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ECONOMICS

PATENT EXAMINATION AND DISGUISED PROTECTION

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DISCUSSION PAPER 13.07

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ABSTRACT: This paper proposes a game theory model in which a foreign multinational corporation (MNC) and a domestic firm compete in the domestic market. In this model the domestic patent office could influence the firms' profit curves by controlling the pendency and grant probability of the MNC's patents. Hence, patent examination could be used implicitly or explicitly as a tool to protect the domestic firm and help it to catch up or even leapfrog ahead technologically. Numerical simulations are then conducted to identify potential features of such protection and to establish hypotheses for empirical testing using patent data from selected countries.

KEY WORDS: Patent Examination; Technological Leapfrog; Strategic Trade Behavior

JEL: D43, L13, O31, O34

1. Introduction

Overt discrimination against foreign inventors used to be stated clearly in patent laws. For example, according to the United States Patent Act in 1793, patent rights were only to be granted to US citizens.¹ The Act was amended in 1800 to allow the ownership of patents by foreigners who had been residents in the United States for at least two years (de Carvalho, 1995, p.16). Though this restriction on foreigners was removed in the 1836 Act, British applicants were still charged an application fee of \$500 per patent, and other foreigners were charged \$300, far more than the \$30 charge for US citizens.²

Today, such overt discrimination is removed from the patent laws of most nations. However, similar practices still exist in the form of lower grant probability and longer grant lag for foreign applications (Wineberg, 1988; Kotabe, 1992; Linck and McGarry, 1993). A recent example is the patent war between Apple and Samsung which was ignited in April 2011. Among the seven utility patents that Apple accused Samsung of patent infringement for, only one was successfully registered in the Korean patent office.³ Samsung struck back with a suit against Apple for six patent infringements.⁴ Although these six patents were successfully registered in the US patent office, they were examined on average for 4.5 years. In contrast, Apple's seven patents on average only waited for 3.8 years in the US patent office, eight months less than those for Samsung's. In the electronic industry, eight months can be long enough for the invention of a new product.⁵ Could these variations in patent examination be the consequences of discriminatory policies against foreign patents?

¹ United States Patent Act 1793, Chapter 11, Section 1.

² United States Patent Act 1836, Section 9.

³ The US patent numbers for those seven patents are 7812828, 7669134, 6493002, 7469381, 7844915, 7853891 and 7863533.

⁴ The US patent numbers for those six patents are 7668563, 6937700, 7835729, 6920602, 7050410 and 6882636.

⁵ For example, the iPhone 3GS only dominated the market for a single year before the iPhone 4 got released.

The existing literature has focused on the design of patent regimes so as to provide the best mechanism for patent protection (Helpman, 1993; Gould and Gruben, 1996; Grossman and Lai, 2004; Iwaisako, *et al.*, 2011). It is generally assumed that foreign patents receive national treatment. Even under a weak patent regime with no discrimination, imitations may occur when the imitation cost is low, and thus imitation itself is profitable (Mansfield *et al.*, 1981). Nonetheless, imitation will not occur if it requires substantial R&D investment or involves large amounts of uncertainty. In this case discriminatory policies may be employed to protect domestic inventions or imitations.

The Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) established in 1994 explicitly prohibits any such discrimination.⁶ However, empirical studies show that discrimination still exists. Webster *et al.* (2007) argue that foreign patent applications in the Japanese patent office are less likely to be granted than Japanese ones, and that US patent applications in European patent offices also have a relatively low grant probability. Yang (2008) shows that the US patent office seems to treat domestic and foreign applications equally, while the Chinese patent office appears to preferentially treat domestic applications. Although discriminatory policies in international trade have been widely documented, we have found up to now no study that investigates the rationale of disguised protection in the patent sector.⁷ This paper therefore attempts to understand the mechanism underlying the implicit or explicit use of patent examination procedures to protect local industries. It also explores how discriminatory practices have evolved since TRIPS were introduced.

⁶ TRIPS Article 27.1 requires that “patents shall be available and patent rights enjoyable without discrimination as to the place of invention, the field of technology and whether products are imported or locally produced”.

⁷ For the trade literature, the readers may refer to Dixit (1984), Bhattacharjea (1995), Brander (1995), Zigic (2000), Trebilcock and Giri (2004), Lee (2007) and Kovac and Zigic (2012).

The remainder of this paper is organized as follows. We propose a theoretical model in Section 2 and conduct numerical simulations to form the hypotheses in Section 3. We then discuss the empirical models and data issues in Section 4. The regression results are presented in Section 5. Section 6 concludes this paper.

2. The Theoretical Model

Two firms, a foreign multinational corporation (Firm 1) and a local firm (Firm 2), are assumed to play a three-stage dynamic game where they compete with each other in Firm 2's domestic market. In stage 1, Firm 1 introduces a new invention and hence produces a higher quality (s_1) than found in the existing products. To protect its invention, Firm 1 lodges a patent application for its invention in the host country. Given the patent assessment rules in most nations, the application is automatically published in the public domain, usually 18 months after the lodgment regardless of whether the patent is eventually granted or rejected (Aoki and Spiegel, 2009). During this period, Firm 1 has no legal intellectual property right (IPR) to fight against Firm 2's potential imitation. Therefore, in stage 2, Firm 2 decides whether to imitate Firm 1's products and chooses its own quality (s_2) if it enters the market. In the final stage, Firms 1 and 2 compete in prices (p_1 and p_2).⁸

Firm 2's payoff function is its expected profit. There is risk for firm 2 in imitating Firm 1's technology during the examination period, as Firm 1 could sue Firm 2 for patent infringement

⁸ Motta (1993) argues firms differentiate more under Bertrand than under Cournot. His paper also shows the economy is better off when firms compete on prices. Enormous literature has contributed to the comparison of Bertrand and Cournot competitions in the context of product differentiation (Lambertini and Mantovani, 2010; Tremblay and Tremblay, 2011; Naimzada and Tramontana, 2012). Since it is not the theme of our paper, we assume the two firms are in Bertrand competition.

during that period once the patent is granted.⁹ However, the risk can be associated with large profits. Suppose Firm 2 is the only firm that takes the risk to imitate Firm 1's new product.¹⁰ Hence, during the examination period (T years), a dual oligopolistic market structure appears and the firms earn oligopolistic profits (Π_1^O and Π_2^O , respectively). However, once the patent is rejected or the patent expires, additional firms enter the market and push the profits to zero. We assume that production is costless and Firm 2 invests in R&D (C_2) to absorb Firm 1's invention ($0 \leq s_2 \leq s_1$), or even develops a higher quality product ($s_2 \geq s_1 \geq 0$). If the patent is rejected, then Firm 2 will keep its profits. If the patent is granted, Firm 1 can claim for patent infringement and hence collect compensation (F). If P is the probability of the patent being granted, then Firm 2's expected profit can be written as

$$E(\Pi_2) = [(1 - P)\Pi_2^O + P(\Pi_2^O - F)] - C_2. \quad (1)$$

Correspondingly, Firm 1's profit also depends on whether its patent is granted or not. Due to competition from Firm 2, Firm 1 only obtains the oligopolistic profit (Π_1^O) during the examination period. If the patent is rejected, even the oligopolistic profit will disappear, as other firms can imitate without risk and thus the profit of producing that product is reduced to zero under perfect competition. However, if the patent is granted, Firm 1 can enjoy a monopolistic profit, usually for around 20 years (Π_1^{M20}).¹¹ Hence, Firm 1's expected profit can be written as

⁹ For example, under the US patent law "inventors can obtain reasonable royalties from others who make, use, sell, or import the invention during the period between the time the patent application is published and the patent is granted" (<http://www.uspto.gov/news/pr/2000/00-72.jsp>).

¹⁰ It is possible for more than one local firm to join in the competition during the patent examination period. The number of local firms entered is affected by the strictness of IPR protection and local firms' capability in imitation and innovation. Thus the assumption of only one local firm's entrance reflects a relatively strong IPR protection and weak capability of local firms. However, we will show even under this assumption the local firm could still leapfrog ahead if disguised protection exists.

¹¹ Again this happens under a strong IPR protection regime. In a weaker regime, local firms may stay in the market during the 20-year protection term. However, we will show later that the strategic patent policy could work even under strong IPR protection regimes (also see footnote 10).

$$E(\Pi_1) = [(1 - P)\Pi_1^O + P(\Pi_1^O + \Pi_1^{M20} + F)] - C_1, \quad (2)$$

where C_1 is the R&D cost function for Firm 1. We derive the R&D cost function so that it is consistent with the knowledge production functions discussed by Färe (1974), Griliches (1979), Suliman (1997) and Furmana *et al.* (2002). Essentially, the cost function reflects the intuition that the marginal product of R&D investment is diminishing, as the progress of new technologies is constrained by the existing knowledge stock. Thus Firm 1's R&D cost function can be written as (see appendix A for the proof)

$$C_1(s_1) = \frac{\alpha}{n} \frac{s_1}{1 - s_1}, \quad (0 \leq s_1 < 1), \quad (3)$$

where n is the number of markets or countries that Firm 1 enters. Since Firm 1 is a multi-national corporation, its R&D costs can be shared by its subsidiaries worldwide. α is a scaling parameter to capture industrial characteristics. A larger α indicates that a larger proportion of earnings is invested in R&D in a specific industry.

