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Sequential Patent Grants for Cumulative Innovations and Inefficiency Problem

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The patent authority eventually faces either an adverse selection problem or a moral hazard problem that asymmetric information causes when it has imperfect information about the attributes of innovations This paper analyzes whether the current patent system with uniform patent life can still be an effective incentive scheme of R&D investments in cumulative innovations with inventor privately informed on innovation cost.

This paper looks into the nature of inventors' sequential arrivals and bilateral private information inherent in cumulative innovations, specifically research tools and its commercialization Under the current patent system, the inventor of a research tool (inventor A) can collect profit either by self-development or by forming an R&D joint venture with the subsequent inventor (inventor B) since revenues accrue only to commercial product Due to the inventor's private information, however, a negotiation over an R&D joint venture between sequential inventors is not always reached. That leads to patent race for commercialization between A and B, which results in duplicative investments and inefficient production. Bilateral information asymmetry and the structure of sequential innovations call for a new paradigm to design a self-selecting mechanism beyond a general form of 1 principal - 1 agent model

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I . Introduction

The patent system is an incentive scheme to encourage innovation by granting an exclusive property right to an inventor for a limited period of time[1]. However, patent system has been challenged that current span of patent life may not be suitable for optimal innovation encouragement and that the profit division through patent rights in cumulative innovation may not function properly. A serious impediment to the implementation of the optimal patent system is that only the inventors can privately observe the characteristics of the innovations such as the innovation value or the innovation cost. This paper is intended to analyze the patent system for cumulative innovations under information asymmetry[2][3].

Most innovations in modern industries can be regarded as cumulative innovations for which the earlier innovation provides a building foundation for the late technical progresses(Scotchmer 1991). Cumulative innovations are categorized into at least four manifestations that are i) improvements of previous products; ii) cost reductions for producing earlier products; iii) applications of earlier basic technologies and iv) enabling technologies such as research tools(Scotchmer 1991, 1999b)

Some literature contend that the current patent policy, that sequentially provides a uniform patent life for each sequential innovation, exhibits a limitation in dealing with cumulative innovation processes. They argue that patent

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1) A patent application comprises two parts, a specification of the innovation and a set of claims A specification requires that the inventor briefly describes the problem and the steps to solve it Claims define the scope of the innovation that is a technological territory against infringement(Merges and Nelson, 1994).

2) The object of the theory of mechanism design is to explore the means(institutional setting as a contract) of implementing a specific allocation of available resources through a device of principal-agent model, when the relevant information is dispersed in the economy(Salanie 1998).

3) As the informed party and the uninformed party create a bilateral monopoly situation, we need to specify how the parties can bargain over the terms of exchange. The Principal-Agent model is a simplifying device to avoid complex bargaining under asymmetric information by allocation all bargaining power to one of the parties(Salanie 1998).

policy for cumulative innovations should be two-fold depending on the ability of an inventor of the first innovation(hereafter referred to as A)[4]. If A lacks technology of developing subsequent innovations, an optimal patent policy is to transfer full surplus from the subsequent inventor(hereafter referred to as B) to A. Insufficient transfer discourages A's incentive for R&D, which may in turn stifle the whole line of innovations. On the other hand, if A is capable of developing the second-generation innovation but inefficiently, the patent policy should address an additional challenge of the efficient innovation[5] A socially optimal patent system should induce the participation of efficient inventors for the continuation of further innovations and the improvement of the social welfare

In the following, we restrict our attention to research tools in this paper. Specifically, A invents a research tool that can be commercialized by himself or B. Each inventors are privately informed about their respective costs of commercialization. Research tools are technologies that have no commercial value and their subsequent commercial innovations capture all market profits[6].

Schankerman and Scotchmer(1999) searches for a policy instrument that helps the current patent system to achieve the efficient commercialization of research tools when the inventors' costs are observable. Patent protects the patentee by either excluding competitors ex ante or imposing remedies for

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4) Arora and Fosfuri(1998) analyze the role of specialized engineering-construction firms(henceforth SEFs) on the technology diffusion in the chemical industry Licensing is the main way that SEFs extract profits from their innovations They found SEFs biased **towards small firms in licensing** Put differently, SEFS were more important sources of technology for firms that lacked the technological capability to develop the technology in-house, small chemical companies and third world firms. Technological diffusion led by SEFs, therefore, contributes less concentrated market In contrast, big producers innovated their own technologies and create competitors through licensing

5) An optimal patent system should (1) minimize a deadweight loss associated with a patent system, (2) help inventor A collect maximum surplus from the following applications, and (3) assign the application to the more efficient inventor.

6) Examples of research tools include Cohen-Boyer patent on the gene-insertion technology, the Genetech patent on a gene-expression technology, and Cornell university's gene guns(Scotchmer 1991, Schankerman and Scotchmer 1999).

infringement ex post[7]. A natural way of remedying infringement is to impose money damages[8] The doctrine of damages determines the inventors' bargaining shares in the case of infringement which, in turn, establishes their bargaining positions in an ex ante agreement[9] Schankerman and Scotchmer shows that the inventors reach an agreement to achieve efficient commercialization if appropriate measures are taken to figure damages from infringement(*unjust enrichment*). However, this charming result does not survive information asymmetry. Private information on the inventors' costs hides threat points resulting in a breakdown of the negotiation process[10]

This paper shows the current patent systems cannot be the efficient mechanism for research tool by analyzing how nature of sequential innovations and asymmetric information cripple patent system It also sheds a few useful implications on how research should go on to design an optimal patent system for research tools.

The rest of paper is organized as follows. Section 2 introduces the model and the key assumptions as the foundation of this paper. Section 3 examines a

7) Courts judge allowable patent scope when a dispute arises The accused device is ruled infringing if it fall within the allowed claims: doctrine of equivalents. On the other hand, there are three ways in which an accused device is ruled not infringing: i) the claims are invalid(lack of requisite requirements, fraudulent conduct, extant public use), ii) the device is outside the claims, iii) the device represents major advances over the original(doctrine of reverse equivalents). See Merges and Nelson(1994) for more details. The doctrine of laches requires that a timely effort should be made to stop infringement Otherwise, the right to recover damages or to enjoin infringement will be nullified

8) An alternative remedy for infringement is the injunction rule to stop selling the infringing product, which also involves money damages through a negotiation after all(Schankerman and Scotchmer 1999). To be precise, however, the injunction rule should be distinguished from the damage rule. See merges(1996) for details.

