Empirical Implications of Sequential Innovation and Legal Action

Yasuhiro Arai
(Aomori Public College)
Fumitoshi Moriya
（Kobe City University of Foreign Studies）

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Yasuhiro Arai† and Fumitoshi Moriya‡

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Abstract

This article compares two hypotheses, sequential innovation and legal action, and theoretically obtains the testable implications to specify which hypothesis is crucial in empirical evidence. Our main results are that we distinguish between the two hypotheses based on i) whether the cross-term coefficient of the number of patents and the dummy of patent law are positive or negative and ii) whether the variance of the patent distribution is decreased.

KEYWORDS: Intellectual Property Rights, Sequential Innovation, Multitask

JEL Classification: D42, K39, L86

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†Aomori Public College

‡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). This objective comes from the fact that innovative knowledge is a public good: if patent law did not exist, i) it would be difficult for inventors to prevent others from using their inventions (i.e., they would be non-rival and non-exclusable); ii) in a competitive economy, inventors could not afford sunk costs such as those related to the research and development (R&D); iii) the level of investment in R&D would be excessively low in society. To prevent underinvestment, patent law provides the patent holder with an "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 defines the duration and breadth of the patent.

Although it seems reasonable to think that the enhancement of patent protection would stimulate the R&D activities of firms, the existing empirical studies do not statistically confirm it. For example, Lerner (2002, 2009) examines 177 events (modifications of patent law) in 51 countries and finds that enhancement of patent protection decreases the number of filings. Sakakibara and Branstetter (2001) find that extending of patent duration does not statistically increase R&D expenditure in Japanese pharmaceutical firms. Qian (2007) considers the establishment of pharmaceutical patents in 26 developing countries and finds a positive relationship between the establishment of patent law and the citation-weighted number of filings by controlling for economic development and educational attainment.

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

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

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

The final result concerns the empirical implications for distinguishing between the two hypotheses. We suggest introducing as a control variable the number of patents the firm previously holds, and examining whether the cross-term coefficient of the number of patents and the dummy of patent law is positive or negative. If the coefficient is statistically positive, we infer that the sequential hypothesis is crucial to the subject under investigation, and vice versa. 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 the legal action hypothesis in section 4. In section 5, the empirical implications are obtained based on the results of section 3 and section 4. Section 6 provides some concluding remarks on our argument.

2 Framework

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

The patent for 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 for technology B is endogenously allocated between the two firms in stage 2. Firm i succeeds (respectively, fails) in developing technology B with probability $D_i \in [0, 1]$ (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 that succeeds in developing technology B does not always obtain the patent since the competitor may also succeed. With that possibility in mind, firm i acquires 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 firms succeed in obtaining the new technology; this is represented in the second term.

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

In the subsequent section, we introduce the two factors, sequential innovation and legal action. Sequential innovation indicates the technological restriction whereby the firm that 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. Legal action indicates the unproductive action that improves monopoly profit of patent A. Examples of legal action include patent holders searching for patent infringement by their competitors and suing illegal users 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 innovation. In the second stage, firm i faces the following optimal problem:

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

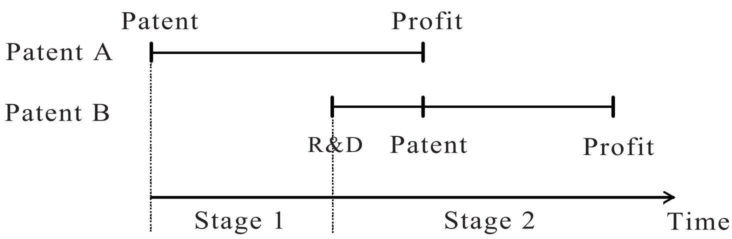

Figure 1: Timing of the benchmark model

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

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

The two firms face strategic substitution, that is, $D_i'(D_j) < 0$. Since an increase in the effort of firm j decreases the probability that firm i acquires 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.,

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

Therefore, high protection of intellectual property rights strengthens incentive for innovation.

Proposition 1. *Suppose the model without sequential innovation or 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

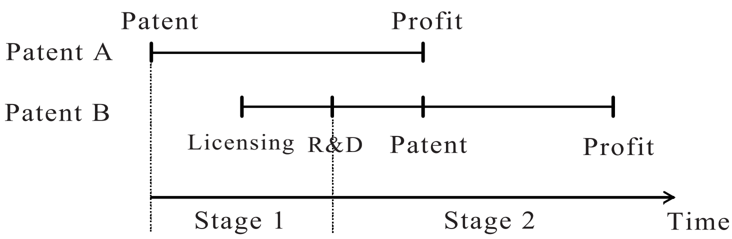

Figure 2: Timing of sequential innovation

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

When we consider the sequential innovation case, we have to pay attention to the 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), in contrast, 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 product is patentable and that the breadth of the first patent is large. Similar assumptions to those our models are 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] By definition, this cost becomes large when the amount of contract T is large.

