Why does Protection for Intellectual Property Rights Strengthen an Incentive?*

Yasuhiro Arai† and Fumitoshi Moriya‡

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Abstract

This article aims at comparing two hypotheses, i.e., sequential innovation and legal action, and at theoretically obtaining the testable implications to specify which hypothesis is crucial in empirical evidence. Our main results are that we distinguish the two hypotheses, depending on i) whether the cross-term coefficient of (the number of patent) and (the dummy of patent law) is positive or negative, and ii) whether to decreases the variance of the patent distribution or not.

KEYWORDS: Intellectual Property Rights, Sequential Innovation, Multitask

JEL Classification: D42, K39, L86

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†Hitotsubashi University

‡Kobe City University of Foreign Studies

1 Introduction

A principal objective of patent law is the promotion of innovation by granting monopoly power to inventors (Menell and Scotchmer (2007)). The objective comes from the fact that innovative knowledge is public good; if the patent law would not exist, i) it would be difficult for inventors to exclude other from using the inventions (i.e., non rival and nonexclusable), ii) in competitive economy inventors could not afford sunk costs such as the research and development (R&D) expenditure, iii) the level of investment in R&D is excessively small low in society. To prevent the underinvestment, patent law provides patent holder with "exclusive right," that is, "the right to exclude others from making, using, offering for sale, or selling the invention." (35 U.S.C. 154) and define duration and breadth of patent.

Although it looks reasonable that enhancement of patent protection level stimulates R&D activities of firms, the existing empirical studies present something of a paradox: the data do not statistically confirm it. For example, Lerner (2009) and Lerner (2002) examine 177 events (modifications of patent law) in 51 counties and find that enhancement of patent protection decreases the number of filings. Sakakibara and Branstetter (2001) finds that extension of patent duration does not statistically increase R&D expenditure in Japanese pharmaceutical firms. Qian (2007) consider the establishment of pharmaceutical patents in 26 developing countries and find the positive relationship between the establishment of patent law and the citation-weighted number of filings by controlling for economic development, educational attainment.

The theoretical studies offer two possible factors for explaining the observation. One is "sequential innovation" (Bessen and Maskin 2009, Chang 2000, Denicolo 2000, Green and Scotchmer 1995, and Scotchmer 1991). They begin with the fact that the technical progress is sometimes cumulative, that is, some invention (called by "application technology") is necessary for another invention (called by "basic technology"). In this case, firms have to bargain for licensing the basic technology in order to engage in innovative activity for the application technology, but the profit is not divided to maximize their incentive, because 1) the inventor for basic technology cannot recoup the sunk cost of the basic technology (Green and Scotchmer 1995); or 2) asymmetrical information entails information rent (Bessen and Maskin 2009). Therefore, the inefficient outcome of the bargaining for licensing reduces innovators' incentive. Another (but informal) possible explanation is "legal action"(Jaffe and Lerner 2004). In reality, firms have an option to spend their efforts to the prevention of illegal copies of patented technology through litigation. Such legal action is unproductive activity. However, firms can increase the profit from the patented products by taking the legal action. Patent law promotes not only innovation but also unproductive activity such as legal action. If the benefit of the latter outweighs of the former, enhancement of patent protection level decreases firms' incentive for innovation.

Which explanation is consistent with the puzzling empirical evidence? How do we distinguish the two hypotheses? This article aims at theoretically obtaining the testable implications for judging which hypothesis is crucial. To accomplish the purpose, we construct a model where there are two firms named by firm 1 and 2. Firm 1 already holds patent A, while firm 2 does not. The two firms compete for another new patent B. In sequential innovation model, we assume firm 2 does not execute a new patent B without the use of patent A, that is , firm 2 does not develop patent B without permission of firm 1. Alternatively, we introduce the legal action which patent holder (Firm 1) can take to improve the profit of patent A by giving up developing patent B. Examples of legal action include searching for illegal use of patent A or suing illegal users for damages.

By comparing the results of both models, we obtain three results as follows. First, in both models, the enhancement of patent law does not always stimulate the incentives of R&D. Second, it makes opposite effects on incentives of firms in each model. In sequential innovation model, the enhancement increases the incentive of the patent holder, while decreases incentive of non-patent holder. Greater profit of patent B, brought by the enhancement, discourages the patent holder to license patent A with non-patent holder and thus the enhancement unable non-patent holder to develop patent B. In legal action model, the enhancement increases the incentive of non-patent holder but decreases that of patent holder. Because the enhancement increases the profit of patent A, the patent holder is reluctant to develop a new technology. That is why the enhancement makes heterogeneous effects.