Accordingly, Firm 2's R&D cost function can be written as (see appendix A for the algebraic proof)

$$C_2(s_2 | s_1) = \frac{\alpha(s_2 - \gamma s_1)}{1 + \gamma s_1 - s_2}, \quad (\gamma s_1 \leq s_2 < 1 + \gamma s_1), \quad (4)$$

where C_2 is not only a function of s_2 but also related to s_1 . It implies Firm 2's R&D activities benefit from Firm 1's published knowledge (s_1). γ represents Firm 2's ability to absorb s_1 and hence is called the absorptive capacity.

Once a lawsuit for patent infringement is lodged in the court, the court shall decide compensation for the damage (F). Different countries follow different rules to determine the specific amount of compensation. According to Coury (2003), compensation in the US, the UK and France is calculated on the basis of the patentees' lost profits as a result of the infringement.

However, the punishment in Italy, Canada, Japan and Germany is based on either the patentees' lost profits or the infringers' illegal profits. This system is also adopted in China and South Korea.¹² Coury argues that in practice it is more common and easier to calculate the fine on the basis of the infringers' illegal profits. In addition, if the infringers do not have enough assets to cover the patentees' losses, then the executed compensation will have to be reduced. Therefore, in this paper we assume that the amount of compensation to be paid is a function of infringers' illegal profit. Symbolically,

$$F = \mu\beta \text{Max}(0, \Pi_2^O - C_2), \quad (5)$$

where β is the degree of punishment for patent infringement and μ is the degree of infringement. A higher degree of imitation may incur a higher probability of litigation. We use the quality distance to measure the degree of infringement, that is $\mu = 1 - |s_1 - s_2|$.

Both Firm 2's profit (Π_2^O) and Firm 1's profits (Π_1^O and Π_1^{M20}) depend on the length (T) of the examination of Firm 1's patent. Thus, they are integrated values of the annual profits π_2^O , π_1^O and π_1^M , respectively. If ρ is the annual discount rate, we can write

$$\Pi_2^O = \int_0^T e^{-\rho t} \pi_2^O dt = \frac{1 - e^{-\rho T}}{\rho} \pi_2^O, \quad (6)$$

$$\Pi_1^O = \int_0^T e^{-\rho t} \pi_1^O dt = \frac{1 - e^{-\rho T}}{\rho} \pi_1^O, \quad (7)$$

and

$$\Pi_1^{M20} = \int_T^{T+20} e^{-\rho t} \pi_1^M dt = \frac{e^{-\rho T} (1 - e^{-20\rho})}{\rho} \pi_1^M. \quad (8)$$

¹² Readers may refer to the Chinese Patent Law (Article 65) and the Korean Patent Act (Article 128).

In stage 3 of the game, Firms 1 and 2 compete with each other and receive oligopolistic profits $\pi_1^o = p_1 \times q_1(p_1, p_2)$ and $\pi_2^o = p_2 \times q_2(p_1, p_2)$, where p and q stand for price and quantity respectively. The derivation of the demand functions $q_1(p_1, p_2)$ and $q_2(p_1, p_2)$ using the standard consumer utility functions for differentiated products is presented in appendix B. If Firm 2 produces a lower quality ($s_2 < s_1$), then the demand functions are

$$q_1 = 1 - \frac{p_1 - p_2}{s_1 - s_2} \quad (9)$$

and

$$q_2 = \frac{p_1 - p_2}{s_1 - s_2} - \frac{p_2}{s_2} . \quad (10)$$

Therefore, the Bertrand duopoly solutions of profit maximization are (see appendix B for the algebraic proof)

$$p_1^* = \frac{2s_1^2 - 2s_1s_2}{4s_1 - s_2} \quad (11)$$

and

$$p_2^* = \frac{s_1s_2 - s_2^2}{4s_1 - s_2} . \quad (12)$$

The corresponding profits are

$$\pi_1^o = \frac{4(s_1 - s_2)s_1^2}{(4s_1 - s_2)^2} \quad (13)$$

and

$$\pi_2^o = \frac{s_1s_2(s_1 - s_2)}{(4s_1 - s_2)^2} . \quad (14)$$

If Firm 2 produces a higher quality ($s_2 > s_1$), the demand functions are changed to (see appendix B):

$$\tilde{q}_2 = 1 - \frac{p_2 - p_1}{s_2 - s_1} \quad (15)$$

and

$$\tilde{q}_1 = \frac{p_2 - p_1}{s_2 - s_1} - \frac{p_1}{s_1}. \quad (16)$$

Hence, the annual profits are also changed to

$$\tilde{\pi}_1^o = \frac{s_1 s_2 (s_2 - s_1)}{(4s_2 - s_1)^2} \quad (17)$$

and

$$\tilde{\pi}_2^o = \frac{4(s_2 - s_1)s_2^2}{(4s_2 - s_1)^2}. \quad (18)$$

It is shown in appendix B that if firm 1's patent is granted, and hence protected for 20 years, the demand for Firm 1's product is

$$q_1 = 1 - p_1 / s_1. \quad (19)$$

In this case, Firm 1 receives a monopolistic profit

$$\pi_1^M = s_1 / 4. \quad (20)$$

By integrating the above results into the expected profit functions (1) and (2), we obtain Equations (21) and (22) in the case of $s_2 < s_1$:

$$E(\Pi_2) = [(1 - P)\Pi_2^o + P(\Pi_2^o - F)] - C_2 = \Pi_2^o - P \times F - C_2 = \frac{1 - e^{-\rho T}}{\rho} \frac{s_1 s_2 (s_1 - s_2)}{(4s_1 - s_2)^2} - P \times (1 - s_1 + s_2) \beta \text{Max} \left(0, \frac{1 - e^{-\rho T}}{\rho} \frac{s_1 s_2 (s_1 - s_2)}{(4s_1 - s_2)^2} - \frac{\alpha(s_2 - \gamma s_1)}{1 + \gamma s_1 - s_2} \right) - \frac{\alpha(s_2 - \gamma s_1)}{1 + \gamma s_1 - s_2}, \quad (21)$$

$$\begin{aligned}
E(\Pi_1) &= [(1-P)\Pi_1^O + P(\Pi_1^O + \Pi_1^{M20} + F)] - C_1 = \Pi_1^O + P(\Pi_1^{M20} + F) - C_1 \\
&= \frac{1-e^{-\rho T}}{\rho} \frac{4(s_1-s_2)s_1^2}{(4s_1-s_2)^2} + P \frac{e^{-\rho T}(1-e^{-20\rho})}{\rho} \frac{s_1}{4} + \\
&P \times (1-s_1+s_2) \beta \text{Max} \left(0, \frac{1-e^{-\rho T}}{\rho} \frac{s_1 s_2 (s_1-s_2)}{(4s_1-s_2)^2} - \frac{\alpha(s_2-\gamma s_1)}{1+\gamma s_1-s_2} \right) - \frac{1}{n} \frac{\alpha s_1}{1-s_1}.
\end{aligned} \tag{22}$$

In the case of $s_2 > s_1$, the expected profits are

$$\begin{aligned}
E(\tilde{\Pi}_2) &= \tilde{\Pi}_2^O - P \times F - C_2 = \frac{1-e^{-\rho T}}{\rho} \frac{4(s_2-s_1)s_2^2}{(4s_2-s_1)^2} \\
&- P \times (1-s_2+s_1) \beta \text{Max} \left[0, \frac{1-e^{-\rho T}}{\rho} \frac{4(s_2-s_1)s_2^2}{(4s_2-s_1)^2} - \frac{\alpha(s_2-\gamma s_1)}{1+\gamma s_1-s_2} \right] - \frac{\alpha(s_2-\gamma s_1)}{1+\gamma s_1-s_2}
\end{aligned} \tag{23}$$

and

$$\begin{aligned}
E(\tilde{\Pi}_1) &= \tilde{\Pi}_1^O + P(\Pi_1^{M20} + F) - C_1 = \frac{1-e^{-\rho T}}{\rho} \frac{s_1 s_2 (s_2-s_1)}{(4s_2-s_1)^2} + P \frac{e^{-\rho T}(1-e^{-20\rho})}{\rho} \frac{s_1}{4} \\
&+ P \times (1-s_2+s_1) \beta \text{Max} \left(0, \frac{1-e^{-\rho T}}{\rho} \frac{s_1 s_2 (s_1-s_2)}{(4s_1-s_2)^2} - \frac{\alpha(s_2-\gamma s_1)}{1+\gamma s_1-s_2} \right) - \frac{1}{n} \frac{\alpha s_1}{1-s_1}.
\end{aligned} \tag{24}$$

In the case of $s_2 = s_1$, Equations (21) and (23) become identical, as do Equations (22) and (24).

In this situation, the game shrinks to identical-quality Bertrand competition. It will not occur according to proposition 1.

PROPOSITION 1: *The case in which s_2 equals s_1 is not an equilibrium solution.*

PROOF: In the case of $s_2 = s_1$, Equations (21) and (23) give the same profit function for Firm 2:

$$E(\Pi_2) = 0 - P \times \beta \text{Max} \left(0, -\frac{\alpha(s_2-\gamma s_1)}{1+\gamma s_1-s_2} \right) - \frac{\alpha(s_2-\gamma s_1)}{1+\gamma s_1-s_2} = -\frac{\alpha(s_2-\gamma s_1)}{1+\gamma s_1-s_2} \leq 0 \tag{25}$$

Thus if Firm 2 chooses the same quality as s_1 , it will record a loss or a negative profit. In this case, the choice of not entering the market would be a preferred strategy for Firm 2, rather than entering the market and choosing $s_2 = s_1$. Therefore, the case of $s_2 = s_1$ will not occur as an equilibrium.