9) Two doctrines of damages, 'unjust-enrichment' and 'lost profit/lost royalty' (Schankerman and Scotchmer 1999): "The objective of the unjust-enrichment doctrine is to deprive the infringer of the fruits of his illegal act The objective of the lost profit/lost royalty doctrine is to restore to the patentee the benefits which A would have deprived without the infringement"

10) Schankerman and Scotchmer(1999) also address that the patentee's counterfactual damages is difficult for the court to discern when the costs are private information

benchmark case to obtain the basic shape of optimal mechanism. Section 4 shows that the current patent system cannot be the optimal mechanism in the world of bilateral hidden information. Section 5 concludes this paper with several suggestions for extending our result.

Ⅱ. Model

1. Notations

Consider a situation where A developed a new research tool by investing verifiable cost c_0 and applies for a patent grant[11]. Given a time span(a number of years of patent life, for instance) $T \in R_+, z = \frac{1}{r}(1 - e^{-rT})$ represents the discounted length, where r denotes the interest rate (i.e. $\frac{1}{r}$ is discount rate). With a slight abuse of terminology, we refer to the discounted length as the patent length hereafter.

'π' is the per-period monopoly profit by selling the commercial product[12]. 'd' denotes the per-period deadweight loss associated with monopoly production. Hence, 'πz' and 'dz' are the present discounted profits and the present discounted deadweight loss respectively when a monopolist supplies the

11) Providing research incentive through patent life prior to the first investment is close to the environment of Gilbert and & Riordan's study(1995), although they do not the discuss the patent policy explicitly. The patent version of their study contrasts with our model in several respects. They examine the structural efficiency to provide a sufficient incentive for research tool and its application. A research tool is not developed yet. Two inventors are capable of developing full innovations separately. Integrated development by a single inventor is socially preferred to joint developments by two inventors. The reason is that joint developments raise information rents to prevent the inventors from overstating their costs of innovations.

12) The size of profit subsumes the marginal cost of producing the commercial product. Alternatively, we can assume the marginal cost of production is '0'

commercial product for the length of time span z We also define 'w' as the per-period social welfare from the commercial product sold by a monopolist The per-period social welfare rises to 'b' where $b=w+d$ in the competitive market(after a patent expires, for instance), since the deadweight loss of monopoly pricing disappears. Thus, the present discounted social welfare in gross term that the research tool and its commercial product generates is,

$$\int_0^{\infty} w \cdot e^{-rt}dt + \int_T^{\infty} d \cdot e^{-rt}dt$$

Or equivalently, $\frac{b}{r} - dz$, where the first term is gross social benefit from the commercial product and the second term denotes the total deadweight loss for the life of monopoly.

We will denote A and B by subscripts $i=1$ and $i=2$ respectively. We also use the subscript '$-i$' to denote inventor i's competitor by following traditional notation. Let $s_i \in \{0, 1\}$ indicate whether the inventor i develops the commercial product from the research tool or not. '$s_i=1$' denotes that the inventor i develops the commercial product by investing c_i Alternatively the inventor i's R&D cost function of commercialization is represented by $s_i c_i$ that is increasing in both s_i and c_i. $s_i c_i$ also shows that $\frac{\partial^2}{\partial s_i \partial c_i}(s_i c_i)$ is non-negative and weakly increasing in c_i, which is called as 'single cross property'[13]. '$s_1+s_2=1$' should hold to avoid the duplicative efforts for commercialization. We restrict attention to a set of assignment rules $\{s_1, s_2\}$ that includes the efficient one from a social perspective.

2. Assumptions

***Assumption* 1)** The research tool enables both A and B to develop the

13) With single cross property and inverse hazard rate, a mechanism that satisfies the local incentive compatibility constraints is sufficiently globally incentive compatible For inverse hazard rate, see assumption 3.

commercial product[14] Put differently, the inventors' R&D efforts are substitutes to develop the commercial product[15].

Assumption 2) B can access the research tool only when it is patented, and therefore is known to the public. For simplicity, there is no time lapse between the research tool's patent grant and the commercial product's arrival[16].

Hence, we ignore the case where two inventors coordinate research before the research tool is patented[17].

Assumption 3) To invent the commercial product, the inventor i could invest R&D cost c_i. The inventors observe their own costs but the patent office does not[18]. But the patent office knows c_i is drawn from the distribution function F_i defined over the interval Θ_i with density f_i. From the patent office's perspective, two inventors are *ex ante* symmetric, i.e., $\Theta_1 = \Theta_2 \equiv [\underline{c}, \bar{c}]$ and $f_i(c_i) = \frac{1}{(\bar{c} - \underline{c})}$, $F_i(c_i) = \frac{c_i - \underline{c}}{\bar{c} - \underline{c}}$ for i = 1, 2, independently. For a simple notation, we use $\Theta \equiv \Theta_1 \times \Theta_2$ and $\triangle c \equiv \bar{c} - \underline{c}$.

The assumption about the distribution function implies that $\frac{F_i}{f_i} = c_i - \underline{c}$ is

14) Green and Scotchmer(1995), Scotchmer(1996) consider a case where A cannot develop applications and analyzes licensing arrangement among successive inventors Although the existence of multiple followers may strengthen A's bargaining position, licensing ex post is dominated by ex ante agreement for RJV(for related work, see Scotchmer 1996, Denicolo 2000). On the other hand, Schankermanand Scotchmer(1999) assume that the patent holder of the research tool and the potential infringer are capable of developing the commercial product

15) For the case where two innovations are perfect complements, see Merges and Nelson(1994), Gilbert and Riordan(1995)

16) If it takes time to develop multiple commercial applications, A may not apply for the patent grant due to the risk of preemption. See Matutes et al (1996) for multiple applications and timing of patent grants

17) We may assume that the idea of research tool without a patent is copied costlessly Anton and Yao(1993)'s scheme to extract a positive surplus even without a patent may not apply for this case in the respect that there is only one follower

18) Schankerman and Scotchmer(1999) assume R&D costs, c_1 and c_2 are observable.

increasing in c_i for i = 1, 2, which is referred to as 'the inverse hazard rate'.