The final result is concerned with empirical implications for distinguishing two hypotheses. We suggest to introduce as a control variable the number of patent which firm previously holds, and to examine whether the cross-term coefficient of (the number of patent) and (the dummy of patent law) is positive or negative. If the coefficient is statistically positive, we infer that the sequential hypothesis is crucial in the subject of investigation, and vise verse. The empirical implication comes from the heterogeneous effects of patent law.

The remainder of the paper is organized as follows. Section 2 develops our model. We examine the sequential innovation hypothesis in section 3 and legal action hypothesis in section 4. In section 5, the empirical implications are obtained based on the result of section 3 and section 4. Section 5 provides some concluding remarks on our argument.

2 Framework

Basic Framework We consider a market in which firm 1 and firm 2 who have the competence for R&D. In this market, they potentially develop two kinds of technology, A and B. The competition for the patents is represented in the two stage game as Figure 1.

The patent concerning technology A is exogenously allocated between the two firms in stage 1. Without loss of generality, we assume that firm 1 holds patent A. The patent concerning technology B is endogenously allocated between the two firms in stage 2. Firm i succeeds (respectively, fails) in developing technology B with the probability of $D_i \in [0,1]$ (respectively, $1 - D_i$), by spending R&D cost $c_i D_i/2$. $c > 0$ represents a parameter concerning the marginal cost. The firm who succeeds in developing technology B does not always obtains patent since the competitor may also succeed. With consideration of that possibility, firm i acquires the new patent B with

$$D_i(1 - D_j) + \frac{1}{2}D_i D_j.$$

We assume that firm i obtains patent B with probability 1/2 when both firm succeed to obtain the new technology, which is represented in the second term.

To keep our analysis simple, we adopt the following two assumptions. First, it is assumed that both patents generates the same monopoly profit M and the enhancement of patent protection increases the monopoly profit. The second assumption is that firms chooses the inner solution $D_i \in (0,1)$, that is, $0 < M \leq c$.

In the subsequent section, we introduce the two factor, i.e., sequential innovation and legal action. We call by sequential innovation the technological restriction that the firm who holds patent A cannot develop technology B. In the other words, firm 2 chooses $D_2 = 0$ if firm 2 fails to bargain for patent A of firm 1. We define as legal action the unproductive action that improves monopoly profit of patent A. The example of legal action is that patent holders search for the patent infringement of their competitors and sue the illegal user for damages.

Benchmark result Before examining the effects of sequential innovation and legal action, we establish the standard argument that the enhancement of patent protection stimulates the innovation. In the second stage, firm i faces the following optimal problem,

$$\max_{D_i} \left\{ D_i(1 - D_j) + \frac{1}{2}D_i D_j \right\} M - \frac{c}{2}D_i^2. \tag{1}$$

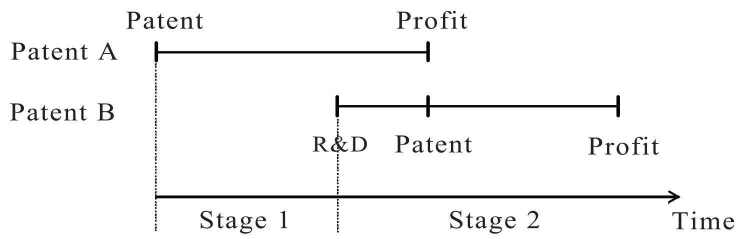

Figure 1: Timing of benchmark model

By First order condition, we obtain the best-response function of firm i, i.e.,

$$D_i(D_j) = \frac{M(2 - D_j)}{2c}.$$

Two firms faces strategic substitution, that is, $D_i'(D_j) < 0$. Since an increase in effort of firm j decreases the probability that firm i acquires the patent B (i.e., $1 - D_j/2$), firm i decreases its effort. By solving the best-response functions of both firms, we obtain the optimal effort level and the profit of firm i as follows.

$$D_i^* = \frac{2M}{2c + M}, \tag{2}$$

$$\pi_i^* = \frac{2cM^2}{(2c + M)^2}. \tag{3}$$

By differentiating (2) by M, we observe the positive relationship between monopoly profit and the incentive of firms, i.e.,

$$\frac{\partial D_i^*}{\partial M} = \frac{4c}{(2c + M)^2} > 0$$

where the inequality comes from the fact that $0 < M \leq c$. Therefore, high protection for intellectual property rights strengthens an incentive for innovation.