In stage 2, Firm 2 chooses its quality to maximize its profit. That is

$$\text{Max}\left[E(\Pi_2)\right], \text{ subject to } 0 \leq \gamma s_1 \leq s_2 < s_1 < 1 \quad (26)$$

or

$$\text{Max}\left[E(\tilde{\Pi}_2)\right], \text{ subject to } 0 \leq s_1 < s_2 < 1 + \gamma s_1. \quad (27)$$

Solutions to these maximization problems depend on both s_2 and s_1 . In stage 1, if Firm 1 can calculate Firm 2's best response curve and thus decide its best quality level (s_1^*), then Firm 2 can compare $\text{Max}\left[E(\Pi_2)\right]_{s_1=s_1^*}$ and $\text{Max}\left[E(\tilde{\Pi}_2)\right]_{s_1=s_1^*}$ and decide whether or not to produce a better quality (leap-frogging Firm 1). Proposition 2 ensures the existence of an equilibrium.

PROPOSITION 2: A pure strategy Nash equilibrium exists in this game.

PROOF: This is a finite game of perfect information; i.e. Firms 1 and 2 know all parameters and the structure of the game and each firm knows what the other firm knows. Then, by Zermelo's Theorem, a Nash equilibrium will exist (See Schwalbe and Walker (2001) for Zermelo's Theorem).

3. Simulation Results

There are seven parameters in the maximization problem, ρ , α , β , γ , n , T and P , and hence it is difficult to solve the problem in a closed form. Moreover, the compensation function, Equation (5), is non-differentiable, which makes it impossible to solve the maximization problem algebraically. Therefore, we try to solve it through numerical simulations.

To start, the seven parameters are calibrated to certain values. We follow the suggestion of Weitzman (2001) and set the annual discount rate (ρ) to be 0.04. β reflects the strictness of the patent law. If $\beta > 1$, not only the loss due to infringement is recovered, but as well as this, the

infringer will be fined with punitive damages. However, punitive damages are not generally available for patent infringement within the G7 countries. In fact, Coury (2003) points out that the United States is the only country which awards punitive damages. Therefore, we set $\beta=1$ as the initial value. γ represents the ability to absorb existing knowledge and falls into the interval $[0, 1]$. Thus we first use 0.5 as the initial value of γ . n is the number of patent offices worldwide with which a patent is lodged. Firm 1 lodges at least two patent applications for its invention; one in its home country and the other in Firm 2's home country. Thus we set the initial value of n to be 2. α is the ratio of R&D expenditures over the profits in a sector, which will vary across industries. We set its initial value to be 0.1 (see more detail in appendix A). Finally, we use the US patent office practice as the baseline case to set the initial values for the grant probability (P) and grant lag (T) to be close to their means of 0.5 and 2, respectively (as shown in Table 2 later).

Figure 1 shows the simulation results for the baseline setting in which the parameters $\{\rho, \alpha, \beta, \gamma, n, T, P\}$ are fixed at $\{0.04, 0.1, 1, 0.5, 2, 2, 0.5\}$.¹³ Figure 1(a) illustrates Firm 2's best response quality (s_2^*) as s_1 varies from zero to one. $s_2^*(s_1)$ is Firm 2's best response curve when Firm 2's quality is inferior to Firm 1's quality. $\tilde{s}_2^*(s_1)$ is Firm 2's best response curve when leapfrogging occurs. Figure 1(b) gives out profits curves for $\Pi_1(s_1|s_2^*)$, $\tilde{\Pi}_1(s_1|\tilde{s}_2^*)$, $\Pi_2(s_2^*|s_1)$ and $\tilde{\Pi}_2(\tilde{s}_2^*|s_1)$. In the case of $s_2 < s_1$, Firm 1 will achieve its maximum profit of 1.43 with the quality (s_1) of 0.83. The follower Firm 2 will in turn choose s_2 of 0.18 and obtain a profit of 0.03. In the case of $s_2 > s_1$, Firm 1 receives a smaller maximum profit of 1.11 ($\tilde{s}_1^*=0.82$). Firm 2 will receive a negative profit (-0.01) and thus choose not to enter the market. Therefore, there is a unique

¹³ Matlab is used for the calculation. The program script is available upon request.

equilibrium under the condition $s_1=0.83>s_2$. In this case, Firm 1 will take the first-mover advantage and not allow Firm 2 to pursue leap-frogging.

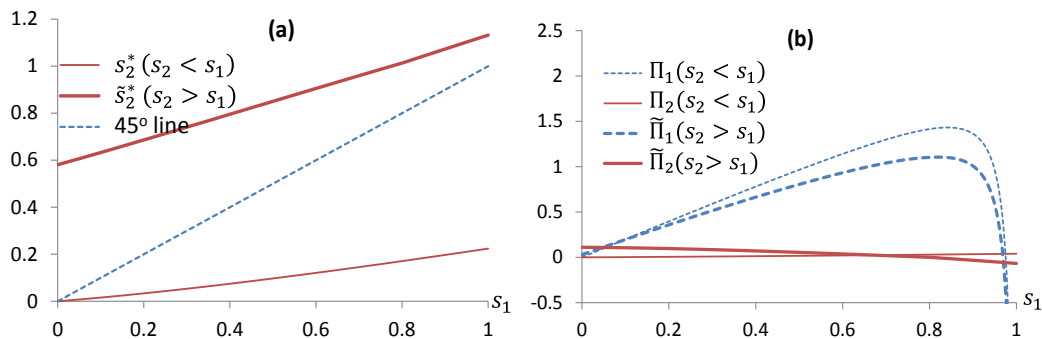


Fig. 1. Simulation results for $\{\rho, \alpha, \beta, \gamma, n, T, P\} = \{0.04, 0.1, 1, 0.5, 2, 2, 0.5\}$.

However, the patent authority could help Firm 2 to leap-frog Firm 1 by prolonging Firm 1's patent examination pendency. Figure 2 shows that when the grant lag is extended to six years, leap-frogging will occur. Even though Firm 1 may obtain its maximum profit of 1.74 when s_1 is set to be 0.85, Firm 2 will not bear with this. Instead, Firm 2 will always choose a higher quality than Firm 1, which will enable Firm 2 to earn a positive profit. Therefore, by taking Firm 2's later choice into consideration, Firm 1 will realize in the beginning that achieving a profit of 1.74 is not feasible. Hence it will accept the second best result (1.13) by setting s_1 to be 0.80. Firm 2 then enters the market, chooses leap-frogging ($s_2=1.17 > s_1$) and obtains a profit of 0.26. Therefore, equilibrium is reached with Firm 2 leap-frogging ahead.

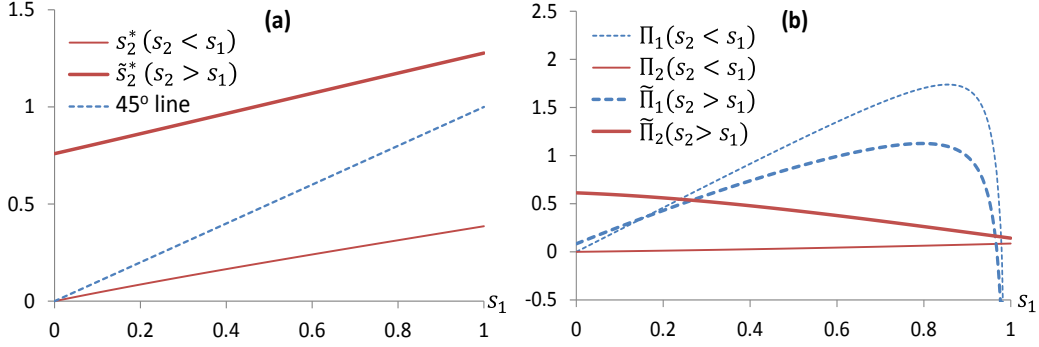


Fig. 2. Simulation results for $\{\rho, \alpha, \beta, \gamma, n, T, P\} = \{0.04, 0.1, 1, 0.5, 2, \underline{6}, 0.5\}$.

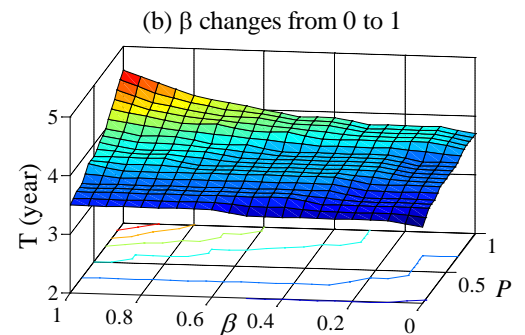
This example shows that a patent office can promote technological leap-frogging by prolonging the foreign patent examination process. Later we will illustrate that in order to encourage domestic firm leap-frogging, both grant lag and grant probability can be manipulated. If a patent office chooses to discriminate against *all* foreign patents, we then define this type of practice as *institutional* discrimination. However, to evade international anti-discrimination protocols (such as the TRIPS), a country could move from institutional discrimination to *strategic* discrimination. The latter refers to discrimination which doesn't apply to *all* foreign patents but rather targets *key* patents or patent fields. The aim of strategic discrimination, along with other industrial policies such as R&D subsidies (see Spencer and Brander, 1983), is to promote technological catching-up or leap-frogging in these key patent fields. In reality, do patent offices strategically discriminate against foreign patents? To answer this question, we need to test our models empirically. Therefore, in the following discussions, hypotheses of strategic discrimination are developed for testing through the analysis of a patent database.

