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경제학석사 학위논문

The Impact of National Treatment
on Innovation Incentives and
National Welfare

지적재산권의 내국민대우가 혁신 유인과 국가
후생에 미치는 영향

2021 년 8 월

서울대학교 대학원
경제학부 경제학 전공
송근상

The Impact of National Treatment on Innovation Incentives and National Welfare

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이 논문을 경제학석사 학위논문으로 제출함

2021 년 8 월

서울대학교 대학원

경제학부 경제학 전공

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송근상의 경제학석사 학위논문을 인준함

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Abstract

The Impact of National Treatment on Innovation Incentives and National Welfare

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This paper compares two patent protection environments: national treatment environment and home bias environment. I show that under both environments, the R&D games between a domestic and a foreign firm have unique Markov perfect equilibria in cut-off strategies. The amount of aggregate experimentation is the same for both environments while the intensity of experimentation is larger under national treatment environment. A comparison of the two environments in terms of national welfare with respect to the level of market competition shows a non-linear relationship.

Keyword : strategic experimentation, multi-armed bandit, R&D race, intellectual property rights, national treatment principle

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1. Introduction

In a globalized economy, multinational corporations sell their products in multiple markets. To secure enough profit in the international product market, these firms patent their own technologies in many countries. Such phenomenon calls for an international patent system. The results of the endeavor were Paris convention and TRIPs agreement. In this paper, I focus on one aspect of the international patent treaties: National treatment principle. This principle stipulates that member states should treat foreign patent applicants no less favorable than its own nationals with regard to the intellectual property rights.

However, empirical researches have found out that although national treatment is stipulated in principle, it is not upheld in practice (Yang 2008; Webster, Jensen, and Palangkaraya 2014; de Rassenfosse, Jensen, Julius, Palangkaraya, and Webster 2019; Mai and Stoyanov 2019). One anecdotal evidence is a patent war between Apple and Samsung in 2010s. While the court of Republic of Korea favored Samsung, the US court favored Apple.

Intuitively, discriminating foreign firms in terms of IP rights bring more national welfare. Domestic firms can enjoy some profit by engaging in the product market, and consumers also benefit from the market competition. On the other hand, such discrimination also harms national welfare because foreign firms now have less incentive to innovate. If the government wants to maximize the national welfare, it decides whether or not to abide by the national treatment principle based on such trade-off. The objective of this paper is to analyze simple strategic experimentation models that capture two

different patent protection environments (national treatment environment and home bias environment), and compare the equilibria in terms of innovation incentive and national welfare.

In this paper, I solve strategic experimentation games with asymmetric payoffs. I show that in both environments, there is a unique Markov perfect equilibrium and the equilibrium strategies can be characterized by certain cut-offs. With regard to the innovation incentive, the aggregate amount of experimentation is the same for both environments. However, the R&D is less intense under home bias environment. As for national welfare, I conduct comparative statics with regard to the level of product market competition when the patent right is violated. The result is that the benefit of one environment over the other has non-linear relationship. The net benefit of Home bias environment is maximized when the market competition is intermediate.

This paper contributes to three lines of research. First of all, it is related to the international patent system literature. Grossman and Lai (2004) establishes a macroeconomic model to analyze the role of harmonization, which is one another important issue in international IPR treaties. Geng and Saggi (2015) uses the framework of Grossman and Lai (2004) to analyze the role of NTP on incentivizing innovation. This paper is distinctive from these as I adopt a microeconomic model to focus on the R&D incentives of individual firms under different IPR environments.

Theoretically, my work contributes to the strategic experimentation model. The canonical framework of strategic experimentation was proposed by Bolton and Harris (1999) and Keller, Rady, and Cripps (2005; henceforth KRC). Besanko and Wu

(2013) used the strategic experimentation model with exponential bandit following KRC and considered market structure to compare R&D competition and cooperation. Das, Klein, and Schmid (2019; henceforth DKS) tackles the issue of asymmetric ability between players in the strategic experimentation game. Das and Klein (2020) takes a further step to consider the effect of the degree of patent protection on R&D choices. In this paper, I adopt the strategic experimentation framework of KRC and add an asymmetry as DKS. However, I solve a game when there is an asymmetry in the payoff that each player faces. Moreover, I analyze the role of market structure as Besanko and Wu (2013) did.

This paper is also related to the R&D race literature. The line of research was initiated by Loury (1979) and Dasgupta and Stiglitz (1980). Choi (1991) and Malueg and Tsutsui (1997) introduced the learning aspect into the R&D literature. I follow these papers and use multi-armed bandit framework for the R&D game. Unlike them, I focus on the payoff asymmetry for a biased patenting environment. There are some papers that consider asymmetry between players of R&D games. Rosen (1991) examines the role of initial firm size on R&D strategy in terms of the amount and the riskiness of investment. Fershtman and Markovich (2010) analyzes a multi-stage R&D model with an asymmetry on abilities. My work differs from those as I consider an asymmetry on payoffs.

The rest of the paper is organized as follows. Section 2 describes the strategic experimentation model with asymmetric payoffs. In section 3 and 4, I conduct equilibrium analyses of the strategic experimentation games under two environments, respectively. I compare the two environments in terms of innovation incentives and

national welfare in section 5. Section 6 contains concluding remarks.

2. Model

In this model, 2 firms are locked in an R&D race. Firm 1 is a domestic firm, while firm 2 is a foreign firm. Both firms have 2 projects at hand. Following the multi-armed bandit literature, projects and arms are used interchangeably. One project is safe (S), and the other project is risky (R). The time is continuous. Each firm has 1 indivisible unit of input which could be allocated either to the safe arm or to the risky arm. At every instance, the firm decides whether to put this resource into the risky arm or to the safe arm. Let's denote $k_i \in \{0,1\}$ as the amount of input allocated to the risky project. Clearly, $(1 - k_i)$ is the amount of input that is allocated to the safe project.

