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R & D competition and patent values

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ABSTRACT

Research and development (R & D) competition is standard, and it heavily affects patent values. This study captures R&D competition's effects on patent values using game-theory approaches. Cost-reduction patent values increase with technology level and decrease with the competition. Technology spillover's impact on innovation depends on R & D's properties. This study elucidates cooperative R & D and the allocation mechanism, and also develops the theory of cooperative innovation.

Introduction

Realizing patent or intellectual property (IP) is extremely important to promote the economy worldwide. To attain certain targets, firms have to compete to launch research and development (R & D) activities. For example, several firms compete to develop a coronavirus disease 2019 (COVID-19) vaccine to cope with the spread of COVID-19 (Graham, 2020; Heaton, 2020; Le et, al., 2020). Since April 8, 2021, 155 COVID-19 vaccines have been developed worldwide—including mRNA-1273 of Moderna,Ad5-nCoVof CanSino Biologicals, INO-4800 of Inovio, andLV-SMENP-DC and pathogen-specific aAPC of Shenzhen Geno-Immune Medical Institute (Le et al., 2020). To date, only nine COVID-19 vaccines are permitted for use. Efficient COVID-19 vaccines are now in production owing to R&D competition. (Minin et al., 2021).

According to the earlier example, the R&D competition stimulated the progress of COVID-19 vaccines. Moreover, according to data obtained from the China National Intellectual Property Administration (cnipa.gov.cn), launched on July 13, 2022, the rewards of patents are 4.5 times of investments in 2021 and 4.4 times in 2020.Thus, capturing R&D competition's effects is important. Based on the above background, this study addresses R&D competition affecting patent prices using game theory approaches. Moreover, patents are closely related to technological levels. The technology level generally measures the degree of technological expertise and advances. Therefore, production efficiency and cost are two important symbols of technology levels. This study refers to the technology level with the costs incurred on production. Higher technology-level patents yield lower marginal production costs.

This study's contributions lie in both its theories and applications. This study establishes a theory on R & D competition-related patent prices. Low-level patents harm consumer surplus, presenting both the effects of technology spillover on R&D and conditions for technology spillover to improve (or reduce) R & D. Further, it elucidates cooperative R & D mechanisms and allocation benefits.

Policy implications have been proposed for applications. The government should identify technology levels corresponding to patents and reject patents with low technology levels. Further, technology spillover impacts R&D, and IP protection should consider the situation to promote R & D. Moreover, cooperative R & D should be encouraged.

The remainder of this paper is organized as follows. Section 2 reviews the literature on patent values and stresses the importance of the topic. Section 3 establishes a model of patent values for the two research firms. Subsequently, Section 4 analyzes and discusses the model. Finally, Section 5 concludes the paper.

Literature review

Since the pioneering work of Arrow (1962), R&D has been conducted by scholars and society worldwide. Acemoglu et al. (2018) argued that innovation is the basis of economic growth, whereas Aghion and Jaravel (2015) discussed that technological innovation and spillover stimulatesocietal progress. Kogan et al. (2017) found that technological innovation improves resource allocation and has yielded economic growth in recent years. Nie and Yang (2020) argued that cost-reduction innovation promotes consumer surplus. The importance of innovation indicatesthat patents are needed to encourage innovation.

Patent values are important because they are crucial in patent industrialization. For example, Cockburn et al. (2016) found that

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patents globally affect new drug diffusion. Quintino et al. (2021) found that intellectual property assets significantly affect innovation efficiency. Taehyuk and Ilwon (2021) highlighted that patents yield first-mover advantages for firms in the entire market. Ribeiro and Shapira (2020) identified differences in patents between public and private firms and demonstrated that private firms benefit more from patents. Based on this, Fan et al. (2018) proposed optimal patents under incomplete information in theory.

Research on patent values has highlighted various factors affecting patent prices. For instance, Nie, Chen and Wang (2021) discussed patent prices under oligopoly competition and proved that weaker firms exhibit a stronger intention to buy patents to pursue advantageous firms. Chen et al. (2022) argued that firms earn from the bundling sale pattern of patents if the two patents are closely related under Cournot and Stackelberg competition. Nie, Wang and Wen (2023) argued that technology standards promote patent values. Sen and Stamatopoulos (2019) proved that price-decreasing taxes decrease patent values. Nie, Wang and Wen (2022) argued that technology spillovers reduce patent prices. Interestingly, based on the human genome, Williams (2013) addressed how research tools on patents harm innovation and opposed intellectual property protection on research tools. Recently, under incomplete information, Song and Zhao (2021) found that strategic disclosure of intellectual property may stimulate innovation and suggested the exact IP protection to promote innovation. Donduran and Ünveren (2021) discussed cooperative innovation or cooperative patents and found that competitive R&D yields overinvestment.