In our model, whether leap-frogging can occur or not is determined by the seven parameters $\rho, \alpha, \beta, \gamma, n, T$ and P . However, patent offices can manipulate only two of them, the grant lag (T) and grant probability (P). Thus we will examine what threshold values of T and P are needed for domestic firm leap-frogging when the other parameters vary. Figure 3(a) depicts the

simulation results given $\{\rho, \alpha, \beta, \gamma, n\} = \{0.04, 0.1, 1, 0.5, 2\}$. Leap-frogging occurs in the shadowed area. If P and T do not reach the threshold boundaries, the domestic firm (Firm 2) will not be motivated enough to leap-frog ahead. The boundary curve is monotonously increasing. This should not be difficult to understand. When Firm 2 anticipates the rejection of Firm 1's patent it is willing to enter the market and imitate Firm 1's invention, as there is little chance of being punished. However if the grant probability is large, then Firm 2 will not enter the market unless its expected profit during the examination period can compensate for its expected loss due to the infringement. Thus to encourage Firm 2's entrance, the examination period (T) must be large when the grant probability is small.

The boundary curve will shift as the other parameters vary. For example, Figure 3(a) is a snapshot from when β is fixed to one. Figure 3(b) illustrates that when β varies from 1 to 0, the shifting boundary curves will join to form a surface. The surface slides down as β and P approach zero. The contours on the P - β panel further demonstrate that the surface is monotonously down sliding. In reality, β (the degree of punishment for patent infringement) is independently determined by the court rather than the patent office. Thus it is taken by patent offices before any discriminative actions are executed. Figure 3(b) suggests that in a stricter anti-infringement law system, more severe discriminative tools are needed for leap-frogging. Thus we obtain our first hypothesis (H1).

H1: In a regime where the punishment for patent infringement is severe (larger β), a longer T or lower P is needed for the realization of leap-frogging.



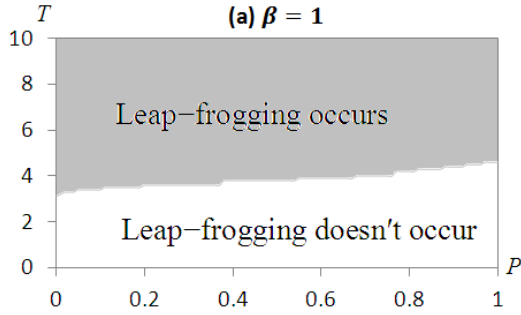


Fig. 3. Simulation results given $\{\rho, \alpha, \gamma, n\} = \{0.04, 0.1, 0.5, 2\}$.

α measures the proportion of R&D investment. γ captures Firm 2's absorptive capability of s_1 , which indicates a country's comparative advantages in international specialization. Figure 4(a) shows the shape of the surfaces given that $\{\rho, \beta, \gamma, n\}$ are fixed at $\{0.04, 1, 0.5, 2\}$. Figure 4(b) demonstrates the situation that occurs when γ varies with $\{\rho, \alpha, \beta, n\}$ being fixed at $\{0.04, 0.1, 1, 2\}$. These two figures lead to our second (H2) and third (H3) hypotheses.

H2: In a sector with high R&D intensity (bigger α), a lower P or longer T is needed to achieve leap-frogging.

H3: In a sector where a domestic firms' absorptive capability is weak (smaller γ), a lower P or longer T is needed to promote leap-frogging.

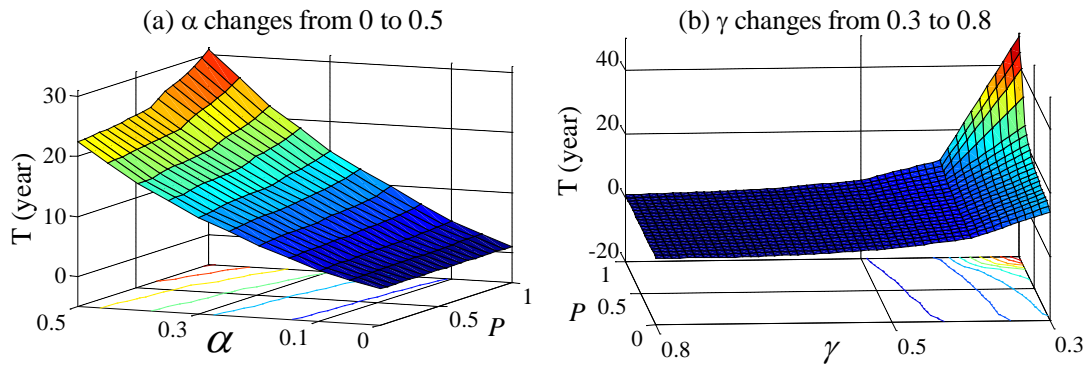


Fig. 4. Simulation results when α and γ changes, respectively.

Each patent corresponds to a specific n , which measures the importance of an invention. When no discrimination exists, more important patent applications will be processed quickly (Dranove and Meltzer, 1994). However, if strategic discrimination is employed, the opposite is true. Figure 5(a) is obtained given that $\{\rho, \alpha, \beta, \gamma\}$ are fixed at $\{0.04, 0.1, 1, 0.5\}$. It implies

H4: The more countries a foreign invention gets registered in (bigger n), the lower the P or longer the T value is required to promote domestic firm leap-frogging.

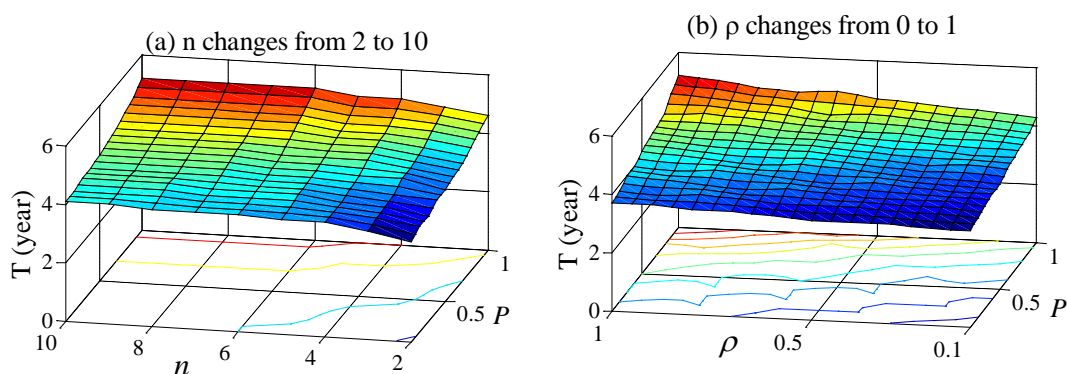


Fig. 5. Simulation results when n and ρ change, respectively.

ρ is the annual discount rate which varies across firms. Figure 5(b) depicts the surface as ρ varies when $\{\alpha, \beta, \gamma, n\}$ are fixed at $\{0.1, 1, 0.5, 2\}$. The shape of the surface is very different from the previous ones. It is not monotonously sliding down as ρ decreases, which is more clearly shown by the spikes of the contours. Therefore, the effect of ρ on P or T is no longer linear. Moreover, in business ρ is determined by each firm's capital cost and there is rarely an instrumental variable that can capture such cost. Therefore, we will not test the effect of ρ in our econometric models.

Finally, all the surfaces in Figures 3, 4 and 5 are monotonously down sliding as P decreases. This indicates a clear substitute relationship between P and T . If higher grant probability (P) for

Firm 1's patent is anticipated, then a longer grant lag (T) is needed to support possible leap-frogging of Firm 2. Thus we obtain

H5: A combined tool of grant probability (P) and grant lag (T) makes it easier to promote leap-frogging.

4. Econometric Models and Data Issues

In this section, we aim to test empirically whether and how the grant probability (P) and grant lag (T) are affected by the variables $\{\alpha, \beta, \gamma, n\}$. For this purpose, we first discuss the measurement of the variables specified in the model. The grant probability (P) is not directly observable. However, we can observe whether a patent is granted or not. Denote g_i as a binary variable for patent i ($g_i = 1$ if the patent is granted and $g_i = 0$ if the patent application is rejected). Thus the grant probability can be written as $P_i(g_i = 1 | \mathbf{X})$. \mathbf{X} is the vector of $\{A, R, N\}$ that represents the variables $\{\alpha, \gamma, n\}$. Because g_i only takes two discrete values, we can specify $P_i(g_i = 1 | \mathbf{X})$ in a Logit model

$$P_i(g_i = 1 | \mathbf{X}) = \frac{1}{1 + \exp(-\mathbf{X}'\mathbf{B})}. \quad (28)$$

The logistic function ensures the right-hand side value in Equation (28) always falls into interval $[0, 1]$. Similarly, the grant lag (T) can be featured into a count model. By definition, the lag can be calculated as the time period between a patent's first publication date (not granted yet) and the last publication date when it is granted. Since T is a count number and always positive, it can be modeled as follows

$$T_i = \exp(\mathbf{X}'\tilde{\mathbf{B}} + \tilde{\boldsymbol{\varepsilon}}_i), \quad (29)$$

where the exponential form ensures that the right-hand side will be positive. In Equations (28) and (29), \mathbf{B} and $\tilde{\mathbf{B}}$ are the vectors of coefficients, while $\boldsymbol{\varepsilon}_i$ and $\tilde{\boldsymbol{\varepsilon}}_i$ stand for error terms. More specifically, $\mathbf{X}'\mathbf{B}$ can be expanded as ($\mathbf{X}'\tilde{\mathbf{B}}$ is similar):

$$\mathbf{X}'\mathbf{B} = b_0 + b_V V + b_A A + b_G R + b_N N + b_{V1} A \times V + b_{V2} R \times V + b_{V3} N \times V, \quad (30)$$

where the dummy variable V distinguishes the origin of a patent. $V=0$ indicates it is a domestic application, whereas $V=1$ indicates it is filed by a foreign applicant. $A \times V$, $R \times V$ and $N \times V$ are the interaction terms.