If a firm pulls the safe arm at period t , it enjoys a flow payoff of $s > 0$ for sure. On the other hand, if it pulls the risky arm, the flow payoff depends on the state of the world. For simplicity, I assume that there are only 2 states of the world; the good state and the bad state. Two firms do not observe the state of the world, but know that the state is common for both of them. If the state is bad, pulling a risky arm brings 0 payoff with probability 1. If the state is good, a breakthrough occurs stochastically. When a breakthrough occurs, firm i earns some positive flow payoff of π_i^j at every instant from then on. Here π_i^j means a flow payoff that firm i can earn when firm j makes a breakthrough. The arrival time of the breakthrough follows an exponential distribution with parameter λ .

In this paper, I consider and compare two environments where the structure of π_i^j differ. The first environment is the National treatment environment (henceforth NT environment), where firm 1 and firm 2 are treated equally in terms of patent protection. In this case, $\pi_i^j = \pi^M$ if $i = j$ and $\pi_i^j = 0$ if $i \neq j$. This means a strong level of patent protection for both the domestic and foreign firms so that the firm which made a breakthrough can safely earn a monopoly profit in the product market while the other firm can never infringe on it. Hence when a breakthrough occurs, the other firm returns to the safe arm to earn s from then on.

The second environment under consideration is the Home bias environment (henceforth HB environment). Here the domestic firm and the foreign firm are treated differently. To be specific, the foreign firm (firm 2)'s invention is not well protected while firm 1's invention is still well protected. In short, $\pi_1^1 = \pi^M, \pi_2^1 = 0$ following firm 1's breakthrough, but $\pi_1^2 = \pi_2^2 = \pi^D$ if firm 2 makes the breakthrough first. π^D is a duopoly profit in the product market. If firm 1 makes a breakthrough, it is obvious that firm 2 returns to the safe project.

To see only the interesting cases, we assume that $s < \pi^D$. It's also not unusual to assume that $\pi^M \geq 2\pi^D$ as if otherwise, the monopoly firm can easily mimic the duopoly market outcome for more profit.

Each firm cares about its expected dynamic sum of payoffs. I assume that both firms have a common discount rate r . For an expositional reason, I assume that $r \leq \lambda$.

Lastly, I assume that the two firms share a common prior p_0 , and the past actions and the outcomes are commonly observable to both

firms. These assumptions guarantee that firm 1 and firm 2 also share a common posterior p_t . As there is no breakthrough in the bad state, one occurrence of a breakthrough makes $p_t = 1$. In the absence of a breakthrough, the posterior belief follows the following law of motion:

$$dp_t = -\lambda(k_{1,t} + k_{2,t})p_t(1 - p_t)dt$$

Following the previous literature, the equilibrium concept I adopt here is Markov perfect equilibrium (henceforth MPE). In particular, I focus on Markov strategies where the posterior belief p_t is used as a state variable. A Markov strategy for firm i is defined as a left-continuous function $k_i: [0,1] \rightarrow \{0,1\}$. I rule out strategies with infinite switches. If the continuous time model is interpreted as an asymptotics of a discrete time model as in Heidhues, Rady, and Strack (2015), such behavior surely cannot happen. A plausible assumption that there is an infinitesimal switching cost also justifies the restriction.

3. National Treatment Environment

I first consider the National treatment environment where both the domestic and foreign firms enjoy the symmetric level of patent protection.

3.1. Best Responses

Firm i 's average value function is written as

$$v_i(p) = \max_{k_i \in \{0,1\}} \{(1 - k_i)rsdt + k_i r \lambda p \pi^M dt + e^{-r dt} E[v(p + dp) | p, k_1, k_2]\}$$

By rearranging terms, one can derive the following Bellman equation:

$$v_i = s + k_j b^S(p, v_i) + \max_{k_i \in \{0,1\}} k_i \{b^M(p, v_i) - c^M(p)\} \quad (1)$$

The first term s in the right hand-side of the equation is the average payoff that firm i can guarantee by always pulling the safe arm. The second term $b^S(p, v_i) = \lambda p(s - v_i - (1 - p)v_i')/r$ is the expected marginal benefit when firm j pulls the risky arm. When firm j pulls the risky arm, it affects firm i in two ways. Firstly, if it makes a breakthrough, firm i automatically has to return to the safe arm. Secondly, if there is no news, it sends a signal to the firms that it is less likely that the state is good. The third term $(b^M(p, v_i) - c^M(p))$ is the net expected marginal payoff from firm i 's pulling the risky arm itself. $b^M(p, v_i) = \lambda p(\pi^M - v_i - (1 - p)v_i')/r$ is the marginal benefit while $c^M(p) = s - \lambda p \pi^M$ is the immediate marginal opportunity cost. Similar to the marginal benefit of firm j 's experimentation, firm i 's experimentation has two effects. If any good news arrives, its value immediately rises to the monopoly profit π^M . On the other hand, if pulling the risky arm does not bring any news, it is a signal that the state might be bad. Unlike firm j 's experimenting, own experimentation incurs an immediate opportunity cost. At time t , if firm i inputs its resource to the R&D investment, it can earn π^M with probability λp . At the same time, it cannot pull the safe arm which surely gives an instant payoff of s .