We address some policy implications based on the corresponding theory and prior empirical research. Lim (1998) argued that patent policy plays an important role in influencing R&D. Zeng et al. (2014) proposed price regulation to promote innovation. Kwon (2021) proposed a patent policy to identify weak patents to strengthen patent industrialization and maintain high-level innovation.

Although competition affecting patent values has been discussed previously, no studies have considered patent values under R&D competition, which signifies that a potent entrant of a patent invariably exists, and this potent entrant impacts the research firm to price patents. This study aims to fill this research gap by capturing the patent values under R & D competition. Moreover, the duopoly competition model is introduced into R & D competition. In this model, the technology level is related to the marginal costs incurred on production. Industrial organizations have been introduced in the R & D field. This enriches the R & D model and analysis framework.

Model establishment

The model is established with a patent and two research firms in this industry. Che, Iossa and Rey (2021) assumed that research firms exist in the industry. We assume Nproduction firms in this industry with marginal costs $c_i > 0, i = 1, 2, \cdots, \mathrm{N}$. Without loss of generality, we assume that $0 < c_1 \le c_2 \le \cdots \le c_\mathrm{N}$. The firms' corresponding outputs are $q_i, i = 1, 2, \cdots, \mathrm{N}$.Moreover, all firms' production is identical for all users. The costs incurred on production are $C_i(q_i) = c_i q_i$. The final goods' price is p, and the inverse demand function is expressed as follows:

$$p = A - \sum_{i=1}^{N} q_i. \tag{1}$$

Producers. Without this patent, firms' profits are stated as follows:

$$\pi_i = (A - \sum_{i=1}^{N} q_i) q_i - c_i q_i. \tag{2}$$

This patent is priced as $p_p > 0$, and the costs incurred by this patent are$c_p > 0$. Moreover, based on the exclusion rules, we further assume that this patent is sold to a unique production firm. We assume that firm K buys this patent and that the corresponding profit function is

$$\pi_K = (A - \sum_{i=1}^{N} q_i) q_K - \bar{c} q_K - p_p. \tag{3}$$

$$\pi_i = (A - \sum_{i=1}^{N} q_i) q_i - c_i q_i, i = 1, 2, \cdots, \mathrm{K}-1, \mathrm{K}+1, \cdots, \mathrm{N}. \tag{4}$$

Moreover, the market size is sufficiently large, and this study invariably assumes that $A >> \max_{j=1,2,\cdots,\mathrm{N}}\{c_j\}$. The market size is exceedingly larger than the marginal costs incurred on production, which guarantees all firms' production.

Research firms. Two research firms in this industry that compete in R&D are introduced and denoted as $\{A, B\}$. The two research firms launched a patent competition, and one achieved a patent. We assume that the two research firms spend $I = (I_A, I_B)$ in R&D. The probability of obtaining a patent along with the production costs $\bar{c}$ is

$$pr = (pr_A, pr_B) = \Big(1 - \exp[-h_A(I_A + \gamma I_B)], 1 - \exp[-h_B(I_B + \gamma I_A)]\Big). \tag{5}$$

In Eq. (5), $\gamma \in [0, 1]$ indicates the degree of technology spillover. $h_j(\bullet), j \in \{A, B\}$ satisfies $h_j(0) = 0, j \in \{A, B\}$ and is concave; that is, $\frac{dh_j(x)}{dx} \ge 0$ and $\frac{d^2 h_j(x)}{dx^2} < 0$.The assumption regarding this patent, along with the production costs $\bar{c}$, is to simplify the model, and it is easy to extend the general situation.

The timing of game theory is as follows: In the first stage, two research firms compete in R & D, and a research firm owns a patent and prices to production firms. In the second stage, a production firm buys this patent, and no firms buy it. In the final stage, firms compete in terms of quantity.

Discussion

Backward induction is adopted to discuss the above model. The third stage is addressed, the second stage is discussed, and finally, the first stage is analyzed.

The third stage

The third stage is discussed in two cases. One is that no firm buys this patent, and the other is that firm K buys this patent.