We use the industry indicator A to measure α which is the proportion of R&D investment as defined in Section 3, and thus is a sector-specific variable. Each patent application in a patent office is assigned with one or more of the International Patent Classification (IPC) codes. However, the IPC codes are technological categories rather than industrial categories (such as NACE).¹⁴ Hence, following Schmoch *et al.* (2003), we convert each IPC code to a NACE code.¹⁵ Furthermore, the NACE codes fall into four groups; high-tech, medium-high-tech, medium-low-tech and low-tech industries.¹⁶ Therefore, we construct the industry indicator (A) by assigning integers 1-4 to the four industrial categories. If a patent is assigned with multiple IPC codes, we use the average value of the integers.

Firm 2's ability to absorb Firm 1's technology (γ) is measured by R_i , which is defined as the ratio of the total number of *native* patent applications to the total number of the *native and*

¹⁴ NACE is short for Nomenclature Generale des Activites Economiques dans l'Union Europeenne and is used in European Union countries.

¹⁵ Currently two versions of NACE are available, NACE Rev 1.1 and NACE Rev 2. We use NACE Rev 1.1 in this paper.

¹⁶ The four industrial levels are defined by the statistical office of the European Union (Eurostat - http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/Annexes/htec_esms_an2.pdf).

foreign applications in patent i 's IPC field.¹⁷ Patents in different technological fields have different values for R_i . A higher value of R_i indicates that the domestic firms have stronger absorption ability in their technological fields.¹⁸ R_i is time-variant because new applications are lodged every day. Therefore, even patents in the same technological fields can have different values of R_i as they can be granted at different times.

We measure the number of markets or countries entered by a multi-national corporation (n) by examining the number of patents (N) in a patent family (Lanjouw *et al.*, 1998; Burke and Reitzig, 2007). A patent family refers to the same invention which is patented in more than one country.¹⁹ A patent applicant only lodges applications in countries where the invention can bring the owner a profit, as each application has a fee and maintenance costs. Thus, a larger N implies a larger number of markets that can be used to share the R&D costs of the invention.

The patent data used in this study is taken from the European Patent Organization Worldwide Patent Statistical Database (also known as PATSTAT). This database covers about 70 million patent records from over 80 countries. However, we only extract the patent applications registered in the patent offices of the US, the UK, Germany, Japan, South Korea and China. Furthermore, we only use the patents filed in more than one country ($N \geq 2$). One reason is that the hypotheses stated in the preceding section are based upon analysis of the *firms'* behavior. However, a large number of the patents are actually filled by *individual* inventors who are not covered by the theoretical model. Individual inventors have stricter financial constraints than firms and thus usually only lodge applications in the home patent office. Therefore, by focusing on the applications that are lodged in multiple countries, we can eliminate most of the patent

¹⁷ Each IPC code subgroup corresponds to a patent field. The IPC eighth edition (in 2006) covers 61,397 subgroups.

¹⁸ If a patent is categorized into multiple IPC code subgroups, then only the main (first) code is used.

¹⁹ A patent family may contain more than one patent granted in a patent office. In this case, we only keep one patent from each patent office so that N is not overestimated (United States Patent and Trademark Office web site: <http://www.uspto.gov/main/glossary/#patentfamily>).

applications filed by individuals. The other reason for this constraint ($N \geq 2$) is due to the measurement used for the domestic firms' absorption ability (R). R is the ratio of the number of native patent applications over the total number of applications in each patent field. However, a higher R may not represent higher absorption ability if the patent field is crowded with less important native patents. Thus the constraint ($N \geq 2$) will improve the reliability of R as a measure of the domestic firms' absorptive ability. For the same reason, only invention patents are used in our sample, and utility models as well as design patents are excluded.

In the empirical analysis, we will use different samples for the two sets of regressions. Both issued and rejected patents are used in the Logit model or Equation (28). However, only issued patents are used in the count model or Equation (29). The reason is that the grant lag can be manipulated by both patent examiners and patent applicants. As Palangkaraya *et al.* (2008) point out, applicants prefer a short examination process when the expected grant probability is high, but favor a slow examination process when the expected grant probability is low. Hence, the grant lag of rejected patents can be deliberately delayed by applicants. On the contrary, the grant lag of approved patents is mainly affected by the patent examiners. As we want to test the behavior of patent offices rather than applicants, only data from approved patents is used to estimate Equation (29), so that the effect of applicants can be eliminated.

Figure 6 demonstrates the distribution of patents from 1974 to 2009. Those patents are divided by their origin (home or foreign countries) and assessment results (issued or rejected). Figure 6 shows that the PATSTAT dataset is not complete in certain years where the rejected patents have not been reported. For example, the rejected foreign patents in the US patent office are only recorded from 2002 onwards (Figure 6a). For the Logit model, both the granted and

rejected patent data are required. As a result, only data from selected years is used for our regressions.

Similarly, recorded data for the grant lags also varies across countries and over time (see Figure 7). In particular, Germany and Korea adopt a different system for patent publication. Under this system, patent applications are not published before they are granted. This is clearly shown in Figure 7c and 7e that only a few applications are published before they are granted. Our count data model hence does not cover these two countries.

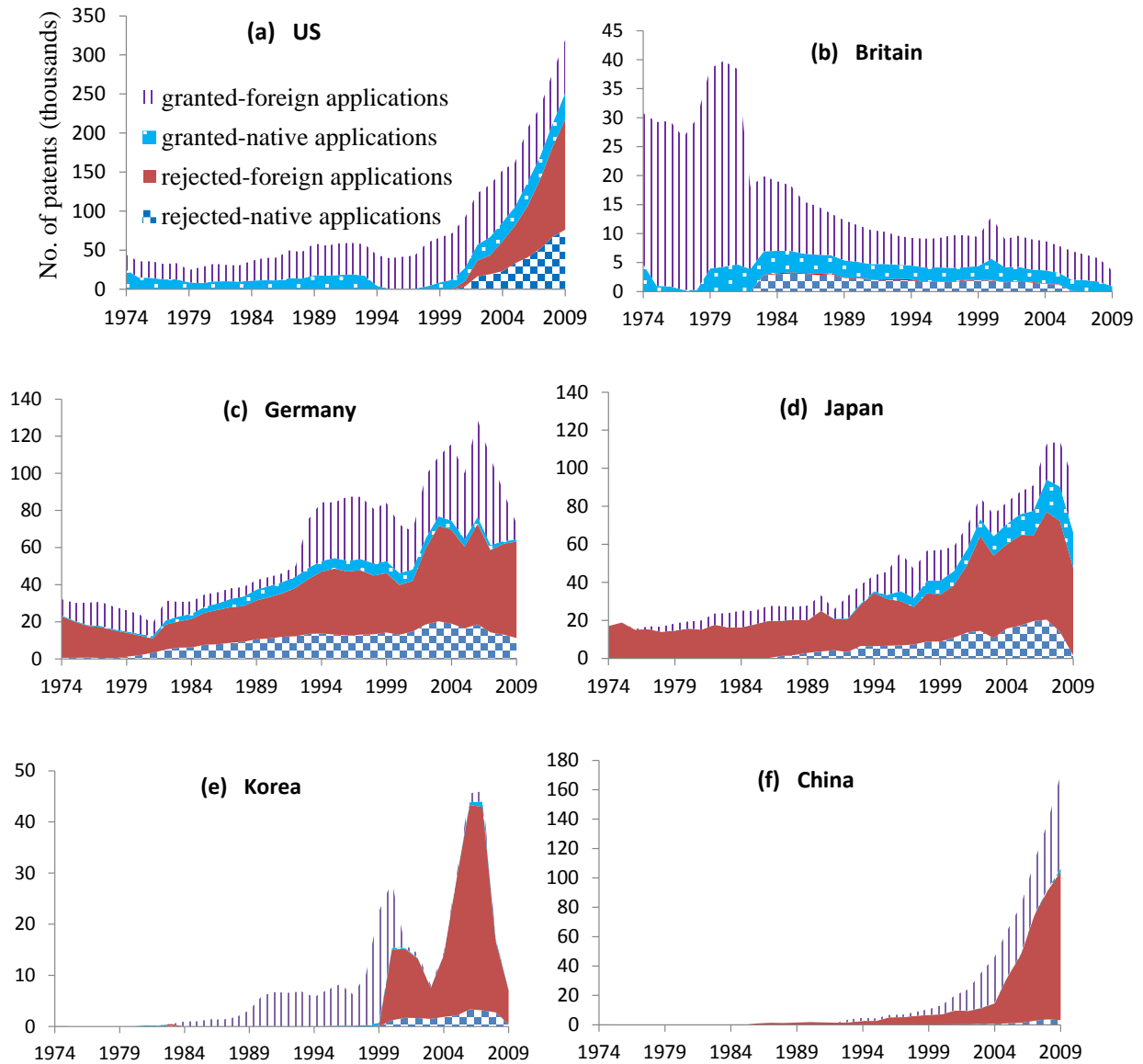


Fig. 6. Numbers of granted and rejected patents ($N \geq 2$) in selected countries.