The maximum net profits generated by both innovations during the time span z is equal to $\pi z - c_o - c_i$ when an inventor i develops the commercial application[19]. Since $w \geq \pi$ yields $\frac{b}{r} - dz \geq \frac{w}{r} \geq \pi z$ for a given $z \in R_+$ in our model, an inventor has no incentive to invest in a research tool and its commercial product if they are socially undesirable[20]. However, a fixed patent life may fail to provide a sufficient R&D incentives for socially desirable cumulative innovations if R&D costs are high enough[21]. This case illuminates why differentiated patent lives can be socially optimal.

Assumption 4) $\frac{w}{r} \geq c_0 + \bar{c}$: That is, we consider the special environment where production of commercial product is improving social welfare regardless of innovation costs[22].

Accordingly, the only concern of the patent authority is the production of commercial product at minimum social cost. The task for the patent authority is the decision of production assignments between the two inventors.

With the assumptions 1 through 3, the setting is well depicted by a team commercialization that includes the patent office and two inventors. However, the efficient commercialization is challenged by the sequential innovations under asymmetric information where each inventor's commercialization cost is known only to that inventor.

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19) If A does both innovations, his net profits is $\pi z - c_o - c_1$. In contrast, when B commercializes the research tool, $\pi z - c_o - c_2$ is the net profits that two inventors will share

20) $\frac{b}{r} - dz < c_0 + c_i$ implies $\pi z < c_0 + c_i$.

21) $\frac{b}{r} - dz \geq c_0 + c_i > \pi z$

22) This assumption is strong because it is always socially preferable to commercialize the research tool that creates any positive social benefit by using differentiated patent lives A harder problem is to figure out *ex ante* whether it is socially preferable to invest in research tool in a more general setting.

3. Socially Efficient Commercialization under Full Information

As a benchmark performance, we first characterize the socially optimal commercialization under the patent system[23]. Suppose the patent office identifies both inventors and their commercialization costs when A comes up with the research tool for a patent grant. Note that it is not socially optimal that both inventors race for the commercial product since their commercializing efforts are perfect substitutes as we assume. Since we study the case where the patent office uses patents to provide R&D incentives, we consider a case where the patent office assigns the commercialization to one of the inventors with a patent.

For a given patent life z, the present discounted consumer surplus is equal to $\frac{b}{r} - dz + \pi z$. The last term represents the payments to the monopolist (assignee) during the patent life[24]. Accordingly, the net social welfare that is the sum of consumer surplus and the inventors' revenues minus the costs associated is represented by,

$$\frac{b}{r} - dz - c_i - c_0$$

when the inventor i develops the commercial product[25]. Hence, the patent office achieves the efficient commercialization by choosing the more cost efficient inventor. Put differently, for the *ex post efficient* commercialization, the as-

23) If the patent office observes costs, it could enforce the optimal commercialization without resort to patents Patent would be suboptimal incentive scheme if costs and values of innovation are not private information. Patent authority can simply choose the most efficient inventor for R&D by providing sufficient incentives.

24) If B develops the commercial product and collects revenues, two inventors share it ex post. Since the commercial product infringes the patent right of the research tool, the patent office need to establish the damage rules to provide a maximum surplus for A

25) We implicitly assume that $\pi z \geq c_0 + c_i$ holds for this analysis.

signment functions s_1^*, s_2^* $\Theta_1 \times \Theta_2 \rightarrow \{0, 1\}$ should satisfy,

$$s_1^*(c_1, c_2) = 1,\ s_2^*(c_1, c_2) = 0 \text{ if } c_1 < c_2,$$
$$s_1^*(c_1, c_2) = 1,\ s_2^*(c_1, c_2) = 1 \text{ if } c_1 > c_2. \tag{2.1}$$

Ⅲ. R&D Procurements for Sequential Innovations via An Optimal Revelation Mechanism

The nature of research tool and its commercial product is captured by the structure of sequential innovations. It should be reminded that research tools are technologies with no commercial value, but it fosters profit-generating commercial innovations. This section demonstrates that **the structure of sequential innovations** may be more critical impediment to the implementation of the socially optimal commercialization than **private information**. We show that the *ex post efficient* commercialization is truthfully implementable so long as B is known to the patent office before issuing a patent for the research tool, even when R&D costs are private information.

For the purpose of this section specified above, we introduce two-tier *multilateral mechanism*. First, the patent authority grants a patent right to A for his research tool so that A can claim his patent right is infringed and can seek monetary compensation if someone else develops the commercial product. Put differently, the patent breadth for the research tool is infinite Second, we can consider a mechanism in a two-tier hierarchy where both inventors(second tiers) report their cost information simultaneously but separately to the patent office(first tier)[26]. The patent office grants the cost-efficient inventor a patent whose life is long enough to induce truth-telling about their cost information and to compensate the actual cost of R&D. This *multilateral mechanism*

26) This mechanism of multilateral patent grants in a two-tier hierarchy is virtually an auction mechanism

assigns the inventor commercial development and specifies the patent lives as rewards/compensation for the inventors' reports on their true cost types of commercializing the research tool[27].

The second part of multilateral mechanism needs more explanation. It seems to be unrealistic that two competing inventors submit simultaneously their plans of commercialization to the patent office However, we may take an example such as licensing wireless service provider with spectrum allocation. The providers apply for license with submitting plans of service provision to the licensing office at the same time, who designates providers among the applicants and assigns them spectrum by selecting mechanism such as beauty contest or auction.

Formally, *a multilateral mechanism*(the superscript '*ML*' denotes this mechanism hereafter) is a menu of patent lives taking the form of where $s^{ML} = (s_1^{ML}, s_2^{ML})$, $Z^{ML} = (Z_1^{ML}, Z_2^{ML})$ and for $i = 1, 2$.

We use $\tilde{\Pi}_1^{ML}(\tilde{c}_1, c_1) \equiv E_2[s_1^{ML}(\tilde{c}_1, c_2) \cdot (\pi Z_1^{ML}(\tilde{c}_1, c_2) - c_1 - c_0)]$ to denote the profit for A who reports his type as $\tilde{c}_1$ given a menu of patent lives $\{Z_1^{ML}(c_1, c_2), s_i^{ML}(c_1, c_2)\}$ for $i = 1, 2$ offered by the patent authority[28].