Following KRC, the characterization of the best responses of the firms makes the equilibrium analysis tractable. By the Bellman equation (1), it is immediate that firm i chooses $k_i = 1$ if $b^M(p, v_i) \geq$

$c^M(p)$, and $k_i = 0$ if $b^M(p, v_i) \leq c(p)$. By adding and subtracting some terms, one can obtain an alternative representation of the best responses:

$$k_i \begin{cases} = 1 & \text{if } v_i(p) > D_i(p; k_j) \\ \in \{0, 1\} & \text{if } v_i(p) = D_i(p; k_j) \\ = 0 & \text{if } v_i(p) < D_i(p; k_j) \end{cases}$$

This relationship means that player i 's best response depends on whether the v_i function in the (p, v_i) -plane is above or below the affine function

$$D_i(p; k_j) = s + k_j c^M(p) - \frac{1}{\mu} (\pi^M - s) k_j p$$

When $k_j = 0$, $D_i(p, 0)$ is simply a constant function s . When $k_j = 1$, $D_i(p, 1)$ is a decreasing affine function which passes through a point $(p, v) = (\frac{\mu s}{(1+r)\pi^M - s}, s)$. Let's define $\bar{p} = \frac{\mu s}{(1+r)\pi^M - s}$. Note that this posterior belief is exactly the point where a firm would stop experimenting if it was the only participant in the R&D race. One additional remark is that because of the assumption $\mu \leq 1$, and $\pi^M > 2s$, \bar{p} is strictly smaller than 1.

The next step is to derive explicit solutions for payoff functions.

3.2. Markov Perfect Equilibrium

On intervals of beliefs where the mutual best responses are uniquely determined, one can solve for the value function explicitly up to a constant. When both firms are pulling the safe arm, obviously $v_i(p) = s$. If $k_i = 1$ while $k_j = 0$, then v_i satisfies

$$(r + \lambda p)v_i + \lambda p(1 - p)v'_i = \lambda p(1 + r)\pi^M. \quad (2)$$

The solution to the ODE (2) is

$$v_i(p) = \frac{(1 + r)\pi^M}{1 + \mu}p + C\Omega_1(p), \quad (3)$$

where $\Omega_n(p) = (1 - p)\left(\frac{1-p}{p}\right)^{\frac{\mu}{n}}$.

Secondly, if $k_i = 0$ while $k_j = 1$, v_i satisfies the following ODE:

$$(r + \lambda p)v_i + \lambda p(1 - p)v'_i = (r + \lambda p)s, \quad (4)$$

whose explicit solution is

$$v_i(p) = s + C\Omega_1(p). \quad (5)$$

Finally, when $k_i = k_j = 1$,

$$(r + 2\lambda p)v_i + 2\lambda p(1 - p)v'_i = \lambda p((1 + r)\pi^M + s). \quad (6)$$

whose solution is

$$v_i(p) = \frac{(1 + r)\pi^M + s}{2 + \mu} + C\Omega_2(p). \quad (7)$$

I now give a characterization of MPE. It turns out to be in cut-off strategies and the equilibrium is unique.

Proposition 1. *There exists a unique Markov perfect equilibrium in cut-off strategies. The MPE is characterized by a cut-off \bar{p} . Each firm experiments until the common posterior belief falls down to \bar{p} and then simultaneously switched to the safe arm. Firm i 's equilibrium payoff is given by*

$$v_i(p) = \begin{cases} s & \text{if } p \in [0, \bar{p}] \\ \frac{(1 + r)\pi^M + s}{2 + \mu}p + C_{rr}\Omega_2(p) & \text{if } p \in (\bar{p}, 1] \end{cases} \quad (8)$$

where $C_{rr} = \frac{2s((1+r)\pi^M - (1+\mu)s)}{(2+\mu)((1+r)\pi^M - s)\Omega_2(\bar{p})} > 0$.

Proof. Proving the existence of the proposed equilibrium follows from a verification argument. It is enough to show that when firm j 's strategy is fixed to the cut-off strategy with cut-off \bar{p} , the very same strategy is indeed firm i 's best response.

In the range $[0, \bar{p}]$, if firm i pulls the safe arm, then $v_i(p) = s = D_i(p; 0)$ in that range so that a deviation is not profitable. On the other hand, in the range $(\bar{p}, 1]$, if firm i pulls the risky arm, then v_i satisfies the differential equation (6). As $D_i(p; 1) < s$ in that range, it is enough to show that $v_i \geq s$.

First note that from the value matching condition, $v_i(\bar{p}+) = s$. Then from the equation (6), $v_i'(\bar{p}+) = 0$. Since $v_i''(p) = C\Omega_2''(p)$ by equation (7) and $\Omega_2''(p) \geq 0$, showing $C > 0$ implies v_i is non-decreasing in that region and the existence is proved. From the value matching condition, $C = C_{rr}$ can be derived as stated in the proposition and it is indeed larger than 0 because of the assumption that $\mu \leq 1$ and $\pi^M > 2s$.

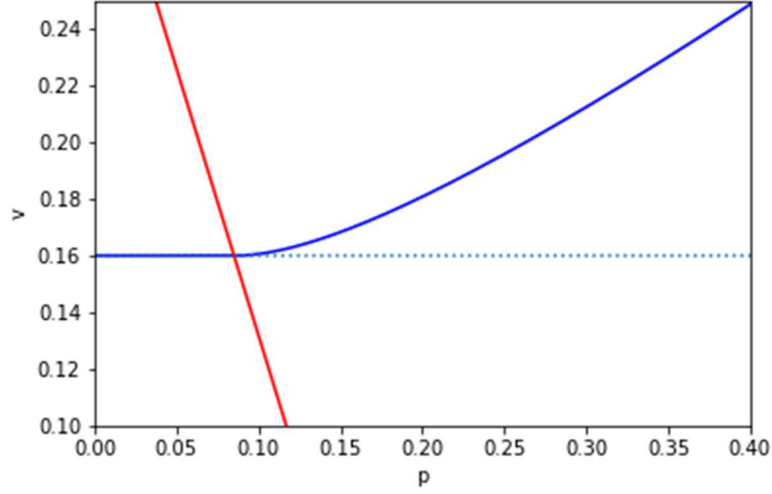
To show uniqueness, first define $p' = \inf \{p: (k_i, k_j) \neq (0, 0)\}$. Then clearly $v_i(\bar{p}+) = s$. If $p' < \bar{p}$, there must exist some $p < p'$ in the right-neighborhood of \bar{p} where at least one firm (WLOG, i) is pulling the risky arm. Suppose firm j also pulls the risky arm at p . Then as $p < \bar{p}$, $D_i(p; 1) > s$. Hence if p is sufficiently close to p' , $v_i(p)$ locates below $D_i(p; 1)$ so that it is better for firm i to pull the safe arm at the posterior belief p . This implies that at most one firm should be pulling the risky arm in the right-neighborhood of p' . Then in that neighborhood, v_i satisfies the differential equation (2). As $v_i(p') = s$, the assumption that $p' < \bar{p}$ implies $v_i'(p') < 0$. Then it is optimal for firm i to pull the safe arm in the right

neighborhood of p' . Therefore, $p' \geq \bar{p}$ should be met and both firms must pull the safe arm at every $p \leq \bar{p}$ in equilibrium.