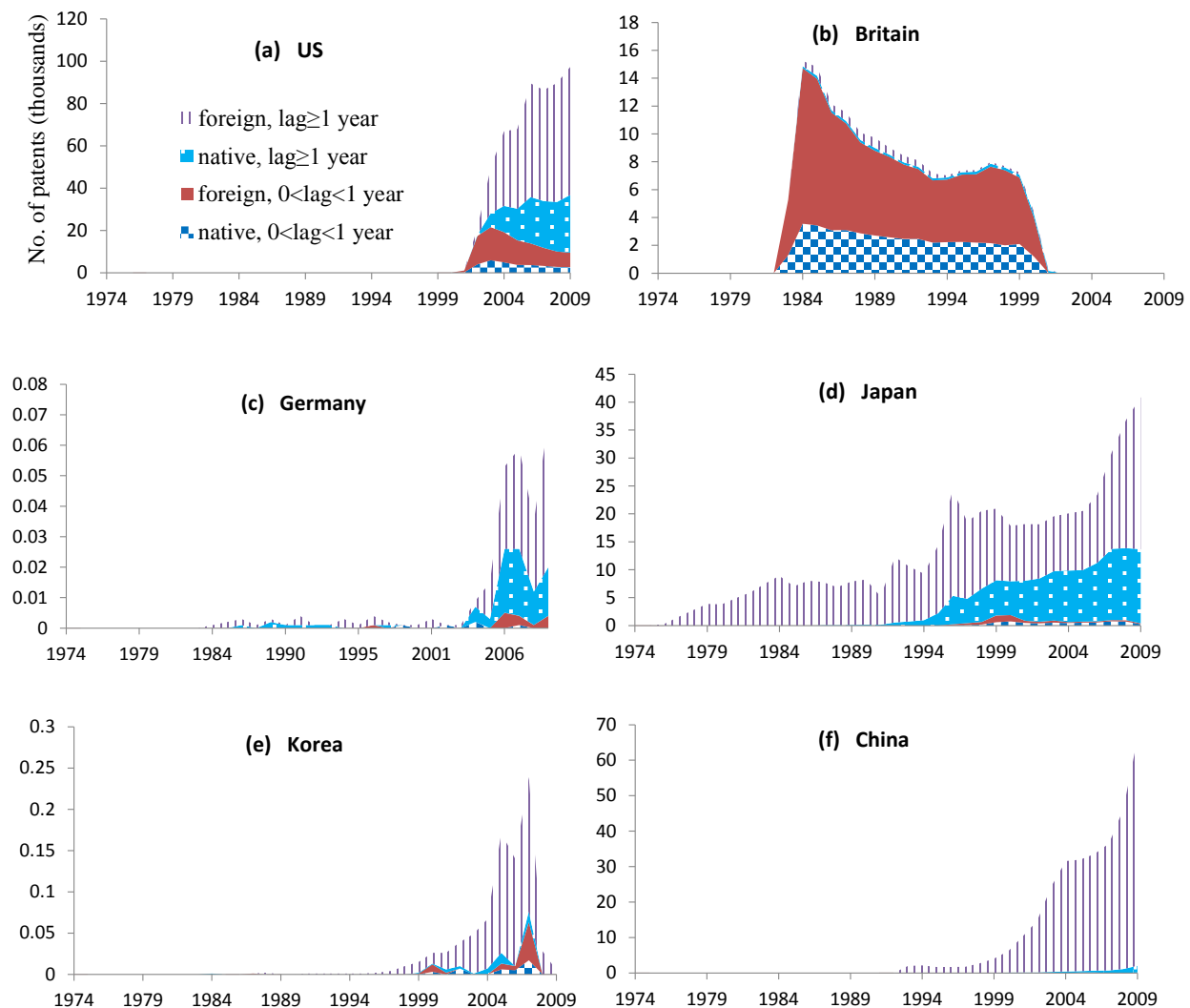


Fig. 7. Distribution of the grant lags ($N \geq 2$) in selected countries.

Summary information about our database is listed in Table 1.²⁰ Due to data clearance the final samples used are much smaller than the size of the original database. For instance, over 2.5 million applications were lodged in the US patent office during 2002-2009. However, only 62 percent (1.6 million) of them were lodged in other patents offices ($N \geq 2$). In the Japanese patent

²⁰ The summary statistics don't match in the two models. For example, about 160 thousand patents that were granted to native applicants in the US are used in the count model while 216 thousand are used in the Logit model. This discrepancy occurs because we delete the patents with zero-day grant lag. After 2000, the US patent law adopted a patent publication system which requires applications being published before they are granted (Monheit and Pabst, 2001). However, there are exceptions under which certain applications shall not be published before a decision is made (Article 122, US Patent Law). Thus these patents show a zero-day grant lag and hence do not reflect the discriminatory policies discussed in this paper and should not enter the regression.

office, only 18 percent of the original data is used for our regression analysis. British and Japanese data is split into pre-1994 and post-1994 groups so that potential policy changes in the post TRIPS era can be investigated.

Table 1
Data summary (in thousand).

	US	Britain Pre-TRIPS	Britain Post-TRIPS	Germany	Japan Pre-TRIPS	Japan Post-TRIPS	Korea	China
Panel A: Data used in the Logit model								
Publication Year	2002-2009	1984-1993	1994-2004	1994-2009	1979-1993	1994-2009	2000-2009	1994-2009
Native-Rejected	327	26	19	239	N/A	183	20	14
Native-Granted	216	31	27	78	N/A	151	3	6
Foreign-Rejected	542	1	1	642	N/A	600	184	417
Foreign-Granted	520	77	59	514	N/A	242	20	309
Total	1,605	135	106	1,473	N/A	1,176	227	747
Original Data	2,589	199	204	2,194	398	6,529	1,043	1,538
Panel B: Data used in the Count model								
Publication Year	2002-2009	1984-1993	1994-2000	1994-2009	1979-1993	1994-2009	2000-2009	1994-2009
Native-Granted	160	30	15	N/A	2	129	N/A	6
Foreign-Granted	408	76	34	N/A	107	225	N/A	309
Total	568	106	49	N/A	108	354	N/A	315
Original Data	1,279	146	91	972	837	2,185	198	551

Source: Authors' own calculation using the PATSTAT database.

5. Regression Results and Discussions

The mean and standard deviation values for the main variables are presented in Table 2. In the regressions, variables A , R and N are centered near their means (1, 0.1 and 5, respectively) for the convenience of interpretation. As a result, the estimated coefficients of the foreign dummy (ν) indicate how foreign applications are treated differently in comparison with home applications in the reference group with $A=1$ (high-tech industries), $R=0.1$ (low native patent concentration) and $N=5$ (important inventions). According to the theoretical model, strategic discrimination would be more likely adopted in high-tech industries (**H2**), in the fields with lower concentration of native patents (**H3**) and towards more important inventions (**H4**). Thus, the estimated coefficients of V capture the degree of discrimination.

Table 2

The mean and standard deviation (in parenthesis) of key variables.

	US	Britain	Germany	Japan	Korea	China
Panel A: Logit model						
Publication year	2002-2009	1984-1993	1994-2004	1994-2009	1979-1993	1994-2009 2000-2009 1994-2009
Patent family (<i>N</i>)	4.05 (3.35)	5.08 (4.48)	4.21 (3.43)	6.33 (4.01)	N/A N/A	5.60 (4.16) 6.10 (3.81) 6.17 (4.14)
Industrial level (<i>A</i>)	1.52 (0.73)	1.98 (0.79)	1.88 (0.82)	1.79 (0.74)	N/A N/A	1.63 (0.72) 1.55 (0.70) 1.60 (0.72)
Native ratio (<i>R</i>)	0.32 (0.21)	0.16 (0.15)	0.23 (0.18)	0.24 (0.15)	N/A N/A	0.15 (0.16) 0.06 (0.13) 0.01 (0.06)
Grant ratio	0.46 (0.50)	0.80 (0.40)	0.81 (0.39)	0.40 (0.49)	N/A N/A	0.33 (0.47) 0.10 (0.30) 0.42 (0.49)
Panel B: Count model						
Publication year	2002-2009	1984-1993	1994-2000	1994-2009	1979-1993	1994-2009 2000-2009 1994-2009
Patent family (<i>N</i>)	4.28 (3.45)	5.24 (4.27)	4.39 (3.35)	N/A N/A	8.69 (5.63)	5.76 (4.59) N/A (4.78)
Industrial level (<i>A</i>)	1.52 (0.68)	1.97 (0.78)	1.88 (0.79)	N/A N/A	1.90 (0.69)	1.67 (0.72) N/A (0.71)
Native ratio (<i>R</i>)	0.29 (0.20)	0.16 (0.16)	0.22 (0.18)	N/A N/A	0.00 (0.01)	0.12 (0.15) N/A (0.05)
Grant lag (days)	733.03 (436.22)	201.20 (86.86)	157.97 (88.27)	N/A N/A	2467.45 (896.38)	2063.63 (1030.79) N/A (538.98)

Source: Authors' own calculation using the PATSTAT database.

Tables 3 and 4 present the regression results for the Logit and count models, respectively. The maximum-likelihood estimation (MLE) method is employed in both cases. For the Logit model, the logistic distribution is adopted. For the count model, two types of distribution can be applied; the Poisson distribution and the negative binomial distribution (Hausman *et al.*, 1984). The Poisson distribution has an implicit restriction, that is, the variance of the sample is equal to the mean. However, a count dataset is commonly observed with different values for its variance and mean. Therefore, researchers routinely employ a more general specification, usually the negative binomial distribution which allows for over-dispersion (the variance being larger than the mean). The dispersion value in Table 4 measures the degree of dispersion. If the dispersion value equals zero, the model is reduced to the Poisson model (McCullagh and Nelder, 1989). However, all the dispersion values in Models 8-13 are greater than zero, which confirms that the dependent

variable is over-dispersed. This means that the negative binomial distribution fits our count models better than the Poisson distribution.