Proposition 1. *Suppose the model without sequential innovation and legal action. Firm i's effort level D_i^* is an increasing function of monopoly profit M.*

In the subsequent sections, we extend the basic model to examine the effects of sequential innovation and legal action on the incentive for innovation.

3 Sequential Innovation Hypothesis

In this section, we discuss R&D incentive under the sequential innovation case. We assume that the successive innovation (patent B) builds on the

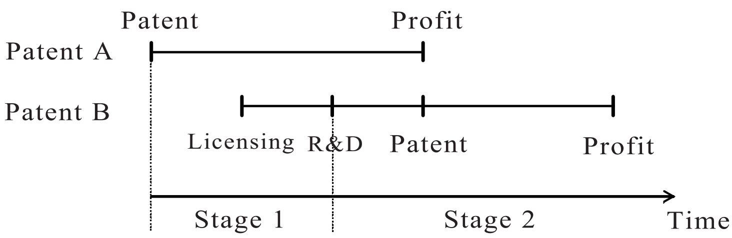

Figure 2: Timing of sequential innovation

preceding one (patent A). To examine the effect of sequential innovation, we consider the game as Figure 2.

When we consider the sequential innovation case, we have to pay attention to the patent breadth of the preceding patent and the patentability of the second innovation. For example, Green and Scotchmer (1995) assumes that the second innovation is patentable. They discuss how the division of profit between the first innovator and the second innovator is affected by the first patent's breadth. Scotchmer (1996), on the other side, assumes that the first patent's breadth is large enough. She considers how the division of profit depends on the patentability of the second innovation. To focus on the innovator's incentive, we assume that the second products is patentable and the breadth of the first patent is large. The similar assumptions to our models is made in Bessen and Maskin (2009).

Under these assumptions, firm 2 has an incentive to bargain for patent A to develop technology B. The patent competition is modified as follows:

1. Firm 1 offers a fixed price contract $T \geq 0$,
2. Firm 2 decides whether to accept it or not,
3. If firm 2 accepts it, firm 2 can choose $D_2 \in [0, 1]$; otherwise, firm 2 cannot develop technology B ($D_2 = 0$).

We assume that firm 1 has to pay the negotiation cost αT ($0 < \alpha < 1$) to make a licensing contract.[1] The definition of the negotiation cost means that the cost becomes large when the amount of contract T is large.

3.1 Without licensing contract

First, we consider the subgame in which firm 1 does not offer the licensing contract. In this case, the non-patent holder does not engages in R&D ($D_2 = 0$), since patent A holder (firm 1) does not allow non-patent holder (firm 2) to use patent A's technology. Then, this subgame is equivalent to the benchmark at $D_2 = 0$.

[1] Laffont and Tirole (1993) adopts this type of costs.

The maximization problem of patent holder (firm 1) is given by

$$\max_{D_1} \; D_1 M - \frac{c}{2} D_1^2.$$

Then, optimal effort level is

$$D_1^{SN} = \frac{M}{c}, D_2^{SN} = 0 \tag{4}$$

Firms' profits are respectively given by

$$\pi_1^{SN} = \frac{M^2}{2c}, \pi_2^{SN} = 0 \tag{5}$$

3.2 With licensing contract

In this case, firm 1 permits firm 2 to develop the new technology based on firm 1's patent. After signing the licensing contract and paying the fixed payment T, the patent competition is the same as that in benchmark. Therefore, the optimal effort level is given by

$$D_i^{SL} = \frac{2M}{2c + M}.$$

Anticipating the R&D behavior of both firms, firm 1 holding patent A faces

$$\max_{T} \left\{ D_1^{SL}(1 - D_2^{SL}) + \frac{1}{2} D_1^{SL} D_2^{SL} \right\} M - \frac{c}{2}(D_1^{SL})^2 + (1 - \alpha)T,$$

$$\text{subject to } \left\{ D_2^{SL}(1 - D_1^{SL}) + \frac{1}{2} D_1^{SL} D_2^{SL} \right\} M - \frac{c}{2}(D_2^{SL})^2 - T \geq 0,$$

where the constraint means that firm 2 accepts the patent licensing contract. The optimal patent price T^* is

$$T^* = \frac{2cM^2}{(2c + M)^2}$$

Firm 1's profit with licensing contract is

$$\pi_1^{SL} = \frac{2cM^2}{(2c + M)^2} + (1 - \alpha)T^*, \pi_2^{SL} = 0 \tag{6}$$

3.3 Analysis

We are prepared to discuss the firm 1's licensing strategy under sequential innovation hypothesis. Next proposition shows firm 1's optimal strategy.