For the posterior beliefs $p \in (\bar{p}, 1]$, first note that \bar{p} is the very same cut-off of the single-agent optimal stationary Markovian decision. Then it is clear that $p' = \bar{p}$, since otherwise, each firm faces a single-agent problem so that conducting an experimentation is optimal. From a similar argument, $(k_i, k_j) = (0, 0)$ can be ruled out in this range. Next, we can show that both firms must be pulling the risky arm in the right-neighborhood of \bar{p} . If firm i is pulling the safe arm in that neighborhood while firm j isn't, $v_i = s > D_i(p; 1)$. Hence it is profitable for firm i to deviate to the risky arm. On the other hand, both firms pulling the risky arm is a mutual best response. This implies that v_i is increasing and convex in the right-neighborhood of \bar{p} .

Now suppose that there is some $p > \bar{p}$ where $(k_i, k_j) = (0, 1)$ happens in equilibrium. Then as $D_i(p; 1) < s$ at that belief, $v_i(p) \leq D_i(p; 1) < s$ should hold as well. As $v_i \geq s$ in the right-neighborhood of \bar{p} , there must exist some $\hat{p} \in (\bar{p}, p)$ such that $v_{i(\hat{p})} = s$ and $v'_i(\hat{p}) \leq 0$. From equation (2), (4), and (6), $(k_i(\hat{p}), k_j(\hat{p})) = (0, 1)$ is the only consistent action. Then it means that in some left-neighborhood of \hat{p} , $(0, 1)$ is played in equilibrium. However, $v'_i(\hat{p}) \leq 0$ implies that $v_i \geq s > D(p; 1)$ in such neighborhood, meaning that pulling the risky arm is optimal for firm i . Therefore, only $(1, 1)$ can happen in equilibrium for $p \in (\bar{p}, 1]$, establishing the uniqueness of MPE. \square

Figure 1 illustrates the equilibrium value function on the (p, v) -plane. The parameters for this example are $(s, \pi^M, \pi^D, r, \lambda) = (0.16, 1, 0.44, 0.1, 0.2)$. There is a remark to be made here. The strategy



that each firm takes in the unique equilibrium coincides with the single-agent decision and the optimal decision when firms form a cartel. This result is analogous to the counterpart of Das and Klein (2020) and that of Besanko and Wu (2013) with no payoff externality. A few twists in the model can alter the result. For

Figure 1. Equilibrium value function under NT environment instance, if the duration of patent protection is finite, then the firm who failed to make a breakthrough can still benefit from the opponent's invention once the patent is expired. Then there is some positive payoff externality. In addition, the value of the safe project might deteriorate. One can think of a cellular phone that was replaced by smartphone. In this case, one firm's experimentation brings a negative payoff externality. Then the equilibrium can be different as

well.

4. Home Bias Environment

Now I turn to the home bias environment where the regulator ignores national treatment principle and favors the domestic firms against the foreign firms. The foreign firm's patent is not well enforced under this environment. The infringement by the domestic firm is not punished, and the firms engage in an oligopolistic product market competition. The domestic firm's patent is well enforced so that the domestic firm can safely reap the monopoly profit if it makes a breakthrough.

4.1. Best Responses

In this environment, the domestic firm (firm 1)'s Bellman equation of the value function is given as,

$$v_1 = s + k_2 b^D(p, v) + \max_{k_1 \in \{0,1\}} \{k_1 (b^M(p, v) - c^M(p))\}. \quad (9)$$

Likewise, the foreign firm (firm 2)'s Bellman equation of the value function is given as,

$$v_2 = s + k_1 b^S(p, v) + \max_{k_2 \in \{0,1\}} \{k_2 (b^D(p, v) - c^D(p))\}. \quad (10)$$

New terms $b^D(p, v)$ and $c^D(p)$ are defined analogously as the counterparts were at section 3¹. For firm 1, own experimentation brings the marginal payoff of $b^M(p, v)$, while at the same time it incurs

¹ $b^D(p, v) = \lambda p(\pi^D - v - (1 - p)v')/r$, $c^D(p) = s - \lambda p\pi^D$.

an instant opportunity cost $c^M(p)$. Under the HB environment, firm 1 enjoys the better marginal payoff from firm 2' s experimentation ($b^D(p, v)$), due to the duopoly profit when firm 2 makes a first breakthrough. For firm 2, it enjoys the same benefit from firm 1' s experimentation as firm 1 can have the same level of protection as in the NT environment. On the other hand, the marginal cost and benefit of own experimentation differs from the previous section because it can only earn a duopoly profit even if it wins the R&D race.