Table 3
Regression results of the Logit model.

	US	Britain Pre-TRIPS	Britain Post-TRIPS	Germany	Japan Post-TRIPS	Korea	China
Model	1	2	3	4	5	6	7
Intercept	0.22 (0.01)***	-0.04 (0.01)**	0.03 (0.02)	-1.40 (0.01)***	0.51 (0.01)***	-2.00 (0.03)***	-0.65 (0.04)***
Foreign dummy (<i>V</i>)	-0.12 (0.01)***	3.97 (0.04)***	4.06 (0.05)***	1.17 (0.01)***	-1.51 (0.01)***	-0.56 (0.03)***	-0.11 (0.04)***
Patent family (<i>N</i>)	0.05 (0.00)***	-0.03 (0.00)***	0.01 (0.00)***	-0.11 (0.00)***	0.20 (0.00)***	-0.06 (0.01)***	0.14 (0.01)***
Industrial level (<i>A</i>)	0.15 (0.00)***	-0.07 (0.01)***	-0.09 (0.01)**	0.21 (0.01)***	0.04 (0.00)***	0.19 (0.02)***	0.24 (0.02)***
Native ratio (<i>R</i>)	-1.99 (0.02)***	2.29 (0.06)***	2.37 (0.06)***	0.19 (0.03)***	-2.22 (0.02)***	-0.58 (0.09)***	-1.24 (0.11)***
<i>V</i> × <i>N</i>	0.00 (0.00)	-0.01 (0.01)**	-0.06 (0.01)***	0.12 (0.00)***	-0.16 (0.00)***	0.09 (0.01)***	-0.05 (0.01)***
<i>V</i> × <i>A</i>	-0.12 (0.00)***	0.21 (0.04)***	0.12 (0.04)**	-0.18 (0.01)***	0.03 (0.01)***	-0.33 (0.02)***	-0.14 (0.02)***
<i>V</i> × <i>R</i>	1.22 (0.02)***	-3.51 (0.18)***	-3.08 (0.19)***	-0.43 (0.03)***	-2.49 (0.03)***	-4.61 (0.17)***	-1.98 (0.12)***

Notes: Standard errors in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Source: Authors' own calculation using the PATSTAT database.

The estimated coefficients in Tables 3 and 4 are not the direct marginal effects because the two original models, Equations (28) and (29), are non-linear. The estimated coefficients stand for the marginal effects on the log odds ratio in the Logit regressions and on the log grant lag in the negative binomial regressions.²¹ However, the log odds ratio is a monotonously increasing function of the grant probability, and the log grant lag is monotonously increasing against the grant lag. Hence, the non-linearity doesn't affect the interpretation of the results.

²¹ The odds ratio is defined as the ratio of "the probability that a patent application is granted" to "the probability that the application is rejected".

Table 4

Regression results of the count model (negative binomial regressions).

	US	Britain	Britain	Japan	Japan	China
		Pre-TRIPS	Post-TRIPS	Pre-TRIPS	Post-TRIPS	
Model	8	9	10	11	12	13
Intercept	6.75 (0.00)***	5.27 (0.00)***	5.14 (0.01)***	7.45 (0.02)***	7.58 (0.00)***	6.87 (0.01)***
Foreign dummy (V)	-0.11 (0.00)***	0.02 (0.00)***	-0.14 (0.01)***	0.18 (0.02)***	0.06 (0.00)***	0.20 (0.01)***
Patent family (N)	0.00 (0.00)***	0.00 (0.00)***	-0.02 (0.00)***	0.00 (0.00)	-0.01 (0.00)***	0.02 (0.00)***
Industrial level (A)	-0.13 (0.00)***	0.01 (0.00)***	-0.01 (0.00)	-0.06 (0.01)***	0.00 (0.00)	-0.03 (0.01)***
Native ratio (R)	-0.09 (0.01)***	-0.11 (0.01)***	-0.12 (0.02)***	-1.25 (0.18)***	-0.81 (0.01)***	-0.03 (0.04)
$V \times N$	0.01 (0.00)***	-0.01 (0.00)***	0.00 (0.00)	0.00 (0.00)	0.01 (0.00)***	-0.01 (0.00)**
$V \times A$	0.01 (0.00)***	0.02 (0.00)***	0.03 (0.01)***	0.03 (0.01)**	0.00 (0.00)	0.00 (0.01)
$V \times R$	0.05 (0.01)***	0.15 (0.02)***	0.09 (0.03)***	-0.88 (0.21)***	-0.58 (0.01)***	-0.24 (0.04)***
Dispersion	0.39	0.12	0.26	0.16	0.32	0.17

Notes: Standard errors in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Source: Authors' own calculation using the PATSTAT database.

A negative coefficient of V in the Logit models (Models 1-7) means that the grant probability on average is lower for foreign patents than that for native ones. A positive estimated coefficient of V in the count models (Models 8-13) implies that the grant lag is on average longer for foreign patents than that for native ones. Therefore, the sign of the estimated coefficients of V indicates whether discriminatory policies exist. For example, the estimated coefficients of V are positive in Models 3 and 4 and negative in Model 10, which indicates no evidence of discriminatory policies being employed in Britain and Germany during the post-TRIPS period.

In Model 1, the negative coefficient of V seems to imply that the grant probability in the US patent office is lower for foreign innovators than for native innovators. However, the corresponding coefficient of V in Model 8 is negative, which implies that foreign patents also

have shorter pendency. As a combined tool of grant probability (P) and grant lag (T) is required for promoting leap-frogging (**H5**), the evidence is not sufficient to conclude that discrimination exists in the US system. A similar situation applies to pre-TRIPS Britain. In contrast, our findings indicate the possibility of discrimination in Japan, Korea and China. Foreign patents in these countries' patent offices tend to receive lower grant probability (negative coefficients of V in Models 5-7) as well as longer grant lags (positive coefficients of V in Models 11-13). To judge whether such discrimination is employed strategically or institutionally, other indicators have to be examined. Strategic discrimination means that the grant probability of foreign patents will be negatively related to N (**H4**) and positively related to A and R (**H2** and **H3**), while the grant lag for foreign patents will be positively related to N and negatively related to A and R . In other words, hypotheses 2-4 (**H2**, **H3** and **H4**) imply that the estimated coefficient of $V \times N$ shall have a negative value in the Logit model and a positive one in the count model, while those of $V \times A$ and $V \times R$ shall be positive in the Logit model and negative in the count model.

The regression results show that **H2**, **H3** and **H4** are verified in Models 5 and 12, which represent the post-TRIPS Japan. Only the negative coefficient of $V \times R$ in Model 5 is unexpected. Due to data limitation, only the Logit model is applicable for the Korean data (Model 6). The estimated coefficients of $V \times N$, $V \times A$ and $V \times R$ in Model 6 are not consistent with **H2**, **H3** and **H4**. Thus the discriminatory policy in Korea could be institutional rather than strategic. China and pre-TRIPS Japan stand between these two cases. As discussed in Section 3, institutional discrimination is a more serious and overt form of protection for native firms, while strategic discrimination is rather selective and disguised. Given the size of the Japanese economy, if discriminatory policies were to be implemented, strategic discrimination would be a better choice since it is more likely to escape international monitoring and retaliations. The same

argument applies to current day China. However, as a relatively smaller economy, Korea would be less scrutinized if institutional discrimination was to be used.

Our results also show that the behavior of national patent offices seems to be affected by TRIPS. Since the passing of TRIPS in 1994, foreign applications seem to have been treated better in the Japanese and British patent offices (we do not have similar data from other countries). For example, foreign patents in the UK tend to have higher grant probability (refer to the coefficients of V in Models 2 and 3) and shorter pendency (Model 9 vs. Model 10 and Model 11 vs. Model 12). Furthermore, the estimated coefficient of $V \times A$ becomes insignificant in Model 12, which indicates that in post-TRIPS Japan, foreign patents in the low-tech industries are no longer subjected to severe discrimination.

Finally, **H1** implies that if the punishment for patent infringement (β) is stricter, more severe discrimination would be needed in order to promote domestic firm leap-frogging. According to the OECD (2008, p.107), the General Trade-Related Index of Counterfeiting for economies (GTRIC-e) is often negatively correlated with β . The GTRIC-e score for China is 0.9748, which is much higher than the score for Korea (0.6085) and Japan (0.0419). Therefore, if both Japan and China adopt strategic discrimination, **H1** implies that the discrimination would be more severe in Japan than in China. Models 5, 7, 12 and 13 provide some insight into this question.²² The magnitude of the estimated coefficients of $V \times N$, $V \times A$ and $V \times R$ indicate the degree of discrimination. **H1** implies that the estimated coefficient of $V \times N$ in Model 5 should be smaller than that in Model 7, and that the coefficient of $V \times N$ in Model 12 should be larger than that in Model 13. These are confirmed by the regression results. The estimated coefficients of other interaction terms (except those of $V \times R$ in Models 5 and 7) also support **H1**.

²² Japanese and Chinese data is comparable because the data covers the same time period (1994-2009) and variables A , R and N are centered to the same values.

