the case of licensing because the Northern innovator can receive the rent after technology transfer in the case of licensing but not in the case of imitation. The interpretation is similar to that of proposition 4: since the existence of a license fee that partly discourages Southern follower firms from acquiring advanced technologies leads to the lower frequency of technology transfer to the South, as it causes more production and fewer research activities in the North.

6 Concluding Remarks

The international transfer of technology is brought about through various channels, including licensing. This paper has presented a quality-ladder type of product-cycle model where licensing is introduced as the channel of technology diffusion. In this model, we supposed that firms in developing countries must incur costs and input resources in their efforts to win a license contract. In practice, such licensee firms often play an important role in reducing technological backwardness in recipient countries. Our model captures the activity of firms in the 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, owing to the analysis of the dynamic system, our study has yielded some results with respect to the short-run effects of a change in the parameters. Many existing studies compromise such analysis by only drawing conclusions about the long-run effects, whereas our dynamic analysis enables us to determine both the short-run and the long-run effects.

Although the model developed in this paper will assist us to comprehend better innovation and international transfer of technology through licensing, some topics are left open for future research. For instance, one could consider a "hybrid" between our model and that presented in Yang and Maskus. In that model, Northern firms could use their resources for licensing activities, for example, to monitor the transfer of technology, and the Southern firms could use their resources for licensing negotiations. To maintain simplicity, we have assumed that only Southern firms use their resources to reach a license agreement, while Yang and Maskus assumed that only Northern firms use their resources to succeed in licensing. Because the difference in assumptions generates the distinct stability property of the steady state between our model and that in Yang and Maskus, examination of the stability of the hybrid model remains an important task for future studies. Perhaps one may be able to discover a range of parameters that stand for the labor inputs of both parties necessary to the licensing activities in which the stability of the hybrid model is ensured.[20]

One could also consider an extended version of our model in the sense that licensing and another mode of technology transfer coexist. So as to focus on licensing, we have excluded channels of technology transfer other than licensing. Consequently, our analysis is restricted in the following ways. First, our licensing model does not take into account imitation activities, although these are widely observed and constitute a major source of technology acquisition in the early development stage. On that point, our results are more likely to be applied to middle-income countries than less-developed countries. Second, we have assumed that foreign direct investment is impractical. In reality, however, there are two types of middle-income developing countries: one encourages domestic firms to learn advanced technologies through licensing from firms in developed countries, whereas the other prefers FDI by multinational firms to licensing. Clearly, we take only the former as the object of our analysis. Hence, to provide a North–South technology licensing model where a mode of technology transfer exists in addition to licensing is also an important topic for future study.[21] Our model would probably then be a good starting point for these

[20] The authors thank an anonymous referee for these points.

[21] For example, Antràs (2005) has constructed a simple model such that under the environment of incomplete contracts, a Northern research firm can choose the mode of manufacturing: to transact with an independent Southern firm (licensing) or to integrate the Southern manufacturing plant vertically (multinationalizing), although the model assumed the innovation process to be exogenous for the purpose of simplicity.

explorations.

A Appendix

In this appendix, we derive the effect of an increase in κ 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:

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

As the equation $y^2 + (b_{11} - b_{22})y - b_{11}b_{22} - b_{12}b_{21} = 0$ 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:

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

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 increases. 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 $\partial I_0/\partial \kappa|_{n_0^S = \bar{n}^S, V_{L,0} = \bar{V}_L} > 0$. 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 readily 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 marginal increase in κ.

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:

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

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 means that licensing intensity at time zero reacts positively to a marginal increase in 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.