The same method can be used to characterize each firm' s best response. For any posterior belief p , each firm pulls either the safe or the risky arm based on the relative position of v and some affine function $D_i(p; k_j)$. The followings are the representation of two firms' best responses:

$$k_1^* \begin{cases} = 0 & \text{if } v_1(p) < D_1(p; k_2) \\ \in \{0, 1\} & \text{if } v_1(p) = D_1(p; k_2) \\ = 1 & \text{if } v_1(p) > D_1(p; k_2) \end{cases}$$

$$k_2^* \begin{cases} = 0 & \text{if } v_2(p) < D_2(p; k_1) \\ \in \{0, 1\} & \text{if } v_2(p) = D_2(p; k_1) \\ = 1 & \text{if } v_2(p) > D_2(p; k_1). \end{cases}$$

Here, $D_1(p; k_2) = s + k_2 c^M(p) - \frac{1}{\mu}(\pi^M - \pi^D)k_2 p$ and $D_2(p; k_1) = s + k_1 c^D(p) - \frac{1}{\mu}(\pi^D - s)k_1 p$. As one can see, D_i is a constant function when the opponent is pulling the safe arm. On the other hand, it is an affine function with a negative slope which passes through a certain point (\bar{p}_i, s) . From a simple calculation, one can obtain $\bar{p}_1 = \frac{\mu s}{(1+r)\pi^M - \pi^D}$ and $\bar{p}_2 = \frac{\mu s}{(1+r)\pi^D - s}$.

As for \bar{p}_1 and \bar{p}_2 , note that $\bar{p}_1 \in (0, 1)$ by the assumptions $\mu \leq 1$ and $\pi^M > 2\pi^D > 2s$. Meanwhile, \bar{p}_2 can be larger than 1. The necessary and sufficient condition for \bar{p}_2 to be smaller than 1 is

$$(1+r)\pi^D > (1+\mu)s.$$

4.2. Markov Perfect Equilibrium

Before moving on to the characterization of the equilibrium, solving for the value functions explicitly can be useful. Unlike section 3, the value functions vary by the identity of the firm conducting the experimentation. When both firms are pulling the safe arm, i.e., $(k_1, k_2) = (0, 0)$, obviously $v_1 = v_2 = s$. The followings are the differential equations and the explicit solutions for all other cases.

● $(k_1, k_2) = (1, 0)$:

$$(r + \lambda p)v_1 + \lambda p(1 - p)v'_1 = \lambda p(1 + r)\pi^M \quad (11)$$

$$v_1(p) = \frac{(1 + r)\pi^M}{1 + \mu}p + C\Omega_1(p) \quad (12)$$

$$(r + \lambda p)v_2 + \lambda p(1 - p)v'_2 = (r + \lambda p)s \quad (13)$$

$$v_2(p) = s + C\Omega_1(p) \quad (14)$$

● $(k_1, k_2) = (0, 1)$:

$$(r + \lambda p)v_1 + \lambda p(1 - p)v'_1 = rs + \lambda p\pi^M \quad (15)$$

$$v_1(p) = s + \frac{\pi^D - s}{1 + \mu}p + C\Omega_1(p) \quad (16)$$

$$(r + \lambda p)v_2 + \lambda p(1 - p)v'_2 = \lambda p(1 + r)\pi^D \quad (17)$$

$$v_2(p) = \frac{(1 + r)\pi^D}{1 + \mu}p + C\Omega_1(p) \quad (18)$$

● $(k_1, k_2) = (1, 1)$:

$$(r + 2\lambda p)v_1 + 2\lambda p(1 - p)v'_1 = \lambda p\{(1 + r)\pi^M + \pi^D\} \quad (19)$$

$$v_1(p) = \frac{(1+r)\pi^M + \pi^D}{2+\mu} p + C\Omega_2(p) \quad (20)$$

$$(r + 2\lambda p)v_2 + 2\lambda p(1-p)v_2' = \lambda p\{(1+r)\pi^D + s\} \quad (21)$$

$$v_2(p) = \frac{(1+r)\pi^D + s}{2+\mu} p + C\Omega_2(p) \quad (22)$$

Now I characterize the MPEs under HB environment:

Proposition 2. *There is a unique Markov perfect equilibrium under HB environment. Equilibrium strategies are in cut-off strategies where each cut-off coincides with the single-agent cut-off \bar{p} and \bar{p}_2 . Each firm conducts experiment above its cut-off level and stops experimenting below the cut-off. If $\bar{p}_2 > 1$, firm 2 never enters the R&D race and always play safe. The equilibrium payoff for each firm is given by*

$$v_1(p) = \begin{cases} s & \text{if } p \in [0, \bar{p}] \\ \frac{(1+r)\pi^M}{1+\mu} p + C_1^{rs}\Omega_1(p) & \text{if } p \in (\bar{p}, \bar{p}_2] \\ \frac{(1+r)\pi^M + \pi^D}{2+\mu} p + C_1^{rr}\Omega_2(p) & \text{if } p \in (\bar{p}_2, 1] \end{cases} \quad (23)$$

and

$$v_2(p) = \begin{cases} s & \text{if } p \in [0, \bar{p}_2] \\ \frac{(1+r)\pi^D + s}{2+\mu} p + C_2^{rr}\Omega_2(p) & \text{if } p \in (\bar{p}_2, 1] \end{cases} \quad (24)$$

If $\bar{p}_2 < 1$. If otherwise, last cases of v_1 and v_2 are removed. Constants C_1^{rs}, C_1^{rr} , and C_2^{rr} are determined by value matching conditions and they are all non-negative. v_2 is smooth while v_1 has a kink at $p = \bar{p}_2$.

Proof. Proving the existence of the proposed equilibrium follows from the verification argument. Let's fix firm 1's strategy as

described in the proposition. In the range $[p, \bar{p}]$, firm 2 is essentially facing the single-agent problem and it is optimal to play safe. In the range $(\bar{p}, \bar{p}_2]$, if firm 2 is playing safe, equation (14) with value matching condition at \bar{p} indicates $v_2 = s$ in that range. As $D_2(p; 1) > s$ in this range, pulling the safe arm is indeed optimal. It means that if $\bar{p}_2 > 1$, firm 2 is playing its best response. Finally, in the range $(\bar{p}_2, 1]$ when $\bar{p}_2 < 1$, equation (22) with value matching condition at $p = \bar{p}_2$ reveals that $C_2^{rr} \geq 0$. Equation (21) also reveals that $v_2'(\bar{p}_2 +) = 0$. Hence v_2 is non-decreasing, convex and smooth in that region, implying that it is well above $D_2(p; 1)$ so that pulling the risky arm is firm 2's best response.