$\tilde{\Pi}_2^{ML}(\tilde{c}_2, c_2) \equiv E_1[s_2^{ML}(c_1, \tilde{c}_2) \cdot \pi Z_2^{ML}(c_1, \tilde{c}_2) - c_2 - c_0)]$ is symmetrically defined for B. We also define $\Pi_1^{ML}(c_1) \equiv \tilde{\Pi}_1^{ML}(c_1, c_1)$ and $\Pi_2^{ML}(c_2) \equiv \tilde{\Pi}_2^{ML}(c_2, c_2)$. The patent authority chooses $\{\Theta, s^{ML}, Z^{ML}\}$ to solve the minimization program that

27) The revelation principle implies that an optimal revelation mechanism provides an upperbound for the performance that any other organizational arrangement can attain(Melumad, Mookherjee and Reichelstein 1992).

28) We can assume that B is enforced to transfer c_0 to A if B obtains the patent for the commercial product. Otherwise, $\tilde{\Pi}_1^{ML}(\tilde{c}_1, c_1)$ should be defined as $E_2[s_1^{ML}(\tilde{c}_1, c_2) \cdot \pi Z_1^{ML}(\tilde{c}_1, c_2) - c_1)] - c_0$ because A cannot withdraw c_0 when A is not chosen

$$\min_{s_1^{ML}, s_2^{ML}, Z_1^{ML}, Z_2^{ML}} E\{s_1^{ML}(c_1, c_2) \cdot Z_1^{ML}(c_1, c_2) + s_2^{ML}(c_1, c_2) \cdot Z_2^{ML}(c_1, c_2)\}$$

$$\text{subject to for all } c_i \in \Theta_i, i=1, 2 \tag{3.1}$$

$$(\text{IR}_1)\ \prod\nolimits_1^{ML}(c_1) \geq 0,$$

$$(\text{IR}_2)\ \prod\nolimits_2^{ML}(c_2) \geq 0,$$

$$(\text{IC}_1)\ c_1 \in \arg\max_{\tilde{c}_1} \tilde{\prod}\nolimits_1^{ML}(\tilde{c}_1, c_1),$$

$$(\text{IC}_2)\ c_2 \in \arg\max_{\tilde{c}_2} \tilde{\prod}\nolimits_2^{ML}(\tilde{c}_2, c_2),$$

$$s_1^{ML}(c_1, c_2) + s_2^{ML}(c_1, c_2) = 1.$$

'$s_i^{ML}(\cdot, \cdot) = 1$' denotes that the inventor i develops the commercial product by investing c_i[29]. Here $Z_i^{ML}(c_1, c_2)$ is the patent life granted to the inventor i. IRi and ICi represent the participation constraint and the incentive compatibility constraints respectively for the inventor i[30]. For IR$_2$, the courts can enforce the monetary transfer c_0 to A when B turns out to be cost efficient in developing the commercial product and therefore obtains a patent grant[31].

The proposition 1 show that we can design a direct revelation mechanism with multilateral patent grant that implements the socially efficient commercialization described by (2.1) and minimizes patent lives.

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29) We use the notation that $E[\cdot] = \int_{\underline{c}}^{\bar{c}} \int_{\underline{c}}^{\bar{c}} (\cdot) \frac{1}{\Delta c} dc_2 \frac{1}{\Delta c} dc_1$ and $E_i[\cdot] = \int_{\underline{c}}^{\bar{c}} (\cdot) \frac{1}{\Delta c} dc_i$

30) Alternative representations of the participation constraints and the incentive compatibility constraints for two inventors are

(IR$_1$') $\pi Z_1(c_1, c_2) - s_1(c_1, c_2)c_1 - c_0 \geq 0$ for all $c_2 \in \Theta_2$,

(IR$_2$') $\pi Z_2(c_1, c_2) - s_2(c_1, c_2)c_2 - c_0 \geq 0$ for all $c_1 \in \Theta_1$,

(IC$_1$') $c_1 \in \arg\max_{\tilde{c}_1} [\pi Z_1(\tilde{c}_1, c_2) - s_1(\tilde{c}_1, c_2)c_1]$ for all $c_2 \in \Theta_2$,

(IC$_2$') $c_2 \in \arg\max_{\tilde{c}_2} [\pi Z_2(c_1, \tilde{c}_2) - s_2(c_1, \tilde{c}_2)c_2]$ for all $c_1 \in \Theta_1$.

However, according to Mookherjee and Reichelstein's result(1992), the stronger constraints (IRi') and (ICi') can replace (IRi) and (ICi) without changing the expected value of the principal's(the patent authority's) objective.

31) c_0 is observable and verifiable as we assumed Since A has patent right on the research tool, A can collect c_0 through a patent suit against the commercial product developed by B.

Proposition **1) [Efficient multilateral patent grants]**

Suppose that B is known to the patent authority at the time of granting a patent for research tool. The multilateral mechanism $\{s^*, Z^{ML}\}$ with $s^* = (s_1^*, s_2^*)$ defined in (2.1) and $Z^{ML} = (Z_1^{ML}, Z_2^{ML})$ defined in (3.2) is incentive compatible and individually rational.

$$Z_1^{ML}(c_1, c_2) = \frac{1}{\pi}(c_2 + c_0),\ Z_2^{ML}(c_1, c_2) = 0 \quad \text{if } s_1^*(c_1, c_2) = 1,\ s_2^*(c_1, c_2) = 0$$
$$Z_1^{ML}(c_1, c_2) = 0,\ Z_2^{ML}(c_1, c_2) = \frac{1}{\pi}(c_1 + c_0) \quad \text{if } s_1^*(c_1, c_2) = 0,\ s_2^*(c_1, c_2) = 1 \tag{3.2}$$

Proof) Global incentive compatibility for A requires that for all $c_1 \in \Theta_1$,

$$\Pi_1^{ML}(c_1) \geq E_2[s_1*(\tilde{c}_1, \zeta) \cdot (\pi Z_1^{ML}(\tilde{c}_1, \zeta) - c_1 - c_0)].$$

By the definition of $\Pi_1^{ML}(c_1) = \frac{1}{\Delta c}\int_{\underline{c}}^{\bar{c}}[s_1*(c_1, \zeta) \cdot (\pi Z_1^{ML}(c_1, \zeta) - c_1 - c_0)]\, d\zeta$,

the inequality reduces to,

$$\int_{c_1}^{\bar{c}}[(\zeta + c_0) - (c_1 + c_0)]d\zeta \geq \int_{\tilde{c}_1}^{\bar{c}}[(\zeta + c_0) - (c_1 + c_0)]d\zeta,$$

or equivalently,

$$\int_{c_1}^{\tilde{c}_1}[\zeta - c_1]d\zeta \geq 0.$$

For any $\tilde{c}_1 > c_1$, the argument in the square bracket is positive for each $\zeta \in [c_1, \tilde{c}_1]$, which proves that the inequality holds. Similarly, the same argument applies to the global incentive compatibility for B.