Case 1. no firm buys this patent

Without a patent, this situation constitutes classical Cournot competition. Equilibrium is calculated using (2). The profit functions are all concave, and the equilibrium is determined by the first-order optimal conditions as follows:

$$\frac{\partial \pi_i}{\partial q_i} = A - \sum_{j=1}^{N} q_i - q_i - c_i = 0, i = 1, 2, \cdots, \mathrm{N}. \tag{6}$$

The equilibrium is

$$q_i^{1,*} = (A - c_i) - \frac{\sum_{j=1}^{N}(A - c_j)}{N+1}. \tag{7}$$

The assumption of $A >> \max_{j=1,2,\cdots,\mathrm{N}}\{c_j\}$ implies that each output is positive. Moreover, the corresponding price and profits are represented

$$p^{1,*} = A - \frac{\sum_{j=1}^{N}(A - c_j)}{N+1}. \tag{8}$$

$$\pi_i^{1,*} = \left[(A - c_i) - \frac{\sum_{j=1}^{N} (A - c_j)}{N+1} \right]^2. \quad (9)$$

Case 2. firm K buys this patent

In this case, equilibrium is achieved using Eq. (3). Like case 1, the equilibrium is outlined as follows:

$$q_i^{2,*} = (A - c_i) - \frac{\sum_{j=1 j \neq K}^{N} (A - c_j)}{N+1} - \frac{(A - \bar{c})}{N+1},$$
$$q_K^{2,*} = \frac{N(A - \bar{c})}{N+1} - \frac{\sum_{j=1 j \neq K}^{N} (A - c_j)}{N+1}. \quad (10)$$

The corresponding price and profits are

$$p^{2,*} = A - \frac{\sum_{j=1, j \neq K}^{N} (A - c_j)}{N+1} - \frac{(A - \bar{c})}{N+1}. \quad (11)$$

$$\pi_i^{2,*} = \left[(A - c_i) - \frac{\sum_{j=1 j \neq K}^{N} (A - c_j)}{N+1} - \frac{(A - \bar{c})}{N+1} \right]^2, i = 1, 2, \cdots, K-1, K+1, \cdots, N,$$
$$\pi_K^{2,*} = \left[\frac{N(A - \bar{c})}{N+1} - \frac{\sum_{j=1 j \neq K}^{N} (A - c_j)}{N+1} \right]^2 - p_p. \quad (12)$$

Based on the above equilibrium, we obtain the following conclusion:

Proposition 1 Patent realization promotes total output or consumer surplus under $\bar{c} \leq c_K$. Otherwise, the consumer surplus undergoes a loss owing to patent industrialization.

Proof. See Appendix. ■

Remarks: Condition $\bar{c} > c_K$indicates that the technology level with patent realization is higher than in the initial stage. In this situation, patent industrialization promotes output while reducing the price of final goods. Thus, the consumer surplus is correspondingly improved. Otherwise, the technology is extremely low, and this industry suffers a loss because of the introduction of patents. The policy implies encouraging high-value patents or technology threshold values while preventing low-technology patents. A restriction on the technology level is suggested for the government to improve consumer surplus. Patent applications should focus on technology levels.

Second stage

At this stage, firm Kdetermines whether to buy this patent. This firm buys the patent if and only if the following principles apply for a profit-incentive firm:

$$\pi_K^{2,*} = \left[\frac{N(A - \bar{c})}{N+1} - \frac{\sum_{j=1 j \neq K}^{N} (A - c_j)}{N+1} \right]^2 - p_p \geq \pi_K^{1,*} = \left[(A - c_K) - \frac{\sum_{j=1}^{N} (A - c_j)}{N+1} \right]^2. \quad (13)$$

The above inequality implies that the firm benefits from this patent. We re-write Eq. (13) as follows:

$$p_p \leq V^* = \left[\frac{N(A - \bar{c})}{N+1} - \frac{\sum_{j=1 j \neq K}^{N} (A - c_j)}{N+1} \right]^2 - \left[(A - c_K) - \frac{\sum_{j=1}^{N} (A - c_j)}{N+1} \right]^2$$
$$= \frac{N[c_K - \bar{c}}{N+1} (q_K^{2,*} + q_K^{1,*}). \quad (14)$$

We denote $V^* = \frac{N(c_K - \bar{c})}{N+1} (q_K^{2,*} + q_K^{1,*})$by the threshold value for a firm to buy this patent. For the above threshold value, the following result holds:

Proposition 2 Under$\bar{c} \leq c_K$, the patent price's threshold value increases with the technology level and decreases with the competition.

Proof. See Appendix. ■

Remarks: This proposition illustrates the relationship between the technology level and threshold values. Higher technology levels imply lower expected costs, and the threshold values are correspondingly promoted.

The relationship between competition and innovation has long been debated. Arrow (1962) proposed that competition promotes innovation. Gilbert and Newbery (1982) opposed Arrow's assumptions and demonstrated that monopolists are more incentivized to launch innovation. The above conclusion also supports the important idea of Gilbert and Newbery (1982) in theory from another angle.