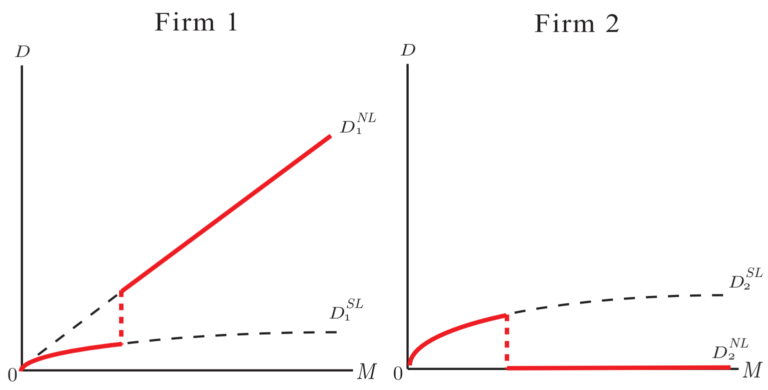

Figure 3: Effort level under the sequential innovation model

Lemma 1. *If $M \leq M^S = 2(\sqrt{2-\alpha} - 1)c$, firm 1 makes a licensing contract. Otherwise, no licensing is optimal.*

The optimal strategy is determined by a trade-off between loss of the patent competition and the benefit of cost-sharing. If firm 1 does not make a licensing contract, he enjoys monopoly profit by avoiding the patent competition, while he bears all the R&D cost $cD_i^2/2$. If firm 1 makes a licensing contract, he suffers loss from the patent competition and bargaining, but enjoys benefit from sharing the R&D cost with firm 2, since the marginal cost is increasing function to D_i and a licensing contract allows firm 1 to obtain the partial benefit of the cost-sharing.

Lemma 1 also shows that the loss of the competition gradually dominates the benefit of cost-sharing as the profit of patent (M) becomes larger. Recall that the best-response function depends on the profit of patent M (i.e., $D_i(D_j) = M(2 - D_j)/2c$). The slope of the best-response function becomes steeper as M increases. This means that the larger profit of the patent induces the more inefficient R&D level (D_1, D_2) (in comparison with that under monopoly) through the patent competition. In sum, the larger M causes the severer competition and thus the loss increases.

Next proposition shows the optimal R&D level of the firms.

Proposition 2.

(1) Firm 1's R&D level is an increasing function of M.

(2) Firm 2's R&D level is an increasing function of M if $M \leq 2(\sqrt{2-\alpha} - 1)c$. Otherwise, firm 2's effort level becomes zero.

Figure 3 represents the optimal R&D level of the firms. Since firm 1 have less incentive to licenses firm 2 as M increases, firm 2 cannot develop the new technology because this model assumes sequential innovation. On the other hands, no license contract gives firm 1 the monopoly power and firm 1's R&D jumps upward. The R&D levels of both firms thus jump at the threshold $M = M^S$.

Therefore, the switching from licensing to no licensing makes the R&D level of firm 2 downward, while making firm 1's upward. Because of these effects, we obtain the following proposition.[2]

Proposition 3. *If $\alpha > 0$, the probability of innovation $1-(1-D_1)(1-D_2)$ is not monotone increasing in M. In particular, the probability of innovation discontinuously go downward at $M = M^S$.*

4 Legal Action Hypothesis

In this section, we discuss another scenario that may reduce innovators' incentive. Firms usually spend their effort not only for the development but also for the legal action that prevents illegal use of their invention. Firm can enjoy the profit M from developed patent through the legal action. If he does not monitor and prevent illegal copy of his patent, his profit becomes $\hat{M}$ that is smaller than M. However, the effort to the legal action does not contribute to develop the new technology. If firm has an option to spend his effort to the legal action, the effort level to the development may decrease. In this section, we assume that the firm who launch the legal action does note develop the new technology. We try to discuss the legal action hypothesis by extending the benchmark model. To examine the effect of legal action, we consider the two stage game as Figure 4.