A simple computation yields $\Pi_1^{ML}(c_1) = \frac{1}{\Delta c}\int_{c_1}^{\bar{c}}[\zeta - c_1]d\zeta = \frac{1}{2}\frac{1}{\Delta c}(\bar{c} - c_1)^2 \geq 0$, which shows that the individual rationality for A holds. The similar step establishes the individual rationality B inventor Q.E.D.

In effect, the mechanism in the proposition 1 is a second-price sealed-bid auction where each inventor is allowed to submit a sealed bid and the lowest-cost inventor obtains a patent whose life long enough to compensate the second-lowest cost. In the setting of a second-price sealed-bid auction, reporting true cost is a weakly dominant strategy for each inventor and therefore it implements the socially optimal assignment of commercialization.

Corollary 1) (a) The expected patent life to implement the multilateral mechanism is

$$E\{s_1*(c_1, c_2)\cdot Z_1^{ML}(c_1, c_2)+s_2^*(c_1, c_2)\cdot Z_2^{ML}(c_1, c_2)\}=\frac{1}{\pi}\frac{[1}{3}(2\bar{c}+\underline{c})+c_0.$$

(b) Hence, the expected revenues for the inventors during the expected patent life under the multilateral mechanism is equal to $[\frac{1}{3}(2\bar{c}+\underline{c})+c_0]$

We can decompose the expected revenues into

$$c_0+E\left[s_1^*(c_1, c_2)c_1+\int_{c_1}^{\bar{c}}s_1^*(\zeta, c_2)d\zeta\right]+E\left[s_2^*(c_1, c_2)c_2+\int_{c_1}^{\bar{c}}s_2^*(c_1, \zeta)d\zeta\right] \quad (3.3)$$

where s_1^*, s_2^* are the assignment functions sought in (2.1). The expected revenues associated with the multilateral patent grants figures the expected span of the patent life to procure socially optimal R&Ds for research tool and its commercialization. The socially optimal patent life should be minimal but long enough to generate sufficient revenues that can cover all costs including informational rents borne by the inventors The optimal life should be longer than to compensate the true costs in order to induce the inventors' revelation of their types. That is, additional years of protection allow the inventors to capture informational rents. Therefore, total marketing revenues with the commercial products during the patent life need to compensate the true costs and to provide the informational rents. $E_{1,2}\left[\int_{c_1}^{\bar{c}}s_1^*(\zeta, c_2)d\zeta\right]$ and $E_{1,2}\left[\int_{c_2}^{\bar{c}}s_2^*(c_1, \zeta)d\zeta\right]$ are the amounts of informational rents to each inventor in exchange for their revelations of private information[32].

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32) This multilateral mechanism in a two-tier hierarchy is contrasted with Gandal and Scotchmer's mechanism(1993), because the former is not restricted by the-constraint of budget balance Gandal and Scotchmer also address that the first best outcome can be implemented even when a moral hazard is involved if there is no restriction on contracting, for instance, budget balance

Ⅳ. Private Information and Current Patent Policy for Cumulative Innovation

Section 3 shows that private information does not hinder socially efficient commercialization even though it requires additional patent life to by informational rents. This section adds **the structure of sequential innovations**, which cripples working of patent system with uniform life.

How do patents work for cumulative innovations? Basically, patent grants exclusive property right to an inventor for a limited period of time so that the patentee extracts the social benefit that he creates. For isolated innovations, patent right provides incentives by securing the patentee against any intervention by competitors. In contrast, in cumulative innovations where earlier innovations provide a building foundation for all technical progress, the role of patent right is to establish bargaining positions for inventors, not to exclude competitors. With these established bargaining positions, inventors can coordinate their investments by dividing profits appropriately through a negotiation. Accordingly, hidden bargaining positions impede the proper working of patent rights. For instance, private information about innovation value or its cost blurs bargaining positions and each inventor cannot observe counterpart's position.

This section proves that two separated patents with uniform life for individual innovations(the research tool and its commercialization) may not resolve the two inefficiencies. These inefficiencies are unavoidable since the relation among the patent authority and two inventors under the current patent system does not fit two-tier multilateral hierarchy or three-tier hierarchy either in an organizational context. In other words, nor is B known to the patent authority in advance, neither does A have all the bargaining power in a negotiation with B. Nonetheless, three-tier hierarchical organization is much close to the nature of sequential patent grants in cumulative innovations.

Assumption 5) B is not known either to the patent office or to A at the time of granting a patent to A[33].

The structure of granting multi patents for sequential innovations whose R&D costs are private information hinders the patent office from inducing the efficient commercialization At the time of granting the patent for the research tool, the patent office may not know who is going to be B, or her cost of commercialization either. To motivate the need of an optimal patent policy for research tools, we show why the current patent system is suboptimal under the circumstances we consider.

Suppose the patent office grants uniform patent life $z^U = \frac{1}{r}(1 - e^{-rT^U})$ for the research tool and its commercial product separately. If the right measure of damages is established, a negotiation between two sequential inventors can lead to the efficient commercialization as long as the costs are observable[34]. However, privately informed inventors would not reveal their true costs of commercialization willingly, which is a challenging issue and motivates our paper. Proposition 2 shows why we cannot expect the efficient commercialization under current patent system, when costs are private information[35].

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33) If the patent office identifies B before the patent issue, it can use a mechanism with multilateral contracts to induce an efficient commercialization. We can also assume that the discovery of commercial product is so serendipitous that no integration between inventors is possible before the first innovation is made, although A knows who will be the second(Scotchmer 1991). If they are ready for an integration before the first patent application, they can use a mechanism to coordinate their R&D efforts for efficient commercialization(for related study, see Gandal and Scotchmer 1993)

34) Schankerman and Scotchmer(1999) show that the legal doctrine of *unjust-enrichment* replicates an *ex post efficient* assignment when costs are observable

35) For a mechanism to implement a decision function, the decision function must satisfy not only incentive compatibility but also participation constraint. Otherwise, voluntary trade cannot be expected to arise However, The participation constraint limits the set of implementable decision functions(Myerson and Satterthwaite, 1983). Myerson and Satterthwaite theorem shows under very general conditions, it is impossible to achieve ex post efficiency in bilateral trade settings when agents have private information and trade is voluntary(Mas-colell, Whinston, and Green, 1995)

Proposition **2)** Suppose the patent office grants the **patents with uniform life** $z^U = \frac{1}{r}(1 - e^{-rT^U})$ for the research tool and the commercial product separately. Then we cannot expect the efficient commercialization regardless of the leading breadth and the damage rules.