3.1 Without the 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 engage in R&D ($D_2 = 0$) since patent A holder (firm 1) does not allow the 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 the patent holder (firm 1) is given by

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

Then, the 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 the 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 the 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, which holds 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 the 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 discuss firm 1's licensing strategy under the sequential innovation hypothesis. The next proposition shows firm 1's optimal strategy.

Lemma 1. *If $M \leq M^S = 2(\sqrt{2-\alpha}-1)c$, firm 1 makes a licensing contract. Otherwise, not licensing is optimal.*

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

Lemma 1 also shows that the loss of 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 a more inefficient level R&D (D_1, D_2) in comparison with that under monopoly through the patent competition. In sum, the larger M causes more severe competition and thus the loss increases.

The next proposition shows the optimal R&D levels 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 shows the optimal R&D levels of the firms. Since firm 1 has less incentive to provide the license to firm 2 as M increases, firm 2 cannot develop the new technology because this model assumes sequential innovation. In contrast, no license contract gives firm 1 monopoly power and firm 1's R&D increase sharply. The R&D levels of both firms thus change drastically at the threshold $M = M^S$.

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

[2] One might think that this result does not capture the decrease in the number 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 empirical observations, because the patent law reforms observed in the empirical literature cause not continuous change of M, but binary change.

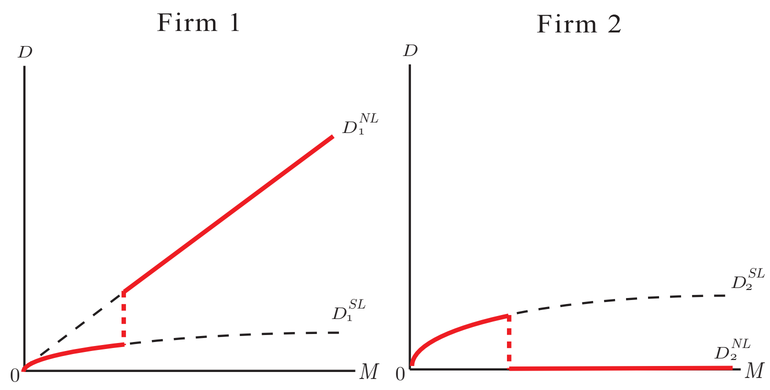

Figure 3: Effort level under the sequential innovation model

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 decreases 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 development but also for the legal action that prevents illegal use of their invention. A firm can enjoy the profit M from a developed patent through legal action. If a firm does not prevent the illegal copies of its patent, his profit becomes $\hat{M}$ which is smaller than M. However, the effort used for the legal action does not contribute to the development of the new technology. If a firm has an option to spend its effort on the legal action, the effort for the development may decrease. In this section, we assume that a firm that undertakes the legal action does not develop new technology. We discuss the legal action hypothesis by extending the benchmark model. To examine the effect of legal action, we consider the two stage game shown Figure 4.

4.1 With Legal Action

If firm 1 chooses legal action, it can enjoy the monopoly profit M in period 1. However, it cannot develop a new innovation in period 2 since it spends its effort on legal action. In period 2, the effort levels are

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

Firms' profits in the second period are given by

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

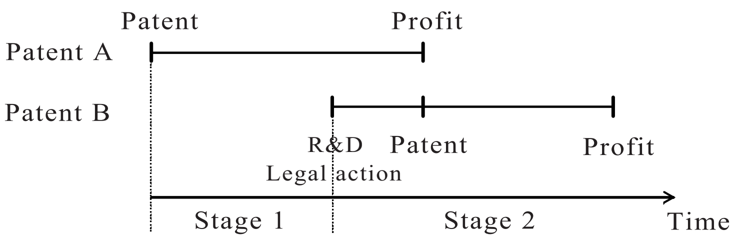

Figure 4: Timing of the legal action model

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

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

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

4.2 Without Legal Action

If firm 1 does not choose the legal action, both firms spend their effort to develop new technology. In addition, they can undertake legal action 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 its effort on legal action, its profit becomes $\hat{M}$, which is smaller than M because of 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 choose 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 compare firm 1's profit with and without legal action. The following lemma states the firm 1's strategy under this scenario.

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

[3] In this model, we assume that $\hat{M}$ is independent of 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 the patent.

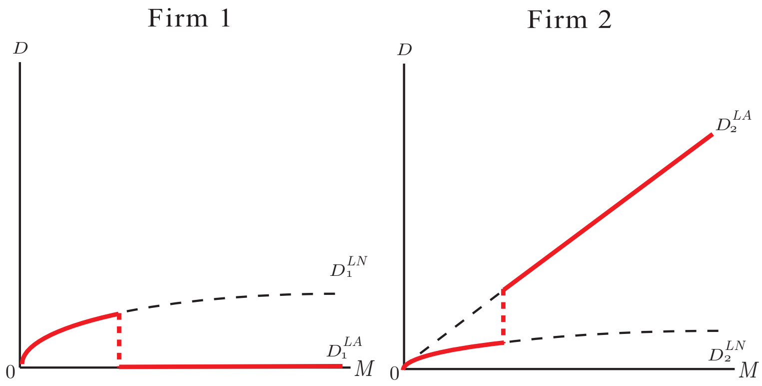

Figure 5: Effort level under the legal action model

The optimal strategy is determined by a trade-off between the improvement of the profit of the initial patent (patent A) and the profit by acquiring the patent in the future (patent B). If firm 1 chooses legal action, it can improve the profit of patent A in the first period, but gives up acquiring the patent in the future. As M increases, firm 1 increasingly prefers legal action to R&D activity. Because the expected profit of patent B involves the possibility that firm 2 acquires 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 undertake legal action. Otherwise, firm 1's effort level becomes zero.