4.1 With Legal Action

If firm 1 chooses a legal action, he can enjoy the monopoly profit M in period 1. However, he can not develop the new innovation in period 2 since he spends his effort to the legal action. In period 2, the effort level are

$$D_1^{LA} = 0, D_2^{LA} = \frac{M}{c} \tag{7}$$

Firms' profits in second period are given by

$$\pi_1^{LA} = 0, \pi_2^{LA} = \frac{M^2}{2c} \tag{8}$$

[2]One might think that this result does not capture the decrease of the patents in industries or countries in the empirical studies, because this result does not mean that the probability of innovation is decreasing in M. However, this theoretical result can be related to the empirical observation, because the patent law reforms observed in the empirical literature causes not continuous change of M but the binary change.

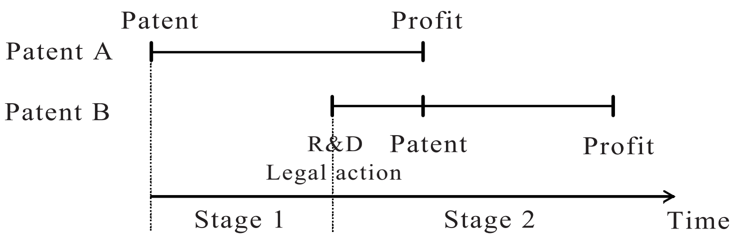

Figure 4: Timing of legal action model

If firm 1 applies the legal action, only firm 2 spends the effort to the development. Firm 1's profit with legal action is

$$\pi_1^{LA} = M + 0. \tag{9}$$

Firm 1 can earn the monopoly profit perfectly in period 1. However, his profit in second period becomes zero since he can not make new products. Then, firm 1's profit under the legal action is sum of M and zero.

4.2 Without Legal Action

If firm 1 does not apply the legal action, both firms spend their effort to develop the new technology. In addition to that, they can launch the legal actions in the second stage. Then, effort level is given by

$$D_1^{LN} = D_2^{LN} = \frac{2M}{2c + M} \tag{10}$$

When firm 1 does not spend his effort to the legal action, his profit becomes $\hat{M}$ that is smaller than M because of the illegal activity such as piracy.[3] In this model, we also assume that $\hat{M} < 7c/9$. If $\hat{M}$ violates this limit, firm 1 does not have an incentive to apply legal action. Then, firm 1's total profit without legal action is

$$\pi_1^{LN} = \hat{M} + \frac{2cM^2}{(2c + M)^2} \tag{11}$$

4.3 Analysis

We can compare the firm 1's profit with legal action and that without legal action. Next lemma says the firm 1's strategy under this scheme.

Lemma 2. *Let M^L be the threshold satisfying $\pi_1^{SN} = \pi_1^{SL}$. If $M \leq M^L$, firm 1 does not launch the legal action. Otherwise, he makes the legal action.*

[3] In this model, we assume that $\hat{M}$ is independent with M. Here, the profit without legal action $\hat{M}$(the profit with legal action M) is interpreted as the lower (upper) bound of the profit of patent.

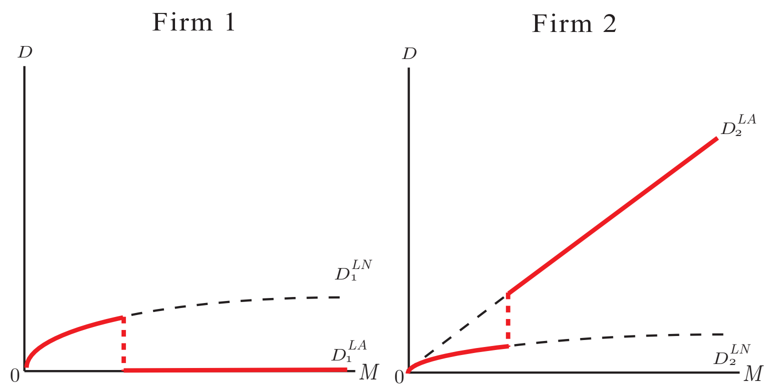

Figure 5: Effort level under the legal action model

The optimal strategy is determined by a trade-off between the improvement on the profit of initial patent (patent A) and the profit by acquiring the patent in the future (patent B). If firm 1 makes a legal action, he can improve the profit of patent A in the first period, but give up acquiring the patent in the future. As M increases, firm 1 more prefers legal action to R&D activity. Because the expected profit of patent B involves the possibility that firm 2 acquire the patent B, the marginal effect of patent A always outweighs the marginal effect of the expected profit of patent B.