Proof) A has two options for the research tool: apply for a patent grant or keep it secrecy until he self-develops the commercial product.

Case1) Alternatively, A may keep the research tool under secrecy until he completes the commercial product[36]. Unless A applies for a patent grant in the first place, there is no chance for B to arrive, which may break the efficient commercialization. End of story.

Case 2) Alternatively, suppose A applies for the patent for the research tool and obtains it. The expected profits from marketing the commercial product provides threat points for *ex ante* a RJV agreement between the inventors. Let α represent the probability that A obtains a patent right for the commercial product in a race.

First, suppose the leading breadth setfor the research tool is not high enough that the commercial product does not infringe the patent for the research tool. For a given patent length z^U, therefore, A would collect the expected profit $\alpha\pi z^U - c_1$ in the race[37]. The expected profit for B is given by $(1-\alpha)\pi z^U - c_2$. These threat points privately informed form **a bilateral trade setting.**

Second, suppose the leading breadth for the research tool is high enough, for

36) Matutes et al(1996) study the case where theinventor of research tool develops multiple applications one at a time They show that adjusting scope dominates length protection because the former provides more flexibility for the patent holder(time of exercise) and induces rival's early application There is a delay in introducing the first application or research tool without effective protection for A

37) If Ais able to keep his research tool under secrecy until A succeeds in developing the commercial application, A would not apply for the patent grant for the research tool in the first place Alpha = 1.

instance, infinite breadth If B obtains the patent right for the commercial product, B should compensate A's damages by her illegal use of the research tool. The damage should be a value within $[\pi z^U - \bar{c}, \pi z^U - \underline{c}]$. Let $\beta \pi z^U$ where $\beta \in (0, 1)$ represent the size of damage. Therefore, the expected profit for A from the race is given by $[\alpha + (1-\alpha)\beta]\pi z^U - c_1$ By contrast, the expected profit for B in the race is $[(1-\alpha)(1-\beta)]\pi z^U - c_2$. We encounter **a bilateral trade setting** again where private information on the commercialization costs cannot establish threat points.

The rest of the proof below shows an inefficient trade(no voluntary trading) under bilateral asymmetric information, which is an application of *Myerson and Satterthwaite theorem.*

The expected profits from the commercial product provide basis of threat points for *ex ante* agreement. For a general proof, we assume γ represents A's share of the profits from marketing the commercial product[38]. For a given patent period z^U, therefore, A would collect the expected profit $\gamma \pi z^U - c_1$ in a patent race. Let y denote the size of payment that B pays to A in exchange for commercialization. And let X indicate whether a trade occurs or not, i.e. X takes '1' if a trade occurs and '0' otherwise. Then the expected trade surplus for A during a given patent period z^U is $y - (\gamma \pi z^U - c_1)X$. The expected trade surplus for B is given by $-y + \{(1-\gamma)\pi z^U - c_2\}X$.

The expected trade surplus for A with c_1 can be written as,

$$\Pi_1(c_1) = E_2[y(c_1, c_2) - \{\gamma \pi z^U - c_1\}X(c_1, c_2)]$$
$$= Y_1(c_1) - \{\gamma \pi z^U - c_1\}X_1(c_1)$$

where $Y_1(c_1) \equiv E_2 y(c_1, c_2)$, $X_1(c_1) \equiv E_2 X(c_1, c_2)$.

38) For instance, $\gamma = [\alpha + (1-\alpha)\beta]$.

In contrast, the expected trade surplus for B with c_2 is,

$$\Pi_2(c_2) = E_1[-y(c_1, c_2) + \{(1-\gamma)\pi z^U - c_2\}X(c_1, c_2)]$$
$$= -Y_2(c_2) + \{(1-\gamma)\pi z^U - c_2\}X_2(c_2)$$

where $Y_2(c_2) \equiv E_1 y(c_1, c_2)$, $X_2(c_2) \equiv E_1 X(c_1, c_2)$.

Let define $\Phi_1(\tilde{c}_1, c_1) = Y_1(\tilde{c}_1) - \{\gamma\pi z^U - c_1\}X_1(\tilde{c}_1)$ where $\tilde{c}_1$ denotes the reported cost.

By using the local incentive compatibility condition in the envelope theorem, we derive,

$$\Pi_1'(c_1) = \frac{d}{dc_1}\Phi_1(\tilde{c}_1, c_1)|_{\tilde{c}_1 = c_1} = \frac{d}{dc_1}\Phi_1(c_1, c_1) = X_1(c_1) \geq 0.$$

Hence, the expected surplus for A including the informational rent is given by,

$$\Pi_1(c_1) = \Pi_1(\underline{c}) + \int_{\underline{c}}^{c_1} X_1(\tau)d\tau.$$

Likewise $\Pi_2'(c_2) = \frac{d}{dc_2}\Phi_2(\tilde{c}_2, c_2)|_{\tilde{c}_2 = c_2} = \frac{d}{dc_2}\Phi_2(c_2, c_2) = -X_2(c_2) \leq 0,$

and

$$\Pi_2(c_2) = \Pi_2(\bar{c}) + \int_{c_2}^{\bar{c}} X_2(\tau)d\tau$$

If X is *ex post* efficient social choice function, the following two equalities should hold since the social welfare is maximized when the lower cost inventor commercializes the research tool

$$X_1(c_1) = E_2[X(c_1, c_2)] = \int_{\underline{c}}^{c_1} 1 \cdot \frac{1}{\Delta c} dc_2 \frac{1}{\Delta c}(c_1 - \underline{c}) \text{ and}$$

$$X_2(c_2) = E_1[X(c_1, c_2)] = \int_{c_2}^{\bar{c}} 1 \cdot \frac{1}{\Delta c} dc_1 \frac{1}{\Delta c}(\bar{c} - c_2).$$