6. Conclusions

This paper explored two questions; 1) whether discrimination against foreigners exists in the patent examination procedures, and 2) whether such discriminatory practice is strategic or institutional. In parallel with strategic trade barriers, discriminatory policies in the invention field could be used to foster technological catch-up or even leap-frogging. A combined tool of lower grant probability and longer grant lags can be utilized to discriminate against foreign patents. We built a game theory model to simulate how this tool could be employed strategically. The traditional discrimination is *institutional* in the sense that all foreign patents are discriminated against. However, this overt discrimination can be very easily detected. Instead of abolishing discriminatory policies, a country could switch to a more disguised type of discrimination, *strategic* discrimination, which targets certain key patent fields. Our simulation results help to identify the characteristics of these key patents; that is, they are important inventions, in high-tech industries and costly for imitation.

Our empirical findings provide no clear evidence of the existence of discrimination in the US, British and German patent offices. However, Japanese, Korean and Chinese patent offices are linked with implicit or explicit protection of their local firms according to our analysis. This study also shows that TRIPS could have pushed the Japanese patent office away from institutional discrimination and influenced the office to switch to a strategic discrimination policy. The Korean patent office seems to maintain its institutional discrimination during the post-TRIPS period, perhaps because the Korean economy is much smaller and thus subject to less monitoring internationally. The Chinese patent office seems to stand between the Japanese and Korean offices, and may move towards the Japanese model as the Chinese economy will soon become the world's largest economy.

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Appendix A: Derivation of R&D Cost Functions

We derive the R&D cost function from the knowledge production function. New knowledge is created by new R&D investment based on established knowledge (Griliches, 1979; Furmana *et al.*, 2002). Thus the knowledge production function can be written as

$$s_t = K(s_{t-1}, r_t), \quad (\text{A.1})$$

where s_t denotes new technology in period t , created by R&D investment (r_t) in the period t on the basis of the existing technology (s_{t-1}). Without loss of generality, we assume an additive form for (A1) and obtain

$$s_t = \gamma s_{t-1} + \tilde{K}(r_t), \quad (\text{A.2})$$

where $\gamma \in [0,1]$ reflects the absorptive capability of the existing knowledge stock. Function $\tilde{K}(r_t)$ measures how much new knowledge is induced by R&D investment.

The marginal product of R&D investment is not unlimited but rather constrained by the existing knowledge stock. For example, even infinite R&D investment could not introduce the iPhone 4 in the year 1950. Thus the marginal product of R&D investment must converge to zero

as the investment increases to infinity.²³ This means that given a certain stock of knowledge (s_{t-1}) only a bounded technology improvement (\bar{s}) is feasible.

$$\lim_{r_t \rightarrow \infty} s_t = \gamma s_{t-1} + \lim_{r_t \rightarrow \infty} \tilde{K}(r_t) = \gamma s_{t-1} + \bar{s}, \quad (\text{A.3})$$

and

$$\lim_{r_t \rightarrow 0} s_t = \gamma s_{t-1} + \lim_{r_t \rightarrow 0} \tilde{K}(r_t) = \gamma s_{t-1}. \quad (\text{A.4})$$

A proper cost function should be in harmony with the knowledge production function. However, the commonly employed quadratic form of cost functions doesn't satisfy this condition. A typical quadratic cost function can be represented as $r = (1/2)s^2$ (Kovac and Zigic, 2012). This cost function implies that as $r_t \rightarrow \infty$, $s_t \rightarrow \infty$ which violates condition (A3).

The simplest form of a cost function that satisfies conditions (A3) and (A4) is²⁴

$$r_t = C(s_t) = \frac{s_t - \gamma s_{t-1}}{\gamma s_{t-1} + \bar{s} - s_t}. \quad (\text{A.5})$$

This is the baseline cost function that we assume for Firms 1 and 2. Firm 1 is a multi-national corporation. The cost of R&D is divided by the number of markets or countries (n) that it enters. Thus the R&D cost function of Firm 1 can be written as

$$C_1(s_{1,t}) = \frac{1}{n} \frac{s_{1,t} - \gamma s_{1,t-1}}{\gamma s_{1,t-1} + \bar{s} - s_{1,t}}, \quad (\text{A.6})$$

²³ The zero marginal product of a specific input in a production function has long been acknowledged. For instance, Färe (1974) and Suliman (1997) have studied zero marginal product of labor in production functions.

²⁴ Other forms of the cost function also exist. In fact, for any positive real numbers m and a_m ,

$C(s_t) = \sum_m a_m \left(\frac{s_t - \gamma s_{t-1}}{\gamma s_{t-1} + \bar{s} - s_t} \right)^m$ are all eligible choices. However, since the selection of cost functions doesn't

affect the main conclusions of this paper, we will adopt the simplest function (A.5).

where $s_{1,t-1}$ denotes the stock of knowledge that Firm 1 faces when it conducts innovation on quality improvement. Without loss of generality, we normalize the initial knowledge stock ($s_{1,t-1}$) to zero and standardize the upper bound of R&D productivity (\bar{s}) to one. This gives Firm 1's cost function as

$$C_1(s_1) = \frac{1}{n} \frac{s_1}{1-s_1}, \quad (0 \leq s_1 < 1). \quad (\text{A.7})$$

The denominator ($1-s_1$) ensures the property of diminishing marginal product of R&D investment.

Firm 2 only operates in the domestic market and hence its cost cannot be shared in other markets. However, its R&D activities can benefit from the knowledge of Firm 1's published patent (s_1). Thus Firm 2's cost function can be written as

$$C_2(s_2 | s_1) = \frac{s_2 - \gamma s_1}{\gamma s_1 + 1 - s_2}, \quad (\gamma s_1 \leq s_2 < 1 + \gamma s_1). \quad (\text{A.8})$$

Finally, we add a scaling parameter α to capture the industrial characteristics. The share of a firm's revenue spent on R&D investment changes substantially across sectors. Thus we use a larger α to indicate a larger proportion of earnings that is invested in R&D investment in an industry:

$$C_1(s_1) = \frac{1}{n} \frac{\alpha s_1}{1-s_1}, \quad (0 \leq s_1 < 1), \quad (\text{A.9})$$

and

$$C_2(s_2 | s_1) = \frac{\alpha(s_2 - \gamma s_1)}{1 + \gamma s_1 - s_2}, \quad (\gamma s_1 \leq s_2 < 1 + \gamma s_1). \quad (\text{A.10})$$

In the numeric simulation exercises (Section 3) we have to choose an initial value for α . Añón Higón and Manjón Antolín (2012) estimated that the share of R&D investment in revenue was

0.4019 for foreign multinationals in the UK. Chan *et al.* (2001) also showed that R&D expenditures typically amount 30 percent to 80 percent of a firm's earnings in the US. Hence, we assume the share of R&D investment in revenue is 0.4 and obtain

$$\frac{1}{n} \frac{\alpha s_1}{1-s_1} = 0.4 \times \pi_1. \quad (\text{A.11})$$

During the period of patent protection, Firm 1 can receive profit $\pi_1^M = s_1/4$ (Equation 20).

Thus we get

$$\alpha = 0.4 \times \frac{s_1}{4} \times \left(n \frac{1-s_1}{s_1} \right) = 0.1 n \times (1-s_1). \quad (\text{A.12})$$

The initial value of n and s_1 are taken as 2 and 0.5, respectively (Section 3). Thus a proper initial value for α is 0.1.

Appendix B: Derivation of Demand Functions

We assume that products are vertically differentiated. Each consumer is characterized by a parameter θ and has the following utility function (Motta, 1993):

$$U_\theta = \begin{cases} \theta s - p, & \text{if the consumer buys good with quality } s \text{ and price } p, \\ 0, & \text{if the consumer does not buy.} \end{cases} \quad (\text{B.1})$$

θ indicates the consumer's appreciation of quality. We assume that θ is uniformly distributed over the interval $[0, 1]$ (Li and Song, 2009).

Based on the qualities and prices offered by Firms 1 and 2, consumers can choose to either buy the product (from Firm 1 or Firm 2) or not buy it at all. Consumers' choices determine the two firms' demand functions. In the case of $s_1 > s_2$, the marginal consumer who is indifferent

about buying either quality s_1 or quality s_2 is determined by $\theta s_1 - p_1 = \theta s_2 - p_2$. Hence $\theta_{12} = (p_1 - p_2) / (s_1 - s_2)$. As a result, the demand function for a good of quality s_1 can be derived as

$$q_1 = \int_{\theta_{12}}^1 d\theta = 1 - \frac{p_1 - p_2}{s_1 - s_2}. \quad (\text{B.2})$$

Similarly, the marginal consumer who is indifferent between buying a good of quality s_2 and not buying anything at all is determined by $\theta s_2 - p_2 = 0$, Hence, $\theta_{20} = p_2 / s_2$. Thus the demand function for the good of quality s_2 is

$$q_2 = \int_{\theta_{20}}^{\theta_{12}} d\theta = \frac{p_1 - p_2}{s_1 - s_2} - \frac{p_2}{s_2}. \quad (\text{B.3})$$

Based on the same method, in the case where Firm 2 produces a higher quality ($s_2 > s_1$), the demand functions are

$$q_2 = 1 - \frac{p_2 - p_1}{s_2 - s_1} \quad (\text{B.4})$$

and

$$q_1 = \frac{p_2 - p_1}{s_2 - s_1} - \frac{p_1}{s_1}. \quad (\text{B.5})$$

Firm 1 will get the monopolistic profit π_1^M once its patent is granted. In this case, the marginal consumer who is indifferent between buying the good of quality s_1 and not buying any good at all is determined by

$$\theta s_1 - p_1 = 0. \quad (\text{B.6})$$

Hence $\theta_{10} = p_1 / s_1$. Now the demand function is

$$q_1 = \int_{\theta_{10}}^1 d\theta = 1 - \frac{p_1}{s_1}. \quad (\text{B.7})$$

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