Now let's fix firm 2's strategy as given in the proposition and find out if firm 1's proposed strategy is indeed its best response. Analogous to the previous argument, firm 1 is facing a single-agent problem in the range $[0, \bar{p}_2]$ so pulling the risky arm if and only if $p > \bar{p}$ is the best response. Thus if $\bar{p}_2 > 1$, the proposed strategy is firm 1's best response. The value matching condition at $p = \bar{p}_1$ yields $C_1^{rs} \geq 0$ and equation (11) leads to $v_1'(\bar{p}_1) = 0$. Hence v_1 is non-decreasing and convex in that range. To see the case where $p \in (\bar{p}_2, 1]$ when $\bar{p}_2 < 1$, it is enough to show that $C_1^{rr} \geq 0$. The value matching condition at $p = \bar{p}_2$ leads to

$$\frac{(1+r)\pi^M}{1+\mu}\bar{p}_2 + C_1^{rs}\Omega_1(\bar{p}_2) = \frac{(1+r)\pi^M + \pi^D}{2+\mu}\bar{p}_2 + C_1^{rr}(\bar{p}_2).$$

By the assumption $\mu \leq 1$, one can easily derive $\frac{(1+r)\pi^M}{1+\mu} \geq \frac{(1+r)\pi^M + \pi^D}{2+\mu}$.

Together with the fact that $C_1^{rs} \geq 0$, $C_1^{rr} \geq 0$ also holds.

Turning to the uniqueness, it can be easily shown that below \bar{p}_1 , both firms should be pulling the safe arm. Let's define $p' = \inf \{p: (k_1(p), k_2(p)) \neq (0,0)\}$ and suppose that $p' < \bar{p}$. If (1,1) is

played near p' , v_2 is well below $D_2(p, 1)$ at such belief. Hence it could not happen in equilibrium. If only one firm is conducting an experimentation in the right-neighborhood of p' , such firm is facing a single-agent problem and it is optimal to opt out.

Now it is clear that $p' = \bar{p}$ since if $p' > \bar{p}$, firm 1 faces a single-agent problem at p' and has an incentive to extend its experimentation below that belief. It can be easily shown that only (1,0) can happen in the right-neighborhood of \bar{p} in equilibrium. If (0,1) is played instead, it can be derived from equation (17) that $v'_2(\bar{p}+) < 0$. This implies that firm 2 is willing to deviate to pull the safe arm. If (1,1) is played instead, by the value matching condition v_2 is close to s so that it locates below $D_2(p; 1)$ near \bar{p} implying the incentive to pull the safe arm.

The above result can be extended to $(\bar{p}, \bar{p}_2]$. The only possible equilibrium behavior in that range is (1,0). Define $p'_2 = \inf \{p: k_2(p) = 1\}$. Then regardless of firm 1's behavior at that belief, $v_2(p'_2) = s$. Suppose $p'_2 < \bar{p}_2$. If $k_1 = 1$ in some right-neighborhood of p'_2 , v_2 locates below $D_2(p; 1)$ so that it is optimal for firm 2 to play safe. Then it contradicts with the definition of p'_2 . If $k_1 = 0$ in some right-neighborhood of p'_2 , the value matching condition together with equation (17) leads to $v'_2(p'_2) < 0$, implying that pulling the safe arm is firm 2's best response. Thus $p'_2 \geq \bar{p}_2$ and firm 2 always pulls the safe arm below $p = \bar{p}_2$ in equilibrium. Given such result, it is optimal for firm 1 to pull the risky arm in $(\bar{p}, \bar{p}_2]$.

The final step is to show that only (1,1) is compatible with the equilibrium in $(\bar{p}_2, 1]$. For that, first note that p'_2 exactly coincides with \bar{p}_2 . If not, it should be the case that $k_1 = 0$ along $(\bar{p}_2, p'_2]$ since otherwise, $D_2(p; 1)$ will locate below $v_2 = s$ in that range. However,

the value matching can never happen for v_1 at $p = \bar{p}_2$ in this case. Therefore, $p'_2 = \bar{p}_2$. Moreover, in the right-neighborhood of \bar{p}_2 , firm 1 must be pulling the risky arm because $v_1 \geq s$ in that neighborhood while $D_1(p; 1) < s$. Given these results, equation (21) and (22) combined with the value matching reveals that v_2 is non-decreasing and convex in the right-neighborhood of \bar{p}_2 .

Now suppose that (1,0) is played at some belief above \bar{p}_2 in equilibrium. Then there must be some $\hat{p}_2 > \bar{p}_2$ such that $v_2(\hat{p}_2) = s$ and $v'_2(\hat{p}_2) \leq 0$. Such characteristics are only consistent with (1,0). However, it holds that $v_2 \geq s > D_2(p; 1)$ in the left-neighborhood of \hat{p}_2 so there is a profitable deviation. Next, suppose that (0,1) is played at some belief above \bar{p}_2 in equilibrium. Then there must exist some $\hat{p}_1 > \bar{p}_2$ such that $v_1(\hat{p}_1) = s$ and $v'_1(\hat{p}_1) \leq 0$. Such properties are consistent only with (1,0) and the same argument leads to the contradiction. Therefore, only (1,1) is consistent with the equilibrium behavior in $(\bar{p}_2, 1]$, which completes the proof. \square

Figure 2 gives an example of equilibrium value functions under certain parameters. The parameters are the same as those of figure 1. A discriminatory patent enforcement can have two effects. First, the domestic firm may have an incentive to free-ride on the foreign firm's experimentation to earn a duopoly profit without incurring any opportunity cost. According to proposition 2, this effect is negligible as firm 1 does not free-ride on firm 2's R&D investment. This is because I assumed that $\pi^M > 2\pi^D$. The duopoly profit is too small to make firm 1 free-ride. To be more specific, the domestic firm does not free-ride when $\bar{p}_1 < \bar{p}_2$. Secondly, the foreign firm is discouraged from experimenting because it can only earn a small

profit flow of π^D even if the firm makes the breakthrough. This one is effective so that firm 2 stops experimenting at $\bar{p}_2 > \bar{p}$.