Proposition 4.

(1) Firm 1's effort is an increasing function of M when firm 1 does not launch the legal action. Otherwise, firm 1's effort level becomes zero.

(2) Firm 2's effort is an increasing function of M.

Intuition of this proposition is similar to proposition 2. If firm 1 has the legal action, his R&D level becomes zero since he can not develop the new technology in the second period by the assumption. Since no R&D of firm 1 gives firm 2 the monopoly power, the incentive of firm 2 discontinuously goes upward. Then the optimal R&D level is summarized in figure 5.

Note that this effect under the legal action hypothesis is opposite to that under the sequential innovation hypothesis. While the incentive of the holder of initial patent (firm 1) jumps downward under the legal action hypothesis, it jumps upward under the sequential innovation. This comes from the different functions of the initial patent between both hypotheses. Under legal action hypotheses, the initial patent prevents the holder to take the future patent. Under the sequential innovation hypotheses, the holder can eliminate the competition of the future patent by using the initial patent.

Finally we obtain the following proposition.

Proposition 5. *Suppose the model with legal action. If $\hat{M}$ is smaller than $(4\sqrt{2}-5)c$, the probability of innovation, i.e., $1-(1-D_1)(1-D_2)$, is not monotone increasing in M.*

5 Theoretical Implications and The existing Empirical Studies

In this section, we discuss the relationships between our results and the existing empirical studies. We consider a patent reform which rises the protection level of patents. Let $\underline{M}$ be the monopoly profit *before* the reform and $\bar{M}$ be the monopoly profit *after* the reform. We assume $\bar{M} \geq \underline{M}$.

Proposition 3 and 5 show that the probability of innovation in an industry $(1-(1-D_1)(1-D_2))$ is not monotone increasing with respect to the protection level M in both sequential innovation model (thereafter, SI) and legal action model (thereafter, LA). In particular, the probability decreases if $\bar{M}$ and $\underline{M}$ are intermediate.

This result corresponds to the existing empirical studies based on countries level data, if we identify the probability as the number of patents in the industries or countries. Lerner (2009) and Lerner (2002) examine 177 events (modifications of patent law) in 51 counties and find that enhancement of patent protection decreases the number of filings. Qian (2007) consider 26 developing countries from 1978 to 1995 and find no significant relationship between applications of patent law to pharmaceutical firm and innovation such as citation-weighted U.S. patents award and R&D expenditure. More interestingly, it is found that patent law has positive effects on innovation conditional on levels of GDP. If the GDP influences the level of M, our model can suggest one reason of this result.[4]

Proposition 2 and 4 show that R&D behaviors of firms are different depending on whether firms hold initial patent A or not. Furthermore, The adopted hypothesis, SI or LA, determines which firm reduces the R&D effort responding to the enhancement of patent. In SI model, the R&D effort of initial patent holder, i.e., D_1, increases as protection level becomes higher, while the R&D effort of no holder (D_2) can be decreasing (Figure 3). In LA-Model, the different behaviors between patent holder and non-patent holder are also observed but the effect of higher protection level is opposite (Figure 5).

Proposition 2 and 4 also have both positive and negative implications for the empirical studies. The negative side is that the existing studies using firm-level data has a problem: while the empirical studies (e.g., Sakakibara and Branstetter 2001) assume that reforms of patent law have the same effect on firms regardless of the number of their patent, the assumption can

[4]Of course, this observation can be explained from macro economic perspective. See Boldrin and Levine (2008).

be theoretically inadequate. This suggests that "the number of patents" should be introduced as control variable.

On the other hands, the positive side is that the difference of R&D behavior allows us to distinguish which hypothesis fits with observations. To address the positive side, we consider the following situations.

- Consider a patent reform which rises the protection level of patents (from $\underline{M}$ to $\bar{M}$).
- Let $\underline{D}_i^k$ be firm i's optimal R&D effort before patent enhancement and $\bar{D}_i^k$ be i's optimal R&D effort after patent enhancement, where $k = \{SI, LA\}$ represents the adopted hypothesis.
- We assume that $1-(1-\underline{D}_1^k)(1-\underline{D}_2^k) \geq 1-(1-\bar{D}_1^k)(1-\bar{D}_2^k)$ for any k.