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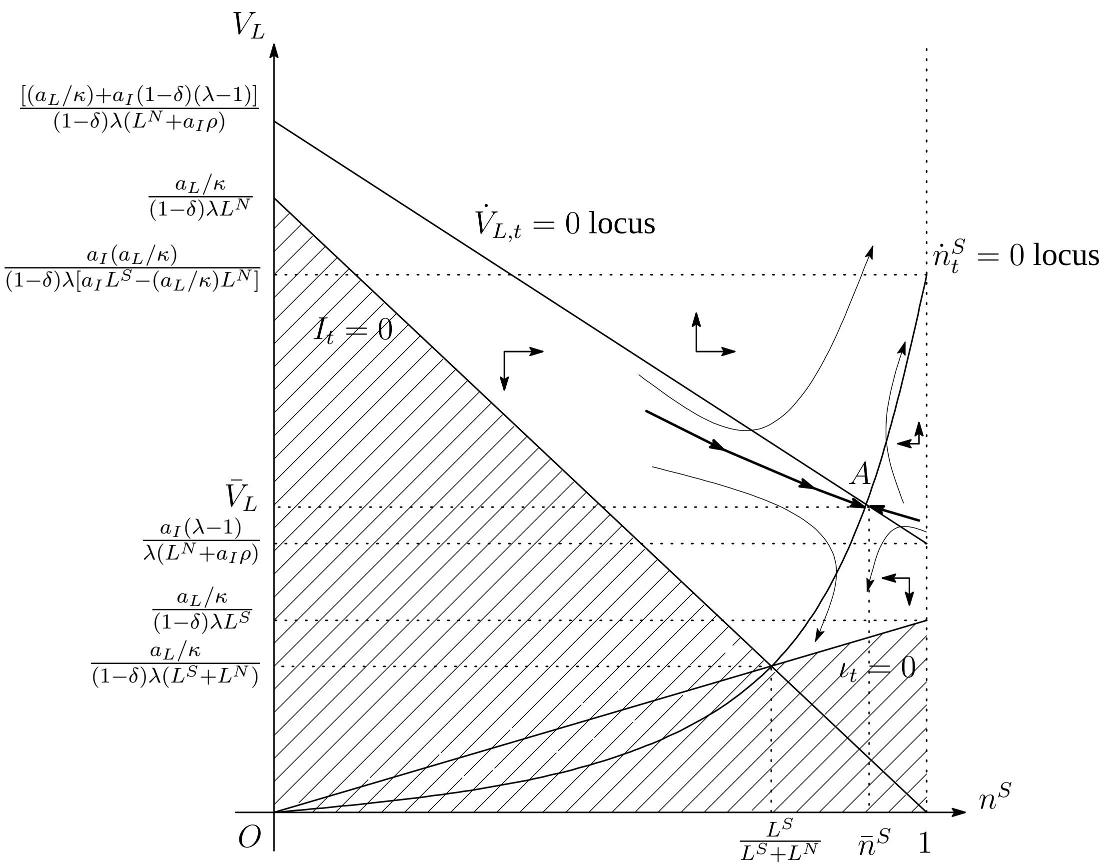