It is also noteworthy that the equilibrium is unique. Other papers such as KRC and DKS describe multiple equilibria, especially the ones with switches. In this paper, firm 2 cannot free-ride on firm 1's effort, rendering firm 2 to cease experimenting below \bar{p}_2 . As for firm 1, it has some incentive to free-ride on firm 2's effort. However, at posterior beliefs above \bar{p}_2 , firm 1 is too optimistic to stop experimenting only for a humble profit π^D . Just like the remark made in section 3, the results might change if the profit flow of the safe project deteriorates after a breakthrough.

The uniqueness results in proposition 1 and 2 together with cut-off strategy property of the unique MPEs in both environments

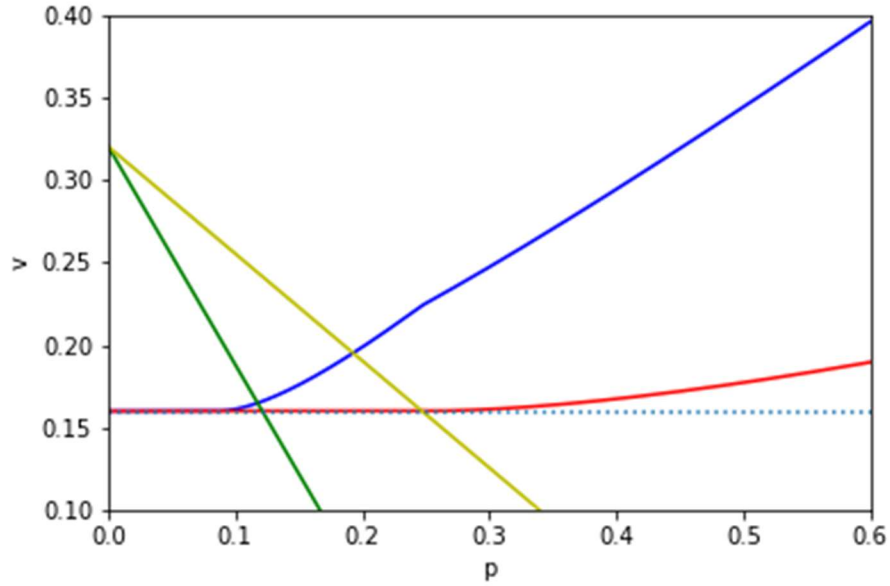


Figure 2. Equilibrium value functions under HB environment facilitate welfare comparison, which is covered in the next section.

5. Welfare Analysis

In this section, I compare the two environments covered in section 3 and 4 in terms of R&D behavior and national welfare.

As in KRC, let's define the amount of experimentation as

$$\int_0^\infty K_t dt = -\frac{1}{\lambda} \int_{p_0}^{p'} \frac{1}{p(1-p)} dp = \frac{1}{\lambda} [\log \Omega(p)]_{p_0}^{p'}$$

where p' is the posterior belief at which every firm ceases to experiment.

As $p' = \bar{p}$ for both environments, the amount of experimentation given no breakthrough is equal. On the other hand, there is a difference in the intensity of experimentation between two environments. While NT environment shows a bang-bang feature, i.e, both firms experiment until the belief falls down to \bar{p} and stop simultaneously, the foreign firm retreats to the safe arm well before the belief becomes \bar{p} in HB environment. In the latter environment there is a positive measure of beliefs where only the domestic firm conducts experimentation. Hence HB environment results in less intense R&D behavior.

From the perspective of the domestic regulator, there are more than profits of domestic and foreign firms; consumer surplus must be taken into account as in Besanko and Wu (2013). In my model, the regulator faces a trade-off when making a decision between the two environments. If the domestic firm infringes on the foreign firm's patent, the regulator enjoys a larger static national welfare as the domestic firm earns some profit and consumers benefit from the lower price. However, such infringement discourages the foreign firm from experimenting. If this is the case, the breakthrough comes at a

slower rate so that the regulator may have to wait for a long time before it can reap the potential surpluses. The relative magnitude of the two effects depends on the relative size of the monopoly profit, duopoly profit, and consumer surplus, which in turn depends on the market structure of the product market.

Let c^S denote the consumer surplus when the market structure is given as S ($S \in \{D, M\}$). Likewise, let π^S denote one firm's profit given the market structure S . Now let's define the national welfare under the market structure S as $w^S = \pi^S + c^S$. National welfare is the sum of the domestic firm's profit and the consumer surplus.

The next step is to calculate the expected average welfare under the two IPR environments and compare those. For that, I begin with calculating the stopping time when no breakthrough is observed. Under NT environment, the experimenting time t^* satisfies the following equation:

$$\bar{p} = \frac{p_0 e^{-2\lambda t^*}}{(1 - p_0) + p_0 e^{-2\lambda t^*}}$$

which could be rearranged as $t^* = \frac{1}{2\lambda} (\log(\frac{1-\bar{p}}{\bar{p}}) - \log(\frac{1-p_0}{p_0}))$. In this environment, both the domestic and the foreign firm experiment for t^* and then simultaneously quit if there has been no breakthrough.