The first stage

This patent is sold if and only if the following conditions are fulfilled:

$$c_p \leq p_p \leq V^*. \quad (15)$$

From Eq. (14), this research firm benefits from this R&D; otherwise,$p_p > V^*$suggests that the production firm has no intention to buy this patent because the price is extremely high. $c_p > p_p$indicates that the research firm incurs high costs, and the trade between the research firm and production firm fails. When Eq. (15) is not satisfied, the government may subsidize the research firm or production firm to advance R&D and patent industrialization (Nie et al., 2020; Che, Iossa & Rey, 2021). For the research firm, the expected earnings are $pr_j p_p$. The participation condition is as follows:

$$pr_j p_p \geq I_j = c_p. \quad (16)$$

Otherwise, the firm quits R&D to avoid undertaking losses. Eq. (16) can be restated as follows:

$$[1 - \exp\left(-h_j(I_j + \gamma I_{-j})\right)] p_p \geq I_j. \quad (17)$$

In (17), $-j \in \{A, B\}, -j \neq j$. Considering the patent values, we obtain the following conclusion:

Proposition 3 High technology spillover levels reduce innovative investment under $\exp\left(-h_j(I_j + \gamma I_{-j})\right) p_p \frac{\partial h_j}{\partial I_j} > 1$. Otherwise, technology spillovers promote innovative investments.

Proof. See Appendix. ■

Remarks: Under high technology spillover and $\exp\left(-h_j(I_j + \gamma I_{-j})\right) p_p \frac{\partial h_j}{\partial I_j} > 1$, this R&D exhibits a high probability of success, and firms reduce RR & D because all firms benefit from the opponents' R & D. Thus, high technology spillover yields a free-rider phenomenon. The policy implication is the launch of copyright protection to reduce technology spillovers for highly potential R & D. Thus, firms tend to invest in R&D.

From $\exp\left(-h_j(I_j + \gamma I_{-j})\right) p_p \frac{\partial h_j}{\partial I_j} < 1$, R & D faces low patent prices and a low probability of success, and technology spillover encourages R&D investment. The corresponding policy implication is encouraging technology spillover because technology spillover stimulates innovation.

Otherwise under $\exp\left(-h_j(I_j+\gamma I_{-j})\right)p_p\frac{\partial h_j}{\partial I_j}\geq 1$, technology spillover deters innovation, and the policy implication is the launch of strict patent protection to prevent technology spillover. Thus, R & D is maintained.

In summary, the policy implication is that optimal copyright protection depends on innovation properties. To launch optimal policies, patent properties and the market should be highlighted carefully.

We further discuss a symmetric situation wherein $h_A = h_B$occurs. Moreover, cooperative R & D has also been addressed (Wang &, Nie,2021). Firms cooperatively innovate if and only if the following conditions hold.

$$[1-\exp\left(-h_A(I_A+I_B)\right)]p_p\geq I_A+I_B. \quad (18)$$

We assume that two research firms launch R & D as $(I_A^{*,3}, I_B^{*,3})$. This cooperative R&D's earnings are in $p_p - I_A^{*,3} - I_B^{*,3}$. These extra earnings' allocation is:

$$\left(\frac{(p_p - I_A^{*,3} - I_B^{*,3})I_A^{*,3}}{I_A^{*,3}+I_B^{*,3}}, \frac{(p_p - I_A^{*,3} - I_B^{*,3})I_B^{*,3}}{I_A^{*,3}+I_B^{*,3}}\right). \quad (19)$$

In summary, because of technology spillover, firms underinvest in R&D. A cooperative R&D mechanism is proposed, and allocation is suggested based on the investment.

Concluding remarks

This study focuses on R&D's effects on patent value. Conversely, cost-reduction patent values increase with the technology level and decrease with the competition. By contrast, technology spillover may stimulate or deter innovation depending on R&D's properties. Further, cooperative R & D and the allocation mechanism are proposed.

Based on these results, we suggest some policy implications. First, the government should identify patents with a high technology level because patents with low technology negatively impact social welfare. Second, IP protection should consider the R & D process and patent values to promote innovation. Proposition 3 supports the condition of protecting the IP to avoid technology spillover. Finally, cooperative R&D should be encouraged to improve the likelihood of success.

This study's conclusions will be useful in management. Firms should seek patents with a high technology level because they promote social welfare. Low technology patents may damage the market and reduce social welfare. Therefore, firms need to select patents with a high technology level.