Figure 1: Phase diagram

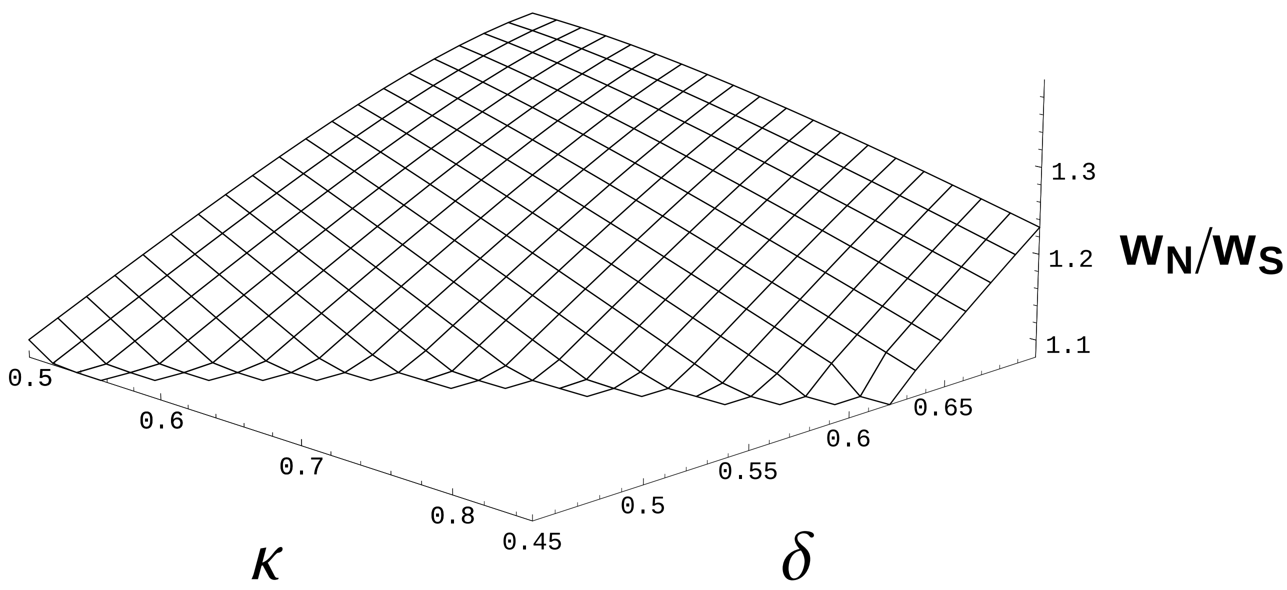

Figure 2: Relative wage rate corresponding to each value of δ and κ

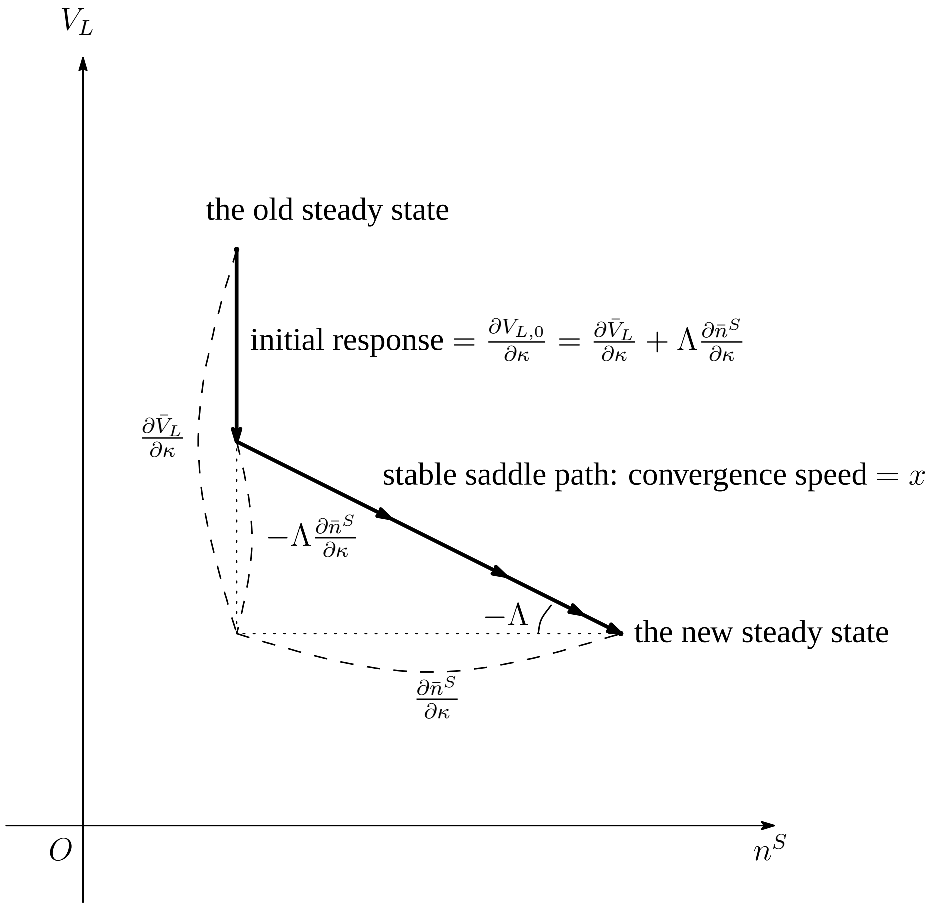

Figure 3: Response to a rise of κ at the initial time and in the long run