By the assumption (final one), we focus on the situation in which the patent reform reduces the probability of innovation.[5] This assumption is adequate because we are interested in why the enhancement of patent law induces less number of patent in industries.

By using the results in section 3 and 4, we observe that the firm behavior depends on the patent law reform and the number of patent which it holds. The probability that non-patent holder (firm 2) acquires new patent B before the reform is represented by

$$D_2^k(1-D_2^k) + \frac{1}{2}D_2^k D_1^k.$$

This probability changes depending on the reform dummy (λ) and the patent number (η_i) as table 1.

Table 1: The additional effects in R&D behavior of firm i

	Before reform ($\lambda = 0$)	after reform ($\lambda = 1$)
Non patent holder ($\eta_i = 0$)	–	$\bar{D}_2^k(1-\frac{1}{2}\bar{D}_1^k) - \underline{D}_2^k(1-\frac{1}{2}\underline{D}_1^k)$
Patent holder ($\eta_i = 1$)	$\underline{D}_1^k - \underline{D}_2^k$	$(\bar{D}_1^k - \bar{D}_2^k) - (\underline{D}_1^k - \underline{D}_2^k)$

Therefore, we obtain the probability as

$$\underline{D}_2^k(1-\frac{1}{2}\underline{D}_1^k) + \lambda[\bar{D}_2^k(1-\frac{1}{2}\bar{D}_1^k) - \underline{D}_2^k(1-\frac{1}{2}\underline{D}_1^k)] + \eta_i(\underline{D}_1^k - \underline{D}_2^k)$$
$$+ \eta_i\lambda[(\bar{D}_1^k - \bar{D}_2^k) - (\underline{D}_1^k - \underline{D}_2^k)].$$

The last term in the above expression represents the increase of probability if the number of patent increases and the patent law is enhanced. The sign

[5] We also assume the existence of $\bar{M}$ and $\underline{M}$.

of the term is different, depending on which hypothesis we adopt. In the sequential innovation hypothesis, the last term is positive because $\bar{D}_1^{SI} - \underline{D}_1^{SI} \geq 0$ and $\bar{D}_2^{SI} - \underline{D}_2^{SI} \leq 0$ (Figure 3). The legal action hypothesis implies that the second term is positive because $\bar{D}_1^{LA} - \underline{D}_1^{LA} \leq 0$ and $\bar{D}_2^{LA} - \underline{D}_2^{LA} \geq 0$ (Figure 5). Therefore, the sign of coefficient on (the number of patent) $\times$ (the dummy of patent law reform) determines which hypothesis is statistically accepted.[6]

Another positive implication for empirical studies is related to the change in the variance of patent distribution. In the legal action hypothesis, variance of patent distribution in industries decreases since the initial patent prevents the incentive of the patent holder for innovation. The variance increases in the sequential innovation hypothesis, as the initial patent prevents the invention of the non-patent holder.

6 Concluding Remarks

In this paper, we have investigated the difference between the sequential innovation hypothesis and the legal action hypothesis. Our main result is that patent law makes the different effects on incentives of firms and two testable implications are obtained. While we believe the importance of these results, some remarks should be noted.

First, we specify the bargaining cost as αT. The assumption allows us to focus on the important cases. If the bargaining cost is fixed for M, there are two thresholds value in which firm 1 is indifferent between no license contract and license contract (see (12) in appendix). This means that the optimal choice as to whether to offer patent license or not changes from licensing to no licensing and from no licensing to licensing, as monopoly profit increases. Since our interest attaches to the case in which the patent law reduces the incentive of firms, the change from licensing to no licensing is abstracted.

Second, our important assumption is that firms bargain for the initial patent *ex ante*. The existing literature investigates both ex ante bargaining and ex post bargaining. For example, Scotchmer (1996) consider ex post bargaining and argue that the sequential innovation hurts the incentive of initial patent holder. Our model captures not this effects but the effect discussed in Bessen and Maskin (2009).

Finally, only two patents are considered in our model. If we consider more than two technologies, the results can depend on ownership and technological relationships among the patents. In our paper, technology B is assumed to be an application of technology A. If we introduce technology C, there are four possibilities: given that C is another basic of technology B, i) one firm holds both technology A and B, ii) each firm holds either

[6] See Hall and Ziedonis (2001).

technology A or B, and iii) C is another application of technology B. What effects the ownership and technology relationship make? What differs between SI-model and LA-model? This direction is an interesting for our future research.