Considering the above analysis, issues for further research are elucidated. To simplify the model, this study assumes that the technology level corresponding to the patent is fixed. Extending this study to the general situation wherein the technology level depends on R & D can be interesting. Moreover, various government strategies can be adopted to support R & D. Combining government policies and elucidating this aspect in detail would be interesting.

Data availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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Appendix

Proof of proposition 1

From Eqs. (7) and (11), where $\bar{c}\leq c_K$, we obtain

$$p^{2,*} = A - \frac{\sum_{j=1,j\neq K}^{N}(A-c_j)}{N+1} - \frac{(A-\bar{c})}{N+1} < p^{1,*} = A - \frac{\sum_{j=1}^{N}(A-c_j)}{N+1}.$$

Therefore, $\bar{c}\leq c_K$indicates that patent realization promotes total output or consumer surplus. Otherwise, we obtain$\bar{c} > c_K$

$$p^{2,*} = A - \frac{\sum_{j=1,j\neq K}^{N}(A-c_j)}{N+1} - \frac{(A-\bar{c})}{N+1} > p^{1,*} = A - \frac{\sum_{j=1}^{N}(A-c_j)}{N+1}.$$

Thus, patent realization reduces the total output or consumer surplus.

The relevant conclusions are achieved, and the proof is complete. ■

Proof of proposition 2

Based on Eq. (14), where$\bar{c}\leq c_K$, the threshold value of the patent price is restated as:

$$V^* = \left[\frac{N(A-\bar{c})}{N+1} - \frac{\sum_{j=1 j\neq K}^{N}(A-c_j)}{N+1}\right]^2 - \left[(A-c_K) - \frac{\sum_{j=1}^{N}(A-c_j)}{N+1}\right]^2$$

$$= \frac{N(c_K-\bar{c})}{N+1}(q_K^{2,*}+q_K^{1,*}) > 0.$$

Moreover, by Eq. (10), we find that $q_K^{2,*}$increases with the technology level corresponding to this patent and decreases with the competition. Therefore, the patent price's threshold value increases with the technology level and decreases with the competition.

The relevant conclusions are achieved, and the proof is complete. ■

Proof of Proposition 3

According to Eq. (17), the lowest R&D is $[1-\exp\left(-h_j(I_j+\gamma I_{-j})\right)]p_p = I_j$.This formulation is rewritten as

$$p_p - \exp\left(-h_j(I_j+\gamma I_{-j})\right)p_p - I_j = 0. \quad (A1)$$

Considering the $p_p$and I_{-j}, the solution to (A1) is I_j^*. Furthermore, (A1) is restated as

$$f(I_j,\gamma) = p_p - \exp\left(-h_j(I_j+\gamma I_{-j})\right)p_p - I_j = 0. \quad (A2)$$

(A2) implies

$$\frac{\partial f(I_j,\gamma)}{\partial I_j} = \exp\left(-h_j(I_j+\gamma I_{-j})\right)p_p\frac{\partial h_j}{\partial I_j} - 1,$$
$$\frac{\partial f(I_j,\gamma)}{\partial \gamma} = \exp\left(-h_j(I_j+\gamma I_{-j})\right)p_p\frac{\partial h_j}{\partial \gamma} > 0. \quad (A3)$$

The above inequality arises from the assumption of $\frac{dh_j(x)}{dx}\geq 0$. Moreover, according to the implicit function theorem, when $\exp\left(-h_j(I_j+\gamma I_{-j})\right)p_p\frac{\partial h_j}{\partial I_j} > 1$, we obtain$\frac{\partial f(I_j,\gamma)}{\partial I_j} > 0$and the following formulation.

$$\frac{\partial I_j^*}{\partial \gamma} = -\frac{\frac{\partial f(I_j,\gamma)}{\partial \gamma}}{\frac{\partial f(I_j,\gamma)}{\partial I_j}} < 0. \quad (A4)$$

Otherwise, $\exp\left(-h_j(I_j+\gamma I_{-j})\right)p_p\frac{\partial h_j}{\partial I_j} < 1$, or$\frac{\partial f(I_j,\gamma)}{\partial I_j} < 0$, the following relationship holds

$$\frac{\partial I_j^*}{\partial \gamma} = -\frac{\frac{\partial f(I_j,\gamma)}{\partial \gamma}}{\frac{\partial f(I_j,\gamma)}{\partial I_j}} > 0. \quad (A5)$$

Therefore, a high level of technology spillover reduces innovative investment under $\exp\left(-h_j(I_j+\gamma I_{-j})\right)p_p \frac{\partial h_j}{\partial I_j} > 1$. Otherwise, technology spillovers will promote innovative investments.

The relevant conclusions are achieved, and the proof is complete. ■

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