With the *ex post* efficient social choice function, the expected surplus for each inventor now reduces to

$$\Pi_1(c_1) = \Pi_1(\underline{c}) + \int_{\underline{c}}^{c_1} (\tau - \underline{c}) \frac{1}{\Delta c}\, d\tau = \Pi_1(\underline{c}) + \frac{1}{\Delta c}\frac{1}{2}(c_1 - \underline{c})^2 \text{ and}$$

$$\Pi_2(c_2) = \Pi_2(\bar{c}) + \int_{c_2}^{\bar{c}} (\bar{c} - \tau) \frac{1}{\Delta c}\, d\tau = \Pi_2(\bar{c}) + \frac{1}{\Delta c}\frac{1}{2}(\bar{c} - c_2)^2.$$

Therefore, total expected profits for both inventors to participate voluntarily in trading should be equal to,

$$E_1\Pi_1(c_1) + E_2\Pi_2(c_2) = \Pi_1(\underline{c}) + \Pi_2(\bar{c}) + \frac{1}{\Delta c}\frac{1}{3},$$

where $E_1\Pi_1(c_1) = \Pi_1(\underline{c}) + \frac{1}{\Delta C}\frac{1}{6}$, $E_2\Pi_2(c_2) = \Pi_2(\bar{c}) + \frac{1}{\Delta c}\frac{1}{6}$.

With non-negative conditions that $\Pi_1(\underline{c}) \geq 0$, $\Pi_2(\bar{c}) \geq 0$, we derive

$$E_1\Pi_1(c_1) + E_2\Pi_2(c_2) \geq \frac{1}{\Delta c}\frac{1}{3}$$

However, the expected surplus that a voluntary trading can generate is only

$$\int_{\underline{c}}^{\bar{c}} \int_{\underline{c}}^{\bar{c}} (c_1 - c_2) X(c_1, c_2) \frac{1}{\Delta c}\, dc_2 \frac{1}{\Delta c}\, dc_1 = \frac{1}{\Delta c}\frac{1}{6}.$$

Therefore, we cannot find a Bayesian incentive compatible social choice function that is *ex post* efficient and gives two inventors non-negative expected surplus from participation. Put differently, no voluntary trading can have a Bayesian Nash Equilibrium that leads to an *ex post* efficient commercialization. Q.E.D.

Proposition 2 is crucially conditioned on the assumption that costs are lump-sum and the timing of innovation does not depend on the unobservable cost parameters. If however, efficient rates of investment and the timing of investments depend on the unobservable cost parameters, there may be no conflict between efficiency, budget balance, incentive constraints and individual rationality[39].

When an RJV contract is not agreed, one of the following cases occurs. First, no inventor develops the commercial product, which is the worst case from a social perspective. Second, only one inventor develops the commercial product, which does not always lead to efficient commercialization. The developer might have higher cost than the non-developer. Third, two inventors may race to obtain the patent grant for the commercial product. Although A is the patentee for the research tool, A shares the commercial profits if the commercial product is patentable and B obtains the patent for the commercial product[40]. B always has an option to ignore an RJV contract with A and to pursue the commercial product independently. If her expected profit from the patent race is greater than her cost to do it, B would choose to race[41]. Hence, when B is significantly efficient enough, the patent race results in duplicative R&D efforts and lowers the social welfare[42] One of burdens associated with patent system is the common pool problem that results in excessive duplicative innovation[43] Rewards for a success under a competitive race causes excessive allocation of resources to R&D efforts[44].

39) Gandal and Scotchmer(1993) show that RJV's can achieve the first best with all these constraints in a R&D model with the Poisson distribution.

40) The example of Metallocene catalyst shows a case of successful research joint venture to develop commercial products Metallocene catalysts in chemical industry is the most significant process innovation in recent years Dow and Exxon, two leaders in this area formed research joint ventures with BP and Union Carbide respectively to develop commercial products

41) When B obtains the patent for the commercial product, we can assume that the first patentee and B share total revenue equally without loss of generality

42) The interesting case from biotechnology industry is Bacillus thuringiensis patent disputes between Mycogen and Monsanto. They develop the gene manipulating technology that provides insect-resistant crops(potato, cotton) and obtained separate patent grants They both wanted to seek out-of-courts settlements butin vain. They have exchanged patent infringement suits regarding unauthorized use of gene-manipulating technology and the commercial products based on this technology Courts ruled that no one infringed the other's patent right The litigation cost them more than 10 million dollars. By contrast, the inventors can resolve conflicts in patent rights through contracting such as R&D joint venture(hereafter referred to as RJV) or licensing.

43) The source of common pool problems lies in free use of common property For instance, no one has property right to the fish until they are caught More fishermen have an incentive to catch more fish than if access to the fishery were restricted(Carlton & Perloff 1994)

In general, the current patent policy that sequentially grants patents with a uniform life to the innovations causes two types of inefficiencies when the privately informed inventors fail to coordinate their conflicting incentives for commercialization (Schankerman and Scotchmer, 1999)[45] The first inefficiency comes from the possibility that the inefficient first inventor would commercialize the research tool(referred to as 'control loss')[46] The second inefficiency results from a patent race between the inventors for the commercial product('duplicative efforts') Split bargaining powers by the current patent system with granting multi patents hardly reach an agreement, nor do within proper time under bilateral hidden information.

V. Concluding Remarks and Extensions

With earlier innovations are basis for late technological progress, R&D incentives for successive inventors crucially depend on the way to divide profits

44) To avoid common pool problem, reward should be reduced to a fraction adjustable Wright(1983) introduced a yardstick concept of the marginal patent In contrast, no common pool problem arises with governmental contracts

45) They show that the current patent system with the appropriate measure of damages induces the inventors to achieve efficient commercialization if the inventors' costs are known to each other