7 Appendix

Proof of lemma 1

We compare the firm 1's profit with the licensing contract and that without the licensing contract. From (5) and (6), we obtain the following equation.

$$\pi_1^{SN} - \pi_1^{SL} = \frac{M^2\{(M+2c)^2 - (8-4\alpha)c^2\}}{2c(2c+M)^2} \tag{12}$$

This equation is positive if and only if $M > 2(\sqrt{2-\alpha}-1)c$, because i) $(M+2c)^2-(8-4\alpha)c^2$ is increasing function for $M \geq 0$, ii) $(M+2c)^2-(8-4\alpha)c^2 < 0$ when $M = 0$, and iii) $(M+2c)^2-(8-4\alpha)c^2 > 0$ when $M = c$. Note that the threshold $2(\sqrt{2-\alpha}-1)c$ is smaller than c. Q.E.D.

Proof of Proposition 3

The difference of probability of innovation between with license contract and without license contract is given by

$$D_1^{SN} - [1-(1-D_1^{SL})(1-D_2^{SL})] = \frac{M\{(M+2c)^2 - 8c^2\}}{c\,(2c+M)^2} \tag{13}$$

By applying the similar argument in the proof of lemma 1, we show that there exists an unique threshold making the above expression zero. If $M < 2(\sqrt{2}-1)c$, the probability of innovation with licensing contract is larger than that without licensing contract, and vice versa.

By comparing the threshold in (12) and the threshold in (13), for any $\alpha > 0$

$$2(\sqrt{2}-1)c > 2(\sqrt{2-\alpha}-1)c.$$

Since this means that $D_1^{SN} < [1-(1-D_1^{SL})(1-D_2^{SL})]$ at $M = 2(\sqrt{2-\alpha}-1)c$, we obtain the proof. Q.E.D.

Proof of Lemma 2

We compare the firm 1's profit with the legal action and that without the legal action. From (9) and (11), we obtain the following equation.

$$\pi_1^{LN} - \pi_1^{LA} = \hat{M} - \frac{M(M^2+2Mc+4c^2)}{(M+2c)^2} \tag{14}$$

Let $X(M)$ be the above expression. By differentiating $X(M)$, it yields

$$\frac{\partial X(M)}{\partial M} = -\frac{M^3 + 6cM^2 + 4c^2M + 8c^3}{(M + 2c)^3} \leq 0$$

for any $M \geq 0$. Since $M > \hat{M}$ and $7c/9 > \hat{M}$, we observe that i) $X(0) \geq 0$ and ii) $X(c) < 0$. Therefore, there exists a unique threshold that $\pi_1^{LN} - \pi_1^{LA} = 0$. Q.E.D.

Proof of Proposition 5

Threshold value of innovation The difference between both schemes is given by

$$D_2^{LA} - [1 - (1 - D_1^{LN})(1 - D_2^{LN})] = \frac{M\{(M + 2c)^2 - 8c^2\}}{c\,(2c + M)^2} \tag{15}$$

By applying the similar argument in proof of lemma 1, there exists an unique threshold making the above expression zero. Note that the threshold $(2\sqrt{2} - 2)c$ is smaller than c. If $M < (2\sqrt{2} - 2)c$, the probability of innovation with licensing contract is larger than that without licensing contract, and vice versa.

Comparison between threshold of payoff and threshold of innovation Suppose that $\hat{M} - 7c/9 < 0$. Since the uniqueness of threshold of payoff and the monotone decreasing function of $\pi_1^{LN} - \pi_1^{LA}$ are shown in the proof of Lemma 2, the remaining part of proof is whether $\pi_1^{LN} - \pi_1^{LA}$ is positive or negative when $M = (2\sqrt{2} - 2)c$.

By substituting $M = (2\sqrt{2} - 2)c$ into the equation (14), the profit difference between two schemes is given by the next equation.

$$\pi_1^{LN} - \pi_1^{LA} = \hat{M} - (4\sqrt{2} - 5)c \tag{16}$$

If $\hat{M}$ is smaller than $(4\sqrt{2} - 5)c$, the firm 1's profit with legal action becomes larger than that without legal action, and vice versa. Q.E.D.

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