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

The intuition behind this proposition is similar to that behind proposition 2. If firm 1 chooses legal action, its R&D level becomes zero since it cannot, by assumption, develop new technology in the second period. Since no R&D by firm 1 gives firm 2 monopoly power, the incentive of firm 2 discontinuously increases. 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 the initial patent (firm 1) decreases under the legal action hypothesis, it increases under sequential innovation. This is because of the different roles of the initial patent between the hypotheses. Under the legal action hypothesis, the initial patent prevents the holder from obtaining the future patent. Under sequential innovation hypothesis, the holder can eliminate the competition for 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 Existing Empirical Studies

In this section, we discuss the relationships between our results and the existing empirical studies. We consider a patent reform that increases 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 $\bar{M} \geq \underline{M}$.

Propositions 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 protection level M in both the sequential innovation model (hereafter, SI) and the legal action model (hereafter, LA). In particular, the probability decreases if $\bar{M}$ and $\underline{M}$ are intermediate.

This result corresponds to the existing empirical studies based on country-level data if we identify the probability as the number of patents in the industries or countries. Lerner (2002, 2009) examines 177 events (modifications of patent law) in 51 countries and finds that enhancement of patent protection decreases the number of filings. Qian (2007) considers 26 developing countries from 1978 to 1995 and finds no significant relationship between applications of patent law to pharmaceutical firms and innovation such as citation-weighted U.S. patent awards 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]

Propositions 2 and 4 show that R&D behaviors of firms differ depending on whether firms hold initial the patent A or not. Furthermore, the adopted hypothesis, SI or LA, determines which firm reduces the R&D effort in response to patent protection enhancement. In the SI model, the R&D effort of the initial patent holder, D_1, increases as the protection level becomes higher, while the R&D effort of the firm without the patent (D_2) can be decreasing (Figure 3). In the LA model, different behaviors between the patent holder and the non-patent holder are also observed, but the effect of the higher protection level is opposite to the SI model(Figure 5).

Propositions 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 have 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 patents, this assumption

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

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

The positive side is that differences in R&D behavior allow us to determine which hypothesis fits observations. To address this, we consider the following situation.

- Consider a patent reform that increases 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 $k \in \{SI, LA\}$ 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 final assumption, we focus on the situation in which patent reform reduces the probability of innovation.[5] This assumption is adequate because we are interested in why the enhancement of patent law leads to fewer patents in industries.

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

$$D_2^k(1-D_2^k)+\frac{1}{2}D_2^kD_1^k.$$

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

Table 1: The additional effects on the 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 the probability that the number of patents increases and patent law is enhanced.

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

The sign of the term differs 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 the coefficient on (the number of patents) $\times$ (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, the variance of patent distribution in industries decreases because the initial patent removes the incentive for the patent holder to innovate. The variance increases in the sequential innovation hypothesis because the initial patent prevents the use of invention by 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 has different effects on the incentives of firms, and two testable implications are obtained. While we believe that these results are important, a number of points 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 threshold values in which firm 1 is indifferent between the license contract and no license contract (see (12) in the appendix). This means that the optimal choice as to whether to offer the patent license or not changes from licensing to no licensing and from no licensing to licensing as monopoly profit increases. Since our interest is in the case in which 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) considers ex post bargaining and argues that sequential innovation hurts the incentive of the initial patent holder. Our model captures not this effect, 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 may change depending 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 three possibilities: given that C is another basic technology for B, i) one firm holds both A and B, ii) each firm holds either A or B, or iii) C is another application of B. What effects do ownership and

[6]See Hall and Ziedonis (2001).

technology relationships have? What differs between the SI and LA model? This direction is an interesting one for our future research.

7 Appendix

Proof of lemma 1

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

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 firm 1's profit with and without 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. Differentiating $X(M)$ 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 where $\pi_1^{LN} - \pi_1^{LA} = 0$. Q.E.D.

Proof of Proposition 5

Threshold value of innovation The difference between the 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 a similar argument to the one in the proof of lemma 1, there exists a 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 the licensing contract is larger than that without the licensing contract, and vice versa.

Comparison between the threshold of payoff and the threshold of innovation Suppose that $\hat{M} - 7c/9 < 0$. The uniqueness of the 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 equation (14), the profit difference between two schemes is given by

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

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

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