46) Melumad, Mookherjee and Reichelstein(1992, 1995) use the term 'control loss' for the situation where a middle-agent resists yielding the production to the sub-agent with a lower cost in a hierarchy. Merges(1999) examines the default rules of employee-innovation and the ways of compensating employee-inventors 'Implicit exit option' strengthens the employed inventors'bargaining power An ex-employee can start his own business with backing of venture capital if the bargaining does not lead to an agreement From a social perspective, however, an efficient agreement ex post between employer and employee is better He suggests that the law may remedy the anticommons problem not by restricting the grant of rights but by permitting ex ante contractsthat pre-integrate rights Although employer ownership does not seem unfair with internal reward plans or exit options for employee, there is a concern of anticommons caused by granting many discrete rights The benefits of many discrete rights are preserved without incurring excessive ex post transaction costs under the proper contracts

that entire innovations create. The literature on patent policy for cumulative innovation has long searched for profit-division tools that can provide sufficient R&D incentives for every inventor in the innovation process. Under certain conditions, appropriate patent breadth and *ex ante* RJV agreement together is sufficient enough to achieve the efficient investments even with uniform patent life[47]

However, the problem of profit division in cumulative innovation becomes profoundly complicated with asymmetric information. Since patent breadth sets bargaining positions for a negotiation over surplus, private information is a great impediment to the use of patent breadth as an effective tool. We showed any patent policy that resorts to a bilateral trade between the inventors is not optimal if the inventors are privately informed about their own costs(proposition 2). Sequential nature of patent grants in cumulative innovations causes at least two problems: a problem of collecting the cost information on more than one inventor and a problem of choosing which inventor should invest. In these respects, the efficient commercialization of research tool is not likely to happen under the current patent system that grants uniform patent life for each innovation separately

This paper does have several limitations. First, the value of application that the research tool facilitates is assumed to be public knowledge. If two inventors are differentiated by the application ideas, it is socially optimal when the patent policy induces the inventor with a better ability to commercialize the research tool. Second, a single research tool conceives a single application. A richer model should handle the profit division problem between successive inventors when a research tool provides the basis for multiple applications. Third, this paper does not consider multiple second inventors The more the second inventors, the better bargaining position for A(Scotchmer 1995). Fourth, private information known to inventors is possibly multi-dimensional. Two-dimensional private information in two inventors complicates environment enough to impede mechanism approach Fifth, this paper does not address R&D race for the

47) See Green and Scotchmer(1995)

research tool Denicolo(2000) shows that strong protection may have ambiguous effects on social welfare for overinvestment in basic innovation and underinvestment in its application results.

It is the main research question how the patent authority provides economic incentives for both inventors to participate in such contracts and therefore resolve two efficiency issues first, the development should be undertaken by the lower-cost inventor, second, a race should be avoided since the race duplicates costs. Stated differently, the goal of an optimal patent policy for research tools is to let A share profits with the more efficient second inventor by cooperation, for instance, forming an RJV to develop commercial product

For the future research, we may introduce a three-tier hierarchy with a single patent to research tool only, which simplifies inefficiencies one dimension, 'control loss'. An approach with a three-tier hierarchy is strengthened by the feasibility that licensing can be a better solution than patent. The higher probability of winning a patent race encourages B not to accept unattractive negotiation terms offered by A, the patentee of research tool. One way of weakening B's power over an RJV negotiation is to deny a patent for commercial product so that the court judges that B's commercialization is subservient to the research tool[48].

To avoid control loss, the patent office should consider A's incentive in an RJV contract when it grants a patent for the research tool. As the commercial product is developed after the patent is granted to A, the patent authority cannot *ex ante* observe the inventors'individual contribution to the commercialization. The key to the designing an optimal mechanism for a research tool ishow the patent authority can observe the terms of profit division *ex post* in order to use them to correct A's biased incentive toward self-development. We may call it as *the contingent patent life* Contingency means that patent life should mark down the magnitude of the cost that A considers in offering an RJV to B. From A's prospective, the cost of commercialization with B through an RJV dominates his cost of self-commer-

48) infinite leading breadth or full forward protection

cialization due to informational rent to induce truthful report of cost, which leads to the control loss.

To design delegation mechanism with the contingent patent life, we can resort to Melumad, Mookherjee and Reichelstein's works(1992, 1995)(hereafter, referred to as MMR) delved into a delegation mechanism that can be immune from the problem of control loss even in a hierarchy and proposed a solution under certain circumstances. MMR(1992, 1995) designed a mechanism in a three-tier hierarchy that is immune from the problem of control loss. They introduce a variable that enables the principal to monitor whether the intermediate agent assigns the production optimally even without observing the subcontract. The principal allows the intermediate agent to authorize the payment to the end-agent with the principal's blank check, and rewards the intermediate agent by monitoring his account[49]. Their mechanism induces the intermediate agent to internalize the principal's objective so as to achieve the principal's goal, unless the subcontract is executed before the prime contract[50].

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49) This contractual form is referred to as cost center(MMR 1992)

50) This condition is satisfied in a patent system because B can access the research tool only if it is patented We ignore the case where both inventors collude before the research tool is patent-granted Without a patent protection, A runs the risk that Bexpropriates the research tool Or we may assume that discovery of commercial product is serendipitous

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축차적 혁신에 따른 특허제의 비효율성

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본 연구는 사적 정보를 보유한 혁신자들에 의해 일련의 혁신들이 축차적으로 발생할 때 현행 특허제도가 안고 있는 비효율성 문제를 분석하고 있다. 비록 축차적 혁신이라 하더라도 두 혁신의 발생이 시간차를 두지 않는 경우에는 특허당국은 차가서면경매(second-price sealed bid auction)와 동등한 메카니즘을 활용하면 하나의 특허권만을 부여함으로써 효율적인 혁신을 유도할 수 있다 그러나 축차적 혁신의 본질적 특성상 현행 특허제도는 축차적 혁신에 대해 복수의 특허권을 부여하게 된다. 특히, 두 혁신자가 특허권을 나누어 받게 되는 경우 혁신자들이 보유하고 있는 사적정보에 의해 쌍방정보비대칭성이 발생하고 이러한 환경에서는 특허권자 간의 자발적 협상을 통한 원만한 상용화를 기대하기 불가능해진다 본 연구에서는 축차적 혁신의 한 유형인 리서치 툴의 개발과 상용화 과정을 대상으로 현행 특허제도하 복수특허권 부여에 따른 비효율성을 분석하였다. 축차적 혁신의 시간적 특성을 고려할 때 특허당국과 선 혁신자, 후 혁신자는 위계구조에 놓이게 됨에 따라 특허제도를 통해 효율적 혁신을 유도하기 위해서는 위임메카니즘으로서의 개선이 요구된다.

핵심용어 : 축차적 혁신, 리서치 툴, 쌍방정보비대칭성, 제어손실, 위임메카니즘