Under HB environment, both firm experiment for some time t_2^* and if no firm has made a breakthrough, firm 2 quits and firm 1 continues to experiment for t_1^* . If no breakthrough is observed, firm 1 also quits and pulls the safe arm. By proposition 2, t_2^* and t_1^* satisfy the following equations:

$$\begin{aligned} \bar{p}_2 &= \frac{p_0 e^{-2\lambda t_2^*}}{(1 - p_0) + p_0 e^{-2\lambda t_2^*}} \\ \bar{p} &= \frac{\bar{p}_2 e^{-\lambda t_1^*}}{(1 - \bar{p}_2) + \bar{p}_2 e^{-\lambda t_1^*}} \end{aligned}$$

which could be rearrange as $t_2^* = \frac{1}{2\lambda}(\log(\frac{1-\bar{p}_2}{\bar{p}_2}) - \log(\frac{1-p_0}{p_0}))$ and $t_1^* = \frac{1}{\lambda}(\log(\frac{1-\bar{p}}{\bar{p}}) - \log(\frac{1-\bar{p}_2}{\bar{p}_2}))$.

Now every component to calculate the national welfare is ready. Let W^{env} be the expected average welfare under a specific environment ($env \in \{NT, HB\}$). Then,

$$W^{NT} = r[p_0 \int_0^{t^*} e^{-rt} 2\lambda e^{-2\lambda t} \frac{(w^M + c^M)}{2r} dt + (1 - p_0 + p_0 e^{-2\lambda t^*}) \int_{t^*}^{\infty} e^{-rt} s dt]$$

and

$$W^{HB} = r[p_0 \int_0^{t_2^*} e^{-rt} 2\lambda e^{-2\lambda t} \frac{(w^M + w^D)}{2r} dt + p_0 e^{-2\lambda t_2^*} \int_{t_2^*}^{t_2^* + t_1^*} e^{-r} \lambda e^{-\lambda(t-t_2^*)} \frac{w^M}{r} dt + (1 - p_0 + p_0 e^{-2\lambda t_2^*} e^{-\lambda t_1^*}) \int_{t_2^* + t_1^*}^{\infty} e^{-rt} s dt]$$

Finally, I compare the relative size between W^{NT} and W^{HB} and see how it differs as the product market structure changes. Here I do this by an example. Let's fix the market demand function to be $Q = 2 - P$. Excluding price discrimination cases, the monopoly price would be 1. However, the duopoly price can differ depending on the mode of competition. If the two firms engage in a Bertrand competition, the price would fall down to 0. On the other hand, the price would be close to 1 if two firms can collude. Having this duopoly price as the x -axis, I plot the net benefit of HB environment, which is figure 3.

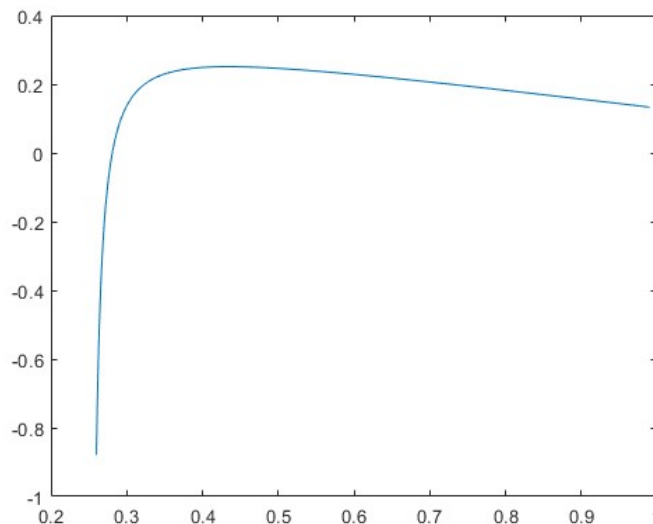


Figure 3. Net benefit of HB environment with respect to the duopoly price

Figure 3 shows that the net benefit of HB environment is maximized when the duopoly price is intermediate. If the duopoly market is too competitive, the foreign firm doesn't have enough incentive to experiment and quit very quickly. Hence the arrival of breakthrough is very slow. If the market is collusive, foreign firm now has enough incentive to experiment, but consumer do not reap much benefit from that.

6. Conclusion

In this paper, I characterized the unique Markov perfect equilibrium under two different patent protection environments: national treatment environment and home bias environment. In both environments, all firms use cut-off strategies in equilibrium with cut-off which coincides with the cut-off of single-agent decision problem. As the minimal posterior belief at which all firms cease to

experiment is identical for both environments, the amount of experimentation is also the same. However, the large single-agent cut-off for the foreign firm under HB environment results in less intensity of aggregate experimentation in HB environment than in NT environment.

I also compared national welfare between the two patent protection environments and did comparative statics with respect to the level of competition in a duopolistic product market with an example. According to this example, having a HB environment is much better for the national welfare if the level of product market competition is intermediate. If the market is very competitive, the foreign firm refrains from doing R&D at the outset so that the speed of innovation is very slow. On the other hand, if the market is very collusive, consumers enjoy less benefit from the domestic firm's patent infringement.

The main drawback of this paper is that I considered only the domestic market when calculating the payoff. In the real world, firms earn profits from the international market and these affects the firms' behavior. One possible future research would be to characterize the equilibria of a strategic experimentation game with general asymmetric payoff to take into account profits from the international market. Analyzing a policy setting game as in Scotchmer (2004) between multiple countries also can be a next step.

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국문초록

본 연구에서는 두 가지의 특허 보호 환경, 외국 출원자에 대한 내국민대우가 잘 지켜지는 경우와 그렇지 못한 경우를 비교한다. 두 환경 모두에서, 자국 기업과 타국 기업 사이의 기술개발 경주 게임에는 마르코프 완전 균형이 유일하게 존재하며, 각 기업은 균형에서 절단전략을 따르는 것을 보인다. 탐험의 총량은 두 환경 사이에 동일하나, 탐험의 밀도는 내국민대우가 지켜지는 환경에서 더 높다. 국가 후생 측면에서의 비교 분석을 통해 두 환경 간의 우열은 제품 시장의 경쟁도에 대해 비선형적인 관계가 있음을 보인다.

주요어 : 전략적 탐험, 멀티 암드 밴딧, 기술개발 경주, 지식재산권, 내국민대우

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